Home Telemonitoring Platforms for Adults with Diabetes Mellitus: A Narrative Review of Literature

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Diabetes mellitus in adults is a global health burden affecting 382 million people and costing over $612 billion worldwide. Remote patient monitoring is often considered to be a technological solution to the challenges in healthcare delivery, yet many studies have shown mixed results or no effect on patient outcomes. A narrative review of literature was conducted to contribute to the field of technology-driven home healthcare delivery by analyzing the systems in context with the monitoring and intervention technologies. This review analyzed papers with home telemonitoring and intervention systems for adults with type 1 or type 2 diabetes. Technologies used were differentiated into four categories: telephones, mobile devices, computers, and other Internet-connected devices. Our findings suggest no clear association between the type of technology used and the outcomes of the participants. Frequency of monitoring and intervention were distinguishable by diabetic outcome metrics.

INTRODUCTION

The global health burden of diabetes is increasing and requiring a greater allocation of healthcare resources to prevent, manage, intervene, and provide long-term care for diabetic complications. In 2014, the estimated average global health expenditure for diabetes care is between $612 billion and $1.1 trillion (da Rocha Fernandes et al., 2016). Complicating the subject further, the strain on diabetes healthcare resources is expected to increase in the coming years. It is estimated that in the next 20 years the number of adults with diabetes will increase by 55%; from 382 million in 2013 to 592 million by 2035 (Guariguata et al., 2014). A key reason for the growth of research in diabetes care and monitoring is the challenge to provide access to quality care, at a reasonable cost (Berwick, Nolan, & Whittington, 2008), to an increasing diabetic patient population.

Adverse events for diabetics can have devastating outcomes. If left untreated, hypoglycemia (glucose ≤70 mg/dl) can lead to weakness, confusion, seizures, coma, and death. Hyperglycemia (≥200 mg/dl) causes shortness of breath, nausea, and ketoacidosis (diabetic coma). There are many long-term complications of the disease including kidney failure, retinopathy, neuropathy, and cardiovascular disease (American Diabetes Association, 2017).

In diabetes care, it is common to have patients self-monitor and intervene between visits to the clinic. Discrete glucose monitors are used across the spectrum of the disease and patients are instructed to follow a protocol based on current glucose readings for administering insulin or oral medications. Patients with type 1 diabetes mellitus (T1DM) are sometimes prescribed continuous glucose monitors (CGM) and insulin pumps to automatically record glucose data and administer the calculated dose of insulin. In addition to medication, patients are often prescribed lifestyle modifications including diet and exercise. Treatment outcomes are often determined by metrics associated with glycated hemoglobin (HbA1c & GHb) and monitored blood glucose (American Diabetes Association, 2017).

Remote Healthcare Delivery

Remote health systems have been implemented by care providers in a variety of settings to reduce strain on resources and to provide better care for all patients. Interventions such as medication delivery, diet logging, and exercise adherence reminders are often used in the *home care* setting. Similarly, the technologies used in the home are often used in *long-term care* in addition to smart and ubiquitous sensors and social support tools to monitor patients remotely. In *community clinics*, such as community resource centers or federally-qualified health centers, video conferencing with clinical specialists and health education can be facilitated by community or social workers in remote or underserved areas. Telemedicine has a long history in the *acute care* setting. Calling or faxing specialists from out of state to review charts and discuss diagnoses has been enhanced with recent technological advances in virtual communication and robotic, remote surgery. Similarly, remote health in *post-acute care* aims to predict patient outcomes after some trauma or recovery period.

Care providers work with chronically-ill patients and their families to develop treatment and long-term care plans to alleviate symptoms and reverse the damage done by these diseases. Intervention protocols are often prescribed and routine appointments scheduled for follow up with the care provider. Advancements in physiological data collection technologies have made devices smaller, affordable, and Internet-connected, allowing patients to self-monitor from home while the device sends data for clinical review. This technology is frequently referred to as remote patient monitoring (RPM) and comes in several modalities. The nature of this technology often allows a patient to 'visit' with the care provider more frequently, and rapidly, should the patient have a concern or an adverse event occurs.

BACKGROUND

Understanding the use of technology for home-based patient care is a multidisciplinary effort. Researchers from many fields have studied the use, effectiveness, cost, and capabilities of home-based health technologies, and new tools for this purpose are still evolving.

