American Journal of
Preventive Medicine

RESEARCH ARTICLE

The Health and Economic Impact of Expanding Home Blood Pressure Monitoring

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Introduction: Home blood pressure monitoring is more convenient and effective than clinic-based monitoring in diagnosing and managing hypertension. Despite its effectiveness, there is limited evidence of the economic impact of home blood pressure monitoring. This study aims to fill this research gap by assessing the health and economic impact of adopting home blood pressure monitoring among adults with hypertension in the U.S.

Methods: A previously developed microsimulation model of cardiovascular disease was used to estimate the long-term impact of adopting home blood pressure monitoring versus usual care on myocardial infarction, stroke, and healthcare costs. Data from the 2019 Behavioral Risk Factor Surveillance System and the published literature were used to estimate model parameters. The averted cases of myocardial infarction and stroke and healthcare cost savings were estimated among the U.S. adult population with hypertension and in subpopulations defined by sex, race, ethnicity, and rural/urban area. The simulation analyses were conducted between February and August 2022.

Results: Compared with usual care, adopting home blood pressure monitoring was estimated to reduce myocardial infarction cases by 4.9% and stroke cases by 3.8% as well as saving an average of $7,794 in healthcare costs per person over 20 years. Non-Hispanic Blacks, women, and rural residents had more averted cardiovascular events and greater cost savings related to adopting home blood pressure monitoring compared with non-Hispanic Whites, men, and urban residents.

Conclusions: Home blood pressure monitoring could substantially reduce the burden of cardiovascular disease and save healthcare costs in the long term, and the benefits could be more pronounced in racial and ethnic minority groups and those living in rural areas. These findings have important implications in expanding home blood pressure monitoring for improving population health and reducing health disparities.
Am J Prev Med 2023;000(000):1−8.

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0749-3797/$36.00
https://doi.org/10.1016/j.amepre.2023.05.010

INTRODUCTION

Hypertension is a key risk factor for cardiovascular disease (CVD), the leading cause of morbidity and mortality around the world.[1−3] In the U.S., nearly half of adults (47%) have *hypertension*, defined as having a systolic blood pressure (BP) >130 mmHg or a diastolic BP >80 mmHg or being on medication for hypertension.[4] Hypertension prevalence is particularly high for non-Hispanic Black adults (56%), whereas BP control among those who have been prescribed BP medications is lower for Hispanic adults (25%) and non-Hispanic Black and Asian adults (25% and 19%, respectively) than for non-Hispanic White adults (32%).[5−7]

Accurate BP measurement is essential in hypertension diagnosis and treatment. Clinic BP monitoring (CBPM) is a common method used to measure BP and diagnose hypertension, but it may result in false diagnoses owing to masked hypertension (normal/high normal BP in the office but elevated at home) and white-coat hypertension (high office BP but normal BP on home measurements).[8] Home BP monitoring (HBPM), which refers to the self-monitoring of BP at home, is more convenient and effective than CBPM in diagnosing and managing hypertension.[9−11]

Despite its high effectiveness, HBPM has not been widely adopted in the U.S. because of limited health insurance coverage and lack of investment in preventive services.[12] A study conducted by the Kaiser Permanente Health System evaluated the cost-effectiveness of HBPM versus usual care among 430 patients who were randomized to receive either intervention.[13] The study found that HBPM was cost saving because patients in the HBPM group had better hypertension control and fewer hypertension-related office visits than those in the usual care group after one year.[13] However, another randomized trial conducted by Kaiser Permanente Colorado found that HBPM resulted in higher healthcare costs than usual care owing to increased use of antihypertensive medications and the additional cost of clinically certified BP monitoring devices.[14] Despite higher costs, HBPM resulted in significantly improved hypertension control and an incremental cost-effectiveness ratio of $3,330 per life-year gained.[14] In Japan, the introduction of HBPM for the diagnosis and treatment of hypertension led to decreased medical costs after five years of implementation owing to improved BP control.[15]

Given the growing interest in the wide adoption of HBPM, the American Heart Association and the American Medical Association published a joint policy statement in 2020 on using self-measured BP monitoring at home.[8] After reviewing the most recent literature, the policy statement concluded that there was still a lack of evidence on the economic impact of HBPM.[8] This study aims to provide additional evidence by assessing the long-term health and economic impact of adopting HBPM among U.S. adults with hypertension.

