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Economic Evaluation of the Home Blood Pressure Telemonitoring and Pharmacist Case Management to Control Hypertension (Hyperlink) Trial

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Abstract

Background—Pharmacist-managed (team-based) care for hypertension with home blood pressure monitoring support interventions have been widely studied and shown to be effective in improving rates of hypertension control and lowering blood pressure; however, few studies have evaluated the economic considerations related to bringing these programs into usual practice.

Objective—To analyze the economic outcomes of the Blood Pressure Telemonitoring and Pharmacist Management on Blood Pressure (Hyperlink) study, a cluster randomized controlled trial which used home blood pressure telemonitoring and pharmacist case management to achieve better blood pressure control in patients with uncontrolled hypertension.

Methods—A prospective analysis compared differences in medical costs and encounters in the Hyperlink telemonitoring intervention and usual care groups in the 12 months pre- and post-enrollment using medical and pharmacy insurance claims from a health care sector perspective. Generalized estimating equation models were used to estimate differences between groups over time. These results, combined with previously published prospective study results on intervention costs and blood pressure outcomes, were used to estimate cost-effectiveness measures for blood pressure control and reduction.

Findings—Total medical costs in the intervention group were lower compared with the usual care group by an average of \$281 per person, but this difference was not statistically significant. Clinic-based office visit, radiology, pharmacy, and hospital costs were also non-significantly lower in the intervention group. Statistically significant differences were found in lipid-related laboratory costs (higher) and in hypertension- (higher) and lipid-related (lower) pharmacy costs. Patterns in

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medical costs were similar for medical encounters. On average, the intervention cost \$7337 per person achieving hypertension control and \$139 or \$265 per mm Hg reduction in systolic or diastolic blood pressure, respectively.

Conclusions—Home blood pressure monitoring and pharmacist case management to improve hypertension care can be implemented without increasing, and potentially reducing, overall medical care costs.

Keywords

Blood pressure; cost and cost analysis; cost-benefit analysis; hypertension; pharmacist; pharmacoeconomics; telemedicine

It is well-documented that about half of the nearly 3 in 10 adults in the United States that have hypertension do not have their blood pressure under control.^{1–3} As a major risk factor for cardiovascular disease, improving blood pressure management is a public health priority for reducing preventable health and economic burden.^{4–9} However, the poor rate of blood pressure control is not simply due to clinical inaction; more than 80% of adults report being aware of their elevated blood pressure and more than 75% report current treatment.² Moreover, adults with hypertension made over 255 million visits with a primary care provider in 2013 and almost half saw their provider four or more times.¹⁰

Dissatisfaction with this status quo has led to development of innovative care models to improve hypertension care. The objective of the Home Blood Pressure Telemonitoring and Case Management to Control Hypertension (Hyperlink) study was to evaluate the effectiveness of an intervention combining two distinct strategies: pharmacist case management linked with home blood pressure telemonitoring. We previously published the success of this intervention in improving blood pressure outcomes; specifically, blood pressure control increased by 18.4% and systolic and diastolic blood pressure decreased by 9.7 and 5.1 mm Hg, respectively, relative to usual care over 12 months.¹¹ This study reports on the effect of the Hyperlink telemonitoring intervention on 12-month medical care utilization outcomes and its cost-effectiveness with respect to improved blood pressure.

Methods

Study design

The Hyperlink study was a two group clinic-randomized controlled trial conducted at HealthPartners Medical Group, a multispecialty practice in the Minneapolis-St. Paul metropolitan area that is part of an integrated health system. Four hundred fifty patients were recruited from 16 study clinics that were matched by size and clinic-level blood pressure control at baseline and then randomly assigned to either a home blood pressure telemonitoring and pharmacist case management intervention or usual care. All recruitment occurred between March 2009 and April 2011. The study protocol was approved by the HealthPartners Institutional Review Board. A detailed description of the Hyperlink rationale and design and main results have been published elsewhere.^{11,12}

Study subjects

Eligible patients were at least 21 years of age and had an elevated blood pressure (systolic blood pressure ≥ 140 or diastolic blood pressure ≥ 90 mm Hg, hereafter abbreviated 140/90 mm Hg) at their two most recent primary care encounters in the previous year. Final inclusion at the research clinic screening required uncontrolled blood pressure ($\geq 140/90$ mm Hg or $\geq 130/80$ mm Hg if diabetes or kidney disease was present)⁴ based on the average of three automated measurements taken using a standardized protocol.¹² Medical exclusion criteria included: advanced kidney disease; acute coronary syndrome, coronary revascularization, or stroke within past 3 months; known secondary causes of hypertension; pregnancy; activity-limiting heart failure; or known left ventricular ejection fraction $<30\%$. Patients were required to have continuous HealthPartners insurance coverage for the full 12 months pre- and post-enrollment to be included in the analysis of medical care utilization costs and visits.

