

# Home telemonitoring of patients with diabetes: a systematic assessment of observed effects

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## Abstract

**Rationale, aims and objectives** Diabetes represents a common chronic disease continuously growing worldwide. Unless closely monitored, it can be associated with serious complications and high expenditures. Telemonitoring is a patient management approach increasingly used with chronic illnesses. It supports timely transmission and remote interpretation of patients' data for follow-up and preventive interventions. No comprehensive review exists on all aspects of diabetes 'home telemonitoring' and its effects. The objective of this study is to provide a systematic review of this approach and its effect at the informational, clinical, behavioural, structural and economical levels.

**Methods** A comprehensive literature review was conducted on Medline and Cochrane Library to identify relevant articles. The keywords used include diabetes, telemonitoring, home monitoring, telecare and telemedicine.

**Results** Seventeen studies using diverse technologies and transmitting different clinical, medical and behavioural data were found. Significant impacts were observed namely at the behavioural, clinical and structural levels. Minimal technical problems and no cost-benefit and cost-effectiveness analyses were reported.

**Conclusion** Close management of diabetic patients through telemonitoring showed significant reduction in HbA<sub>1c</sub> and complications, good receptiveness by patients and patient empowerment and education. Yet, the magnitude of its effects remains debatable, especially with the variation in patients' characteristics (e.g. background, ability for self-management, medical condition), samples selection and approach for treatment of control groups. Further investigation of telemonitoring efficacy and cost-effectiveness over longer periods of time, and larger samples is needed. Assessment of the attitude of providers is also important in light of their heavy workload and issues of reimbursement.

## Introduction

Diabetes represents one of the common chronic diseases that has significant burden on patients and healthcare systems [1]. According to the World Health Organization (WHO), the number of persons suffering from diabetes is increasing worldwide, and the resulting impact of this 'epidemic' on healthcare budgets of different countries is very high [3]. In 2000, almost 171 million persons suffered from diabetes in the world: Western Pacific region (35.8 million); South-east Asia (46.9 million); European region (33.3 million); the Americas (33.0 million); Eastern Mediterranean region (15.2 million); African region (7.0 million). And the prevalence of the disease is expected to reach 366 millions by the year 2030 [2].

The importance and implications of diabetes as a chronic disease have been significantly emphasized. In 2002, diabetes was identified as the sixth leading cause of death in the USA after heart and cerebrovascular diseases, cancer, lower respiratory diseases and accidents [4]. When diabetes occurs in conjunction with other health problems, such as cholesterol and hypertension, the risks of suffering from complications (e.g. heart attacks, strokes) and death increase significantly [5–7]. As such, close monitoring of diabetic patients is necessary to maintain a controlled blood glucose level, and hence minimize long-term complications [8]. It also assists in reducing their risk exposure, and ensuring they receive the necessary care. At the economic level, the healthcare expenditures involved in diabetes care are also significant. In Canada, the burden of the disease and its complications on the healthcare system

approximate 13.2 billion dollars annually [9], and in the US, healthcare expenditures on diabetes reached \$92 billion in 2002 [1]. At the individual level, the total healthcare expenditures per diabetic person are estimated at \$13 243, which is approximately 2–3 times higher than the rate observed if the disease is not present [1].

With the alarming increase in the prevalence of diabetes and its burden on patients and healthcare systems, it becomes necessary to identify patient management approaches that would ensure appropriate monitoring and treatment of diabetes while reducing the cost involved in the process. Telemonitoring is one of the techniques that have been recently used in association with chronic illnesses such as pulmonary diseases, cardiac problems and diabetes [10–12]. Also known as biotelemetry, telemonitoring is defined as the employment of information technology with the goal of monitoring patients over distance [12]. It may involve audio, video as well as other telecommunication technologies [12,13] with the goal of supporting the transmission and remote interpretation of patient data relevant to diabetes care [14,15]. Consequently, the information necessary for healthcare providers becomes available in a timely manner, which allows appropriate follow-up and intervention when needed (e.g. modification in insulin dosage based on changing conditions) [16]. Evidence has shown that intensive diabetes treatment with frequent daily glucose monitoring of the blood may reduce the evolution of complications associated with the disease [17]. Telemonitoring may assist by supporting changes in the treatment and management of diabetes cases in a preventive manner. In this case, unnecessary procedures can be avoided when assistance is sought before the patient's health status worsens and complications, necessitating more advanced interventions, arise (e.g. admission to a hospital) [12]. Examples of early interventions include changing in insulin therapy and lifestyle when there are problems associated with metabolic control [16]. In this paper, we will provide a thorough review of the literature on experimental and quasi-experimental studies involving telemonitoring of diabetes, and present the nature and relative importance of the effects of using this approach at the informational, clinical, behavioural, structural and economical levels.

## Methods

A comprehensive literature search was conducted on Medline and Cochrane Library to identify articles on home telemonitoring that are relevant for this review. We define telemonitoring as an automated process for the transmission of data on a patient's health status from home to the respective healthcare setting. Specifically, diabetes telemonitoring consists of the 'recording, transmission and visualization' of variables involved in the care of diabetes patients using telecommunication technologies [15]. These variables may relate to the blood glucose measures, the patient's physical activity, as well as other physiologic and treatment-related variables [12,15]. When telemonitoring is used in conjunction with a health professional feedback and advice, it is referred to as 'telecare' [18]. The keywords that were used in the literature search include diabetes, telemonitoring, home monitoring, telecare and telemedicine. The references used in the articles that were found were also examined to further identify relevant cited articles.

