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REVIEW ARTICLE

Systematic Review of Self-Measured Blood Pressure Monitoring With Support: Intervention Effectiveness and Cost

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Introduction: Self-measured blood pressure monitoring with support is an evidence-based intervention that helps patients control their blood pressure. This systematic economic review describes how certain intervention aspects contribute to effectiveness, intervention cost, and intervention cost per unit of the effectiveness of self-measured blood pressure monitoring with support.

Methods: Papers published between data inception and March 2021 were identified from a database search and manual searches. Papers were included if they focused on self-measured blood pressure monitoring with support and reported blood pressure change and intervention cost. Papers focused on preeclampsia, kidney disease, or drug efficacy were excluded. Quality of estimates was assessed for effectiveness, cost, and cost per unit of effectiveness. Patient characteristics and intervention features were analyzed in 2021 to determine how they impacted effectiveness, intervention cost, and intervention cost per unit of effectiveness.

Results: A total of 22 studies were included in this review from papers identified in the search. Type of support was not associated with differences in cost and cost per unit of effectiveness. Lower cost and cost per unit of effectiveness were achieved with simple technologies such as interactive phone systems, smartphones, and websites and where providers interacted with patients only as needed.

Discussion: Some of the included studies provided only limited information on key outcomes of interest to this review. However, the strength of this review is the systematic collection and synthesis of evidence that revealed the associations between the characteristics of implemented interventions and their patients and the interventions' effectiveness and cost, a useful contribution to the fields of both research and implementation.

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INTRODUCTION

High blood pressure (BP) or *hypertension*, defined as consistent BP readings ≥130/80 mmHg, is an important risk factor for cardiovascular disease.[1,2] Nearly 116 million American adults have hypertension,[3] only 21% of whom have their condition under control.[3−5] Hypertension contributed to >516,000 deaths in the U.S. in 2019.[6,7] Hypertension prevention and control can lead to substantial health benefits. Researchers have noted that a small reduction

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in systolic BP (SBP) was associated with fewer incidents of heart failure, coronary heart disease, and stroke.[8,9]

Self-measured BP monitoring (SMBP) is a patient-centered intervention for reducing BP, where patients routinely measure their own levels using personal devices and share the readings with their clinicians. Additional support can be combined with SMBP, such as medication management and lifestyle changes, which are proven strategies for lowering BP.[10–16] Several national and international organizations support the use of SMBP to help patients observe and control their BP.[17–30] The Community Preventive Services Task Force (CPSTF) recently recommended the use of SMBP to reduce and control BP on the basis of a systematic review of effectiveness.[31] The CPSTF also found SMBP with support to be cost effective on the basis of a systematic review of the economic evidence; the economic evidence for SMBP alone (without support) was mixed.[32]

Although the evidence on effectiveness and cost effectiveness of SMBP with support are well established,[17–32] there is a lack of systematically synthesized information on the implementation process. Implementation science, "the scientific study of methods to promote the systematic uptake of research findings and other [evidence-based practices] into routine practice,"[33] provides a framework for gathering such information. Although this type of research is gaining interest in healthcare services research, the economics of implementing evidence-based strategies are less studied. This study seeks to contribute to the knowledge base by describing and analyzing the implementation-related information contained in studies that evaluated both the effectiveness and intervention cost of SMBP with support.

The objective of this study is to extend the CPSTF's economic review[32] by describing the patient characteristics and intervention features and how they impacted effectiveness, intervention cost, and intervention cost per unit of effectiveness of SMBP with support interventions. Specific research questions include the following:

1. How effective are the SMBP interventions in reducing SBP?
2. How much do the SMBP interventions cost to implement?
3. How much does the intervention cost to achieve a unit of effectiveness?
4. Which patient characteristics and intervention features are associated with effectiveness, intervention cost, and intervention cost per unit of effectiveness?

METHODS

This study was conducted using methods for systematic review of economic evidence developed by the Centers for Disease Control and Prevention and approved by CPSTF.[34] Much similar to a traditional systematic review, a systematic economic review answers economic research questions, provides a replicable search strategy, describes screening methods, examines the quality/risk of bias of estimates, and reports on a reproducible analysis of the results.[35] The authors applied the PRISMA reporting guidelines.[36] Two reviewers, who are experts in heart disease and stroke prevention, independently screened the evidence using DistillerSR, extracted the data, and conducted the quality assessment, reconciling any discrepancies through conversation with the other coauthors.

This study defines *SMBP* as patients using personal BP measurement devices to routinely record their levels in familiar settings (e.g., their homes or community centers). Readings are shared with the patients' healthcare providers or collaborative care teams during clinic visits, by telephone, or electronically. Readings are monitored and used in treatment decisions to improve hypertension control. SMBP may be combined with additional support, which can include patient counseling on medications (e.g., adherence strategies) and lifestyle changes (e.g., increased physical activity, healthy eating, and avoiding tobacco), patient education for BP self-management, and telephone or web-based tools that enable and enhance patient self-care (e.g., text or e-mail reminders). The interventions may be delivered by nurses, physicians, pharmacists, or lay health workers.[32] Devices used in SMBP include personal measurement devices and other devices for telemetry, telehealth, or telemedicine. Telemetry devices collect and transmit health data. Telehealth or telemedicine devices, in addition to collecting and transmitting data, connect patients and their healthcare teams for treatment and clinical decisions.[37]

Evidence Search and Inclusion/Exclusion Criteria

All studies that were included in CPSTF's cost-effectiveness review were considered for inclusion.[32] The CPSTF review's search period was from the inception of the databases to March 2015; a bridge search was conducted for this review by replicating the search strategy from the CPSTF's cost-effectiveness review and extending the period to March 2021. Terms related to SMBP and support were used to search multiple databases (i.e., MEDLINE, Cochrane Central Register of Controlled Trials, Cochrane Database of Systematic Reviews, Cochrane Economic Evaluations, EconLit, and Centre for Reviews and Dissemination). Additional articles were identified for inclusion through manual searches within the reference lists of the included studies. A detailed description of the evidence search strategy is available in the Appendix (available online). Studies were included in this review if they were published in English, were conducted in a high-income country,[38] met the intervention definition, reported BP change (SBP, specifically) as a primary outcome, and reported intervention cost. Studies focused on preeclampsia, kidney disease, or drug efficacy were excluded. Studies of SMBP interventions that were conducted without additional support were also excluded.