While several reviews have been conducted to identify the effect of remote patient monitoring on glycemic control, findings have not been conclusive. For example, two studies found either no (Farmer, Gibson, Tarassenko, & Neil, 2005) or little positive effect (Montori et al., 2004) on glucose control when using glucometers with feedback to the care provider. Teleconsultations by voice or video call also show no difference in outcomes for diabetics (Verhoeven, Tanja-Dijkstra, Nijland, Eysenbach, & Gemert-Pijnen, 2010). Results of the studies were conflicting or inconsistent in three reviews (Baron, McBain, & Newman, 2012; Greenwood, Young, & Quinn, 2014; Jaana & Pare, 2007).

Other studies show positive results. Two groups found that web-based tools have led to improved outcomes (Angeles, Howard, & Dolovich, 2011; Dalton, 2008). Phone support and interventions were also effective in improving glycemic control in two studies (Liang et al., 2011; Polisena et al., 2009). Angeles et al (2011) indicate multimodal delivery of web-based diabetes support (e.g. computer and mobile phone) could be better than using one technology alone. RPM systems which incorporated more than one technology had better diabetic outcomes in three studies (Ali, Shah, & Tandon, 2011; El-Gayar, Timsina, Nawar, & Eid, 2013; Marcolino, Maia, Alkmim, Boersma, & Ribeiro, 2013).

Understanding a system's functional and physical architecture (i.e. configuration) is an important aspect of designing systems which achieve the desired goals (Buede, 2009). These system organizational issues can be studied from a macro-ergonomics perspective to facilitate a structured, systematic, and transparent decision-making process (Samaras & Horst, 2005). The design of RPM systems of the future should include an assessment of the impact current system structures have had on diabetic outcomes. While several systematic reviews of RPM exist, these reviews either broadly assess the impact of these systems on diabetic outcomes or only review a limited number of technological solutions. In particular, none were found which focused on home telemonitoring technologies and the impact of communication frequency on diabetic outcomes.

The objective of this research is to review a wide range of current RPM solutions while conducting a comparative analysis of systems in terms of data communication frequency and type as well as impact on outcome. For this research, *home telemonitoring* is defined as the active use of a device by the patient in their home to 1) send data electronically to the care provider through a monitoring system and 2) deliver an intervention to the patient. A two-way monitoring and intervention delivery system for adults with diabetes was required for studies to be included in this review. While the broader research focuses on types of technology used for monitoring, transmission methods, types of measurement, and the types of interventions delivered, in this paper, we summarize different home telemonitoring and intervention platforms and different type and frequency of data transmission while providing a classification and comparison with respect to clinical outcomes of adults with diabetes.

METHODS

A narrative review of literature was conducted where trials of telehealth for monitoring and intervention of patients with diabetes mellitus were searched and appraised. The review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (Moher, Liberati, Tetzlaff, Altman, & PRISMA Group, 2009) and the Cochrane Handbook (Higgins & Green, 2011) guidelines for a single-author (Grant & Booth, 2009). The procedures used for article selection, retrieval, and data extraction are detailed below.

Eligibility criteria. Studies of RPM systems for diabetes were included if they met certain criteria. The systems evaluated must have at least two functions: 1) two-way communication between the patient and provider to measure the disease state, and 2) intervention delivery through some technology to improve outcomes. Additionally, the patient should primarily access the system in their home or through a mobile device outside a healthcare facility; studies where the system was based in an outpatient facility or community clinic were excluded. Only outcome measurements with specific diabetic indicators (i.e. HbA1c & GHb, glycated hemoglobin) were included. Studies that included children, pregnant women, or were for diagnosis or management of diabetic complications, such as retinopathy, were excluded. The study was also excluded if the system was not described sufficiently to complete the analysis or if the outcomes were unclear. Review articles, study protocols, studies without patient populations, or papers which only described the system were also excluded.

Search strategy. Four databases were searched in August 2017: MEDLINE (PubMed), Compendex, Web of Science, and Scopus. Citations were exported to EndNote X8 where duplicates were removed and the articles were screened for eligibility by title and abstract. The full text of the remaining articles was retrieved and screened. Citations were excluded if the full text could not be located or was redacted. After the full-text screening was completed, citations from the included papers were added to the final list.

Data extraction. The template for encoding the data from the included studies was created with Google Forms. This tool enabled recording and categorizing the system structure of each study in terms of monitoring technology, intervention type, and outcomes of the participants. Study characteristics, including the design, and participant population, including geographic region and demographics, were also coded.