Intervention

Patients in the intervention group received home blood pressure monitors that store and transmit blood pressure data to a secure website via modem (AMC Health, New York, NY). Pharmacists trained in medication management therapy (MTM) met with patients for a one-hour in-person visit to establish care and instructed them on using the home blood pressure telemonitoring system. Patients were instructed to transmit at least three morning and three evening blood pressure measurements weekly. During the first six months of intervention, patients and pharmacists met every two weeks via phone until blood pressure control was sustained for six weeks, then frequency was reduced to monthly. In the second six months of intervention, phone visits were every two months. During phone visits, pharmacists emphasized lifestyle changes and medication adherence. They assessed and adjusted antihypertensive drug therapy guided by a study algorithm.¹² If at least 75% of readings since the last visit met the home blood pressure goal ($<135/85$ mm Hg or $<125/75$ mm Hg for patients with diabetes or kidney disease), no medication changes were generally suggested. If fewer than 75% of readings met goal, the algorithm recommended treatment intensification. Regardless of blood pressure control, if patients experienced adverse effects, the drug dosage could be lowered or the drug changed. Pharmacists communicated with patients' primary care teams through the electronic medical record following each visit.

Patients in the usual care group worked with their primary care physicians as usual. This could include referral to an MTM pharmacist for consultation and conventional home blood pressure measurement.

Data Sources

Utilization of healthcare services and associated costs from a healthcare sector perspective were collected from insurance claims data systems. All outpatient care was classified using Current Procedural Terminology, Fourth Edition (CPT-4) codes. Hospital-related care was classified using place of care identifiers (e.g., inpatient admissions) and CPT-4 codes corresponding to hospital-based emergency, evaluation/management/observation, and critical care services. Prescription drug costs were derived from pharmacy claims. As is commonly recommended for cost-effectiveness analyses,^{13–15} all costs within each category

—without attempt to distinguish attribution of costs specifically affected by the intervention
—were included in the comparison of total medical costs between arms; however, for context and comparison purposes, costs associated with hypertension- or cardiovascular disease-related diagnoses, labs, or medications were also identified and assessed as secondary measures. Appendix 1 details the classification codes used to identify each category of utilization. All costs are based on combined paid amounts by the health insurance plan and patient and are reported in current U.S. dollars, as collected over the period from 2008–2012.

Statistical Analysis

All statistical analyses were 2-sided and p-values of less than 0.05 were considered statistically significant. Independence of baseline sample characteristics was assessed using t-tests for continuous variables and Chi-square tests for categorical variables. Incremental changes in medical care costs and utilization were assessed using standard health econometric methods and specification testing.^{16–18} Non-normality was confirmed (right-skewed and kurtotic distribution for costs) using standard statistical tests.^{19–21} Medical care costs and encounters were analyzed using a generalized estimating equation model with a time x study group interaction term that accounted for random effects at the subject level (i.e., accounting for the correlation in each subjects' repeated measures over time).²² Random effects at the clinic (cluster) level were tested but not found independent to subject-level effects.²³ The appropriate distribution family was determined using the modified Park test (commonly, gamma or inverse Gaussian for costs and Poisson for count data)¹⁸ and the goodness of fit using a log link function was tested using modified Hosmer and Lemeshow and Pregibon link tests.^{24,25} Confidence intervals were estimated using a Huber/White heteroscedasticity-robust sandwich estimator.²⁶ Sensitivity analyses were conducted to include adjustment by Hispanic ethnicity, which showed some imbalance by study group. Statistical analyses were conducted using SAS version 9.2 (SAS Institute Inc., Cary, NC) and Stata version 11 (StataCorp, College Station, TX).

Cost-effectiveness Analysis

Direct program costs and blood pressure outcomes of the Hyperlink intervention were previously reported (Appendix 2) and reflected the experience of all study patients (i.e., not just those who had a health insurance plan connected to the integrated care system).¹¹ For this report, incremental cost-effectiveness ratios were calculated for achieving blood pressure control and for each mm Hg systolic and diastolic blood pressure reduction. These ratios, all based on 12-month outcomes, measure the incremental change in cost divided by the incremental change in blood pressure outcome for the telemonitoring group relative to usual care. The incremental change in cost has two components: the previously reported direct program costs of administering the intervention and the net incremental effect of the intervention on total medical care costs relative to usual care reported in this study. Primary (base case) cost-effectiveness estimates included incremental total medical care costs only if statistically significant (which was not found to be the case). Two sensitivity analyses were also conducted: one with the inclusion of non-statistically significant incremental total medical costs and a second with the inclusion of statistically significant incremental sub-component costs (in this case, hypertension- and lipid-related pharmacy costs).

Results

Of the 450 patients enrolled in the Hyperlink trial, 299 patients (149 patients assigned to the telemonitoring intervention group and 150 patients assigned to the usual care group) met the pre- and post-index full insurance criterion for inclusion in the analysis of costs and utilization (Figure 1). One subject in the intervention group was excluded due to having very high radiology expenses due to an unrelated cancer diagnosis in the 12-month period prior to the study index date. At baseline, the remaining 298 participants had a mean (standard deviation) age of 63.5 (11.9) years, 46.3% were women, and 86.6% were white (Table 1). Over half had earned a college degree or greater (50.4%) and had a household income of at least \$50,000 (67.5%), and the number who were working full time (41.5%) was about the same as who were retired (43.3%). Mean systolic/diastolic blood pressure at baseline was 148.3/83.2 mm Hg. Few (9.7%) had a prior history of cardiovascular disease, but 31.5% had diabetes or chronic kidney disease and 52.7% were obese. There were more Hispanics in the usual care group (5 vs. 0 in the intervention group, $p=0.03$), which was also the case in the overall study population, but all other baseline characteristics were statistically balanced between groups.

