REMOTE PATIENT MONITORING FOR PATIENTS WITH HYPERTENSION OR DIABETES

A Dissertation

by

SULKI PARK

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Chair of Committee,	Mark A. Lawley
Co-Chair of Committee,	Hye-Chung Kum
Committee Members,	Farzan Sasangohar
	Bobak Jack Mortazavi
Head of Department,	Lewis Ntaimo

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ABSTRACT

Hypertension and diabetes impose significant burdens on healthcare systems, leading to high costs and adverse health outcomes. To address these challenges, remote patient monitoring has emerged as a promising strategy for managing these chronic diseases. Clinical trials have demonstrated its effectiveness in improving blood pressure and glucose control while also being cost-effective in hypertension and diabetes management. However, the real-world implementation of remote patient monitoring presents uncertainties.

This study aims to explore the advantages and obstacles associated with remote patient monitoring for hypertension and diabetes management, utilizing real-world data from Texas Medicaid clients. Specifically, the study seeks to achieve the following objectives: (1) assess the adherence of Texas Medicaid patients to daily blood pressure and glucose monitoring when supported by a remote monitoring services company on a daily basis; (2) evaluate the impact of an adherence reminder call intervention on the rate of daily transmission; (3) investigate the potential correlation between daily adherence and blood pressure and glucose control; and (4) examine the association between remote patient monitoring and hospital charges related to circulatory system diseases. To accomplish these goals, the study will utilize data obtained from a remote patient monitoring company serving Texas Medicaid patients, along with hospital claims from the Dallas-Fort Worth region.

These insights can inform future strategies to optimize remote patient monitoring interventions, ultimately leading to improved healthcare outcomes for individuals with these chronic conditions.

DEDICATION

I would like to extend my heartfelt dedication to my esteemed husband, Sung Jin. Throughout this arduous journey, your unwavering support and presence have been indispensable. I am profoundly grateful for your unwavering belief in me, which has enabled me to reach this significant milestone.

Furthermore, I would like to express my deep love and affection for our beloved daughter, Aryn, whose boundless joy and inspiration have provided me with the strength to overcome every challenge.

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In addition, I wish to express my deepest appreciation to my parent-in-law, and sister-in-law's families for their steadfast support and unconditional love. Their guidance and encouragement have been invaluable throughout this endeavor.

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CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supervised by a thesis committee consisting of Professor Mark A. Lawley and Farzan Sasangohar of the Department of Industrial and Systems Engineering Professor Hye-Chung Kum of the Department of Health Policy and Management, and Professor Bobak Jack Mortazavi of the Department of Computer Science and Engineering.

Professor Qi Zheng of the Department of Epidemiology and Biostatistics statistical provided statistical mentorships for all the studies conducted.

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NOMENCLATURE

PCP	Primary Care Physician
CC	Clinical Contact i.e. PCP and/or Home Health Agency
CSD	Circulatory System Diseases

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1. INTRODUCTION

1.1. Background

Hypertension affects nearly half of the adults in the United States, costs approximately $131 billion annually, and is a major risk factor for cardiovascular disease and stroke (1–3). Researchers have estimated the hazard ratios of cardiovascular events, stroke, and all-cause mortality to be 1.11-1.42, 1.28-1.40, and 1.02-1.13, respectively, for every 10 mm Hg increase in the ambulatory systolic blood pressure value (4). Nonetheless, approximately only 1 in 4 adults with hypertension have their blood pressure under control (1).

In addition, the Center for Disease Control and Prevention estimates that 11.3% of adults (over 37 million) in the United States have diabetes, with prevalence increasing to 23% for those 65 years or older (5). Diabetes is the most expensive chronic condition in the US totaling $327 billion each year (6,7). One out of every four dollars in US health care costs is spent on caring for people with diabetes, and 61% of diabetes costs are spent for people aged 65 years or older.

As the burden of hypertension or diabetes grows, current systems of care will not keep pace with increasing demand, and, thus, developing more effective models and methods of care delivery is essential to the future hypertension or diabetes care (8). Emerging technologies, particularly those involving telehealth models are expected to play a major role (9).

Remote patient monitoring is an emerging strategy to help control chronic diseases such as hypertension or diabetes, with many medical organizations recommending its use in diagnosis, and ongoing chronic disease management (10). Several systematic reviews and meta-analyses of published clinical trials have summarized the evidence that remote patient monitoring led to clinically significant reductions in blood pressure (11–18) and glucose values (19–30) when accompanied by additional support services such as medication titration, education, and lifestyle counseling. This literature search was conducted from bibliographic database, MEDLINE, using the keywords – (remote monitoring OR home telemonitoring) AND (blood pressure OR blood glucose OR hypertension OR diabetes) AND (meta OR review).

Besides, additional clinical trials revealed that remote patient monitoring was cost-effective for hypertension or diabetes management (31–35). This literature search also conducted from MEDLINE, using the keywords – (remote monitoring OR home telemonitoring) AND (blood pressure OR blood glucose OR hypertension OR diabetes) AND (cost).

Although clinical trials are the gold standard, the reported results may not materialize in practice. Physicians have concerns about instrumentation quality, patient skills in taking readings, regular recording and transmission of results, and adherence to a regimen of routine measurement (36). The 2010 and 2014 surveys of Canadian patients at a hypertension clinic where patients were encouraged to conduct home blood pressure monitoring found that only 39.2% and 40.6%, respectively, reported blood pressure

more than 80% of the time (37). Thus, poor patient adherence to daily monitoring and reporting could significantly undermine the positive effects observed in clinical trials.

We note that insurance coverage is a requisite for daily remote patient monitoring. Medicare began paying for remote patient monitoring in November 2018 (38), and Texas Medicaid reimburses physician-prescribed remote patient monitoring for hypertension or diabetes for 60 days, with reauthorization for additional monitoring at physician request (39,40). More generally, reimbursement rates for remote patient monitoring services vary significantly among states and insurers and have an uncertain future (10). Although the temporary support for telehealth services by the Centers for Medicare & Medicaid Services and private insurers as a result of the coronavirus pandemic may lead to permanent changes in the delivery of routine care (41,42), the future of remote patient monitoring coverage is unclear. In this uncertain environment, the analysis of real-world remote patient monitoring implementations is of great importance.

1.2. Objectives

The aims of this study are to (1) investigate how well Texas Medicaid patients adhere to daily blood pressure and glucose monitoring when supported by a daily remote monitoring services company, (2) determine whether an adherence reminder call intervention improves the daily transmission rate, (3) investigate any association between daily adherence and blood pressure and glucose control, and (4) assess any association between remote patient monitoring and hospital charges specifically related to circulatory system diseases (CSD). To achieve these objectives, the study will utilize

data obtained from a remote patient monitoring company that serves Texas Medicaid patients, as well as hospital claims from the Dallas-Fort Worth region.

2. REMOTE PATIENT MONITORING PROTOCOL

In this study, a remote patient monitoring company provided historical monitoring data (from January 2016 to December 2018) for Medicaid clients with hypertension or diabetes in the state of Texas. Detailed workflow processes for remote patient monitoring service are described in Figure 2.1.

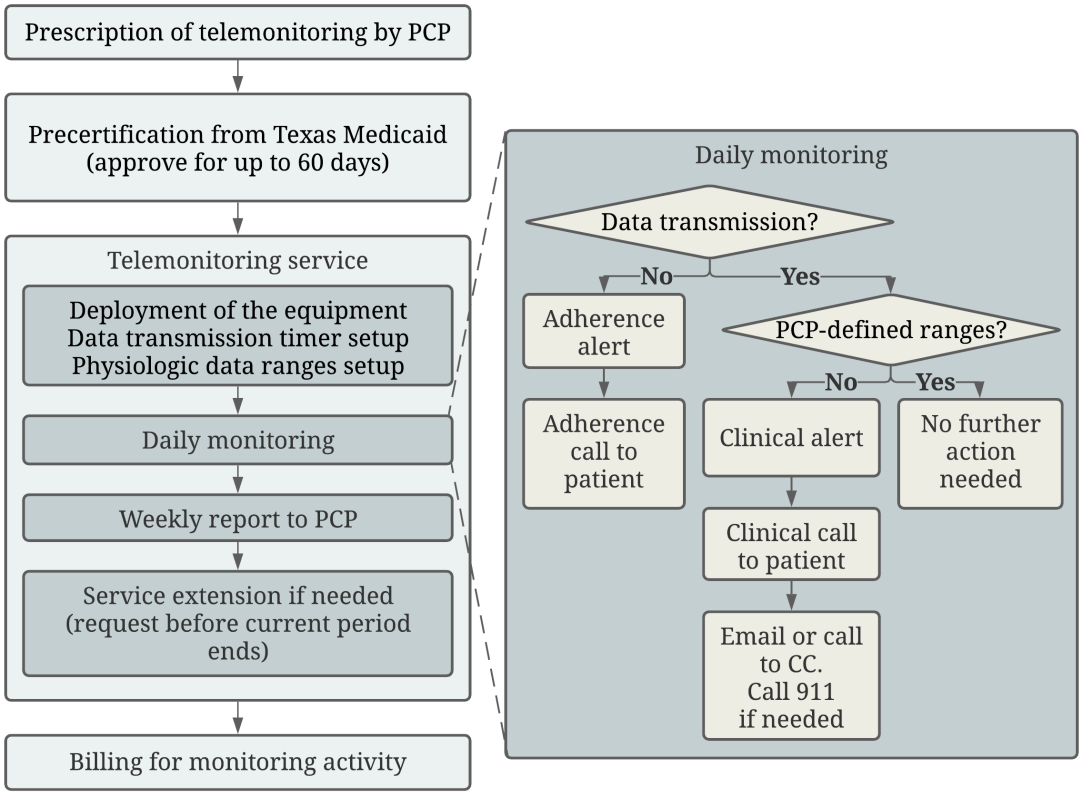

Figure 2.1 Workflow processes for remote patient monitoring service.

The monitoring protocol required patients to be referred by their physician. After Medicaid approval, a company technology deployer visited the patient's home to set up the equipment and provide training. The equipment—Food and Drug Administration–

approved devices—consisted of a monitoring device with Bluetooth technology and a signal transmission unit that transferred the monitoring results to the company's cloud storage. No internet connection or smartphone was required. The training protocols and materials were developed based on American Medical Association guidelines (43). The patients received education on how to use the equipment to take proper readings and were informed about the company's protocols for responding to the patients' technical or clinical needs. The patients were asked to select time by which they would check and transmit their physiologic data. If transmission did not occur by that time, an automated alert prompted a company staff member to make an adherence reminder call to the patient to troubleshoot any technical issues and to ask the patient to check and transmit the readings. Once the patient's data were received, if the patient physiologic data fell outside the physician-defined acceptable ranges, an automated clinical alert was transmitted to a company nurse. The nurse placed a clinical phone call to the patient, categorized the extent of concern, and contacted the provider by email for the lowest level of concern and by both email and phone call for more severe concerns. The company provided weekly summary reports to each provider for the enrolled patients. Under Texas Medicaid rules, a request for reauthorization of the remote monitoring therapy was made every 60 days when the physician prescribed additional monitoring.

3. REMOTE PATIENT MONITORING FOR HYPERTENSION[*]

3.1. Objectives

The aims of this chapter are to (1) investigate how well Texas Medicaid patients adhere to daily blood pressure and pulse rate monitoring when supported by a daily remote patient monitoring services company, (2) determine whether an adherence reminder call intervention improves the daily transmission rate, and (3) investigate any association between daily adherence and blood pressure control.

3.2. Methods

3.2.1. Design

This study targeted Medicaid patients with hypertension from the state of Texas who monitored their blood pressure and pulse rate starting between 2016 and 2018. The remote patient monitoring company provided historical monitored data for Texas Medicaid clients using their service. Only clients with 180 days or more of remote patient monitoring were included in this study. The first 30 days were regarded as a startup period during which the patients learned to use the equipment to measure their vital signs. Data from the first 30 days were excluded from this study; thus, the study period was 150 days (month 1-5).