METHODS

A previously developed microsimulation model of CVD was used to conduct the simulation analyses. The model has been validated and used to assess the health and economic impact of different CVD prevention strategies such as smoking cessation, physical activity promotion, and telehealth-delivered dietary interventions.[16−18] In the model, the behaviors and health factors of simulated individuals evolve simultaneously and interactively as time passes. Changes in health behaviors and factors can then influence the probability of developing CVD for the simulated individual. Published data from the Framingham Heart Study were used to derive the equations for the calculation of the initial and transition probabilities of developing myocardial infarction (MI) and stroke, 2 of the most common and severe CVD outcomes.[19,20] Once a CVD event occurs, individuals are at-risk of secondary or recurrent CVD events and CVD-related death. Each individual was assumed to experience at most 2 CVD-related events per year. The model can track the health conditions of simulated individuals and then calculate the cumulative incidence of each health outcome of interest. The model was programmed using the software AnyLogic, version 8.4, which is a specialized platform for developing complex simulation models.[21]

Study Sample

Data from the 2019 Behavioral Risk Factor Surveillance System (BRFSS) were used to determine the health and demographic profile of U.S. adults with hypertension that will be simulated by the microsimulation model.[22,23] The BRFSS is a telephone survey conducted annually among adults aged ≥18 years in the U.S. The survey includes questions about preventive health practices and chronic health conditions, and the participants provide self-reported responses. Data on the age, sex, race, ethnicity, BMI, rural or urban residence, physical activity, dietary behaviors, diabetes, hypertension, and high cholesterol of all survey respondents were extracted. Then, the mean and SD of age for the simulated population and the proportion of each category for all other variables were estimated. This way, the model can simulate a population with the characteristics that were found in the BRFSS population with hypertension. Because BRFSS does not provide BP measures, BP measures were not used, but hypertension control was treated as a binary variable. The model also assumed that individuals achieving hypertension control owing to the HBPM intervention would have CVD risk lowered to that of the average person with controlled hypertension, and it was estimated that 26.1% of adults with hypertension had their BP under control on the basis of a recent study from the U.S. Centers for Disease Control and Prevention.[6]

Measures

On the basis of a recent meta-analysis of all studies since 2000 that included HBPM in people with hypertension compared with usual care, HBPM is associated with a significant increase in the prevalence of BP control (RR=1.43; 95% CI=1.16, 1.79).[8,10] This evidence was used to capture the effect of HBPM on BP control, which was then linked to long-term CVD outcomes in the microsimulation model. It is worth noting that the modeled intervention was not HBPM alone but a range of HBPM interventions synthesized in the meta-analysis that included cointerventions such as web feedback and telecounseling.[10] On the basis of the meta-analysis, the adoption of HBPM alone would have little to no impact without cointerventions.[10]

This study estimated healthcare cost parameters using actual healthcare payment data estimated from the Medical Expenditure Panel Survey.[24] Specifically, each simulated individual would accrue annual age-specific background cost when the person has not yet developed CVD (i.e., MI and stroke). When a simulated individual has an MI or stroke event, the specific cost associated with the event would be added to the total healthcare costs. A cost-effectiveness analysis was not conducted because the modeled intervention covered a range of interventions synthesized in the meta-analysis. Thus, the intervention costs that may include antihypertensive medication, patient navigation, and telecounseling were not considered. All healthcare costs were discounted at 3% and presented in 2019 U.S. dollars.[25] Sensitivity analysis was conducted to assess the impact of different discount rates on healthcare costs.