All monetary values were converted to 2020 U.S. dollars using purchasing power parities from the World Bank to convert non−U.S. dollar denominations and the Consumer Price Index from the Bureau of Labor Statistics to adjust for inflation.[39,40]

Intervention cost estimates were standardized to per patient per month terms to facilitate comparisons across studies because interventions were expected to differ in duration and sample sizes. The summary of change in SBP, intervention cost, and cost per unit change in SBP are reported in terms of medians and IQRs.

Evidence necessary to answer the research questions was collected from each study for effectiveness, intervention cost, and intervention features. *Effectiveness of an intervention* is defined in this review as the change in SBP (mmHg), as measured in the clinic setting. The components of intervention cost estimates and the methods used by the studies to measure effectiveness and intervention cost were also recorded. The intervention cost is the sum of the cost of inputs used to implement and operate the intervention. The intervention cost per unit of effectiveness is the intervention cost per mmHg change in SBP. Patient characteristics included sample size, race and ethnicity, baseline BP, whether BP was controlled, age, sex, and socioeconomic status. Study characteristics included geographic location and setting. Intervention features were compiled in tabular and narrative formats from intervention descriptions provided in the studies. When available, these included support type (medication management, medication adherence, lifestyle modifications), provider type (nurse, physician, pharmacist, community health worker, other), devices and technology (personal measurement device, personal computer, personal digital assistant, phones, telemetry, telemedicine), and patient−provider interactions (as needed, fixed schedule of meetings).

Given the heterogeneity and the relatively small number of estimates, the authors conducted a qualitative analysis to answer the research questions. The intervention arms from the studies were sorted according to the intervention cost (least to most), effectiveness (most to least), and cost per unit of effectiveness (lowest to highest). The intervention arms sorted into the top 33% and the bottom 33% for intervention cost were then reviewed for intervention features that distinctly characterized them as least costly and most costly (e.g., type of additional support, staffing, devices used, frequency of patient−provider interactions). This process was repeated for effectiveness and cost per unit of effectiveness. The top and bottom third cut off points were chosen to ensure a reasonable number of intervention arms within the top and bottom from which to discern any distinguishing intervention features.

Quality Assessment of Estimates

A tool for quality assessment of economic evidence was developed for the scope and objective of this study, following methods developed by the Centers for Disease Control and Prevention and approved by CPSTF for systematic economic reviews (Appendix, available online). Briefly, 2 raters used the tool to independently assign and later reconcile points that indicate limitations in the quality of the variables related to effectiveness, cost, and intervention features from each study. Each variable was scored as good, fair, or limited on the basis of the total points, and those that received a limited quality score were removed from further consideration and analysis. The quality assessment tool also assessed the estimates for fatal flaws, which are aspects of estimates that lead to misrepresentation of the true effectiveness, cost, or feature of the intervention (e.g., a very poor description of how patients were supported).

Effectiveness estimate. Points were assigned for baseline BP near normal, mean patient age <50 years, sample size <20, biased sample selection, poor description of randomization or not randomized at all, duration <6 months, no comparison group, baseline differences in intervention and control, only reported a post-intervention measure, attrition >20%, and any other aspect that may have impacted the effectiveness of the intervention. The estimate received an assessment of good if points totaled 0−3, fair if totaled 4−6, or limited if ≥7.

Cost estimate. Each cost estimate was first scored for how well it captured the drivers of cost (i.e., the cost of the personal measurement device, labor that delivered the intervention, devices and information technologies used for communication, and cost of any other resource-intensive component known to have been delivered in the intervention). The cost estimate received an assessment of good for capture of drivers if the total number of drivers not included in the estimate were 0−1, fair if it was 2, or limited if it was >2. The cost estimate was then scored for appropriateness of measurement and methods of estimation, with points assigned for sample size <20, inappropriate denominator for per capita cost, data external to study, intervention cost contaminated with other components such as healthcare effects, and any other aspect that may have impacted the cost of the intervention. The cost estimate received an assessment of good for measurement and methods if points totaled 0−2, fair if it totaled 3−4, or limited if ≥5. The final quality assigned to the cost estimate was the lower of the 2 quality assessments.

Intervention features. Points were assigned to the intervention description provided by the studies for failing to adequately describe staffing, materials and devices, activities, frequency of activities, setting, communication modes, time horizons, and any other aspect necessary for understanding the implementation process. Intervention features received a quality assessment of good if the points totaled 0−2, fair if it totaled 3−5, or limited if ≥6. The quality of the intervention cost per unit of effectiveness was based on the lower quality assigned to cost and the quality assigned to effectiveness.

RESULTS

As shown in Figure 1, a total of 1,728 records were identified from the database search, and an additional 38 were identified from the review by Jacob et al.[32] and manual searches. A total of 178 papers were assessed for eligibility. After excluding those that did not meet the inclusion criteria, were duplicates, or did not report hypertension change or cost, 33 papers were included. A total of 9 primary economic studies had multiple papers published on the same program or trial.[41−71] A total of 5 studies included >1 intervention arm.[42,45−48,50,51,63−65] The evidence for this review analyzed 22 studies, with a total of 28 intervention arms described in 33 papers. In the remaining part of this paper, studies with >1 associated paper will be referenced by the primary economic paper.