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[*] Reprinted with permission from "Adherence to Telemonitoring Therapy for Medicaid Patients with Hypertension: Case Study" by Sulki Park, Hye-Chung Kum, Michael A Morrisey, Qi Zheng, and Mark A Lawley, 2021. Journal of Medical Internet Research, 23(9):e29018, Copyright 2021 by Journal of Medical Internet Research.

The number of transmissions before and after the adherence reminder calls was recorded each day, as was the number of adherence reminder calls made. We included all attempted adherence reminder calls, even those that the patients did not answer, because, in these cases, voice mail was left whenever possible. Daily systolic and diastolic blood pressure values were also collected to investigate improvements in blood pressure values during the study period. The mean systolic and diastolic blood pressure values at month 5 for each patient were calculated and compared with those at month 1. If the blood pressure values of the patient were missing for the entire month, that patient was excluded from this analysis.

The patients were separated into adherent and non-adherent cohorts; adherent patients were those who transmitted blood pressure and pulse values on at least 120 of the 150 days (at least 80% of the days, the same threshold used in the study by Milot et al (37)).

3.2.2. Statistical Analysis

To determine whether the patient baseline characteristics differed by population subgroups, we used χ^2 tests for categorical variables and t tests for continuous variables. In addition, z tests for the equity of the two proportions were performed to examine whether the rates of transmission differed by population subgroups. Paired t tests were performed to analyze the changes in blood pressure values at month 5 by comparing them with those at month 1 for each subgroup. Independent t tests were used to compare the changes in blood pressure values between the population subgroups. Analyses were

conducted using SAS version 9.4 (SAS Institute). This study was approved by the institutional review board of Texas A&M University.

3.3. Results

3.3.1. Patient Characteristics

The data of 2093 clients enrolled in hypertension monitoring were provided. Of the 2093 patients, 1325 (63.31%) transmitted data at least once, and 823 (39.32%) transmitted data throughout a continuous 180-day period.

Table 3.1 summarizes their characteristics.

Table 3.1 Demographics and non-alert ranges for overall, adherent, and non-adherent cohorts (N=823).

Characteristics	Patients			
	Overall (N=823)	Adherent (n=475)	Non-adherent (n=348)	*P* value
Age (years), mean (SD)	73.2 (11.7)	73.8 (10.9)	72.3 (12.6)	0.07
Women, n (%)	536 (65.1)	301 (63.4)	235 (67.5)	0.22
Area of residence[a], n (%)				
Dallas	34 (4.1)	13 (2.7)	21 (6)	<.001
Houston	26 (3.2)	11 (2.3)	15 (4.3)	
McAllen	648 (78.7)	368 (77.5)	280 (80.5)	
San Antonio	115 (14)	83 (17.5)	32 (9.2)	
Urban-rural classification[a], n (%)				
Urban	660 (80.2)	360 (75.8)	300 (86.2)	<.001
Suburban or rural	163 (19.8)	115 (24.2)	48 (13.8)	
Assigned non-alert range for systolic blood pressure, n (%)				
Default (90-160 mm Hg)	731 (88.8)	424 (89.3)	307 (88.2)	0.64
Personalized	92 (11.2)	51 (10.7)	41 (11.8)	
Assigned nonalert range for diastolic blood pressure, n (%)				

Default (60-90 mm Hg)	725 (88.1)	422 (88.8)	303 (87.1)	0.44
Personalized	98 (11.9)	53 (11.2)	45 (12.9)	
Assigned nonalert range for pulse, n (%)				
Default (60-120 bpm)	724 (88)	421 (88.6)	303 (87.1)	0.5
Personalized	99 (12)	54 (11.4)	45 (12.9)	

The mean age of the participants was 73.2 (SD 11.7) years, and 65.1% (536/823) were women. All patients included in this study were diagnosed with hypertension and were on pharmaceutical therapy.

Most of the participants (648/823, 78.7%) were from McAllen in south Texas near the Mexican border, and most of them (660/823, 80.2%) resided in urban areas. Of the 823 participants, 731 (88.8%), 725 (88.1%), and 724 (88%) participants had acceptable systolic blood pressure, diastolic blood pressure, and pulse ranges of 90-160 mm Hg, 60-90 mm Hg, and 60-120 bpm, respectively, which were defined by their primary care physician. The remaining 92 (11.2%), 98 (11.9%), and 99 (12%) participants had customized acceptable values above or below these ranges (55-200 mm Hg, 50-120 mm Hg, and 50-120 bpm for systolic blood pressure, diastolic blood pressure, and pulse ranges, respectively).

Table 3.1 also provides descriptive characteristics of the adherent and non-adherent cohorts. The characteristics across the two cohorts were similar, although the adherent cohort had a higher proportion of suburban or rural patients, with more of them living in south Texas ($P<.001$).

3.3.2. Adherence

Figure 3.1 shows the transmission rates (calculated using the following formula: transmission rate = 100 × total number of patients who transmitted readings/823 patients) over the 5-month (150-day) period.

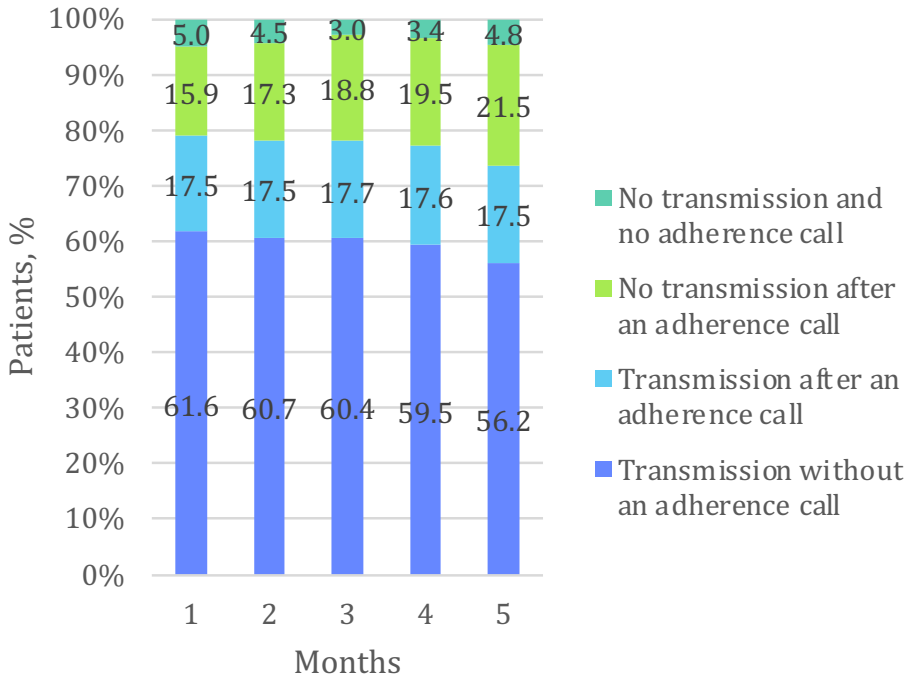

Figure 3.1 Monthly transmission rates for all patients over 150 days of remote patient monitoring (N=823).

The overall mean transmission rates across all 5 months were 59.7% before the adherence reminder call and 77.2% after the call. The mean transmission rates for the first month were 61.6% and 79.1% before and after the call, respectively. These values declined until the fifth month when they reached 56.2% and 73.7% before and after the call, respectively. As indicated by the sky-blue area in Figure 3.1, an average of 17.6% of the data transmissions were received after an adherence reminder call. However, the

percentage of participants not transmitting after an adherence reminder call increased from 15.9% in the first month to 21.5% in the fifth month.

These aggregate findings mask large differences between the adherent and non-adherent cohorts (Figure 3.2).

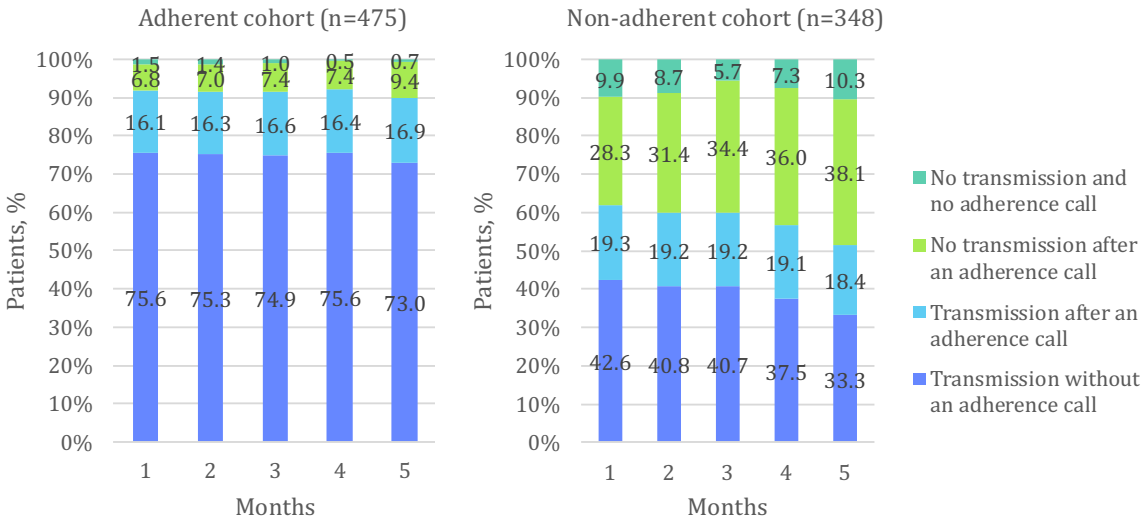

Figure 3.2 Monthly transmission rates for the adherent and non-adherent cohorts over 150 days of remote patient monitoring.

The adherent cohort was much more likely to transmit data without an adherence reminder call, with an overall mean transmission rate of 74.9% compared with only 39% for the non-adherent cohort (P<.001). After the adherence reminder call, these values increased to 91.3% and 58% (P<.001), respectively.

The mean transmission rates for the first month were 75.6% before the adherence reminder call and 91.7% after the call for the adherent cohort and 42.6% and 61.9% before and after the call, respectively, for the non-adherent cohort. These values fluctuated and declined until the fifth month when they reached 73% and 89.9% before and after the call, respectively, for the adherent cohort and 33.3% and 51.7% before and

after the call, respectively, for the non-adherent cohort. On average, an additional 16.5% and 19% transmissions were received after an adherence reminder call from the adherent and non-adherent cohorts, respectively ($P<.001$).

The percentage of participants not transmitting after an adherence reminder call was, on average, 7.6% for the adherent cohort and 33.6% for the non-adherent cohort. These values increased from 6.8% in the first month to 9.4% in the fifth month for the adherent cohort and from 28.3% in the first month to 38.1% in the fifth month for the non-adherent cohort ($P<.001$). We noted that, on average, 8.4% of the non-adherent participants who did not transmit data by the specified time failed to receive an adherence reminder call. This value increased to 10.3% in the fifth month of monitoring. In contrast, only 1.02% of the adherent cohort who did not transmit data failed to receive an adherence reminder call.

As might be expected, adherence was lowest on weekends, especially on Sundays, when the transmission rate (after the adherence reminder call) dropped to 88.4% and 46.3% for the adherent and non-adherent cohorts, respectively (

Table 3.2 and Table 3.3).

Table 3.2 Weekday adherence by month for the adherent cohort (N=475).

Month	Adherence (%)						
	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Month 1	88.7	92.9	93.3	93.4	92.5	91.8	90
Month 2	87.8	92.5	92.8	92.1	92.6	92.7	90.8
Month 3	88.4	91.9	93.1	92.9	92.8	92.4	89.1
Month 4	89.6	92.9	91.8	93.4	93.1	93.1	90.5
Month 5	87.3	91.5	91	90.4	90.7	90.1	88.4
Mean	88.4	92.3	92.4	92.4	92.3	92	89.8
SD	0.8	0.6	0.9	1.1	0.8	1	0.9

Table 3.3 Weekday adherence by month for the non-adherent cohort (N=348).