RESULTS

Applying the search strategy to the four databases resulted in 986 records from which 852 records remained after removing duplicates. Each of these records was screened by title and abstract for eligibility, and any records which were unclear based on title and abstract alone were passed on for full text screening. In total, 210 full text articles were screened for inclusion in the study and 76 records were included in the qualitative synthesis.

Table 1 provides a summary of the synthesis results detailed below. Overall, studies on RPM of diabetic adults have taken place in 26 countries across 4 continents. Most studies occurred between 2008 and 2014 with study durations ranging from 1 month to 5 years, with the most frequent duration of 6 months. The size of the study population was most skewed toward having under 150 participants, and the age group most often included in the intervention group were people in their 50's. Three-quarters of the studies focused solely on patients with type 2 diabetes mellitus (T2DM), 9% on T1DM, and 12% studied both types.

Table 1 – Summary of different types of RPM systems, transmission and intervention technologies used, and a comparison of outcomes

	Transmit and Intervention Technology				Outcomes	
	Telephone	Mobile	PC	Device	Improve	Not Improve
Diabetes Type						
T1DM	0	5	1	1	4	3
T2DM	7	24	15	17	28	29
Both	1	5	3	3	5	4
NS	0	1	0	2	0	3
Data Recording Technology						
Glucometer	3	21	10	23	26	27
Mobile App	0	18	1	2	8	12
BP Monitor	0	5	2	12	9	10
Weight Scale	0	4	1	7	7	5
Telephone	7	3	2	0	5	3
Text Message	1	7	1	0	4	3
Pedometer	0	3	2	2	4	1
CGM	0	0	2	0	2	0
Other	3	7	12	2	10	3
Data Upload Frequency						
Immediately	1	4	1	0	2	4
Daily	3	14	3	15	14	18
Weekly	1	6	4	3	7	5
Biweekly	1	3	3	0	3	3
Monthly	0	0	1	2	2	1
Quarterly	0	0	1	0	0	1
Individual	0	1	0	1	2	0
NS	2	7	6	3	8	7
Measurement and Transmit Concurrence						
Synchronous	5	23	7	16	21	26
Asynchronous	1	4	5	4	7	5
NS	2	8	7	3	9	8
Transmit and Intervention Technology						
Telephone	8	2	2	0	4	4
Mobile	2	35	4	0	17	18
Computer	2	4	19	2	11	8
Device	0	0	2	23	11	12

NS: Not Specified; T1DM: Type 1 Diabetes Mellitus; T2DM: Type 2 Diabetes Mellitus; BP: Blood Pressure; CGM: Continuous Glucose Monitor; Device: Internet-connected home telemedicine device or related technology

Several terms have been used to describe RPM and other patient monitoring technologies. The search terms were specified broadly to cover the range of keywords used in recent literature. Still, several studies included different keywords to describe the type of home monitoring system used. "Telemedicine" was the most popular term used (31%, 24/76) in the studies included; although all studies included were much more closely related to "telemonitoring", this term was only used in 5 studies. Such inconsistent usage of nomenclature when referring to the variety of remote healthcare types may negatively affect the knowledge accumulation in the field.

Transmit and Intervention Technology

The synthesis of the articles included in this review revealed four categories of technology types used in the transmission of data and delivery of interventions. These categories are described below.

Telephone-based technologies. Land-line telephone systems have been used for delivering telemonitoring for many years due to prevalence and ease of access, regardless of socioeconomic status. In addition, POTS-based (plain old telephone service) system development has been relatively inexpensive (Warner, 1997). However, only 11% of reviewed studies (8/76) included telephone-based systems for monitoring patients from home. While these technologies are prevalent in earlier telehealth literature, their usage in recent studies is in decline (this review excluded the papers published before 2010). Five of the studies only used the telephone to collect data from the participants (Anderson, Christison-Lagay, Villagra, Liu, & Dziura, 2010; Crowley et al., 2016; Del Prato et al., 2012; Khanna et al., 2014; Williams et al., 2012); the other three paired data collections with mobile phones and computers (Katalenich et al., 2015; Kesavadev, Shankar, Pillai, Krishnan, & Jothydev, 2012; Kim et al., 2015). Outcomes for telephone systems were split: four had improved, four had not improved.