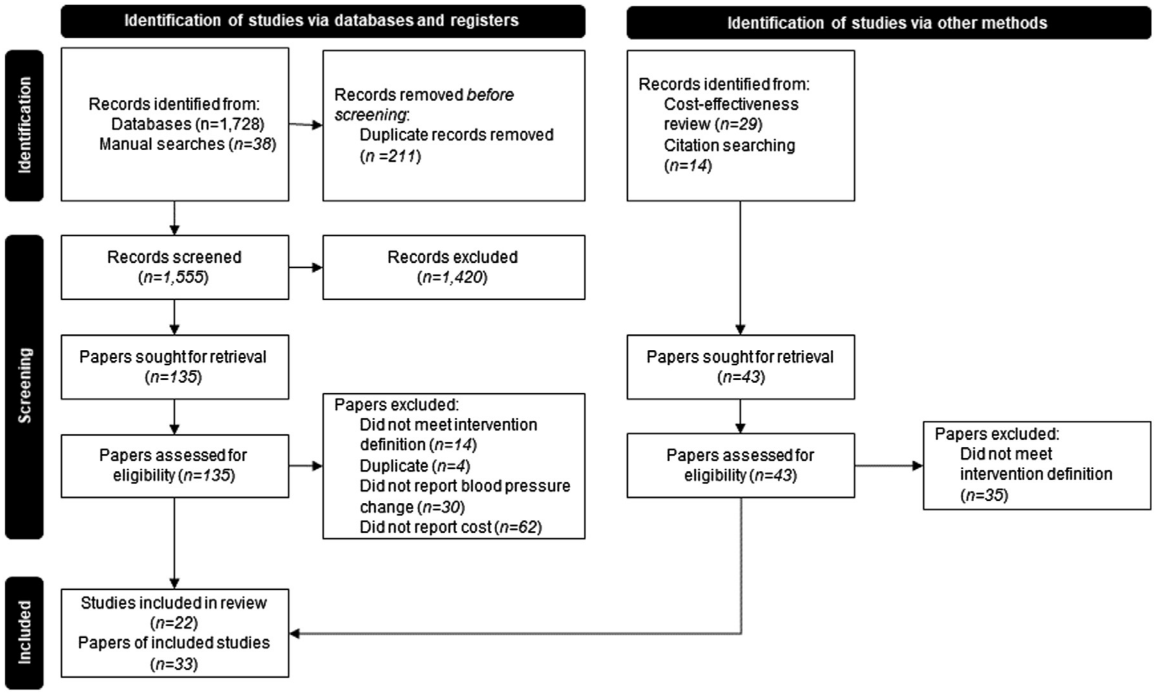

Figure 1. PRISMA 202,037 flow diagram for identification and selection of studies.

Quality of Estimates

A total of 23 estimates of change in SBP were of good quality (82.1%),[43,46,48–50,52–54,56,59,61–63,65,67,69,70,72] 4 were of fair quality (14.3%),[41,42,73] and 1 was of limited quality (3.6%) (Appendix, available online).[71] The more frequent limitations for the effectiveness estimates were short follow-up periods, lack of randomization, selection bias, and lack of control groups. The 1 arm that was of limited quality was due to a fatal flaw that only reported a change in percentage achieving BP control and not the actual change in SBP.[71] A total of 23 estimates of intervention cost were of good quality (82.1%),[43,46,48–50,53,54,56,59,61–63,65,67,69–71] 2 were of fair quality (7.1%),[41,52] and 3 were of limited quality (10.7%).[42,72,73] The more common limitations for quality of intervention cost estimates were insufficient information reported by studies to construct an estimate and the inability to separate the intervention cost from the healthcare cost reported in the study. The descriptions of all intervention arms were of good quality.[41–43,46,48–50,52,53,56,59,61,69–73]

Patient and Study Characteristics

The baseline patient characteristics are provided in Table 1. The median of mean age of patients was 63.0 (IQR=59.0–66.6) years, and the median percentage of patients who were female was 51.3% (IQR=45.8%–63.6%). The median percentage of patients who identified as White was 79.3% (IQR=53.8%–94.7%), and that of those identifying as Black was 43.0% (IQR=7.7%–100.0%) on the basis of 15 studies.[41,42,46,48–50,54,59,61–63,65,67,69,73] Two studies reported Hispanic or Latino representation of 35.8% and 55.6%.[49,69] Unemployment ranged from 5.6% to 93.4% among patients in 10 studies, with an overall mean unemployment status of 45.5%.[46,48,49,52,54,59,61,63,67,69] In the 11 studies that reported insurance status, 23.4% of patients had private insurance, 19.9% had Medicare, 4.7% were Medicaid eligible, and 15.6% were uninsured or self-paid.[43,50,53,59,62,63,65,67,69,71,73] Patients in 4 studies had a mean baseline SBP between 120 mmHg and 140 mmHg,[46,48,54,73] those in 7 studies had a mean SBP between 141 mmHg and 150 mmHg,[42,43,59,67,69,70,72] and those in 11 studies had a mean SBP >150 mmHg.[41,42,49,50,52,53,56,61–63,65]

Studies were conducted mainly in the U.S. (*n*=14, 63.6%),[41–43,46,48–50,52,54,59,65,69,71,73] whereas others were set in Denmark, Italy, Argentina, and the United Kingdom (*n*=8, 36.4%).[53,56,61–63,67,70,72] Of the 11 studies that reported urbanicity, most analyses were based in urban areas (76.9%),[41–43,52,53,59,65,67,69,72,73] although 1 study included both urban and rural areas in their sample (7.7%).[69] No studies were set in rural areas alone.

By definition, SMBP is performed by the patients in their homes or in settings familiar to the patient. As noted in Table 1, a total of 17 studies included primary