Month	Adherence (%)						
	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Month 1	49.6	66.9	67.1	68.6	65.6	63	52.8
Month 2	47.9	64.9	64.2	64.9	64.9	61.8	51.7
Month 3	46.7	64.4	64.1	65.2	63.8	62.1	52.1
Month 4	45.7	60.2	61	61.6	59.9	57.7	50.1
Month 5	41.8	55	55.5	56	55.6	54.2	44
Mean	46.3	62.3	62.4	63.3	62	59.7	50.1
SD	2.6	4.2	3.9	4.2	3.7	3.3	3.2

The Sunday transmission rate was also observed to decrease over the 5-month period from 88.7% to 87.3% for the adherent cohort and from 49.6% to 41.8% for the non-adherent cohort.

Along with adherence to the daily protocol, the data also indicated whether the transmissions received were in or out of the physician-specified range. The average percentage of transmissions in range (calculated using the following formula: average percentage of transmissions in range = 100 × [number of transmissions in range/total number of transmissions]) was found to be 60.9% (SD 26.0) for the adherent cohort and 53.9% (SD 24.9) for the non-adherent cohort. The percentage in range increased for both cohorts over the 5-month period, indicating that remote patient monitoring was effective, from 59.2% in month 1 to 62.3% in month 5 for the adherent cohort and 49.8% in month 1 to 56.7% in month 5 for the non-adherent cohort.

Finally, the data indicated that the transmission results for 2 consecutive days were related. Note that for any given day, there were three possible outcomes: the patient did not transmit, the patient transmitted an out-of-range reading (blood pressure values, pulse rate, or both) or the patient transmitted an in-range reading. We refer to these as transmission events. Frequency analysis indicated an association between the transmission events observed on consecutive days. This is explored in the following sections. The percentages are listed in

Table 3.4.

Table 3.4 Next day transition (N=823).

From/to	Adherent cohort (n=475), %			Non-adherent cohort (n=348), %		
	NT[a]	ORT[b]	IRT[c]	NT	ORT	IRT
NT	32.9	29.3	37.8	61.7	18.5	19.8
ORT	5.6	41.6	52.7	28.9	34.8	36.3
IRT	6.3	32	61.7	29.6	28	42.5

[a]NT: no transmission.
[b]ORT: out-of-range transmission.
[c]IRT: in-range transmission.

3.3.3. Trends in Transmission Events Between 2 Consecutive Days

Adherence on the day after a missed transmission was far below the overall average for both adherent (67.1% vs an average of 91.3%) and non-adherent (38.3% vs an average of 58%) cohorts. Furthermore, the transmissions that were received the day after a missed transmission were less likely to be in range than the average for both cohorts. For the adherent cohort, 37.8% of the missed transmissions were followed by in-range transmissions, indicating that 56.3% (100 × [37.8/67.1]) of the transmissions received the day after a missed transmission were in range, whereas for the non-adherent cohort, 19.8% of the missed transmissions were followed by in-range transmissions, indicating that 51.6% (100 × [19.8/38.3]) of the transmissions received the day after a missed transmission were in range.

Adherence and in-range transmission after out-of-range transmission also showed similar patterns across the 2 cohorts. For the adherent cohort, out-of-range

transmissions were followed by 41.6% of out-of-range transmissions, 52.7% of in-range transmissions, and only 5.6% of no transmissions the next day. For the non-adherent cohort, out-of-range transmissions were followed by 34.8% of out-of-range transmissions, 36.3% of in-range transmissions, and 28.9% of no transmissions the next day. Thus, adherence after an out-of-range day was greater than the overall average (94.6% vs an average of 91.3% for the adherent cohort and 71.1% vs an average of 58% for the non-adherent cohort). Furthermore, the transmissions that were received after an out-of-range transmission were less likely to be in range than the overall average (55.7%—100 × [52.7/94.6]—vs an average of 60.9% for the adherent cohort and 51%—100 × [36.3/71.1]—vs an average of 53.8% for the non-adherent cohort). It is worth noting that when an adherent patient transmitted an out-of-range reading, the next in-range transmission occurred within 2-3 days on average, that is, it took 2-3 days to resolve whatever problem was causing the out-of-range reading and for the patient to regain blood pressure and pulse rate control. However, when a non-adherent patient transmitted an out-of-range reading, the next in-range transmission did not occur for 5-6 days on average, indicating that non-adherent patients were likely to experience elevated levels of blood pressure or pulse rate over a longer period.

Finally, adherence and in-range transmission after an in-range transmission also had similar patterns across the 2 cohorts, with better adherence and more in-range transmissions on the following day. For the adherent cohort, in-range transmissions were followed by 61.7% of in-range transmissions, 32% of out-of-range transmissions, and only 6.3% of no transmissions the next day. For the non-adherent cohort, in-range

transmissions were followed by 42.5% of in-range transmissions, 28% of out-of-range transmissions, and 29.6% of no transmissions the next day. Thus, adherence after an in-range day was greater than the overall average (93.7% vs an average of 91.3% for the adherent cohort and 70.5% vs an average of 58% for the non-adherent cohort). Furthermore, the transmissions that were received after an in-range transmission were more likely to be in-range again the next day than the overall average (65.8%—100 × [61.7/93.7]—vs an average of 60.9% for the adherent cohort and 60.3%—100 × [42.5/70.5]—vs an average of 53.8% for the non-adherent cohort).

3.3.4. Relationship Between Daily Adherence and Blood Pressure Control

Overall, we found that the systolic blood pressure values of the adherent cohort improved by an average of 2.2 mm Hg (P<.001) over 5 months, whereas those of the non-adherent cohort improved by an average of 1.6 mm Hg (P=.02;

Table 3.5).

Table 3.5 Systolic blood pressure changes between month 1 and month 5 (N=781).

	Adherent cohort (n=475), mm Hg	Non-adherent cohort (n=306[a]), mm Hg	*P* value[b]
Month 1			
Values, mean (SD)	133.7 (12.5)	137.9 (15.0)	<.001
Month 5			
Values, mean (SD)	131.4 (12.2)	136.3 (14.4)	<.001
Comparison between month 1 and month 5			
Values, mean (SD)	-2.2 (9.5)	-1.6 (12.0)	.049
P value[d]	<.001	.02	—[c]

[a]A total of 42 patients were excluded because of missing data.
[b]A two-tailed independent t test was performed to compare the systolic blood pressure changes between the adherent and non-adherent cohorts.
[c]Not applicable
[d]A two-tailed paired t test was performed to analyze the differences in systolic blood pressure values between month 1 and month 5 for each cohort.

This improvement in the adherent cohort was significantly higher than that in the non-adherent cohort (*P* =.049).

Furthermore, of the 21 patients with an average systolic and diastolic blood pressure reading of more than 140 and 90 mm Hg for the first month, we found that the systolic blood pressure of the adherent patients (7/21, 33%) improved by an average of 14.8 mm Hg (*P* =.02) over 5 months, whereas that of the non-adherent patients (14/21, 67%) improved by an average of 10.6 mm Hg over 5 months, which was not significantly different (*P*=.11). The diastolic blood pressure of the adherent patients improved by an average of 0.7 mm Hg (p=.004) over 5 months, whereas the improvement over 5 months was not significant for non-adherent patients (0.4 mm Hg; *P*=.39; Table 3.6).

Table 3.6 Diastolic blood pressure changes between month 1 and month 5 (N=781).

Month	Adherent cohort (n=475), mm Hg	Non-adherent cohort (n=306[a]), mm Hg	*P* value[b]
Month 1			
Values, mean (SD)	71.5 (7.9)	74.0 (10.0)	<.001
Month 5			
Values, mean (SD)	70.7 (7.9)	73.6 (9.8)	<.001
Comparison between month 1 and month 5			
Values, mean (SD)	-0.7 (5.6)	-0.4 (7.9)	.09
P value[d]	.004	.39	—[c]

[a]A total of 42 patients were excluded because of missing data.
[b]A two-tailed independent t test was performed to compare the diastolic blood pressure changes between the adherent and non-adherent cohorts.
[c]Not applicable
[d]A two-tailed paired t test was performed to analyze the differences in diastolic blood pressure between month 1 and month 5 for each cohort.

Of the 21 patients with an average systolic and diastolic blood pressure reading of more than 140 and 90 mm Hg for the first month, we found that the diastolic blood pressure of adherent patients (7/21, 33%) improved by an average of 11.0 mm Hg (*P*=.02) over 5 months, whereas that of the non-adherent patients (14/21, 67%) improved over 5 months by an average of 9.7 mm Hg (*P*=.03).

3.4. Discussion

3.4.1. Principal Findings

This study suggests that remote patient monitoring for hypertension can achieve more than 70% adherence among Medicaid clients. Thus, most patients should be able to check and transmit their blood pressure values and pulse rate after the initial training. Furthermore, much higher levels of adherence (up to 90%) are possible for most patients

(57.7% [475/823] of the patients in this study had 80% or more days of transmission) when remote patient monitoring is accompanied by adherence reminder calls. For these patients, adherence levels seemed to decline slightly over the 5-month period.

Furthermore, many Medicaid patients are likely to have trouble with daily adherence (42.3% [348/823] of the patients in this study). For these patients, adherence reminder calls can be helpful, but many daily transmissions will still be missed (approximately 13 days per patient per month in this study). Such patients can likely be identified within the first month of monitoring (not including the startup period), when their adherence rates without the adherence reminder call fall well below 50% (42.6% in this study). Indeed, 75% (260/348) of the patients in the non-adherent cohort in this study were not adherent in the first month of monitoring. For these patients, adherence rates can be expected to degrade significantly over time (by approximately 16% over 5 months in this study). Of the 823 patients, the 475 (57.7%) adherent patients and the 348 (42.3%) non-adherent patients together generated the need for approximately 350 adherence reminder calls per day, a significant workload. Regardless of the case, patients with adherence problems clearly need more than an adherence reminder call. Indeed, interventions that delve into health behaviors will likely be necessary (but perhaps not sufficient) to bring adherence levels up to 80% and beyond. The data suggest that such interventions should be targeted to weekends and to days after missed transmissions when the likelihood of poor adherence is higher.

Just as additional support for better adherence to daily monitoring is necessary, follow-up on an abnormal clinical condition is also important. A potential benefit of

daily monitoring is that health care providers may recognize and address emerging problems before they become urgent. When readings are not transmitted, this opportunity may be lost. If we assume that the percentage of out-of-range transmissions can be applied to the days when data were not transmitted, we can estimate the number of missed transmissions that would have been out of range. Over 150 days of monitoring, this estimate turned out to be 5.1 days ([1–0.913] × [0.391] × 150) per patient for the adherent cohort and 29.0 days ([1–0.580] × [0.461] × 150) per patient for the non-adherent cohort. This represents a total of 12,528 days (29.04 × 348 + [5.10 × 475]) of unmet needs for 823 patients over 150 days of monitoring (approximately 15 days per patient). In other words, 10.2% (12,528/[150 × 823]) of the required follow-up was missed because of lack of adherence (for the non-adherent cohort, this was approximately 20%).

On a positive note, it is encouraging that 58.9% (280/475) of the adherent patients and 54.9% (168/306) of the non-adherent patients experienced an improvement in systolic blood pressure values, and 52.2% (248/475) of the adherent patients and 51.6% (158/306) of the non-adherent patients experienced an improvement in diastolic blood pressure values. The mean systolic blood pressure values of both cohorts improved significantly during the study period, and these improvements were significantly higher in the adherent cohort (P=.049). The mean diastolic blood pressure value of the adherent cohort declined significantly during the study period, but the decline was not significant for the non-adherent patients. These results are consistent with those of clinical trials in the literature. In 18 clinical trials of remote patient monitoring, the average improvement in systolic and

diastolic blood pressure values was 12.1 and 6.3 mm Hg within 6 months (44–61). Of these 18 clinical trials, eight were restricted to patients with systolic and diastolic blood pressure values of more than 140 and 90 mm Hg at baseline, and the other ten trials were restricted to those with blood pressure readings above or below these values. In our study with patients with systolic and diastolic blood pressure values of more than 140 and 90 mm Hg in the first month, the systolic and diastolic blood pressure values of the adherent patients improved by an average of 14.8 and 11.0 mm Hg, which is higher than the average improvement observed in the 18 clinical trials. However, for non-adherent patients with systolic and diastolic blood pressure values of more than 140 and 90 mm Hg in the first month, only the diastolic blood pressure value significantly improved by an average of 9.7 mm Hg.