Medical Costs and Encounters

The change in 12-month total medical care costs favored the intervention group at a decline of \$281.40 per person (95% CI, -\$3133 to \$2550), but the difference was not statistically significant ($p=0.846$; Table 2). That same trend in favorable but not statistically significant differential changes in costs with wide confidence intervals for the intervention group was seen across most categories of costs, including overall clinic-based, pharmacy, and hospital costs. One exception was for laboratory costs. The differential change in overall lab costs was similar in the intervention group compared with the usual care group with a wide confidence range (\$8.50 per person, 95% CI: -\$87 to \$104, $p=0.861$), but differences emerged when examining hypertension- or lipid-related labs (not mutually exclusive; see definitions in Appendix 1), with an increase with intervention of \$15.60 per person (95% CI: -\$2 to \$33, $p=0.085$) for hypertension and an increase of \$14.40 (95% CI: \$3 to \$25, $p=0.010$) for lipid-related labs. Although there was no statistical difference in change of pharmacy costs between groups, costs for hypertension medications increased significantly by \$126.00 per person (95% CI: \$64 to \$188; $p<0.001$) for the intervention group relative to usual care, but this was partially offset by a significant \$44.20 decrease (95% CI: -\$87 to -\$1; $p=0.045$) in costs for lipid-related medications. Finally, there was no significant differential change in overall hospital-related expenditures (-\$102.50; 95% CI: -\$2847 to \$2642; $p=0.942$), but a possible trend toward cardiovascular disease (CVD)-related hospital cost reduction associated with the intervention (-\$497.60; -\$1111 to \$116; $p=0.112$).

As would be expected, changes in medical encounters between groups largely mirrored the patterns seen in medical care costs (Table 3). There was no difference in change of clinic office visits between groups (0.0; 95% CI: -1.1 to 1.1; $p=0.990$). The differential change in the overall number of lab tests was not statistically significant (2.6; 95% CI: -0.4 to 5.6), but there was a clear relative increase in hypertension- (2.0; 95% CI: 1.0 to 3.1; $p<0.001$) and lipid-related (1.7; 95% CI: 1.0 to 2.4; $p<0.001$) lab tests in the intervention group. Hospital

encounters mirrored costs too, with essentially no difference overall (-0.01 ; 95% CI: -0.58 to 0.56 ; $p=0.972$) but a trend toward fewer CVD-related hospital encounters (-0.23 ; 95% CI: -0.52 to 0.16 ; $p=0.105$). Sensitivity analyses that included Hispanic ethnicity as a covariate in the estimation models for changes in medical costs and encounters showed no meaningful differences (data not shown).

Cost-effectiveness

With no significant difference in change in total medical care costs between groups, base case cost-effectiveness results include only the previously reported program costs based on market rates of \$1350 per person (95% CI: \$615 to \$2080).¹¹ As a result, we estimate the Hyperlink telemonitoring intervention cost an average of \$7337 per person achieving blood pressure control, \$139 per mm Hg of reduced systolic blood pressure, and \$265 per mm Hg of reduced diastolic blood pressure (Table 4). If including the non-significant \$281.40 per person reduction in 12-month medical care costs associated with the intervention, these costs would be moderately lower: \$5809, \$110, and \$210, respectively. Finally, although overall pharmacy costs were equivocal, if the \$81.80 per person significant increase in hypertension- and lipid-related medication costs were added to the intervention cost, these costs would increase modestly to \$7782, \$148, and \$281, respectively.

Discussion

In a prospective analysis of an effective team-based hypertension intervention with MTM pharmacist case management and home blood pressure telemonitoring, we found no significant impact on overall short-term medical care costs. Given the high variability in medical care costs and the relatively short follow-up period (12 months), this result is not terribly surprising—nor are the findings by specific spending categories. Although the intervention could have substituted for some primary care office visits, our findings indicate that MTM pharmacist services were primarily a complement to usual care. The significant effects found on pharmacy and laboratory costs are consistent with the intervention's protocol that called for antihypertensive medication intensification to achieve blood pressure control (which likely contributed to the mean number of medication classes for intervention patients increasing from 1.6 to 2.2 over 12 months, $p<0.001$ ¹¹) and laboratory testing with treatment changes in several major classes of antihypertensive drugs. Collateral effects on lipid testing were also expected based on the standard practice of the study's MTM pharmacists, who conducted a comprehensive medication review and cardiovascular risk assessment at the initial visit. The decrease in lipid-related pharmacy costs could have resulted from discontinuation of cholesterol-lowering drug treatment or, more likely, from changing patients from branded drugs to generic drugs. Finally, although not statistically significant, the almost \$500 reduction in CVD-related hospital costs ($p=0.112$) suggests that over a longer period of time, significant cost reductions from adverse CVD events might be realized from this program.

Although more than 150 studies have been conducted to evaluate team-based interventions to improve blood pressure management,²⁷ few have reported on the economic outcomes for these programs. The Community Preventive Services Taskforce reviewed economic

evaluations of team-based hypertension care programs published between 1985 and 2012 and found 21 studies reporting impacts on healthcare costs (i.e., utilization differences beyond the direct delivery costs of the intervention) over this period.²⁸ Among these studies, 8 reported an overall increase in healthcare costs^{29–36} and 10 reported an overall decrease,^{37–46} but only 3 of the former^{26,28,32} and 2 of the latter^{37,39} reported statistically significant changes in costs. The Taskforce calculated an average per person impact on healthcare costs of \$65 per year with an interquartile range of –\$235 to \$318, and findings reported by subsequent studies^{47–49} have not been substantively different. Our non-significant finding for the intervention's effect on total costs (–\$281.4) would fall near the low end of this range, but there was considerable variability in the included cost components (e.g., outpatient, inpatient, emergency, and pharmacy), observation period (6 months to 6 years), and analytical design (e.g., quasi-experimental longitudinal comparisons, pre-post, and randomized controlled trials) across studies, making meta-analytic comparisons challenging.