Table 1. Intervention Arm Patient Characteristics

Study (intervention arm)	Study design and sampling method	Sample size[a]	Mean age, years	% female	Race and ethnicity (%)	Income ≤$50,000 (%), unemployed (%)	Education (% >HS)	Insurance status (%)	Mean BP at baseline (mmHg)	CVD risk factors (%)[b]	Country, setting, F/U
Artinian (2001) (community)[c,42]	RCT, stratified random	26	59.0	88.5	Black= 100	N/A	N/A	N/A	155.3/89.4 (±17.0/11.0)	High BP=100	U.S., Community, 3 months
Artinian (home)[c,42]	RCT, stratified random	26	59.0	88.5	Black=100	N/A	N/A	N/A	148.8/90.2 (±13.8/5.8)	High BP=100	U.S., Community, 3 months
Billups (2014)[43]	RCT, random	175	60.0	38.3	N/A	N/A	N/A	Private=100	148.8/89.6	Uncontrolled HTN=100 HC=61 DM/pre-DM=46	U.S., PC, 6 months
Bondmass (2000)[41]	Pre/Post, NR	33	51.0	73.0	Black=100	75.0,[d] N/A	60.0	N/A	154.1/89.9 (±16/9.6)	High BP=100 Uncontrolled HTN=100 DM/pre−DM=21	U.S., HCC, 3 months
Davidson (2015)[49]	RCT, random	18	47.5	61.0	Black=44.4 Hispanic or Latino=55.6	71.8, 27.8	44.4	N/A	158/89	High BP=100 Uncontrolled HTN=100	U.S., PC, 6 months
Dehmer (2018)[59]	RCT, random, cluster	148	64.6	48.0	White=87.2 Asian=0.7 Black=8.1 Other=4.1	32.2, 5.6	82.8	N/A	158/89	High BP=100 Uncontrolled HTN=100 DM/pre-DM or CKD=36 Other=8	U.S., PC, 18 months
Dixon (2016)[67]	RCT, random, cluster	325	67.2	20.0	White=99.0%	N/A	N/A	Other=100(NHS)	147.6/81.2	N/A	U.K.,PC,12 months
Fishman (2013) (home + pharmacist)[50]	RCT, random	261	Range= 25−75	55.9	White=79.3 Asian=4.6 Black=8.0 Other=8.0	N/A	92	Private=100	152.2/88.9 (±10.4/8.1)	High BP=100	U.S., PC, 12 months
Fishman (2013) (home)[50]	RCT, random	259	Range= 25−75	45.9	White=86.1 Asian=3.5 Black=6.9 Other=3.5	N/A	92.7	Private=100	152.2/89.0 (±10/7.9)	High BP=100	U.S., PC, 12 months
Friedman (1996)[52]	RCT, random	133	76	75.0	Black=10.0	N/A, 91.0	25.0	N/A	169.5/86.1	High BP=100 DM/pre-DM=20	U.S., Community, 12 months
He (2017)[53]	RCT, random	743	56.1	52.6	N/A	N/A	N/A	Uninsured/self-Pay=100	151.7/92.2	Uncontrolled HTN=100 HC=42 DM/pre-DM=24 Other (History of MI and stroke)=13	Argentina, PC, 18 months
Kaambwa (2014)[61]	RCT, random	234	66.6	53.0	White=95.0 Asian=2.0 Black=2.0 Other=1.0	N/A, 16.0	N/A	N/A	151.9/85.2 (±1.2/1.4)	DM/pre-DM=8 Other (CHD)=9	UK, PC, 12 months
Katon (2012)[54]	RCT, random, cluster		57.4	48.0	White=75.0	N/A,10.0	61.0	N/A	136/N/A	N/A	U.S., PC, 12m
Madsen (2011)[56]	RCT, random	105	55.0	51.3	N/A	N/A	N/A	N/A	DT: 153.1/91.2 (±13.2/8.1) NT: 132.0/77.6 (±15.6/8.7)	Uncontrolled HTN=100 DM/pre-DM=8.8	Denmark, PC, 6 months
McManus (2021)[62]	RCT, random	305	65.2	47.5	Black=1.6 Asian=1.3 White=93.8 Other=3.3	N/A	N/A	Other=100% (NHS)	151.7/86.4	High BP=100 Uncontrolled HTN=100 DM/pre-DM=8.6 CVD=6.8 CKD=7.9	U.K, PC, 12 months
Monahan (2019) (SMBP)[63]	RCT, random	395	67.0	46.0	Black=2.0 Asian=2.0 White=95.0 Other=1.0	N/A	N/A	Other=100% (NHS)	152.9/85.1	High BP=100 DM/pre-DM=10	U.K, PC, 12 months

(continued on next page)

Table 1. Intervention Arm Patient Characteristics (*continued*)

Study (intervention arm)	Study design and sampling method	Sample size[a]	Mean age, years	% female	Race and ethnicity (%)	Income ≤$50,000 (%), unemployed (%)	Education (% >HS)	Insurance status (%)	Mean BP at baseline (mmHg)	CVD risk factors (%)[b]	Country, setting, F/U
Monahan (2019) (SMBP + telemonitoring)[63]	RCT, random	395	67.0	47.0	Black=2 Asian=2 White=95 Other=1.0	N/A	N/A	Other=100% (NHS)	153.2/85.5	High BP=100 DM/pre-DM=9	U.K, PC, 12 months
Moultry (2015)[73]	Pre/Post, quasi-experimental (no control)	306	74.0	83.0	Black=100	71.2, N/A	31.2	Medicare=100 Medicaid eligible=39.0	140/N/A	High BP=100 HC=51 DM/pre-DM=38	U.S., home, 6 months
Palmas 2010[70]	RCT, random	844	71.0	63.5	White=48.2 Black=15.3 Hispanic or Latino =35.8 Other=0.7	88.0,[d] 93.4	16.1	Medicare=100	142.8/84.5 (±24.21/11.35)	DM/pre-DM=100	U.S., PC/health center, 12 months
Parati (2009)[72]	RCT, random	187	57.2	45.5	N/A	N/A	N/A	N/A	Clinic: 148.4/88.7 (±12.6/7.4) DT: 139.4/83.9 (±11.0/8.0)	High BP=100 Uncontrolled HTN=100	Italy, PC, 6 months
Pezzin (2011) (basic)[65]	RCT, randomized	197	65.7	64.0	Black=100	45.0[e], N/A	N/A	Medicaid=43.0	155.9/86.7	High BP=100 Uncontrolled HTN=100	U.S, Home and PC, 3 months
Pezzin (2011) (augmented)[65]	RCT, randomized	221	64.2	70.0	Black=100	45.0[e], N/A	N/A	Medicaid=44.0	154.3/86.8	High BP=100 Uncontrolled HTN=100	U.S, Home & PC, 3 months
Reed (2010)[46]	RCT, stratified random	159	61.0	62.0	White=56 Black=43 Other=1.6	18.0[f],62.0	N/A	N/A	126/72	Uncontrolled HTN=30 DM/pre-DM=32	U.S., PC, 24 months
Stoddart (2013)[70]	RCT, random	200	60.5	42.0	N/A	N/A	N/A	N/A	146.2/87.1	Uncontrolled HTN=100	UK, PC, 6 months
Trogdon (2012)[71]	Pre/Post	N/A	Range=18–85	59.4	N/A	N/A	N/A	Private=100	N/A	High BP=100 Uncontrolled HTN=100	U.S., Home, 6m, N/A
Wang (2012) (behavioral)[48]	RCT, Stratified random	131	63.0	8.0	White=53.0 Black=45.0 Other=3.0	N/A, 66.0	N/A	N/A	129/77 (±19/12)	Uncontrolled HTN=42 DM/pre-DM=44 Other (10+ years HTN)=76	U.S., PC, 18 months
Wang (2012) (behavioral and medication)[48]	RCT, Stratified random	122	63.0	14.0	White=44.0 Black=52.0 Other=5.0	N/A, 65.0	N/A	N/A	127/77 (±21/13)	Uncontrolled HTN=35 DM/pre-DM=40 Other (10+ years HTN)=74	U.S., PC, 18 months
Wang (2012) (medication)[48]	RCT, Stratified random	126	64.0	7.0	White=49.0 Black=48.0 Other=3.0	N/A, 66.0	N/A	N/A	132/78 (±21/14)	Uncontrolled HTN=48 DM/pre-DM=43 Other (10+ years HTN)=77	U.S., PC, 18 months
Summary median (IQI)		374.0 (268.0–591.0)	Mean age=63.0 (59.0–66.6)	51.3% (45.8–63.6%)	White=79.3% (53.8–94.7%) Black=43.0% (7.7–100.0%)	Income=45.0 (45.0–71.2) unemployment= 63.5 (21.9–70.5)	52.2 (31.2–82.8)	N/A	SBP=151.7 (144.5–153.2) DBP=86.7 (84.5–89.0)	N/A	F/U=12 months (6–12)