Finally, it is important to appreciate that achieving improved adherence requires considerable effort. Patients must be trained in the correct procedures to monitor their blood pressure and pulse; staff members must monitor daily transmissions and contact patients to encourage participation and to resolve technical issues; and, as noted, additional interventions will be needed for many patients. Texas Medicaid payment levels may have been adequate for this level of intervention, but it is not clear whether Medicare or private insurers will reimburse this level of effort in the future. Clearly, the case for reimbursement would be compelling if hypertension remote patient monitoring could be shown to help avoid even a small number of hospitalizations for stroke and heart disease, which can be extremely expensive.

3.4.2. Limitations

This study included some limitations. It only examined Texas Medicaid clients. It is not clear whether these findings are generalizable to Medicare, privately insured, or uninsured patients with hypertension. It is also unclear whether these findings are generalizable to people with other chronic conditions who would benefit from ongoing monitoring. This study was limited to patients who were referred to the monitoring program. The analysis would be strengthened if there were a control group to more rigorously examine adherence and the impact of the intervention. Finally, the monitoring protocol required the data to be transmitted on a daily basis, which was more frequent than the general home blood pressure monitoring guidelines (10). Excessive and frequent transmission requirements may negatively affect adherence and persistence. In contrast, daily monitoring could help with medication adherence and help avert emergency situations and hospitalizations.

3.5. Conclusion

Adherence reminder calls helped most patients with hypertension to achieve higher levels of adherence to blood pressure and pulse monitoring. Remote patient monitoring improved blood pressure control, similar to the improvement observed in clinical trials. Furthermore, more adherent patients achieved higher levels of blood pressure control. However, the study suggests that additional adherence interventions and support are needed for many patients to achieve high levels of adherence.

4. REMOTE PATIENT MONITORING FOR DIABETES

4.1. Objectives

The aims of this chapter are to (1) determine how well Texas Medicaid patients adhered to daily blood glucose monitoring protocols when supported by a daily remote patient monitoring services company, (2) examine the relationship between adherence and changes in blood glucose levels associated with daily monitoring, and (3) investigate the impact of daily testing time on the mean and variance of blood glucose readings over the study period.

4.2. Methods

4.2.1. Design

This study targeted Medicaid patients with diabetes from the state of Texas who monitored their blood glucose starting between 2016 and 2018. The remote patient monitoring company provided historical monitored data for Texas Medicaid clients using their service. Only clients with 180 days or more on the remote patient monitoring service were included in this study to have sufficient follow up time. The first 30 days were regarded as a startup period during which the patients learned to use the equipment to measure their glucose values, and were excluded from this study; thus, the study period was 150 days (months 1-5). If the blood glucose levels of the patient were transmitted only once or less in any month, that patient was excluded from this study.

The patients were separated into adherent and non-adherent cohorts; adherent patients were those who tested blood glucose levels on at least 120 of the 150 days (at least 80% of the days).

As our study focused on daily basis remote patient monitoring, we selected the last blood glucose reading of the day in cases where a patient transmitted multiple readings due to technical issues or by choice. This decision was made to account for cases where a recheck was needed due to a misreading during the first attempt. Additionally, in situations where multiple readings were received simultaneously due to technical issues, selecting the last reading ensured that the most recent and up-to-date data was used for follow-up.

Transmission rates ([total number of patients who transmitted readings] / [total number of patients] × 100) before and after the adherence calls were recorded each day, as was the number of adherence calls made. In cases where multiple calls were made to a patient, we selected the first call time for our analysis. We included all attempted adherence calls, even those that the patients did not answer, because, in these cases, voice mail was left whenever possible.

Improvements in blood glucose control during the study period was studied using the mean and standard deviation of blood glucose levels at month 1 and 5 for each patient. As glycemic variability is an important metric to consider when assessing glycemic control, changes in standard deviation were analyzed (62). We report out the group mean of these individual patient measures for the month.

In addition, to account for the natural fluctuations in blood glucose levels throughout the day, we also conduct subgroup analysis of blood glucose levels based on their testing time — between 1AM and 10AM, 10AM and 6PM, and 6PM and 1AM. The thresholds were based on the patient daily routine and the actual blood glucose levels. Afterward, to evaluate improvements in blood glucose control considering testing time, we compared the mean and standard deviation of each patient's levels at month 1 and month 5 within each testing time range. This analysis specifically focused on patients who consistently transmitted their data within the specified time intervals every month. Therefore, patients can be included in multiple time intervals depending on their testing habits.

4.2.2. Statistical Analysis

We used χ^2 tests for categorical variables and t tests for continuous variables to compare the patient baseline characteristics between population subgroups. We also performed z tests for the equality of the two proportions to compare the transmission rates between two subgroups. In addition, paired t tests were performed to analyze the blood glucose changes from month 1 to month 5 for each subgroup. And two-sample t tests were performed to compare the blood glucose changes between the subgroups. Analyses were conducted using SAS version 9.4 (SAS Institute). This study was approved by the institutional review board of Texas A&M University.

4.3. Results

4.3.1. Patient Characteristics

A total of 2,099 clients enrolled in remote patient monitoring for blood glucose control (Figure 4.1). Of the 2099 patients, 460 (21.9%) enrolled 180 days or more, and 382 (18.2%) tested their blood glucose levels at least twice every month. Of the 382 patients, 186 (48.7%) were adherent and other 196 (51.3%) were non-adherent to the remote patient monitoring.

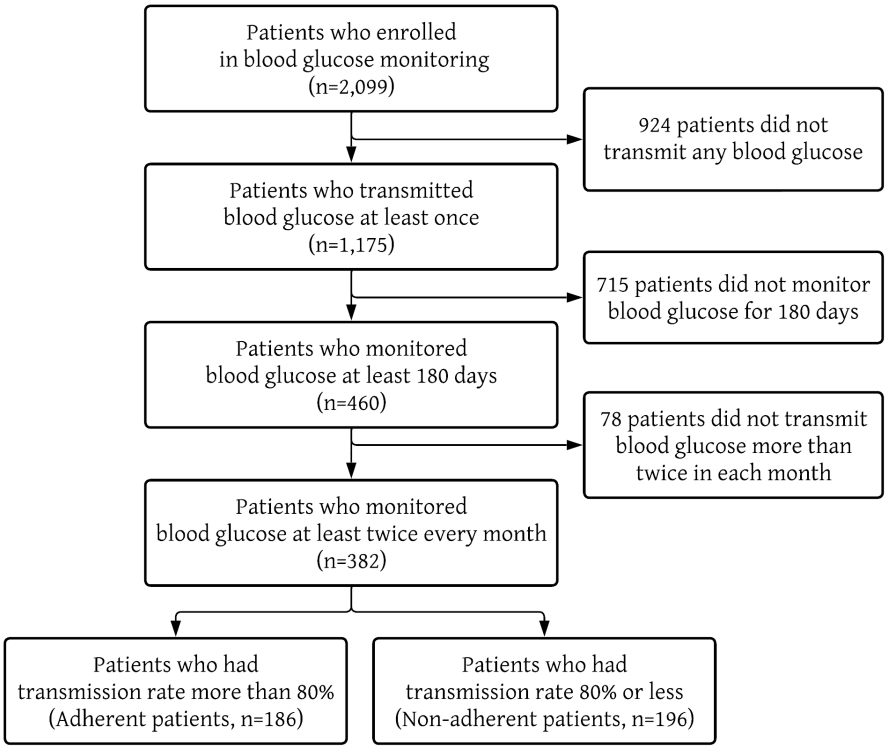

Figure 4.1 Sample flow chart.

Over the 150-day period, the 382 patients generated a total of 43,076 blood glucose transmissions, with 25,396 transmissions from the adherent cohort and 17,680 transmissions from the non-adherent cohort. On average, the adherent cohort sent 136.6 transmissions during the study period (SD 8.4), which corresponded to an average of 27.3 readings per month (SD 3.5, Figure 2). In contrast, the non-adherent cohort

transmitted a mean of 90.2 transmissions (SD 23.9), which corresponded to an average of 18 readings per month (SD 7.2).

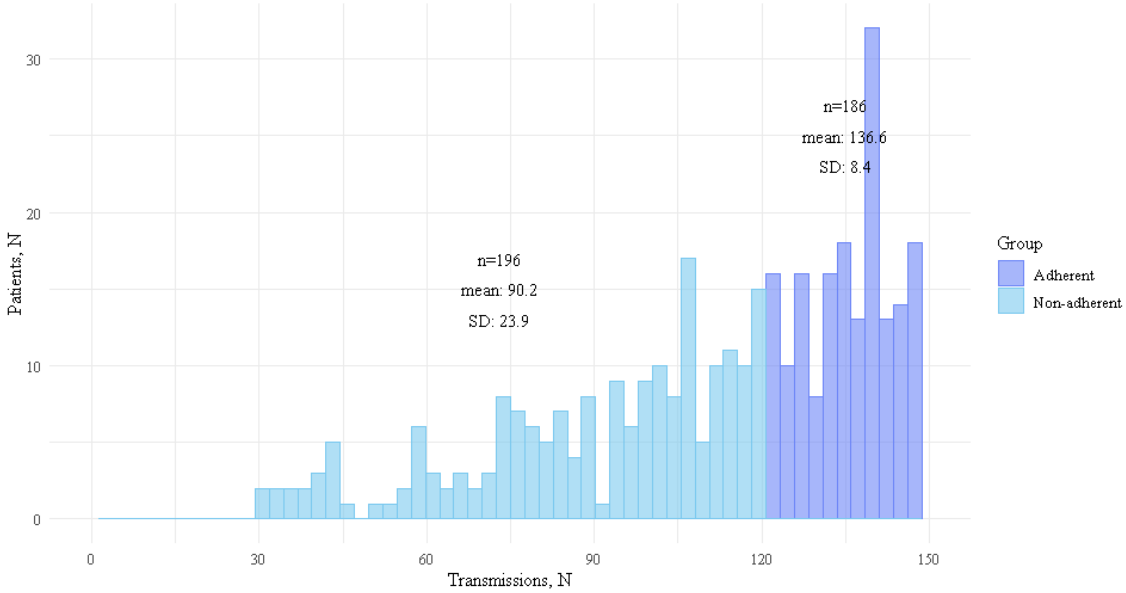

Figure 4.2 Number of transmissions per patients over 150 days for adherent and non-adherent cohort (N=382).

Table 4.1 shows the demographic information including age, gender, and area of residence. The mean age of the patients at starting the service was 70.5 (SD 11.8). More than half of the patients (255/382, 66.8%) were women, and predominantly from McAllen in south Texas (340/382, 82%), and urban area (351/382, 91.9%).

The characteristics across the two cohorts were similar, although the adherent cohort had a lower proportion of women (*P*=.01), with more of them living in McAllen (*P*=.02).

Table 4.1 Demographics for overall, adherent, and non-adherent cohorts (N=382).

Characteristics	Patients			
	Overall (N=382)	Adherent (n=186)	Non-adherent (n=196)	*P* value

Age (years), mean (SD)	70.5 (11.8)	69.7 (10.9)	71.3 (12.6)	0.20
Women, n (%)	255 (66.8)	112 (60.2)	143 (73)	0.01
Area of residence, n (%)				
Dallas	23 (6)	7 (3.8)	16 (8.2)	0.02
Houston or San Antonio	19 (5)	5 (2.7)	14 (7.1)	
McAllen	340 (89)	174 (93.6)	166 (84.7)	
Urban-rural classification, n (%)				
Urban	351 (91.9)	169 (90.9)	182 (92.9)	0.48
Suburban or rural	31 (8.1)	17 (9.1)	14 (7.1)	
Number of transmissions, n	43,076	25,396	17,680	–[a]

Figure 4.3 shows assigned adherence alert time. A majority of participants set their adherence alerts in the morning between 6AM and 12PM (263/382, 69.0%), with 73.7% and 65.6% of the adherent and non-adherent cohorts preferring morning, respectively (137/186, 126/196, *P*=.048).