The Community Preventive Services Taskforce also reviewed the literature for intervention costs and cost-effectiveness estimates.²⁸ Median intervention costs among 20 studies were \$284 (interquartile interval [IQI], \$153–\$670), which fall significantly below the average \$1350 cost to deliver the Hyperlink intervention. Median costs per mm Hg reduction of systolic blood pressure (\$87, IQI, \$52–\$202) and diastolic blood pressure (\$102, IQI, \$51–\$123) reduction and per person achieving blood pressure control (\$3316, IQI, \$2047–\$5422) for reviewed interventions also compare favorably to our respective mean findings of \$139, \$210, and \$7337, with the moderately better effectiveness of the Hyperlink intervention in lowering blood pressure (–9.7 vs –6.7 mm Hg systolic blood pressure) only partially blunting its higher delivery cost. One subsequent study showed similar cost-effectiveness,⁵⁰ but two others demonstrated costs per mm Hg reduction of systolic blood pressure as low as \$23⁴⁷ and \$33.⁵¹

For widespread adoption of interventions like Hyperlink, the case for return on investment will need to be clear for health systems. The best opportunities are in finding ways to deliver effective interventions at the lowest costs, and novel interventions undergoing research evaluation may be more intensive than necessary. In an unpublished analysis of Hyperlink data, we found that maximal blood pressure lowering was achieved by about 4 months, with few, if any, medication changes occurring after that point. Hence, tailoring the duration of the program to the individual needs of each patient could alone help to trim delivery (both pharmacist counseling and telemonitoring) costs by 75% or more. Technological innovation could help to reduce costs as well. When the Hyperlink study began in 2009, the home blood pressure telemonitoring devices required a telephone landline to transmit blood pressure readings and the cost to rent the device and subscribe to this service exceeded \$100 per month. Advances in smartphones, wireless synchronization, and secure web services are expected to decrease the market cost of these services dramatically.

The biggest disease prevention benefits—and cost offsets—to programs improving blood pressure management are expected to come long after the upfront investment and follow-up evaluation period of most experimental programs. Over 12 months, too few cardiovascular events occurred for statistical inference, but we previously found that more were experienced in the usual care group,¹¹ lending support to the weak trend in lower hospital costs we report

for the intervention group. In a model-based analysis of the nationwide U.S. adoption of a slightly less effective team-based intervention program at about 40% of the cost, we found that over 600,000 CVD events could be prevented and net social cost savings could be achieved over 10 years.²⁷ Even with moderately higher costs, a program with the potential for impacting health on this scale may be attractive in meeting the public health challenges set forth by the Million Hearts Initiative.⁶

Several limitations of this study should be noted. First, as is common, the study sample was not powered on economic outcomes, and the sample for this utilization analysis was further restricted to patients who had full HealthPartners insurance coverage during the 12-month pre- and post-intervention index periods (34% sample loss). Second, while 12 months may be enough time to detect moderate changes in primary care utilization attributable to this intervention, the downstream impacts of disease prevention resulting from improved blood pressure management would be expected to be observed over a longer period. Third, limitations on the ability to observe differences in hard disease outcomes restricted our ability to capture the benefits needed to assess a comprehensive cost-effectiveness or cost-utility analysis. We plan to address these limitations in future microsimulation modeling based on this study. Finally, the findings from implementing this intervention in an integrated health system—and for patients with less racial/ethnic diversity, higher average income and education, and stable health insurance coverage—may not be equally replicable in other care settings and populations.

Conclusion

There is extensive and growing evidence on the effectiveness of incorporating pharmacists and other supports, such as home blood pressure telemonitoring, to the management of hypertension, but far less is known about economic outcomes that play a key role in the broader adoption of these programs into care systems. In this study, we demonstrated that the effective Hyperlink program had no significant impact on overall medical costs or utilization over 12 months. In future research, we plan to address important questions about the longer-term impact and cost-effectiveness of this intervention to better inform care systems seeking to implement this program or others like it.

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References

1. Yoon SS, Carroll MD, Fryar CD. Hypertension prevalence and control among adults: United States, 2011–2014. NCHS Data Brief. 2015; (220):1–8.
2. Benjamin EJ, Blaha MJ, Chiuve SE, et al. Heart disease and stroke statistics-2017 update: a report from the American Heart Association. Circulation. 2017; 135(10):e146–e603. [PubMed: 28122885]
3. Valderrama AL, Gillespie C, King SC, George MG, Hong Y, Gregg E. Vital signs: awareness and treatment of uncontrolled hypertension among adults—United States, 2003–2010. MMWR Morb Mortal Wkly Rep. 2012; 61:703–9. [PubMed: 22951452]