[a]Includes the total sample at F/U.

[b]*High BP is* defined as above 130/80 mmHg unless defined otherwise by the study authors. *Uncontrolled HTN is* defined as the patient not taking steps to lower their BP (e.g., taking medications, exercising, and/or healthy diet).

[c]Reported baseline characteristics for the entire sample, not for individual arms.

[d]Reported income ≤$40,000 (2018) USD.

[e]Reported income ≤$10,000.

[f]Reported inadequate income (i.e., difficulty paying bills).

BP, blood pressure; CHD, chronic heart disease; CKD, chronic kidney disease; CVD, cardiovascular disease; DBP, diastolic blood pressure; DM, diabetes mellitus; DT, daytime; F/U, follow up; HC, high cholesterol; HCC, healthcare center; HS, high school; HTN, hypertension; MI, myocardial infarction; N/A, not applicable as limited or no information available; NHS, National Health Service; NR, not reported; NT, nighttime; PC, primary care clinic; SBP, systolic blood pressure; SMBP, self-measured blood pressure monitoring; UK, United Kingdom; USD, U.S. dollar.

care centers and other clinics as a part of the intervention activities.[43,46,48−50,53,54,56,59,61−63,65,67,69,70,72] One study involved a study or research center in addition to the patient homes.[73] In the case of 1 intervention arm, patients had their levels measured at a community center.[42] The mean follow-up period was 10.0 months.[41−43,46,48−50,52,53,56,59,61−63,65,69−73]

Intervention Features

Support type. As shown in Table 2, additional support was provided for medication management in 15 intervention arms,[41,43,48,54,56,59,61−63,65,70,72,73] for medication adherence in 17 arms,[42,46,48−50,52−54,59,61,63,65,67,73] for lifestyle modifications in 15 arms,[42,43,46,48,50,53,54,59,61,62,65,67,73] and for patient education in 13 arms.[41,48,50,54,62,65,67,69−71]

Provider type. Providers included physicians (*n*=9, 40.9%),[48,52,54,56,62,63,69,70,72] nurses (*n*=12, 54.5%),[41,42,46,48,49,54,63,65,69−72] pharmacists (*n*=4, 18.2%),[43,50,59,73] community health workers (*n*=1, 4.5%),[53] and nutritionists (*n*=1, 4.5%).[49] In 12 studies, >1 type of personnel conducted the intervention.[41,48,49,52,54,63,69−73]

Devices and technology. Technologies used in the SMBP intervention included telemetry devices (*n*=12, 54.5%),[41−43,46,48,49,52,56,61,63,70,72] telemedicine devices (*n*=1,4.5%),[69] a personal digital assistant (*n*=1, 4.5%),[56] home BP device (*n*=20, 90.9%),[41−43,46,48−50,52−54,56,59,61−63,65,67,70,72,73] interactive phone systems (*n*=4, 18.2%),[42,43,52,71] an electronic medication tray (*n*=1, 4.5%),[49] mobile phones (*n*=4, 18.2%),[49,53,56,70] a mobile phone application (*n*=1, 4.5%),[49] text messaging services (*n*=3, 13.6%),[53,63,70] and web and server hosting services (*n*=16, 72.7%).[41−43,48−50,53,56,59,61−63,67,69,70,72]

Patient−provider interactions. Patient and provider communication methods regarding hypertension control, lifestyle counseling, and medication adherence varied. Studies reported initial interactions with the patients occurring in the patient's home (*n*=5, 22.7%),[42,52,53,65,73] at clinics (*n*=12, 54.5%),[43,46,56,59,61−63,69,72] in a community center (*n*=1, 4.5%),[42] and by phone (*n*=1, 4.5%).[50] These often included collecting baseline measurements, training on the use of the devices, and providing reading materials on how to lower BP. Subsequent interactions between patients and providers occurred by phone (*n*=14, 63.6%),[41−43,46,48,54,56,59,61−63,65,67,69,72,73] website (*n*=3, 13.6%),[50,56,69] e-mail (*n*=4, 18.2%),[56,63,65,70] text messages (*n*=4, 18.2%),[49,53,63,70] telemetry devices (*n*=14, 63.6%),[41−43,46,48−50,52,56,59,61,63,70,72] telemedicine devices (*n*=1, 4.5%),[69] or home visits (*n*=2, 9.1%).[53,73] A total of 5 studies (22.7%)[41,50,56,70,72] reported additional interactions as needed (e.g., when a provider is alerted that BP is not controlled or when a patient requested contact). Automated messaging was reported in 2 studies (9.1%),[41,70] whereas messaging tailored to the patient was reported in 4 studies (18.2%).[48−50,70] Frequency of interaction was reported to be weekly for 3 studies (13.6%),[42,52,65] biweekly for 2 studies (9.1%),[50,73] and bimonthly for 1 study (4.5%).[46]