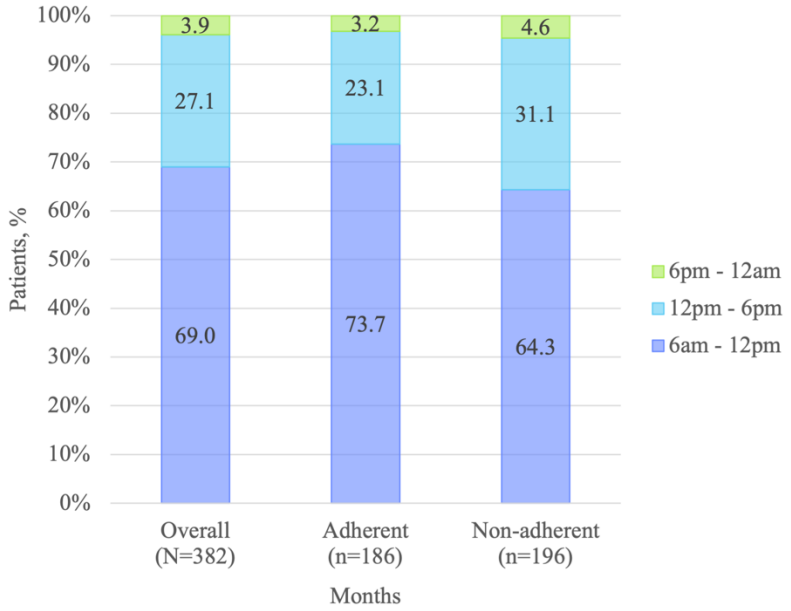

Figure 4.3 Assigned adherence alert time for overall, adherent, and non-adherent cohort (N=382).

4.3.2. Daily Adherence

Figure 4.4 shows the transmission rate over the 5-month (150-day) period. The overall mean transmission rates across all 5 months were 64.3% before the adherence call and 75.6% afterward. The mean transmission rates for the first month were 62.7% and 73.8% before and after the call, respectively. The transmission rates before the adherence call declined from 65.8% in the second month to 63.6% in the fifth month, while those rates after the call reached the highest of 77.4% in the third month and then declined to 75% in the fifth month. As indicated in the second block of each bar in Figure 4.4, an average of 11.3% of the data transmissions were received after an adherence call. However, an average of 20.9% of the participants did not transmit the data after an adherence call.

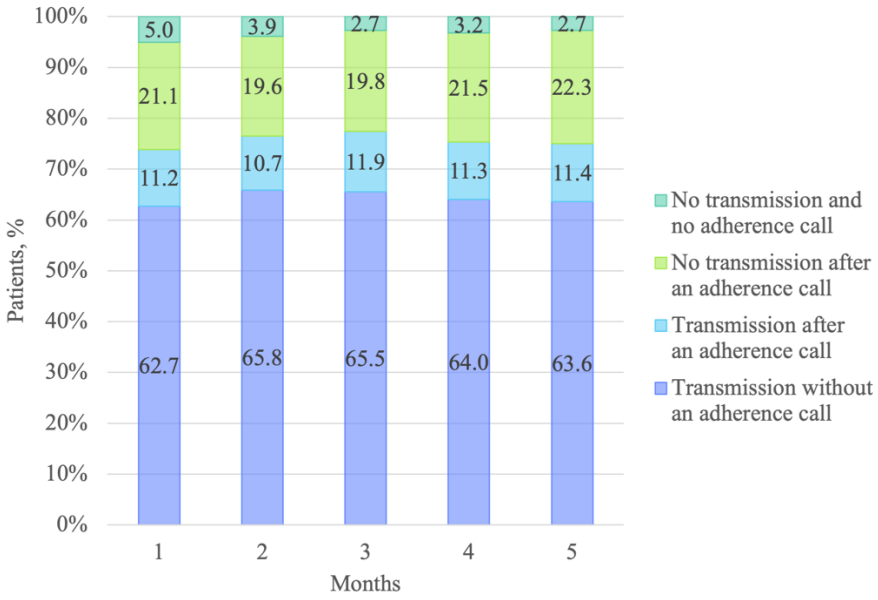

Figure 4.4 Average daily transmission rates by month for all patients over 150 days of telemonitoring (N=382).

The adherent and non-adherent cohorts showed large difference in those rates (Figure 4.5). The adherent cohort was much more likely to transmit data without an adherence call, with an overall mean transmission rate of 82.8% compared with only 45.9% for the non-adherent cohort (P<.001). After the adherence reminder call, these values increased to 91.1% and 60.2% (P<.001), respectively.

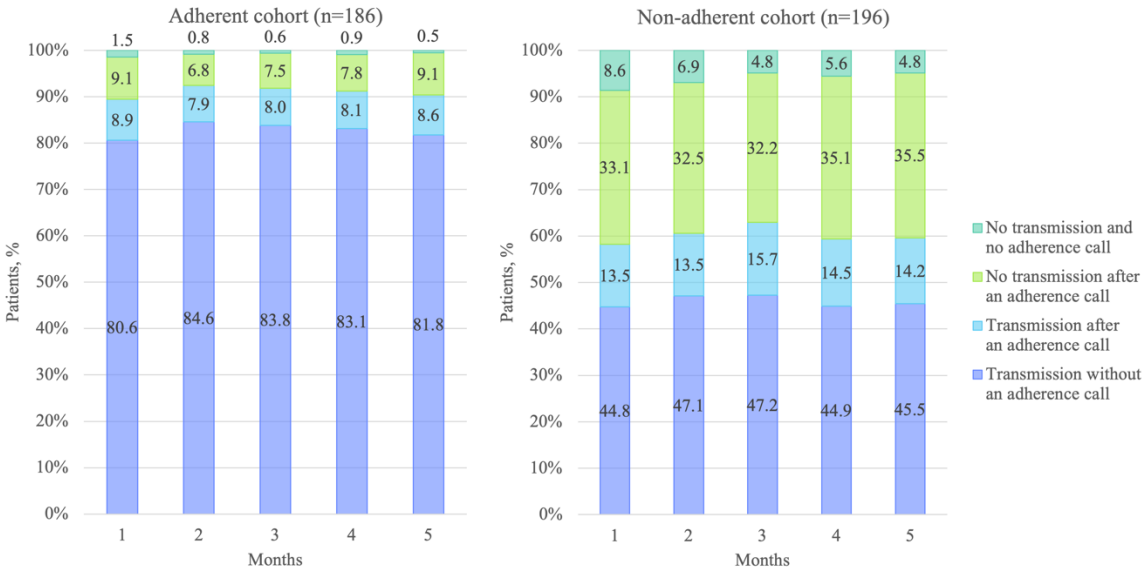

Figure 4.5 Average daily transmission rates by month for the adherent and non-adherent cohort over 150 days of telemonitoring (N=382).

The mean transmission rates for the first month were 80.6% before the adherence call and 89.4% after the call for the adherent cohort. These values reached the highest of 84.6% and 92.4% in the second month and then declined to 81.8% and 90.4% before and after the call, respectively, in the fifth month. On the other hand, the mean transmission rates for the first month were 44.8% and 58.2% before and after the call for the non-adherent cohort. These values reached the highest of 47.2% and 63% in the third month and declined to 45.5% and 59.6% before and after the call, respectively, until the fifth

month. On average, an additional 8.3% of the transmissions were received after an adherence reminder call from the adherent cohort, while an additional 14.3% transmissions were received after the call from the non-adherent cohorts ($P<.001$).

The percentage of participants not transmitting after an adherence reminder call was, on average, 8.1% for the adherent cohort and 33.7% for the non-adherent cohort ($P<.001$). We noted that, on average, 6.2% of the non-adherent participants who did not transmit data by the specified time failed to receive an adherence call. This value decreased to 4.8% in the fifth month of monitoring. In contrast, only 0.9% of the adherent cohort who did not transmit data failed to receive an adherence reminder call.

4.3.3. Adherence Reminder Call

Overall, the adherent and non-adherent cohorts received 4,616 (24.3%) and 14,401 (75.7%) adherence reminder calls over the 5 months. On average, one patient in the adherent cohort received 25.4 adherence calls (SD 19.6) over 5 months, and that was 6.1 (SD 5.2) calls per month. On the other hand, one in the non-adherent cohort received 74.2 (SD 34) adherence calls over 5 months, and that was 15.4 (SD 8.4) calls per month.

Of those 4,616 adherence calls to the adherent cohort, 50.7% (2,341 calls) helped a patient to transmit data, while of those 14,401 adherence calls to the non-adherent cohort, only 29.5% (4,247 calls) resulted in a patient to transmitting data.

A company staff member called a patient within 30 minutes after an adherence alert at median (26 and 27 minutes for the adherent and non-adherent cohorts, respectively). And a patient in the adherent cohort transmitted data in 64.5 minutes after

the adherence reminder call, while it took 95 minutes for the non-adherent cohort at median.

4.3.4. Relationship Between Adherence to Remote Patient Monitoring and Changes in Blood Glucose Control

Overall, we found that mean blood glucose levels of the adherent cohort decreased by an average of 9 mg/dL (P=.002) over 5 months which dropped from 147.2 mg/dL (SD 48.1) at month 1 to 138.2 mg/dL (SD 30.3) at month 5 (Table 4.2).

Table 4.2 Blood glucose changes between month 1 and month 5 (N=382).

Month	Adherent cohort (n=186), mg/dL	Non-adherent cohort (n=196), mg/dL	*P* value[a]
Month 1			
Number of transmissions, n	4,990	3,421	—[b]
Monthly mean, mean (SD)	147.2 (48.1)	154.9 (50.2)	0.13
Monthly variability, mean (SD)[c]	33.3 (24.5)	40(25.1)	0.01
Month 5			
Number of transmissions, n	5,040	3,505	—[b]
Monthly mean, mean (SD)	138.2 (39.6)	157.1 (48.7)	<.001
Monthly variability, mean (SD)[c]	30.3 (19.3)	39.1 (22.9)	<.001
Comparison of monthly mean between month 1 and month 5			
Values, mean (SD)	-9 (38.7)	2.2 (37)	0.004
P value[d]	0.002	0.41	—[b]
Comparison of monthly variability between month 1 and month 5			
Values, mean (SD)	-3 (18.6)	-0.9 (18.9)	0.27
P value[d]	0.03	0.49	—[b]

[a]A two-tailed independent t test was performed to compare the blood glucose changes between the adherent and non-adherent cohorts.
[b]Not applicable.

[c]Standard deviation was calculated to address monthly glucose variability.
[d]A two-tailed paired t test was performed to analyze the differences in blood glucose between month 1 and month 5 for each cohort.

We also found that variability of blood glucose level of the adherent cohort improved 3 mg/dL (*P*=.03) over the 5-month period. However, mean and variability of blood glucose levels of the non-adherent cohort did not significantly change over time.

4.3.5. Blood Glucose Testing Time and Level Differences

To investigate the impact of testing time on blood glucose improvements, we conducted an analysis by grouping blood glucose levels into three categories – between 1 AM and 10 AM, 10 AM and 6 PM, and 6 PM and 1 AM. These time thresholds were determined based on patients' daily routines and the actual blood glucose levels.

Among the adherent cohort, the majority of transmissions occurred between 1 AM and 10 AM, with 69.3% (3,459 transmissions) in month 1 and 72.2% (3,638 transmissions) in month 5 (Table 4.3). Additionally, 18.7% (935 transmissions) and 17.1% (862 transmissions) took place between 10 AM and 6 PM, while 11.9% (596 transmissions) and 10.7% (540 transmissions) occurred between 6 PM and 1 AM for month 1 and month 5, respectively.

Table 4.3 Blood glucose changes from month 1 to 5 in each time interval for the adherent cohort (N=186).