Statistical Analysis

This study includes two simulation scenarios: HBPM and usual care. In the HBPM simulation scenario, all the simulated individuals receive HBPM starting at time zero. Similarly, in the CBPM simulation scenario, the same set of simulated individuals receive CBPM starting at time zero. This setting allows the simulation model to mimic the intervention and control of a clinical trial. For each scenario, 100,000 adults with hypertension and no history of CVD were simulated. Individuals with uncontrolled BP in the intervention group would have a higher chance of having their BP under control than those in the control group with an RR of 1.43.[10] The model then projected the cumulative cases of MI and stroke as well as healthcare costs associated with CVD over a 20-year period (from 2019 to 2039). This simulated population was representative of U.S. adults with hypertension. The averted cases of MI and stroke and healthcare cost savings among U.S. adults with hypertension were calculated should simulated individuals adopt HBPM instead of usual care. This study further calculated the reductions in the incidence of MI and stroke and the associated healthcare costs by sex, race, and ethnicity as well as by their residential location (rural/urban) to examine the impact of HBPM on health disparities in the long term. Across the subpopulations, the same intervention was applied. The simulation analyses were conducted between February and August 2022. Ethics review was exempted because this is a simulation study.

RESULTS

Table 1 reports the demographic characteristics of U.S. adults with hypertension, overall and by race and ethnicity and rural/urban area, on the basis of data from the 2019 BRFSS. The mean age of the overall population was 57.7 years. About 80.2% of non-Hispanic Blacks did not smoke, whereas 86.1% of Hispanics did not smoke. About 51.5% of non-Hispanic Whites had a healthy diet, whereas the proportions were only 43.8% and 41.6% for non-Hispanic Blacks and Hispanics, respectively. Rural residents had fewer healthy behaviors because they had lower percentages of eating a healthy diet, being physically active, or smoking than urban residents. Non-Hispanic Whites were more likely to have high cholesterol and a history of MI than Hispanics and non-Hispanic Blacks. Among all the races, non-Hispanic Blacks had the highest percentage of having a history of stroke at 9.5%.

Table 2 presents the projected MI and stroke cases and healthcare costs among the simulated U.S. adults with hypertension in 20 years. Under the usual care

Table 1. Population Demographics and Health Profiles Among U.S. Adults with Hypertension

		Race/ethnicity			Rural/urban	
Demographic and health variables	**All**	**Whites**	**Blacks**	**Hispanics**	**Rural**	**Urban**
Age, years, mean (SD)	57.7 (0.1)	59.6 (0.1)	55.5 (0.2)	52.3 (0.3)	59.2 (0.2)	57.6 (0.1)
Female, %	49.4	48.4	54.7	50.5	49.4	49.4
Health behaviors						
No smoking, %	83.8	84.0	80.2	86.1	81.1	83.9
Healthy diet,[a] %	49.1	51.5	43.8	41.6	46.8	49.6
Physical active,[b] %	48.1	50.8	41.7	40.4	43.4	48.9
Healthy weight,[c] %	20.8	21.4	17.8	17.5	18.4	21.1
Comorbidities						
Diabetes, %	24.7	22.0	29.4	30.7	26.1	24.5
High cholesterol, %	53.2	54.8	48.2	50.5	54.7	53.0
Cardiovascular disease						
History of MI, %	9.3	9.9	7.2	8.4	11.8	9.1
History of stroke, %	7.4	7.2	9.5	5.7	8.7	7.3

Note: Data were estimated from the 2019 Behavioral Risk Factor Surveillance System.
[a]Healthy diet means a person consumes both fruit and vegetable for 1 or more times per day.
[b]Physically active means a person has more than 150 minutes of physical activity per week.
[c]Healthy body weight means a person has a BMI <25 kg/m^2.

scenario, the model estimated that there would be 238,127 (95% CI=216,219; 260,034) MI cases and 227,790 (95% CI=207,061; 248,518) stroke cases per one million people. If HBPM were adopted, a total of 11,906 MI cases (or 4.9%) and 8,656 stroke cases (or 3.8%) per one million people could be averted. The model also projected that an average of $7,794 in healthcare costs (or 4.4%) per person could be saved over 20 years in this population owing to HBPM adoption and the subsequent reduced CVD cases.