Intervention Effect, Cost, and Cost per Unit of Effectiveness

Effectiveness. The median reduction in SBP was 3.8 (IQR=2.9−6.9) mmHg on the basis of 27 estimates.[41−43,46,48−50,52,53,56,59,61,69,70,72,73] Table 3 denotes the effectiveness sorted according to reduction in SBP. The difference in median effectiveness between the most and least effective set of interventions was 11.2 mmHg. When comparing the 8 intervention arms with the greatest reduction in SBP (median=12.7, IQR=9.2−15.5)[41−43,49] and the least reduction in SBP (median=1.5, IQR=0.6−2.6),[48,50,56,72] the mean age and baseline SBP were 59 years and 152 mmHg and 65 years and 145 mmHg, respectively. Studies that reported greater reductions in SBP had patients with higher baseline SBP and relatively younger patients; engaged nurses and pharmacists as implementers; and utilized smartphones, interactive phone systems, and telemetry devices. Duration, geographic location, and support type did not impact effectiveness.

Implementation cost. The median intervention cost per patient to implement SMBP interventions was $47 per month (IQR=$19−$123) on the basis of 25 estimates.[41−43,46,48−50,52,53,56,59,61,69−71] The sorted order by cost is shown in Table 3. The difference in median intervention cost between the costliest and least costly set of interventions was $167 per patient per month. When comparing the 8 least costly intervention arms (median=$7, IQR=$5−$15)[41,48,49,59,69] with the 8 most costly (median=$174, IQR=$137−$293),[46,50,52,53,70] the mean age, baseline SBP, and intervention group size were 66 years, 148 mmHg, and 347 patients and 58 years, 148 mmHg, and 212 patients, respectively. Studies that reported lower costs included interventions targeting older patients and large sample sizes; engaging community health workers; utilizing smartphones and their applications, websites, and servers; and providing patient−provider interactions on an as-needed basis. U.S.-based studies, those that had home visits, and those that required frequent and standardized patient

Table 2. Self-Measured Blood Pressure Monitoring With Support: Intervention Features

Study (intervention arm)	Type of support	Type of provider	Devices and technology	Frequency and mode of patient–provider interactions
Artinian (2001) (community)[42]	HTN medication adherence and patient lifestyle	Nurse	Telemetry from community health center, IPS	Weekly. Nurse by phone. First meeting face-to-face
Artinian (2001) (home)[42]	HTN medication adherence and patient lifestyle, Home visits	Nurse	Telemetry, IPS, home BP device, Internet	Weekly. Nurse by phone. First meeting face-to-face
Billups (2014)[43]	HTN medication management and patient lifestyle	Pharmacist	Telemetry, Website, IPS, home BP device	As needed. Secure website or phone call. Initial face-to-face
Bondmass (2000)[41]	HTN medication management and patient education, Home visits	Nurse, IT technicians	Telemetry, Server, Home BP device	As needed. Nurse by phone
Davidson (2015)[49]	HTN medication adherence	Research assistants, nurse manager, nutritionist	Telemetry, electronic medication tray, mPhone, mPhone app, server, home BP device	Nurse manager and PCP informed if BP readings were extreme. Automated tailored text messages
Dehmer (2018)[59]	HTN medication management and adherence, and patient lifestyle, Case Manage	Pharmacist	Home BP device, website	Fifteen times. Telephone. First meeting face-to-face
Dixon (2016)[67]	HTN medication adherence, patient education, and patient lifestyle	HIAs	Home BP device, website	Up to 13 scheduled telephone encounters delivered approximately every 4 weeks
Fishman (2013) (home + pharmacist)[50]	HTN medication adherence, patient education, and patient lifestyle	Pharmacist	Website, Home BP device	Biweekly through website. Initial phone call and secure message. Subsequent interactions through the website
Fishman (2013) (home)[50]	Patient education	None	Website, Home BP device	Initial screening in primary care clinic. Instructed to contact PCP if BP not controlled
Friedman (1996)[52]	HTN medication adherence, Home visits	Field technicians, physician	IPS, home BP device	Weekly. Initial screening by phone. Automated questions and responses by phone
He (2017)[53]	HTN medication adherence and patient lifestyle, Home visits	CHW	Text messages, mPhone, Website, Server, Home BP device	Frequency not reported. Face-to-face and text messages
Kaambwa (2014)[61]	HTN medication management and patient lifestyle	Study personnel	Telemetry, Website, Server, Home BP device	Monthly summaries to physician. Initial face-to-face with physician. Phone call to patient triggered by abnormal readings. Request may be made to meet the physician
Katon (2012)[54]	HTN medication management and adherence and patient lifestyle and patient education	Nurse manager, Physician	Home BP device	Nurse manager reviewed BP readings, glucose, and laboratories, contacting patients 2–3 times a month initially and followed up with patients every 4–6 weeks over 12 months, with more frequent calls or visit for not at target or relapses
Madsen (2011)[56]	HTN medication management	Physician	Telemetry, PDA, mPhone, Website, Server, Home BP device	As needed. Physician by PDA, website, and e-mail
McManus (2021)[62]	Medication management and adherence and patient lifestyle and education	Physician	Home BP device, website, internet	As needed. Patient reminders by e-mail. Optional behavioral support by face-to-face, telephone, or e-mail
Monahan (2019) (SMBP)[63]	HTN medication management and adherence	Nurse, physician	Home BP device	Clinicians review readings monthly
Monahan (2019) (SMBP + telemonitoring)[63]	HTN medication management and adherence	Nurse, physician	Home BP device, telemetry, internet, SMS alerts	Automated e-mail messages to providers and participants for drug modifications based on readings. SMS included alerts, warnings, reminders for readings not at goal. Readings are sent weekly and physicians are asked to review readings every month
Moultry (2015)[73]	HTN medication management and adherence, and patient lifestyle, Home visits	Pharmacist, pharmacy students, health educator, public health professional	Home BP device	2 home visits by a pharmacist (initial and 6 months follow-up). Follow-up biweekly phone calls by pharmacy students
Palmas (2010)[69]	T2DM treatment, patient education	Nurse, case manager, endocrinologist, physician	Home telemedicine unit, Computer, Website, Internet, Server	Frequency not reported. Videoconference, secure messaging, and EMR