Month	Transmissions between 1AM and 10AM (n=150), mg/dL[a]	Transmissions between 10AM and 6PM (n=56), mg/dL[a]	Transmissions between 6PM and 1AM (n=28), mg/dL[a]
Month 1			
Number of transmissions, n	3,459	935	596
Monthly mean, mean (SD)	136.9 (49.1)	164.9 (51.6)	205.6 (59.2)
Monthly variability, mean (SD)[b]	24 (16.2)	41.5 (26.8)	53.8 (25.2)
Month 5			
Number of transmissions, n	3,638	862	540
Monthly mean, mean (SD)	130.4 (37.7)	152.9 (46.5)	174.6 (44.8)
Monthly variability, mean (SD)[b]	24.1 (16.4)	34.5 (22)	50 (22)
Comparison of monthly mean between month 1 and month 5			
Values, mean (SD)	-6.5 (46.1)	-12.1 (38.8)	-30.9 (52.1)
P value[c]	0.09	0.02	0.004
Comparison of monthly variability between month 1 and month 5			
Values, mean (SD)	0.04 (15.1)	-6.9 (21.8)	-3.8 (22.1)
P value[c]	0.97	0.02	0.37

[a]Every patient who transmitted in specified time period every month was selected. Therefore, patients in each time interval are not mutually exclusive.
[b]Standard deviation was calculated to address monthly glucose variability.
[c]A two-tailed paired t test was performed to analyze the differences in blood glucose between month 1 and month 5 for each cohort.

To assess improvements in blood glucose control with regard to testing time, the mean and standard deviation for each patient at month 1 and month 5 for each testing time range were calculated. We found that over the 5-month period, the mean blood

glucose levels for the adherent cohort tested from 1 AM to 10 AM, 10 AM to 6 PM, and 6 PM to 1 AM decreased by an average of 6.5 mg/dL (P=.09), 12.1 mg/dL (P=.02), and 30.9 mg/dL (P=.004), respectively.

Regarding the non-adherent cohort, a similar trend was observed, with the majority of transmissions occurring between 1 AM and 10 AM. Specifically, there were 1,784 (52.1%) transmissions in month 1 and 1,878 (53.6%) transmissions in month 5 (Table 4.4). Furthermore, there were 35.2% (1,203 transmissions) and 35.3% (1,236 transmissions) of transmissions between 10 AM and 6 PM, and 12.7% (434 transmissions) and 11.2% (391 transmissions) between 6 PM and 1 AM, in month 1 and month 5, respectively.

However, we did not observe any significant changes in the mean and variability of blood glucose levels among the non-adherent cohort.

Table 4.4 Blood glucose changes between month 1 and month 5 in each time interval for the nonadherent cohort (N=196).

Month	Transmissions between 1AM and 10AM (n=115), mg/dL[a]	Transmissions between 10AM and 6PM (n=94), mg/dL[a]	Transmissions between 6PM and 1AM (n=26), mg/dL[a]
Month 1			
Number of transmissions, n	1,784	1,203	434
Monthly mean, mean (SD)	140.1 (40.1)	169.5 (55.2)	190.6 (69.5)
Monthly variability, mean (SD)[b]	27.9 (18)	45.5 (29.6)	56.1 (23.1)
Month 5			
Number of transmissions, n	1,878	1,236	391
Monthly mean, mean (SD)	145.9 (40)	162.4 (50.2)	191.7 (62.2)
Monthly variability, mean (SD)[b]	28.1 (17.3)	40.6 (22.5)	59.5 (25)
Comparison of monthly mean between month 1 and month 5			
Values, mean (SD)	5.7 (35.7)	-7.0 (39.7)	1.1 (51.7)
P value[c]	0.09	0.09	0.91
Comparison of monthly variability between month 1 and month 5			
Values, mean (SD)	0.2 (16.7)	-5 (28.4)	3.4 (20.9)
P value[c]	0.88	0.09	0.41

[a]Every patient who transmitted in specified time interval every month were selected. Therefore, patients in each time interval are not mutually exclusive.
[b]Standard deviation was calculated to address monthly glucose variability.
[c]A two-tailed paired t test was performed to analyze the differences in blood glucose between month 1 and month 5 for each cohort.

4.4. Discussion

4.4.1. Principal Findings

Achieving target glycemic control is crucial in managing diabetes and preventing complications, which can significantly impact a patient's quality of life (63). Diabetes

management requires regular monitoring of blood glucose levels and frequent communication with healthcare professionals to adjust treatment plans (64). However, accessibility to diabetes specialists may be limited in some areas, and this can affect the quality of care that patients receive. Therefore, alternative remote patient monitoring technology has gained increasing attention to alleviate this burden.

Recent randomized clinical trials have shown promising results for remote patient monitoring interventions in improving glycemic control (64–66). Boaz et al. found that patients with remote patient monitoring experienced a 15 mg/dL decrease in fasting blood glucose levels while patients without remote patient monitoring experienced an increase over a 6-month period. Similarly, Jeong et al. reported 7.6 mg/dL and 12.3 mg/dL improvements in blood glucose levels for patients with telemonitoring (self-monitoring of blood glucose + automated message support) and telemedicine (self-monitoring of blood glucose + video communication) within 24 weeks, respectively, compared to those with conventional monitoring without blood glucose transmission. Franc and colleagues found that twice as many patients in the remote patient monitoring group achieved target fast blood glucose compared to the control group receiving standard care. These findings from randomized clinical trials suggest that remote patient monitoring has the potential to enhance patient care and improve outcomes in diabetes management. However, the effectiveness of remote patient monitoring in the real-world setting is still unclear, with limited data available.

The objective of this retrospective cohort study was to assess the effectiveness of remote patient monitoring among Medicaid clients with diabetes in a real-world setting. Specifically, the study aimed to evaluate the clients' adherence to remote patient monitoring and investigate any changes in their blood glucose levels during the 5-month period. The remote patient monitoring service provided diabetic patients with adherence support to monitor their glucose levels daily and receive immediate clinical feedback. The findings of this study indicate that the overall adherence rate for the remote patient monitoring system among Medicaid clients was over 70% with the help of adherence calls. Moreover, nearly half of the clients (adherent cohort, 186/382, 48.7%) achieved remarkably high adherence levels of approximately 90%, which were sustained throughout the study period with the help of adherence calls.

The study findings reveal that adherence calls played a significant role in improving clients' adherence to blood glucose monitoring, resulting in a 10% increase in adherence rates throughout the 5-month period. Notably, more than half of the clients (non-adherent cohort, 196/382, 51.3%) showed an impressive 14% improvement in adherence due to the calls, while the other clients (adherent cohort) showed an 8% improvement. Despite a slight decline in adherence over time, the adherence calls helped to maintain adherence levels.

However, the study also revealed that the adherence calls faced some challenges, with approximately 80 of the 382 patients (20.9%) failing to transmit their blood glucose levels each day, despite the reminders. The non-adherent cohort was particularly impacted, with approximately 66 out of the 196 patients (33.7%) failing to transmit their

blood glucose levels daily. In contrast, only 15 out of the 186 patients (8.1%) in the adherent cohort did not transmit their blood glucose levels daily. Despite these challenges, the study demonstrated the overall effectiveness of adherence calls in supporting both groups.

During the study period, the adherent cohort showed a decrease in mean blood glucose values, indicating improved glycemic control. Additionally, the glycemic variability, as measured by the standard deviation of blood glucose values, decreased only for the adherent cohort. This finding is particularly important because glycemic variability has been shown to be closely associated with the risk of adverse clinical outcomes and complications (62).

Our study found that blood glucose levels varied considerably throughout the day, with values being lowest in the morning and gradually increasing as the day progressed. Notably, we found that blood glucose values increased from under 120 mg/dL in the early morning to over 180 mg/dL at night. Interestingly, our findings revealed that the adherent cohort experienced significant improvements in blood glucose levels during the afternoon and night when values are typically higher and more variable. However, we did not observe any significant changes in the non-adherent cohort.

This program collected blood glucose readings from 382 patients which accounted for 43,076 days of readings in total. Of these, the majority (84%, or 36,069) had a single reading in a day, while 13% (5,439) had two readings, and 3.6% (1,568) had three or more readings. Although the program was designed to send a reading once a

day, some patients used the remote patient monitoring device to check their blood glucose levels more than once or were asked to retake the reading during a clinical call to address potential issues such as misreading values or if the patient seemed confused when taking readings. The company provided clinical support regardless of how many times patients sent readings outside the pre-defined ranges in a day. When multiple readings were taken on the same day, about 30% (2,067) were taken within the same time range, while 60.3% (4,223) had the first reading taken between 1AM and 10AM, with subsequent readings taken at other times.

For days with all readings taken in the same time range, the median difference between the first and last reading was 16mg/dL. However, for those with readings taken between 1AM and 10AM and at other times, the median difference was 49mg/dL. This difference appears reasonable given that the mean blood glucose level was 135mg/dL between 1AM and 10AM and 186.1mg/dL between 6PM and 1AM. For days with multiple readings, we selected the latest reading for our analysis. This was done to account for cases where a recheck was needed due to a misreading during the first attempt and cases where multiple readings were received simultaneously due to technical issues. Additionally, the last reading is the most recent situation in which the patient would be supported by the program. Furthermore, by analyzing the readings according to their testing time, we were able to minimize the potential issues that may arise from variations in the testing time. This approach allowed us to focus on the blood glucose levels themselves, rather than being influenced by the timing of the tests.

Importantly, our study showed that a single daily transmission of blood glucose data was associated with positive improvements in blood glucose levels, despite the considerable variation throughout the day. This technology may be enabling several interacting factors that contribute to these improvements, such as more timely interaction with providers, improved provider awareness, patient adherence to monitoring protocols, reminders and clinical calls to assist patients when issues arise and to encourage healthy behaviors through a mechanism to better engage with their health, and so forth. All these factors may work together to encourage and empower patients in improving their overall self-management. Fortunately, individuals with diabetes have shown good acceptance of technology (67), which suggests that this model of care has potential. However, improving self-efficacy and adherence among those who are less inclined to participate consistently remains a significant challenge.

4.4.2. Limitations

This study has several limitations that should be noted. Firstly, we had no information on patient medications, activity levels, carbohydrate consumption, or other factors that may have influenced glucose levels. Additionally, we were unable to obtain HbA1C data or determine the type of diabetes (type 1 or type 2) that the patients had. Furthermore, since the study only included patients who were referred to the monitoring program by their physician, we were unable to include a control group for comparison. Finally, the monitoring protocol required data to be transmitted once per day, which is less frequent than the general home blood glucose monitoring guidelines recommend (68).

4.5. Conclusion

This study highlights the potential benefits of remote patient monitoring for diabetes management among Medicaid clients. The study found that the overall adherence rate for the remote patient monitoring system was over 70%, with approximately half of the clients achieving a remarkably high adherence rate of approximately 90%. Adherence calls played a significant role in improving clients' adherence to blood glucose monitoring, resulting in a more than 10% increase in adherence rates throughout the 5-month period for all patients. The adherent cohort showed a decrease in mean blood glucose values and a decrease in glycemic variability, indicating improved glycemic control. However, challenges were faced with approximately 20% of patients failing to transmit their blood glucose levels daily, even with adherence calls. Nonetheless, this study suggests that remote patient monitoring can be an effective tool to enhance diabetes management among Medicaid clients, with the potential to reduce the risk of adverse clinical outcomes and complications associated with diabetes.

5. ECONOMIC EVALUATION OF REMOTE PATIENT MONITORING FOR PATIENTS WITH HYPERTENSION OR DIABETES

5.1. Objectives

The aim of this chapter is to examine the impact of remote patient monitoring on hospital charges related to CSD among Texas Medicaid patients residing in the Dallas-Fort Worth area, who have been diagnosed with hypertension or diabetes.

5.2. Methods

5.2.1. Design

We conducted a comparative study, comparing the experiences of patients receiving remote patient monitoring with matched control groups receiving normal care. The remote patient monitoring company provided historical monitored data, while the Dallas-Fort Worth hospital council provided demographics and hospital claims.

This study focused on Texas Medicaid patients residing in the Dallas-Fort Worth area, diagnosed with hypertension or diabetes, who received authorization for remote patient monitoring services from Texas Medicaid between 2016 and 2018. Among the authorized patients, some opted to accept the service, while others declined. These two cohorts were combined to form the intervention group and their respective matched controls.

For each cohort, the "baseline period" refers to the four quarters (90 * 4 = 360 days) prior to the initiation of the program, while the "study period" encompasses the subsequent four quarters (90 * 4 = 360 days).