4. Chobanian AV, Bakris GL, Black HR, et al. Seventh report of the Joint National Committee on prevention, detection, evaluation, and treatment of high blood pressure. *Hypertension*. 2003; 42(6): 1206–52. [PubMed: 14656957]
5. Rosendorff C, Lackland DT, Allison M, et al. Treatment of hypertension in patients with coronary artery disease: a scientific statement from the American Heart Association, American College of Cardiology, and American Society of Hypertension. *Hypertension*. 2015; 65(6):1372–1407. [PubMed: 25828847]
6. Frieden TR, Berwick DM. The “Million Hearts” initiative--preventing heart attacks and strokes. *N Engl J Med*. 2011; 365(13):e27. [PubMed: 21913835]
7. World Health Organization. A global brief on hypertension: silent killer, global public health crisis. World Health Organization; 2013. Available from http://www.who.int/cardiovascular_diseases/publications/global_brief_hypertension/en/ [Accessed February 21, 2018]
8. Patel SA, Winkel M, Ali MK, Narayan KM, Mehta NK. Cardiovascular mortality associated with 5 leading risk factors: national and state preventable fractions estimated from survey data. *Ann Intern Med*. 2015; 163(4):245–53. [PubMed: 26121190]
9. Heidenreich PA, Trogdon JG, Khavjou OA, et al. Forecasting the future of cardiovascular disease in the United States: a policy statement from the American Heart Association. *Circulation*. 2011; 123(8):933–44. [PubMed: 21262990]
10. Ashman JJ, Rui P, Schappert SM. Age differences in visits to office-based physicians by adults with hypertension: United States, 2013. *NCHS Data Brief*. 2016; (263):1–8.
11. Margolis KL, Asche SE, Bergdall AR, et al. Effect of home blood pressure telemonitoring and pharmacist management on blood pressure control: a cluster randomized clinical trial. *JAMA*. 2013; 310(1):46–56. [PubMed: 23821088]
12. Margolis KL, Kerby TJ, Asche SE, et al. Design and rationale for home blood pressure telemonitoring and case management to control hypertension (HyperLink): a cluster randomized trial. *Contemp Clin Trials*. 2012; 33(4):794–803. [PubMed: 22498720]
13. Ramsey SD, Willke RJ, Glick H, et al. Cost-effectiveness analysis alongside clinical trials II-An ISPOR Good Research Practices Task Force report. *Value Health*. 2015; 18(2):161–72. [PubMed: 25773551]
14. Sanders GD, Neumann PJ, Basu A, et al. Recommendations for conduct, methodological practices, and reporting of cost-effectiveness analyses: second panel on cost-effectiveness in health and medicine. *JAMA*. 2016; 316(10):1093–1103. [PubMed: 27623463]
15. Glick HA, Doshi JA, Sonnad SS, Polsky D. *Economic evaluation in clinical trials*. Oxford: Oxford University Press; 2014.
16. Mullahy J. Much ado about two: reconsidering retransformation and the two-part model in health econometrics. *J Health Econ*. 1998; 17(3):247–81. [PubMed: 10180918]
17. Blough DK, Madden CW, Hornbrook MC. Modeling risk using generalized linear models. *J Health Econ*. 1999; 18(2):153–71. [PubMed: 10346351]
18. Manning WG, Mullahy J. Estimating log models: to transform or not to transform? *J Health Econ*. 2001; 20(4):461–94. [PubMed: 11469231]
19. D’Agostino RB, Belanger AJ, D’Agostino RB Jr. A suggestion for using powerful and informative tests of normality. *The American Statistician*. 1990; 44(4):316–21.
20. Shapiro SS, Wilk MB. An analysis of variance test for normality (complete samples). *Biometrika*. 1965; 52(3–4):591–611.
21. Miller RG, Jr. *Beyond ANOVA: basics of applied statistics*. London: Chapman & Hall; 1997.
22. Liang K-Y, Zeger SL. Longitudinal data analysis using generalized linear models. *Biometrika*. 1986; 73(1):13–22.
23. Raudenbush SW, Bryk AS. *Hierarchical linear models: applications and dataanalysis methods*. 2. Thousand Oaks, CA: Sage; 2002.
24. Hosmer DW, Jr, Lemeshow S, Sturdivant RX. *Applied logistic regression*. 3. New York: John Wiley & Sons; 2013.
25. Pregibon D. Goodness of link tests for generalized linear models. *Applied Statistics*. 1980; 29:15–24.