Figure 1 reports the projected reductions in MI and stroke cases as well as healthcare cost savings by sex, race, and ethnicity. Compared with usual care, HBPM could avert MI cases by 7.63% among non-Hispanic Black women, 5.40% among Hispanic women, and 2.29% among non-Hispanic White women (p<0.001). HBPM could also avert MI cases by 7.14% among non-Hispanic Black men, 5.09% among Hispanic men, and 2.07% among non-Hispanic White men (p<0.001). The reduction in stroke cases follows a similar pattern; that is, HBPM was projected to have a more significant impact on non-Hispanic Black and Hispanic adults and women than non-Hispanic White adults and men.

Figure 2 compares the projected reductions in MI and stroke events in rural residents with those in urban residents under the HBPM versus usual care scenarios. Among rural populations, there could be 21,278 averted MI cases per 1 million people if HBPM were adopted, whereas the averted MI cases in urban areas were 11,012 per 1 million people. Similarly, there could be many more averted stroke cases in rural versus urban adult populations and, therefore, higher healthcare cost savings per person in rural areas. Sensitivity analyses using different discount rates showed that a higher discount rate would result in fewer healthcare cost savings, but it would not change any of the projected patterns because non-Hispanic Blacks and rural residents would continue to have the largest healthcare cost savings if HBPM were adopted (results not shown in the figure).

DISCUSSION

This simulation model suggests that adopting HBPM could result in a significant reduction in MI and stroke cases as well as healthcare cost savings over 20 years compared with usual care. The model also estimated that non-Hispanic Blacks, women, and rural residents could have more averted CVD cases and greater healthcare cost savings from adopting HBPM than non-Hispanic Whites, men, and urban residents. Given that racial and ethnic minorities and rural residents in the U.S. are disproportionately affected by CVD,[26] these findings may have important implications for reducing CVD

Table 2. Projected Numbers of MIs, Strokes, and Healthcare Costs in 20 Years

Policy	Number of MI, Per million adults (95% CI)	Averted cases of MI, per million adults	Percentage reduction	Number of stroke, per million adults (95% CI)	Averted cases of stroke, per million adults	Percentage reduction	Healthcare costs, $ per person (95% CI)	Healthcare cost saving, $ per person	Percentage reduction
Usual care	238,127 (216,219; 260,034)	—		227,790 (207,061; 248,518)	—		176,610 (160,185; 193,035)	—	
HBPM	226,221 (205,408; 247,032)	11,906	5.0%	219,134 (199,192; 239,075)	8,656	3.8%	168,816 (153,116; 184,516)	7,794	4.4%

Note: 95% CIs are reported in parentheses. Healthcare costs were discounted at 3% and presented in 2019 U.S. dollars.
HBPM, home blood pressure monitoring; MI, myocardial infarction.