(*continued on next page*)

Table 2. Self-Measured Blood Pressure Monitoring With Support: Intervention Features (*continued*)

Study (intervention arm)	Type of support	Type of provider	Devices and technology	Frequency and mode of patient–provider interactions
Parati (2009)[72]	HTN medication management	Call center (nurse, physician)	Telemetry, Server, Home BP device	As needed. Nurse by phone. Alert to physician. Nonroutine visit if BP is high. Routine 3 visits face-to-face
Pezzin (2011) (basic)[65]	Home visits, patient and provider education materials	Nurse	Home BP device	2 emails 1 week apart sent to patients and their home care nurse
Pezzin (2011) (augmented)[65]	HTN medication management and adherence, patient education, patient lifestyle, and home visits	Nurse	Home BP device	Study nurse and health educator provided extensive feedback to the home nurse and patient. Biweekly phone calls were made over a 12-week period
Reed (2010)[46]	HTN medication adherence and patient lifestyle	Research assistant, nurse	Home BP device, telemetry	Bimonthly. Nurse by phone
Stoddart (2013)[70]	HTN medication management and patient education	Nurse, physician	Telemetry, Text messages, mPhone, Website, Server, Home BP device	Physician−patient contact if BP is not controlled or therapy change is needed. Automated text and e-mail messages regarding BP control
Trogdon (2012)[71]	HTN patient education and self-management	Analyst, nurse, clerical and quality consultant, health program specialists	IPS	No interaction beyond program management. Patient education through IPS and self-care kit
Wang (2012) (behavioral)[48]	HTN education, medication adherence, and patient lifestyle	Nurse	Telemetry, Server, Home BP device	11 tailored modules. Nurse by phone
Wang (2012) (behavioral and medication)[48]	HTN medication management and adherence, patient education, and patient lifestyle	Nurse, physician	Telemetry, Server, Home BP device	11 tailored modules. Nurse by phone. As needed. Nurse alerted to high BP
Wang (2012) (medication)[48]	HTN medication management	Nurse, physician	Telemetry, Server, Home BP device	As needed. Nurse alerted to high BP

BP, blood pressure; CHW, community health worker; EMR, electronic medical record; HIA, health information advisor; HTN, hypertension; IPS, interactive phone system; IT, information technology. mPhone, mobile phone; PCP, primary care provider; T2DM, type 2 diabetes mellitus; PDA, personal digital assistant; SMBP, self-measured blood pressure monitoring; SMS, short message service.

−provider encounters cost more. Baseline SBP, support type, and the use of telemetry devices did not impact the cost.

Cost per unit of effectiveness. The median monthly intervention cost per mmHg reduction in SBP was $5.50 (IQR=$3.60−$23.10) on the basis of 24 estimates.[41−43,46,48−50,52,53,56,59,61,69,70] Table 3 provides the sorted order. As the cost per mmHg is calculated as the ratio of cost and SBP reduction, intervention arms with a lower cost per mmHg also have lower intervention cost, greater effectiveness, or both. When comparing the 8 arms with the smallest monthly cost per mmHg (median=$2.01, IQR=$1.01−$3.86)[42,43,50,53,70] with the 8 largest (median=$54.90, IQR=$24.80−$106.55),[48,59,69] the mean age, baseline SBP, and intervention group size were 65 years, 151 mmHg, and 312 patients and 62 years, 141 mmHg, and 237 patients, respectively. Studies that reported a smaller monthly cost per mmHg involved patients with higher baseline SBP; had large patient groups; used smartphones, interactive phone systems, and websites; and provided patient−provider interactions on an as-needed basis. As seen with the intervention cost, U.S.-based studies and those that required frequent and standardized patient−provider encounters had the largest monthly cost per mmHg. Patient age, support type, provider type, and the use of telemetry devices did not impact the cost per unit of effectiveness.

In summary, larger patient samples and higher baseline SBP were associated with a lower cost per unit of effectiveness. Patient age is negatively associated with both cost and effectiveness. Neither the type of support nor the type of personnel providing the support was associated with differences in cost per unit of effectiveness, although engaging community health workers was associated with lower cost. Accessible technologies that facilitated patient participation and engagement (e.g., interactive phone systems, websites, smartphones, and telemetry devices) were not associated with much higher costs but were associated with greater effectiveness. Intervention protocols that triggered patient−provider interactions on an as-needed basis rather than a standardized frequency of interactions were associated with lower cost and greater effectiveness.

DISCUSSION

The use of SMBP interventions with support from healthcare professionals is internationally recognized as an effective means of reducing BP as evidenced by the

Table 3. Cost, Effectiveness, and Cost per Unit of Effectiveness and Associated Sort Order of Included Studies