Mobile devices. Mobile phones and tablets are growing in popularity for deploying telehealth systems to patients and help reduce the barrier of technology accessibility (Alvarado et al., 2017; Flodgren, Rachas, Farmer, Inzitari, & Shepperd, 2015). Device manufacturers are enabling even greater ability to facilitate health data collection for research through specialized services (e.g., Apple ResearchKit). Most of the included studies (46%, 35/76) used mobile devices to measure and transmit biometrics; five of those studies also used computers or telephones for data collection (Agboola et al., 2016; Katalenich et al., 2015; Kesavadev et al., 2012; Moattari, Hashemi, & Dabbaghmanesh, 2013; Zhou et al., 2014). Studies using mobile devices had a comparable number of improved (17/35) over not improved (18/35) diabetic outcomes. This is in line with Garabedian, Ross-Degnan, & Wharam (2015) who also found that mobile health (mHealth) tools were effective at improving diabetic outcomes in about half (11/20) of the articles they included.

Personal computers. Personal computers, either laptop or desktop, are a common mode of collecting health data from users. A quarter of the studies (19/76) reported that computers were used to facilitate biometric measurement recording and transfer to the care provider. Of those, two also incorporated telephones (Kesavadev et al., 2012; Kim et al., 2015), four also used mobile phones (Agboola et al., 2016; Kesavadev et al., 2012; Moattari et al., 2013; Zhou et al., 2014), and two included other Internet-connected devices (Chen et al., 2013;

Lim et al., 2016). One study used software developed specifically to collect data from a CGM, and the transmission only needed to occur once a month (Gonzalez-Molero et al., 2012). Another study used discrete glucometers and software to upload the readings once a quarter, at some time prior to the office visit (Leichter, Bowman, Adkins, & Jelsovsky, 2013). These two studies show the unusual difference in data transfer timing of computer-based telemonitoring systems. For computer-based systems, the data measurement and transmission occur asynchronously in 23% of studies compared to 11% for mobile, 13% for telephone, and 17% for other devices. A slightly greater proportion (58%) of studies saw improved outcomes when a personal computer was used for home telemonitoring, whereas the three other systems saw almost no difference in proportion of improved diabetic outcomes.

Internet-connected devices. Many Internet gateway devices have been developed for remote patient monitoring. IDEATel is the longest duration (5 years) and oldest (used since year 2000) study of a device connected directly to the Internet for monitoring diabetes (Weinstock et al., 2011). In this study, a discrete glucometer and blood pressure monitor record measurements from the participant, and the IDEATel system uploads the data to a clinical database (Shea et al., 2013). Many Internet-connected device systems included in this study function similarly (e.g., TeLiPro (Kempf et al., 2017), Intel Health Guide (Klug et al., 2011), HealthPAL (Wei, Nathan, & Wexler, 2015)). Two studies used these devices along with personal computers for data transfer and intervention delivery (Chen et al., 2013; Lim et al., 2016). The ratio of outcome improvement was nearly half for devices; 11 studies saw improved blood glucose with the intervention and 12 did not see improvement over the control group.

DISCUSSION

The multidisciplinary design and development of new RPM and telemonitoring technologies stems from the recent push to achieve the triple aims of improving the quality of the care experience, improving the population's access to healthcare, and reducing the cost of care (Berwick et al., 2008). The healthcare community is reaching to embrace a solution that reduces the burden on care providers while still providing accessible, affordable, quality care to its patients. RPM is seen as the silver bullet to achieving these goals, yet the community is continually let down by ineffective and expensive technologies (Farmer et al., 2005).

While it is true that some systems are cost prohibitive and ineffective, this review shows that the configuration of the system's technology components and policy decisions may have more to do with patient outcomes than telemonitoring itself. In many of the studies reviewed, theory-based methods on understanding health behaviors were used to develop the interventions and messages sent to patients, but the frequency of events throughout the study period did not have a theoretical foundation, if it was mentioned at all. The technology used to record and transmit the data and to receive interventions also leads to different requirements for the system structure.

While work is in progress to obtain a comprehensive understanding of the scope of knowledge and capabilities in health telemonitoring, this short review provides an overview of studied systems with emphasis on analyzing different monitoring and intervention technologies and their impact on outcomes for adults with type 1 or type 2 diabetes. Our findings suggest that different types of technologies used to deliver the monitoring and interventions cannot be clearly associated with impact on outcomes. These findings warrant further investigation of specific characteristics of these technologies that contribute to the studied impacts. Other factors, such as the study duration, concurrence of measurement and transmission of data, and secondary conditions, should also be considered along with the technology selection for conclusive investigation of effects on outcomes.

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