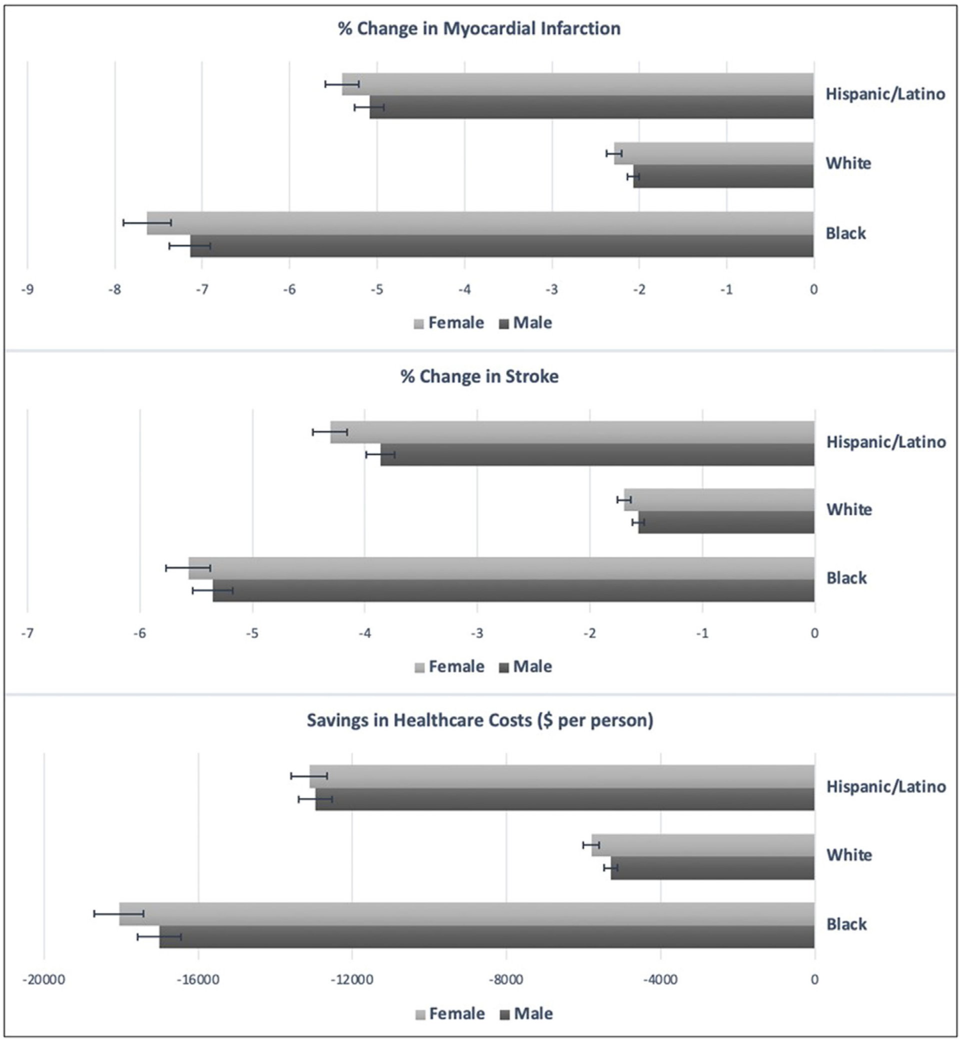

Figure 1. Projected percentage changes in MI and stroke cases and healthcare costs by sex and race/ethnicity comparing HBPM with usual care in 20 years.
HBPM, home blood pressure monitoring; MI, myocardial infarction.

health disparities. It is worth noting that the model used the overall effect of all the HBPM interventions synthesized in the meta-analysis by Tucker et al., so the results would be different for specific HBPM interventions. For example, Tucker et al. showed that about 40% of the total meta-analysis population were from the intervention groups that were ineffective, implying that the simulated benefits would nearly double if HBPM was assumed to be supported appropriately (e.g., with web feedback, education, and individual counseling) and would be almost none if HBPM was implemented with little or no additional support. Also note that the intervention effect may not last for 20 years in reality, so the reduction in CVD burden and healthcare costs are likely to be an overestimate of the effectiveness.