26. White H. A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity. *Econometrica*. 1980; 48(4):817–38.
27. Dehmer SP, Baker-Goering MM, Maciosek MV, et al. Modeled health and economic impact of team-based care for hypertension. *Am J Prev Med*. 2016; 50(5 Suppl 1):S34–44. [PubMed: 27102856]
28. Jacob V, Chattopadhyay SK, Thota AB, et al. Economics of team-based care in controlling blood pressure: a community guide systematic review. *Am J Prev Med*. 2015; 49(5):772–83. [PubMed: 26477804]
29. Borenstein JE, Graber G, Saltiel E, et al. Physician-pharmacist comanagement of hypertension: a randomized, comparative trial. *Pharmacotherapy*. 2003; 23(2):209–16. [PubMed: 12587810]
30. Bunting BA, Smith BH, Sutherland SE. The Asheville Project: clinical and economic outcomes of a community-based long-term medication therapy management program for hypertension and dyslipidemia. *J Am Pharm Assoc* (2003). 2008; 48(1):23–31. [PubMed: 18192127]
31. Cote I, Gregoire JP, Moisan J, Chabot I, Lacroix G. A pharmacy-based health promotion programme in hypertension: cost-benefit analysis. *Pharmacoeconomics*. 2003; 21(6):415–28. [PubMed: 12678568]
32. Devine EB, Hoang S, Fisk AW, Wilson-Norton JL, Lawless NM, Louie C. Strategies to optimize medication use in the physician group practice: the role of the clinical pharmacist. *J Am Pharm Assoc* (2003). 2009; 49(2):181–91. [PubMed: 19289344]
33. Eckerlund I, Jonsson E, Ryden L, Rastam L, Berglund G, Isacson SO. Economic evaluation of a Swedish medical care program for hypertension. *Health Policy*. 1985; 5(4):299–306. [PubMed: 10311450]
34. Fedder DO, Chang RJ, Curry S, Nichols G. The effectiveness of a community health worker outreach program on healthcare utilization of west Baltimore City Medicaid patients with diabetes, with or without hypertension. *Ethn Dis*. 2003; 13(1):22–7. [PubMed: 12723008]
35. Isetts BJ, Schondelmeyer SW, Artz MB, et al. Clinical and economic outcomes of medication therapy management services: the Minnesota experience. *J Am Pharm Assoc* (2003). 2008; 48(2): 203–11. 203–211. [PubMed: 18359733]
36. Munroe WP, Kunz K, Dalmady-Israel C, Potter L, Schonfeld WH. Economic evaluation of pharmacist involvement in disease management in a community pharmacy setting. *Clin Ther*. 1997; 19(1):113–23. [PubMed: 9083713]
37. Carter BL, Barnette DJ, Chrischilles E, Mazzotti GJ, Asali ZJ. Evaluation of hypertensive patients after care provided by community pharmacists in a rural setting. *Pharmacotherapy*. 1997; 17(6): 1274–85. [PubMed: 9399611]
38. Datta SK, Oddone EZ, Olsen MK, et al. Economic analysis of a tailored behavioral intervention to improve blood pressure control for primary care patients. *Am Heart J*. 2010; 160(2):257–63. [PubMed: 20691830]
39. Kulchaitanaroaj P, Brooks JM, Ardery G, Newman D, Carter BL. Incremental costs associated with physician and pharmacist collaboration to improve blood pressure control. *Pharmacotherapy*. 2012; 32(8):772–80. [PubMed: 23307525]
40. Logan AG, Milne BJ, Achber C, Campbell WP, Haynes RB. Cost-effectiveness of a worksite hypertension treatment program. *Hypertension*. 1981; 3(2):211–18. [PubMed: 6783519]
41. Logan AG, Milne BJ, Flanagan PT, Haynes RB. Clinical effectiveness and cost-effectiveness of monitoring blood pressure of hypertensive employees at work. *Hypertension*. 1983; 5(6):828–36. [PubMed: 6418647]
42. Murray MD, Harris LE, Overhage JM, et al. Failure of computerized treatment suggestions to improve health outcomes of outpatients with uncomplicated hypertension: results of a randomized controlled trial. *Pharmacotherapy*. 2004; 24(3):324–37. [PubMed: 15040645]
43. Okamoto MP, Nakahiro RK. Pharmacoeconomic evaluation of a pharmacist-managed hypertension clinic. *Pharmacotherapy*. 2001; 21(11):1337–44. [PubMed: 11714206]
44. Pezzin LE, Feldman PH, Mongoven JM, McDonald MV, Gerber LM, Peng TR. Improving blood pressure control: results of home-based post-acute care interventions. *J Gen Intern Med*. 2011; 26(3):280–6. [PubMed: 20945114]

45. Reed SD, Li Y, Oddone EZ, Neary AM, et al. Economic evaluation of home blood pressure monitoring with or without telephonic behavioral self-management in patients with hypertension. *Am J Hypertens*. 2010; 23(2):142–8. [PubMed: 19927132]
46. Wertz D, Hou L, DeVries A, et al. Clinical and economic outcomes of the Cincinnati Pharmacy Coaching Program for diabetes and hypertension. *Manag Care*. 2012; 21(3):44–54.
47. Billups SJ, Moore LR, Olson KL, Magid DJ. Cost-effectiveness evaluation of a home blood pressure monitoring program. *Am J Manag Care*. 2014; 20(9):e380–7. [PubMed: 25364874]
48. Obreli-Neto PR, Marusic S, Guidoni CM, et al. Economic evaluation of a pharmaceutical care program for elderly diabetic and hypertensive patients in primary health care: a 36-month randomized controlled clinical trial. *J Manag Care Spec Pharm*. 2015; 21(1):66–75. [PubMed: 25562774]
49. Wang V, Smith VA, Bosworth HB, et al. Economic evaluation of telephone self-management interventions for blood pressure control. *Am Heart J*. 2012; 163(6):980–6. [PubMed: 22709750]
50. Fishman PA, Cook AJ, Anderson ML, et al. Improving BP control through electronic communications: an economic evaluation. *Am J Manag Care*. 2013; 19(9):709–16. [PubMed: 24304254]
51. Polgreen LA, Han J, Carter BL, et al. Cost-effectiveness of a physician-pharmacist collaboration intervention to improve blood pressure control. *Hypertension*. 2015; 66(6):1145–51. [PubMed: 26527048]