Study (intervention arm)	Effectiveness: reduction in SBP			Cost per patient per month			Cost per unit of effectiveness: cost per month per mmHg reduction in SBP		
	Estimate quality	mmHg	Sort order[a]	Estimate quality	U.S. $	Sort order[b]	Estimate quality	U.S. $	Sort order[c]
Trogdon (2012)[71]	Limited	N/A	N/A	Good	47.6	14	Limited	N/A	N/A
Artinian (2001) (home)[42]	Fair	24.8	1	Good	67.6	16	Fair	2.8	5
Davidson (2015)[49]	Good	23	2	Good	142.1	20	Good	6.2	13
Artinian (2001) (community)[42]	Fair	13.0	3	Limited	N/A	N/A	Limited	N/A	N/A
Bondmass (2000)[41]	Fair	12.7	4	Fair	178.2	22	Fair	14.0	16
Billups (2014)[43]	Good	12.6	5	Good	47.4	13	Good	3.8	6
Fishman (2013) (home + pharmacist)[50]	Good	9.8	6	Good	40.3	12	Good	4.1	8
He (2017)[53]	Good	7.2	7	Good	6.7	4	Good	0.9	2
Dehmer (2018)[59]	Good	6.6	8	Good	169.0	21	Good	25.6	18
Kaambwa (2014)[61]	Good	5.5	9	Good	29.6	10	Good	5.4	10
Friedman (1996)[52]	Good	4.7	10	Fair	21.4	9	Fair	4.5	9
Monahan (2019)[63] (SMBP + Telemonitoring)	Good	4.7	11	Good	4.9	3	Good	1	3
Stoddart (2013)[70]	Good	4.51	12	Good	18.0	7	Good	4.0	7
Reed (2010)[46]	Good	3.9	13	Good	20.8	8	Good	5.4	11
Palmas (2010)[69]	Good	3.6	15	Good	798.0	25	Good	221.7	23
Pezzin (2011) (augmented)[65]	Good	3.8	14	Good	346.7	24	Good	91.3	21
Wang (2012) (behavioral and medication)[48]	Good	3.6	16	Good	79.9	17	Good	22.2	17
Moultry (2015)[73]	Fair	3.0	20	Limited	N/A	N/A	Limited	N/A	N/A
Madsen (2011)[56]	Good	2.5	22	Good	31.7	11	Good	12.7	15
Monahan (2019)[63] (SMBP)	Good	3.5	17	Good	1.9	1	Good	0.5	1
Wang (2012) (medication)[48]	Good	1.2	24	Good	88.4	18	Good	73.6	20
Fishman (2013) (home)[50]	Good	0.7	25	Good	6.8	5	Good	9.7	14
Katon (2012)[54]	Good	3.4	18	Good	123.0	19	Good	36.2	19
McManus (2021)[62]	Good	3.4	19	Good	4.2	2	Good	1.2	4
Parati (2009)[72]	Good	0.2	26	Limited	N/A	N/A	Limited	N/A	N/A
Wang (2012) (behavioral)[48]	Good	−2.2	27	Good	65.6	15	Good	−29.9	24
Dixon (2016)[67]	Good	2.7	21	Good	15.0	6	Good	5.6	12
Pezzin (2011) (basic)[65]	Good	1.8	23	Good	274.4	23	Good	152.4	22
Totals	Good=23 Fair=4 Limited=1	Median (IQR)=3.8 (2.9−6.9)	-	Good=23 Fair=2 Limited=3	Median (IQR)=47 (18.0−123.0)	-	Good=21 Fair=3 Limited=4	Median (IQR)=5.5 (3.6−23.1)	–

[a]Sorted from most effective (1) to least effective (27).
[b]Sorted from least costly (1) to most costly (25).
[c]Sorted from lowest intervention cost per unit of effectiveness to (1) to highest intervention cost per unit of effectiveness (24). Excludes studies marked with N/A.
N/A, not applicable; SBP, systolic blood pressure; SMBP, self-measured blood pressure monitoring.

current research and numerous guidelines available.[10−30] Previous research also indicates that SMBP interventions with support are cost effective in terms of intervention cost and healthcare costs.[32] However, there is no literature, to the authors' knowledge, examining the impact of patient characteristics and intervention features on the effectiveness, cost, and cost per unit of effectiveness of SMBP interventions.

The methods used in this review prevent drawing causal inference, and all conclusionary statements were therefore couched in terms of the association between observed intervention and population features and outcomes. However, the strength of this study is that it applied systematic review methods in unpacking the implementation of SMBP monitoring interventions for different patient populations. Although causal inferences were precluded with the relatively small number of studies, the results indicating how features and characteristics are associated with higher or lower effectiveness, cost, and cost effectiveness are useful information to guide both researchers and implementers. For example, a wireless-enabled BP home device coupled with a patient website accessible through cell phones is likely optimal for a younger patient population with the prevalent use of smartphones. Synchronous care processes such as expensive telemedicine devices are not necessary for records of home BP readings to guide provider actions that achieve BP control.

Many of the interventions in the included studies were conducted before 2010 and used a variety of devices and technology to facilitate support, with some more costly and sophisticated than others at the time. Recent and improved communication technologies, particularly smartphones, have enabled the use of more interactive digital health interventions. Information was not available to assess how these new technologies will impact cost, effectiveness, and cost per unit of effectiveness of SMBP with support interventions.

Limitations

There are a few limitations to this review. First, the findings from this review are based on qualitative methods that do not account for what may be important covariates of intervention cost, effectiveness, and intervention cost per unit of effectiveness. For example, an intervention may report a smaller intervention cost per mmHg reduction in SBP because it was delivered by a lay health worker instead of by a nurse or physician. However, it may have also cost less because it was delivered to more patients or may have been more effective because the baseline SBP was high. The relatively small number of studies (observations) and the heterogeneity in intervention features precluded the use of analytic methods such as meta-analysis that would have controlled for these covariates.

Second, there was a lack of information regarding coverage for the devices. As telemetry, telehealth, and telemedicine devices become standard features or electronic health and medical records, the cost of these interventions may be impacted. All the included studies were funded trials or demonstrations where the personal BP monitors and any ancillary devices were provided at no cost to the patients. Some healthcare plans and Medicaid offer coverage and reimbursement options for SMBP monitoring interventions; however, coverage remains a limitation to the wider implementation of SMBP.[74] Although the cost of validated devices is relatively inexpensive, questions about financing and reimbursement for the devices and supportive services rendered were not addressed in the included studies or in this review.

Third, the samples of many of the included studies lacked representativeness. This literature lacks information on the benefit of SMBP monitoring interventions for patients of some ethnic minorities. Many studies included majority Caucasians and African Americans, although few included Hispanics or Latinos.

Implications

The use of SMBP interventions with support can beneficially impact patient care and healthcare costs.[31,32] There are implications for future research and public health practice as well because implementation science plays a key role in health care.[17−30,33] Implementation and training resources for SMBP monitoring are available to patients and providers[75−78]; however, the lack of relevant research on the intervention features may contribute to the time lag between research and practice.[79,80] The results of this review contribute to the body of evidence promoting hypertension control for heart disease and stroke prevention with SMBP interventions. Evidence shows that future research in SMBP monitoring interventions, including standardized information and reimbursement for SMBP devices, may support implementation in specific settings.

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SUPPLEMENTAL MATERIAL

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