Several economic evaluations of HBPM have been conducted in the past.[14,15,27,28] However, these studies either focused on a local healthcare system in the U.S. or another country, and thus their findings may not apply to the general U.S. adult population with hypertension. Billups et al. used data from an RCT conducted by Kaiser Permanente Colorado to evaluate the cost-effectiveness of their HBPM program compared with that of usual care and found that the HBPM program was cost-effective in improving BP among 348 patients with hypertension.[14] Lovibond et al. developed a Markov model on the basis of a hypothetical primary-care population in the United Kingdom and assessed the cost-effectiveness of 3 hypertension diagnostic strategies, including HBPM, CBPM, and ambulatory monitoring. Although they found that ambulatory monitoring was the most cost-effective

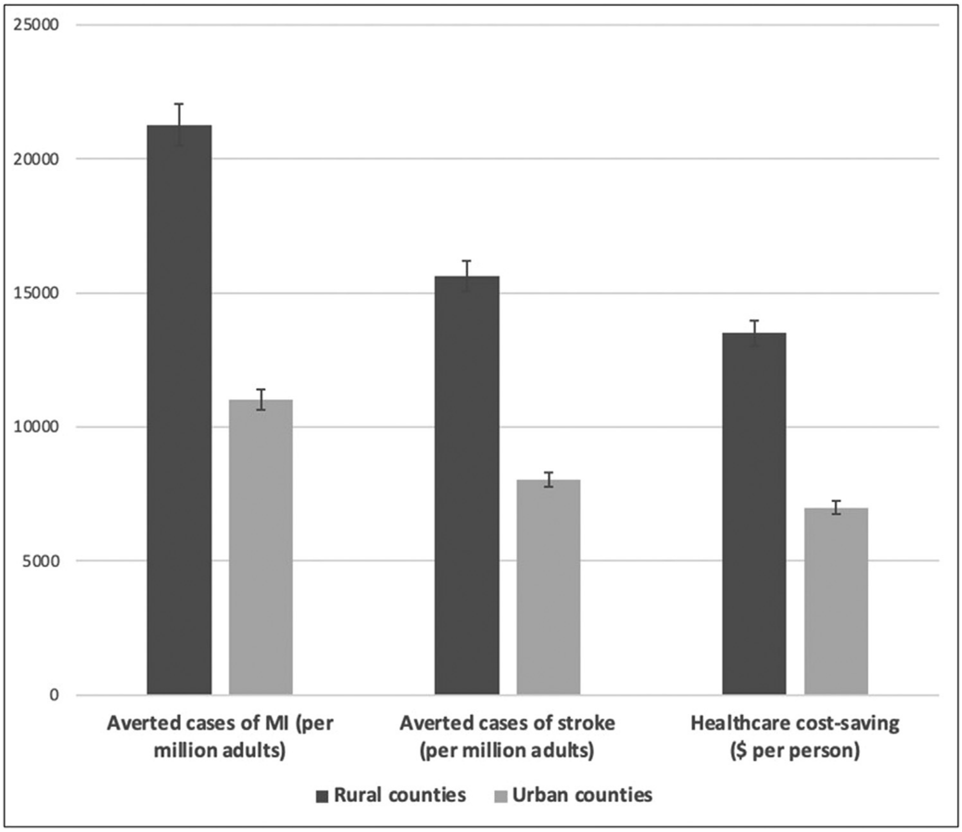

Figure 2. Projected reductions in MI and stroke cases and healthcare costs by rural/urban area comparing HBPM with usual care among adults with hypertension in the U.S. in 20 years.
HBPM, home blood pressure monitoring; MI, myocardial infarction.

strategy, their findings only applied to hypertension diagnosis rather than to management.[28] Fukunaga et al. evaluated the cost-effectiveness of adopting HBPM in Japan and concluded that HBPM would be cost saving in treating and managing hypertension.[15]

In addition to potential health and economic benefits associated with HBPM, studies have shown that BP awareness raised by HBPM can motivate patients to be adherent to therapy, promote participation in daily self-care, and enhance patient communication with healthcare providers.[12] However, the proportion of U.S. adults with hypertension who have adopted HBPM has been low,[29] probably owing to factors such as lack of health insurance reimbursement for BP measurement devices, insufficient patient and provider education on the benefits of HBPM, and poor access to primary care among racial and ethnic minorities and in rural areas. HBPM became more common between 2020 and 2022 because of healthcare disruptions due to the coronavirus disease 2019 (COVID-19) pandemic; consequently, more data should be available in the near future to more precisely evaluate the effectiveness and cost-effectiveness of HBPM compared with those of CBPM.[30]