Figure 1.
Participant Recruitment, Enrollment, and Follow-up

Table 1Baseline Characteristics of Study Patients with Full Insurance Coverage^a

	All patients (N=298)	Telemonitoring intervention (n=148)	Usual care (n=150)
Age, mean (sd)	63.5 (11.9)	64.6 (11.5)	62.5 (12.2)
Women (%)	138 (46.3)	71 (48.0)	67 (46.7)
Race/Ethnicity (%)			
White	258 (86.6)	129 (87.2)	129 (86.0)
Black	24 (8.0)	12 (8.1)	12 (8.0)
Asian	3 (1.0)	1 (0.7)	2 (1.3)
Other	13 (4.3)	6 (4.1)	7 (4.7)
Hispanic ^b	5 (1.7)	0 (0.0)	5 (3.3)
Education^c (%)			
<= High school or GED	46 (15.7)	25 (17.2)	21 (14.5)
Some college or technical school	98 (33.8)	44 (30.3)	54 (37.2)
4 year college degree	48 (16.6)	23 (15.9)	25 (17.2)
> 4 year college degree	98 (33.8)	53 (36.6)	45 (31.0)
Paid work status^c (%)			
Full time	120 (41.5)	58 (40.0)	62 (43.1)
Part time	28 (9.7)	13 (9.0)	15 (10.4)
Not working	16 (5.5)	8 (5.6)	8 (5.6)
Retired	125 (43.3)	66 (45.5)	59 (41.0)
Relationship status^c (%)			
Married, living together	199 (68.9)	106 (73.1)	93 (64.6)
Household income^c (%)			
<\$30,000	37 (14.7)	19 (16.1)	18 (13.4)
\$30–49,999	45 (17.9)	19 (16.1)	26 (19.4)
\$50–99,999	95 (37.7)	41 (34.8)	54 (40.3)
>=\$100,000	75 (29.8)	39 (33.1)	36 (26.9)
Body mass index^c (%)			
Normal (18.5–24.9)	49 (16.7)	23 (15.5)	23 (15.5)
Overweight (25–29.9)	90 (30.6)	40 (27.0)	40 (27.0)
Obese (>=30)	155 (52.7)	70 (48.0)	85 (57.4)
Smoked in last 30 days^c (%)	27 (9.2)	13 (9.0)	14 (9.3)
Comorbidities affecting BP goal (%)			
Diabetes	39 (13.1)	19 (12.8)	20 (13.3)
Chronic kidney disease	37 (12.4)	26 (17.6)	11 (7.3)
Diabetes or chronic kidney disease	94 (31.5)	53 (35.8)	41 (27.3)
Previous history of cardiovascular disease (%)^d	29 (9.7)	12 (8.1)	17 (11.3)
Antihypertensive medication classes, means (sd)	1.6 (1.3)	1.7 (1.3)	1.5 (1.2)
Systolic BP, mm Hg, mean (sd)^e	148.3 (12.7)	149.6 (12.0)	146.9 (12.2)
Diastolic BP, mm Hg, mean (sd)	83.2 (11.7)	83.3 (12.0)	83.2 (11.4)

BP = blood pressure; GED = general equivalency diploma; sd = standard deviation.

^aFull insurance coverage indicates continuous insurance coverage in the 12 months pre and post enrollment into the study.

^b $p < 0.05$.

^cMissing data for 3–29 patients.

^dPrevious history of cardiovascular disease indicates patients who have ever had a heart attack, stroke, heart bypass surgery, or cardiac stent/balloon angioplasty.

^e $p < 0.10$.

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Table 2

Medical Care Costs	Telemonitoring intervention		Usual care		Group differential change from baseline, Mean (95% CI)	P-Value
	Mean	Change from baseline	Mean	Change from baseline		
Clinic-based costs						
At baseline	1524		1503			
At 12 months	1412	-111.9	1426	-76.5	-35.4 (-337 to 266)	0.818
Office visit costs						
At baseline	842		893			
At 12 months	809	-33.1	865	-28.4	-4.8 (-161 to 152)	0.952
Laboratory costs						
At baseline	336		317			
At 12 months	327	-8.9	299	-17.4	8.5 (-87 to 104)	0.861
Laboratory costs, HTN-related						
At baseline	95		87			
At 12 months	107	12.5	84	-3.1	15.6 (-2 to 33)	0.085
Laboratory costs, lipid-related						
At baseline	54		48			
At 12 months	63	9.4	42	-5	14.4 (3 to 25)	0.010
Radiology costs						
At baseline	346		293			
At 12 months	276	-69.9	262	-30.7	-39.2 (-182 to 103)	0.590
Pharmacy costs						
At baseline	1059		1260			
At 12 months	1269	209.3	1613	352.8	-143.5 (-493 to 206)	0.420
Pharmacy costs, HTN-related						
At baseline	180		191			
At 12 months	332	152.5	217	26.5	126.0 (64 to 188)	<0.001
Pharmacy costs, lipid-related						
At baseline	83		109			
At 12 months	86	3.0	156	47.2	-44.2 (-87 to -1)	0.045

	Telemonitoring intervention		Usual care		Group differential change from baseline, Mean (95% CI)	P-Value
	Mean	Change from baseline	Mean	Change from baseline		
Pharmacy costs, HTN- or lipid-related						
At baseline	263		300			
At 12 months	418	155.5	373	73.7	81.8 (5 to 159)	0.037
Hospital costs						
At baseline	2102		1595			
At 12 months	1819	-283.2	1414	-180.7	-102.5 (-2847 to 2642)	0.942
Hospital costs, CVD-related						
At baseline	295		21			
At 12 months	107	-188.4	330	309.2	-497.6 (-1111 to 116)	0.112
Total costs						
At baseline	4685		4357			
At 12 months	4500	-185.8	4453	95.6	-281.4 (-3113 to 2550)	0.846

Total costs comprise of the sum of clinic-based, pharmacy, and hospital costs, defined as follows. Clinic-based costs comprise of the sum of clinic-based office visit, laboratory, and radiology costs. Codes for identifying costs in each category are described in Appendix 1. Mean and incremental changes in costs were estimated using a generalized estimating equation model with a time x study group interaction term. The 95% confidence intervals account for patient random effects and were estimated using a Huber/White robust sandwich estimator. If the patient from the intervention group with very high radiology due to an unrelated cancer diagnosis in the 12-month period prior the study baseline index date was included, the change in radiology costs from baseline for the intervention group would shift to -\$352.30 and the differential change in radiology costs between groups would shift to -\$321.60 (95% CI: \$892 to \$249, p=0.269).