In the intervention group, we included individuals who enrolled in the remote patient monitoring services for a continuous period of four quarters following the initiation of the service. Furthermore, we only considered patients who transmitted their blood pressure and pulse levels for more than 30 days during this period. For the control group, we selected patients who declined to enroll in the remote patient monitoring services and instead opted to receive standard care without remote monitoring.

We then employed propensity-score matching to select control group patients who most resembled the intervention patients. Our matching algorithm aimed to find the best match for each intervention patient based on several factors, including demographics (age, gender, race); presence of hypertension-related conditions (congestive heart failure, cardiac arrhythmia, valvular disease, pulmonary circulation disorders, peripheral vascular disorders, hypertension, diabetes mellitus, renal failure, obesity, depression); adjusted Elixhauser Comorbidity Index (excluding hypertension-related conditions), CSD-related and other baseline hospital charges ,and the number of hospital visits.

To ensure an adequate number of matched controls, we utilized half-year hospital charges and visits for the matching process. We conducted a 1:1 match without replacement on the estimated propensity score of each intervention and control patient using a greedy nearest neighbor matching algorithm. We selected control patients whose estimated propensity score fell within a defined caliper of 0.2.

We excluded patients with quarterly hospital charge amounts over $450,000 as outliers and those who died during the baseline or study period.

We examined the trends in total quarterly CSD-related hospital charges for both the intervention and control groups over time. Additionally, we compared CSD-related hospital charges in the intervention group before and after they started the services, and we compared these findings to changes observed in the control group over the same period. This approach is sometimes referred to as a difference-in-differences analysis.

To gain a deeper understanding, we categorized the hospital charges into different types, including inpatient charges (related to hospitalization), outpatient charges (related to hospital clinic visits), emergency-inpatient charges (related to emergency department visits followed by hospitalization), and emergency-outpatient charges (related to emergency department visits without hospitalization). Furthermore, we analyzed CSD-related charges based on specific conditions – hypertension, heart diseases, cerebrovascular diseases, artery or vein diseases, as well as other or unspecified disorders of the circulatory system.

5.2.2. Statistical Analysis

To determine whether the patient baseline characteristics differed by population subgroups, we used χ^2 tests for categorical variables and t tests for continuous variables. Analyses were conducted using SAS version 9.4 (SAS Institute). This study was approved by the institutional review board of Texas A&M University.

5.3. Results

5.3.1. Patient demographics

A total of 726 clients in the Dallas-Fort Worth area were prescribed remote patient monitoring services between 2016 and 2018. However, out of these, only 287

(39.5%) patients accepted the service (Figure 5.1). Among the 287 patients, 5 (1.7%) patients died during either the baseline or study period, and 70 (24.4%) patients transmitted readings for less than 30 days during the study period. Additionally, 94 (32.8%) patients did not continue monitoring for a year, and 3 (1%) patients were excluded due to extremely high hospital charges in one or more quarters in the baseline and study period. Ultimately, only 110 (38.3%) patients met our inclusion criteria for analysis.

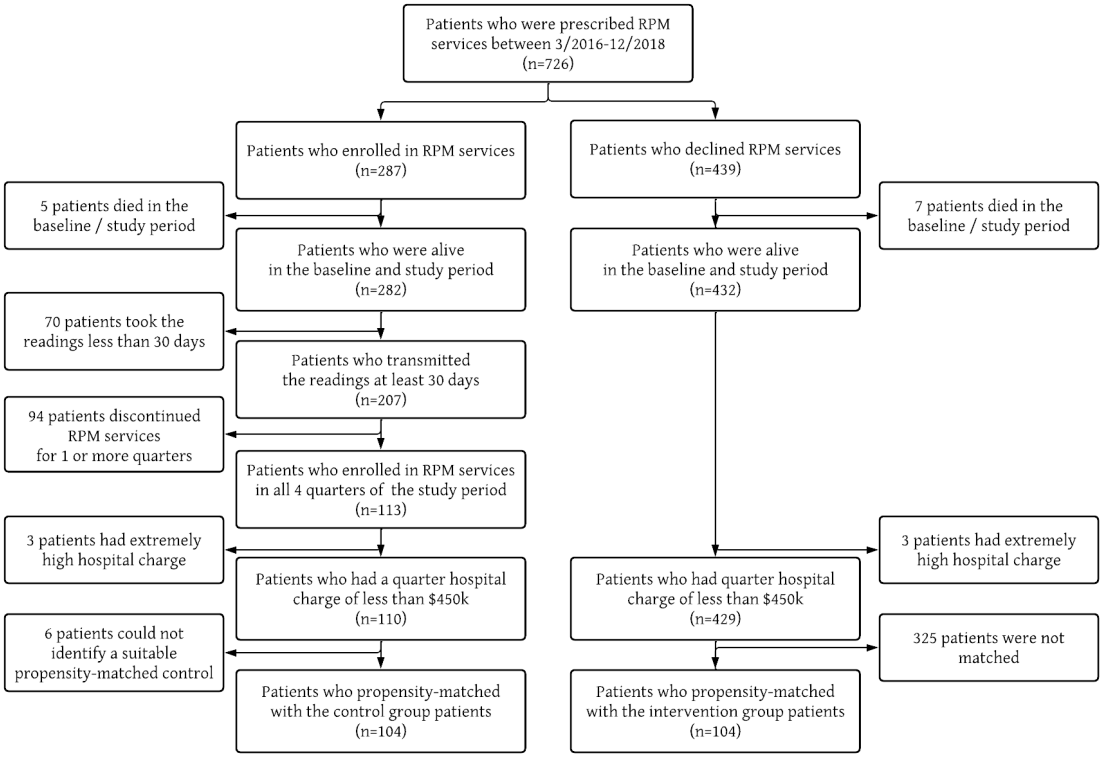

Figure 5.1 Sample flow chart.

Among the 439 (60.5%) patients who declined the remote patient monitoring services, 7 (1.6%) patients died during either the baseline or study period, 3 (0.6%)

patients were excluded due to high hospital charges, and 429 (97.7%) patients remained to be matched with the intervention group.

Out of the initial 110 patients in the intervention group, we excluded 6 (5.5%) patients from our analysis as we were unable to identify an appropriate matched control based on their propensity scores. Therefore, our final analyses included 104 intervention-group members and 104 control-group members.

The post-matching characteristics of both the intervention and control groups are presented in Table 5.1. The patients had a mean age of 69.3 (SD 11.6) and 70.9 (SD 13) for the intervention and control groups, respectively. A majority of the patients in both groups were women (73.1% for the intervention and 74% for the control) and black (63.5% for the intervention and 58.7% for the control).

Table 5.1 Post-matching characteristics for the intervention and control groups (N=208).

Characteristics	Intervention (n=104)	Control (n=104)	*P* value
Age (years), mean (SD)	69.3 (11.6)	70.9 (13)	0.35
Women, n (%)	76 (73.1)	77 (74)	0.88
Race, n (%)			
White	10 (9.6)	9 (8.7)	0.93
Black	66 (63.5)	61 (58.7)	
Hispanic	10 (9.6)	13 (12.5)	
Asian/Pacific	5 (4.8)	6 (5.8)	
Unknown	13 (12.5)	15 (14.4)	
Baseline comorbidities, n (%)			
Congestive heart failure	19 (18.3)	21 (20.2)	0.72
Cardiac arrhythmia	14 (13.5)	13 (12.5)	0.84
Valvular disease	4 (3.9)	2 (1.9)	0.41
Pulmonary circulation disorders	2 (1.9)	3 (2.9)	0.65
Peripheral vascular disorders	3 (2.9)	3 (2.9)	1.00
Hypertension	52 (50)	61 (58.7)	0.21
Diabetes mellitus	36 (41.4)	43 (41.4)	0.32
Renal failure	19 (18.3)	26 (25)	0.24
Obesity	11 (10.6)	9 (8.7)	0.64
Depression	9 (8.7)	10 (9.6)	0.81
Adjusted Elixhauser comorbidity index, mean (SD)	0.9 (1.3)	0.9 (1.4)	0.96
Baseline CSD-related hospital charges ($), mean (SD)			
First half-year	14,486 (45,641)	17,797 (49,005)	0.61
Second half-year	23,535 (69,518)	20,660 (76,794)	0.78
Baseline other hospital charges ($), mean (SD)			

First half-year	1,080 (5,359)	1,882 (11,869)	0.53
Second half-year	1,100 (4,373)	919 (4,420)	0.77
Baseline CSD-related hospital visits, mean (SD)			
First half-year	0.8 (1.4)	1 (1.7)	0.28
Second half-year	1 (1)	0.9 (1.8)	0.78
Baseline Other hospital visits, mean (SD)			
First half-year	0.2 (0.5)	0.2 (0.5)	0.6
Second half-year	0.3 (0.6)	0.3 (0.5)	0.56

Baseline clinical conditions, including hypertension-related comorbidities and adjusted Elixhauser comorbidity index, were also well-matched between the intervention and control groups.

Regarding hospital charges, both the intervention and control groups demonstrated mean CSD-related half-year hospital charges exceeding $10,000 in the initial half-year, and these charges increased to over $20,000 in the subsequent half-year for both groups. The mean half-year hospital charges for other conditions was approximately $1,000 for both groups. Additionally, on average, patients from both groups visited the hospital once for CSD-related reasons within a half-year period.

5.3.2. CSD-related Hospital Charges

Figure 5.2 illustrated the quarterly total CSD-related hospital charges over time for both the intervention and control groups. Following the initiation of remote patient monitoring, the intervention-group demonstrated relatively stable total CSD-related hospital charges during the second quarter compared to the baseline period. In the third quarter, there was a notable decrease in charges compared to the baseline period.

Conversely, the control group experienced a significant increase in CSD-related hospital charges during the second quarter compared to the baseline. These findings indicate that the intervention group demonstrated improvements in CSD-related hospital charges during the second and third quarters compared to the control group. However, in the fourth quarter, the intervention group experienced an increase in CSD-related hospital charges, while the control group experienced a decrease.

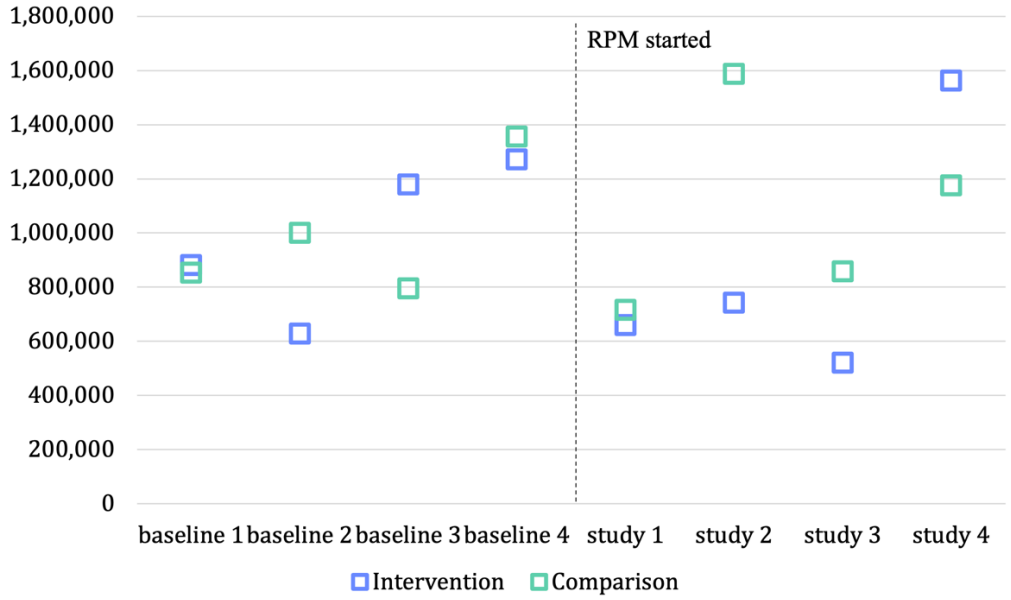

Figure 5.2 Quarterly total CSD hospital charge in the intervention and control group patients (N=208).