Several medical organizations have recommended increased regular use of HBPM by clinicians for most patients with known or suspected hypertension as a way to increase patient engagement and their ability to self-manage their condition, enabling the care team to assist in hypertension control, and preventing heart attacks and strokes.[8] In alignment with this growing call to action on the use and reimbursement of HBPM, this study adds to the literature by investigating the health and economic impact of HBPM and examining the potential of expanding HBPM in reducing disparities in hypertension control and CVD outcomes across populations of different geographies, sexes, races, and ethnic groups. Further research should incorporate patient preferences and adherence into the analysis to understand patient adoption and engagement behaviors in the real world as well as their effects on long-term health and economic impacts.

Limitations

This study has several limitations. First, similar to all simulation models, the microsimulation model used in this study is a simplification of the real world and thus includes assumptions that may not be fully supported on the basis of existing data. For example, the model assumed that health behaviors (e.g., diet, physical activity) would not change as simulated individuals age because introducing changes in other health behaviors would make it difficult for us to identify the net effect of the studied intervention. In addition, hypertension control was treated as a binary variable in the model and thus was not able to capture the difference between different BP control goals. For example, the 2003 7th Joint National Committee recommended a treatment goal of 140/90 mm Hg for all individuals with hypertension, whereas the 2017 American College of Cardiology/American Heart Association hypertension guideline lowered the treatment goal to 130/80 mm Hg. The model in its current version was not able to capture this difference. Second, the CVD risk equations used in the model did not include SES such as education and income, which is an important risk factor for CVD.[31] Thus, it was not feasible to model the impact of the intervention across different SES groups. Third, the BRFSS data that were used to estimate population characteristics only provide self-reported responses rather than more objective measures. Fourth, because the intervention we modeled covered a range of HBPM interventions that involved different forms of cointerventions, it was not feasible to identify intervention costs (or their ranges) that would be needed for a full-scale cost-effectiveness analysis. Fifth, the process for hypertension diagnosis and treatment is dynamic and changing over time with advances in science and technology, but these changes are not foreseeable, and it is difficult to capture their potential complex interactions in this study. Finally, this study is based on the U.S. setting, and thus the findings may not be generalizable to other countries. Nevertheless, an increasing number of middle- and low-income countries began to implement tailored and adaptive HBPM programs in their routine hypertension care. Findings from this study may inspire additional economic evaluation research of HBPM programs outside of the U.S. and support a wider implementation and dissemination of HBPM in global settings.

CONCLUSIONS

This study is the first to assess the long-term health and economic impact of HBPM among U.S. adults with hypertension. The results show that HBPM could substantially reduce the burden of CVD and lead to health-care cost savings in the long term and that the benefits could be more pronounced in racial and ethnic minority groups and those living in rural areas. The heterogeneity of the effects across subpopulations suggests that an HBPM program targeted to the population with uncontrolled hypertension and without previous CVD could yield substantially higher benefits. This provides cardiovascular clinicians and policymakers with important evidence to support a broader adoption of the intervention.

ACKNOWLEDGMENTS

The contents of this article are solely the responsibility of the authors and do not necessarily represent the official views of NIH. YL and DZ contributed equally to this work.

This research study was supported by a grant from the National Institute on Minority Health and Health Disparities (R01MD013886; principal investigator: DZ) and a grant from the National Heart, Lung, and Blood Institute (R01HL141427; principal investigator: YL) of the NIH.

No financial disclosures were reported by the authors of this paper.

CREDIT AUTHOR STATEMENT

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SUPPLEMENTAL MATERIAL

Supplemental materials associated with this article can be found in the online version at https://doi.org/10.1016/j.amepre.2023.05.010.

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