CI = confidence interval; CVD = cardiovascular disease; HTN = hypertension.

Table 3

Medical Care Encounters

	Telemonitoring intervention		Usual care		Group differential change from baseline, Mean (95% CI)	P-Value
	Mean	Change from baseline	Mean	Change from baseline		
Office visits						
At baseline	6.9		7.6			
At 12 months	6.4	-0.5	7.1	-0.5	0.0 (-1.1 to 1.1)	0.990
Lab tests						
At baseline	13.1		12.9			
At 12 months	17.2	4.1	14.3	1.4	2.6 (-0.4 to 5.6)	0.086
Lab tests, HTN-related						
At baseline	5.4		5.2			
At 12 months	8.3	2.9	6.1	0.9	2.0 (1.0 to 3.1)	<0.001
Lab tests, lipid-related						
At baseline	3.0		2.7			
At 12 months	5.2	2.2	3.2	0.5	1.7 (1.0 to 2.4)	<0.001
Hospital-based encounters						
At baseline	0.32		0.43			
At 12 months	0.55	0.24	0.67	0.25	-0.01 (-0.58 to 0.56)	0.972
Hospital-based encounters, CVD-related						
At baseline	0.11		0.03			
At 12 months	0.11	0.00	0.27	0.23	-0.23 (-0.52 to 0.16)	0.105

Codes for identifying encounters in each category are described in Appendix 1. Mean and incremental changes encounters were estimated using a generalized estimating equation model with a time x study group interaction term. The 95% confidence intervals account for patient random effects and were estimated using a Huber/White robust sandwich estimator.

CI = confidence interval; CVD = cardiovascular disease; HTN = hypertension.

Table 4

Cost-effectiveness of Hyperlink Telemonitoring Intervention

	(a)	(b)	(c)	(a + b) / c
	Intervention costs (95% CI)	Net incremental medical care costs (95% CI)	Intervention effect (95% CI)	Intervention cost-effectiveness (Confidence range)
BP Control, %				
Base case	\$1350 (\$615 to \$2080)	0	18.4% (7.9% to 27.0%)	\$7337 (\$2278 to \$26,329) per person achieving BP control
With mean change in total costs ^a	Same	-\$281.1 (–\$3113 to \$2550)	Same	\$5809 (cost saving to \$58,608) per person achieving BP control
With mean change in CVD pharmacy costs ^b	Same	\$81.8 (\$5 to \$159)	Same	\$7782 (\$2296 to \$28,342) per person achieving BP control
SBP, mm Hg				
Base case	\$1350 (\$615 to \$2080)	0	–9.7 (–13.4 to –6.0)	\$139 (\$46 to \$347) per mm Hg SBP ↓
With mean change in total costs ^a	Same	–\$281.1 (–\$3113 to \$2550)	Same	\$110 (cost saving to \$772) per mm Hg SBP ↓
With mean change in CVD pharmacy costs	Same	\$81.8 (\$5 to \$159)	Same	\$148 (\$46 to \$373) per mm Hg SBP ↓
DBP, mm Hg				
Base case	\$1350 (\$615 to \$2080)	0	–5.1 (–7.4 to –2.8)	\$265 (\$83 to \$743) per mm Hg DBP ↓
With mean change in total costs ^a	Same	–\$281.1 (–\$3113 to \$2550)	Same	\$210 (cost saving to \$1654) per mm Hg DBP ↓
With mean change in CVD pharmacy costs ^b	Same	\$81.8 (\$5 to \$159)	Same	\$281 (\$84 to \$800) per mm Hg DBP ↓

Direct intervention costs and effects were published previously.¹¹ Direct costs include time spent with a medication therapy management pharmacist and rental of a home blood pressure with telemonitoring capability. Net incremental medical care costs observed in the intervention group compared to usual care are reported in this study (Table 2). The cost-effectiveness ratio confidence range reflects the sum of most favorable costs from the 95% confidence intervals divided by the most favorable effect from the 95% corresponding confidence interval, on the low end, to the least favorable corollary on the high end. When net costs are negative, cost-effectiveness is usually presented in terms of costs saved per person; to simplify presentation, we present cost-effectiveness in these cases as “cost saving.”

BP = blood pressure; CI = confidence interval; CVD = cardiovascular disease; DBP = diastolic blood pressure; SBP = systolic blood pressure.

^dResults of a sensitivity analysis in which the non-statistically significant net incremental difference in total medical care costs were included in the numerator of the cost-effectiveness ratio.

^eResults of a sensitivity analysis in which the statistically significant incremental sub-component costs (in this case, hypertension- and lipid-related pharmacy costs) were included in the numerator of the cost-effectiveness ratio.