We also conducted a difference-in-differences analysis comparing yearly and quarterly CSD-related hospital charges between the baseline and study periods for both the intervention and control groups. When averaging the yearly spending measures, we observed a decrease of $4,547 in CSD-related hospital charges in the intervention group from the baseline period to the study period (Table 5.2). In contrast, the control group

experienced an increase of $3,209 in CSD-related hospital charges during the same time frame.

Table 5.2 Mean differences in CSD-related hospital charge per patient per year and quarter before and after the remote patient monitoring, among intervention and control groups (N=208).

		Intervention (n=104)	Control (n=104)	Difference ($) [Intervention] - [Control]
Difference ($) [Study] - [Baseline]	Year	-4,547	3,209	-7,756
	Q1	-2,123	-1,311	-812
	Q2	1,101	5,647	-4,546
	Q3	-6,313	602	-6,915
	Q4	2,788	-1,729	4,517

Examining the quarterly spending measures, we found that the intervention group experienced a greater decrease in CSD-related hospital charges during the first and third quarters compared to the control group. Moreover, in the second quarter, a comparison of the two groups suggests a net decline of $4,546 associated with the remote patient monitoring program (1,101 – 5,647 = 4,546). However, in the fourth quarter, the pattern reversed, and the intervention group experienced an increase of $2,788, while the control group exhibited a decrease of $1,729.

Both Figure 5.2 and Table 5.2 demonstrate that the intervention group exhibited improvements in CSD-related hospital charges following the initiation of remote patient monitoring, compared to the control group. This pattern was consistent at the quarterly level, except for the last fourth quarter. To investigate if this pattern was influenced by a few patients with unusually high charges, we truncated the CSD-related hospital charges to every $25,000 (Table 5.3).

Table 5.3 Difference-in-difference patterns by truncated CSD-related hospital charge (N=208).

CSD-related Hospital Charges	Difference-in-Difference patterns				
	Year	Q1	Q2	Q3	Q4
< 450,000	-	-	-	-	+
< 425,000	-	-	-	-	+
< 400,000	-	-	-	-	+
< 375,000	-	-	-	-	+
< 350,000	-	+	-	-	+
< 325,000	-	+	-	-	+
< 300,000	+	+	+	-	+
< 275,000	+	+	+	-	+
< 250,000	-	+	-	-	+
< 225,000	-	+	-	-	-
< 200,000	-	+	-	-	-
< 175,000	-	+	-	-	-
< 150,000	-	+	-	-	+
< 125,000	+	+	-	-	+
< 100,000	+	+	+	+	+
< 75,000	+	+	-	+	+
< 50,000	+	+	-	+	+
< 25,000	-	+	-	-	-

The first row in the table reflects the difference-in-difference patterns observed in Table 5.2. Generally, the pattern remained consistent across each period, except for the first quarter. The first quarter exhibited the lowest differences between the intervention and control groups, making it more susceptible to fluctuations. In other periods, while

the pattern occasionally flipped, it consistently returned to its original trend in later thresholds, with no significant deviations from the original pattern. These observations indicate that the trend observed in Table 5.2 is not primarily influenced by a few patients with high charges.

Furthermore, we conducted a difference-in-difference analysis to compare yearly CSD-related hospital charges after categorizing patients by specific disease conditions, including hypertension, heart diseases, cerebrovascular diseases, artery or vein diseases, and other or unspecified disorders of the circulatory system (Table 5.4).

Table 5.4 Yearly Mean differences in CSD-related hospital charge by specific disease conditions before and after the remote patient monitoring, among intervention and control groups (N=208).

	Intervention (n=104)		Control (n=104)		Difference ($)
	N	Difference ($) [Study] - [Baseline]	N	Difference ($) [Study] - [Baseline]	[Intervention] - [Control]
Hypertension	71	-8,304	80	4,890	-13,194
Heart diseases	49	-18,543	52	5,027	-23,571
Cerebrovascular Diseases	11	32,967	7	-115,512	148,479
Artery / vein Diseases	14	17,122	16	-1,937	19,058
Other / unspecified CSD	7	35,744	7	43,773	-8,029

Among patients with heart diseases in the intervention group, there was a significant decrease of $18,543 in hospital charges after the initiation of remote patient monitoring. In contrast, the control group experienced an increase of $5,027. These

findings indicate that heart disease patients receiving remote patient monitoring achieved a mean cost savings of $23,571 (-18,543 – 5,027 = -23,571) compared to the control group.

However, for patients with cerebrovascular diseases, or artery or vein diseases, the control group exhibited greater savings in hospital charges. However, it is important to note that these results should be interpreted cautiously, as the sample sizes in these subgroups were small, potentially introducing bias into the findings.

Regarding hypertension, the analysis showed a net decrease of $13,194 associated with the remote patient monitoring program (-8,304 – 4,890 = -13,194) in CSD-related hospital charges.

Next, we conducted a difference-in-difference analysis to assess the impact of remote patient monitoring on yearly CSD-related hospital charges, categorizing the claims into inpatient, outpatient, emergency-inpatient, and emergency-outpatient. This analysis aimed to determine which type of encounters demonstrated the most significant effects of remote patient monitoring (Table 5.5).

Table 5.5 Yearly Mean differences in CSD-related hospital charges by encounter types before and after the remote patient monitoring, among intervention and control groups (N=208).

	Intervention (n=104)		Control (n=104)		Difference ($)
	N	Difference ($) [Study] - [Baseline]	N	Difference ($) [Study] - [Baseline]	[Intervention] - [Control]
Inpatient	11	-96,433	8	-44,902	-51,531
Outpatient	31	705	31	4,289	-3,584
ED-inpatient	35	4,296	37	13,594	-9,298
ED-outpatient	63	6,598	66	864	5,734

5.4. Discussion

5.4.1. Principal findings

Chronic diseases such as hypertension or diabetes impose a significant economic burden on healthcare systems, stemming from the substantial costs associated with ongoing healthcare utilization and the productivity losses caused by morbidity and mortality (69–71). For this reason, remote patient monitoring is frequently considered an advantageous approach in cost savings when compared to standard or usual care. However, to guarantee the sustainability and efficacy of remote patient monitoring services, it is imperative to evaluate their cost-effectiveness thoroughly. This evaluation should include a comprehensive analysis of hospital costs before and after the implementation of remote patient monitoring. To achieve this, comprehensive evaluations are necessary, which involve comparing remote patient monitoring to usual care and examining both cost-effectiveness and clinical effectiveness. These evaluations should incorporate evidence regarding costs and outcomes, providing a holistic understanding of the benefits and potential drawbacks of remote patient monitoring services (72,73).

Previous randomized clinical trials have demonstrated the high cost-effectiveness of remote patient monitoring for hypertension (31–35). While clinical trials are considered the gold standard for evaluating interventions, it is important to acknowledge that the reported outcomes may not always translate into real-world practice.

This study aimed to investigate the effects of remote patient monitoring on hospital charges related to CSD among Texas Medicaid patients diagnosed with hypertension or diabetes and residing in the Dallas-Fort Worth area. By comparing the intervention group with a carefully matched control group, we observed notable improvements in CSD-related hospital charges following the implementation of remote patient monitoring, comparing the one-year before and after the intervention. Particularly during the second and third quarters, the intervention group exhibited better outcomes in CSD-related hospital charges compared to the control group. However, in the fourth quarter, the intervention group experienced an increase in charges, while the control group showed a decrease. Further research is required to determine whether this change can be attributed to the delay in disease progression facilitated by remote patient monitoring or the potential fatigue arising from its use. It is notable that the transmission rate of patient data decreased from 71.3% in the first quarter to 58.5% in the fourth quarter, indicating a potential impact on the results.

By analyzing CSD-related hospital charges based on specific disease conditions, patients with heart disease who received remote patient monitoring achieved the most significant cost savings compared to the control group. However, for patients with cerebrovascular diseases or artery/vein diseases, the control group exhibited greater savings in hospital charges. It is crucial to interpret these findings cautiously due to the limited sample sizes in these subgroups.

Furthermore, an analysis of claims categorized by encounter type revealed a substantial impact of remote patient monitoring in reducing hospitalization charges.

Specifically, there was a net decrease of $51,531 in inpatient claims and $9,298 in emergency-inpatient claims, highlighting the significant potential for cost reduction through remote patient monitoring interventions.

These findings shed light on the potential benefits of remote patient monitoring in reducing CSD-related hospital charges among Medicaid patients with hypertension or diabetes. However, further research with larger sample sizes and long-term follow-up is necessary to validate and expand upon these results.

5.4.2. Limitations

This study has several limitations that should be acknowledged. Firstly, the analysis of hospital charge differences yielded insignificant results due to factors such as limited data availability, small sample size, and high variability in charge amounts. Despite employing various modeling approaches, including a two-part model with logistic regression and gamma regression, the findings did not reach statistical significance. Nevertheless, as a case study providing descriptive results, this research contributes to a better understanding of the practical implications of remote patient monitoring costs. Secondly, it is important to note that the study focused solely on one region in Texas, specifically Medicaid recipients. Therefore, the generalizability of these findings to individuals covered by Medicare, private insurance, or those who are uninsured and living with hypertension or diabetes remains unclear. Additionally, the applicability of these findings to individuals with other chronic conditions who could potentially benefit from ongoing monitoring is also uncertain. Future studies with larger

and more diverse populations are needed to enhance the generalizability and applicability of the findings across various healthcare settings and patient populations.

5.5. Conclusion

Chronic diseases such as hypertension or diabetes impose a substantial economic burden on healthcare systems, leading to high costs and productivity losses. Remote patient monitoring is often considered a cost-saving approach compared to standard care. However, thorough evaluations of its cost-effectiveness and clinical effectiveness are essential to ensure its sustainability. This study examined the impact of remote patient monitoring on hospital charges related to chronic systemic diseases among Texas Medicaid patients with hypertension or diabetes. The findings showed improvements in CSD-related hospital charges after implementing remote patient monitoring, particularly for patients with heart disease. However, further research to validate and generalize these findings across diverse healthcare settings and patient groups is needed. Overall, remote patient monitoring holds promise in reducing healthcare costs, but more comprehensive studies are required to fully understand its implications.

6. CONCLUSION

Hypertension and diabetes pose significant burdens on healthcare systems, with high costs and adverse health outcomes. Remote patient monitoring has emerged as a promising strategy for managing these chronic diseases, with clinical trials demonstrating its effectiveness in improving blood pressure and glucose control. However, real-world implementation faces challenges related to patient adherence and insurance coverage.

This study provides compelling evidence of the benefits of remote patient monitoring in improving adherence to blood pressure and glucose monitoring among Medicaid clients. The incorporation of adherence reminder calls significantly enhanced adherence rates, leading to improved blood pressure control in hypertensive patients and decreased mean blood glucose values in individuals with diabetes. These findings align with previous clinical trials, demonstrating the potential of remote patient monitoring to achieve clinically significant reductions in blood pressure and glucose levels.

However, the study also highlights the need for additional interventions and support to ensure high levels of adherence, as a substantial proportion of patients still struggled to transmit their measurements regularly. Overcoming these challenges is crucial to realizing the full benefits of remote patient monitoring in routine practice.

Furthermore, the study emphasizes the potential benefits of remote patient monitoring for diabetes management among Medicaid clients, as evidenced by the high overall adherence rate and improved glycemic control. By reducing the risk of adverse

clinical outcomes and complications associated with diabetes, remote patient monitoring has the potential to significantly impact the well-being of patients and alleviate the economic burden on healthcare systems.

This study also demonstrates positive results, with improvements in hospital charges related to CSD after implementing remote patient monitoring, particularly for patients with heart disease. Nevertheless, further research is necessary to validate and generalize these findings across diverse healthcare settings and patient groups, ensuring a comprehensive understanding of the cost-effectiveness and clinical effectiveness of remote patient monitoring.

In conclusion, remote patient monitoring represents a valuable tool in managing chronic diseases like hypertension and diabetes. It has the potential to improve patient adherence, enhance disease control, reduce healthcare costs, and ultimately improve health outcomes. However, further research and comprehensive studies are warranted to fully realize the potential of remote patient monitoring and ensure its sustainability in healthcare systems.

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