Only articles published in English were included in this review. Articles that did not involve telemonitoring studies (e.g. general reviews, papers describing telemonitoring systems with no sampling or assessment of its impact, papers addressing teleconsultation and telediagnosis) and studies which considered multipathology groups of patients (e.g. pregnant women with diabetes, fetal home telemonitoring, tumour patients, patients with severe motor impairment problems) were excluded from this review. Our goal is to provide a systematic review of diabetes home telemonitoring in general, and an assessment of its effect at the informational, clinical, behavioural, structural and economical levels. Therefore, publications that focused on other topics, such as remote diagnosis and consultation, or special cases of diabetes were excluded. Studies that involved telemonitoring in other settings than home (e.g. ambulance and prison telemonitoring) were also beyond the scope of this review.

## Results

### Overview of diabetes home-telemonitoring studies

As shown in Table 1, 17 studies were found in the literature that examined the application of home telemonitoring to diabetes. The studies were conducted in different parts of the world between 1991 and 2005; 10 of them were in North America, six in Europe, and one in Asia. The duration of the experiments ranged between 3 and 15 months, and nine studies involved an experimental and a non-intervention control group [15,16,18–24]. Four of the remaining eight studies also included two groups, but the control groups involved some sort of intervention. The first study published by Billiard *et al.* used a prospective randomized cross-over trial whereby pairs of patients were assigned to two 3-month periods [25], in which they either use the technology first and then the traditional booklet approach, or vice versa. Shultz *et al.* also used a double cross-over design during which one group used the glucometer and modem for the first 6 months and then the paper diary for 9 months, while the other group used the diary for the first 6 months and then the glucometer and modem for the remaining 9 months [26]. The experiment by Tsang *et al.* [27], which was conducted in China, included one group that was subject to the monitoring system for a period of 12 weeks followed by 12 weeks control period, and another group that had a 12 weeks control period followed by 12 weeks of using the system. In the most recent study by Chumbler *et al.* [28], patients were also divided into two groups. One group consisted of patients with active diabetic wounds necessitating aggressive management and intensive evaluations; these patients were monitored on a weekly basis through exchange of photographs of their wounds [28]. The second group included older diabetic patients who needed careful supervision; they were monitored on a daily basis and were involved in more general discussions related to their condition [28].

The four studies that did not involve a control group receiving some sort of intervention were conducted by Meneghini *et al.* [8], Liesenfeld *et al.* [14], Bellazi *et al.* [29], and Vahatalo *et al.* [30]. The study by Meneghini *et al.* consisted of an ongoing case series with 184 patients (58% were actual users) to assess the extent to which an Electronic Case Manager system was safe and used by

**Table 1** Description of telemonitoring studies of patients with diabetes

Study	Country	Type of patients	Average age	Size of the experimental group	Size of the control group	Study duration	Technology used	Type of transmitted data	Frequency of data transmission	Planned meetings with healthcare professionals
Billiard <i>et al.</i> (1991) [25]	France	Insulin-dependant diabetes mellitus on intensified insulin therapy	32	22*	22*	Two periods of 3 months (booklet and telematic network via a Minitel terminal)	Glucometer M connected to the telephone	Blood glucose	As wished, but always the day preceding a visit	Once a month
Ahring <i>et al.</i> (1992) [19]	Canada	Insulin-dependant diabetes mellitus	41	20	18	3 months	Glucometer M connected to a telephone modem	Blood glucose	Once a week (experimental) and on regular visit (control)	Telephone consultation after each electronic transfer
Shultz <i>et al.</i> (1992) [26]	USA	Patients with diabetes mellitus	–	Group 1: 11 <sup>†</sup> Group 2: 9	Group 1: 11 <sup>†</sup> Group 2: 9	15 months	Glucometer connected to a modem	Blood glucose	Weekly transmission of data to the laboratory	–
Marro <i>et al.</i> (1995) [20]	USA	Paediatric patients with insulin-dependence diabetes mellitus (>6 months)	13	52	54	12 months	Glucometer connected to a modem; Glucofacts Data Management System for data analysis	Blood glucose	Every 2 weeks	Routine clinic visits every 3 months for the experimental and control groups
Edmonds <i>et al.</i> (1998) [21]	Canada	Volunteers with insulin-requiring diabetes mellitus	–	16	17	6 months	Vista 350 telephone system with feedback summary screen	Blood glucose, changes in insulin doses, hypoglycaemic reactions, change in carbohydrate intake, exercise and stress	Minimum of two blood sugar measures a day. Using the system varied between daily usage and less than once per week	–
Meneghini <i>et al.</i> (1998) [8]	USA	Diabetic patients	–	184	–	12 months	Electronic Case Manager computer system and a touch-tone telephone	Blood glucose, lifestyle events (changes in diet, exercise, stress), symptoms (illness, fever, loss of appetite, vomiting, ketonuria), self-administered medication	7 days week <sup>-1</sup>	–
Liesenfeld <i>et al.</i> (2000) [14]	Germany	Children and adolescents with type 1 diabetes (<26 years)	15	54	–	4 months (until reaching optimal glycaemic control)	Hand-held glucometer with electronic memory, and a palmtop with integrated analogue modem	Blood glucose, injected insulin, meals, exercise	Daily measurement of blood glucose at least five times; transfer of data at least once a week	No visits to the diabetologist clinic were done; only communication via telephone

Author (Year)	Country	Patients	Intervention	Control	Sample Size	Follow-up	Intervention Details	Control Details	Outcomes	
Plette <i>et al.</i> (2000) [22]	USA	Adults with diabetes mellitus from two general medicine clinics speaking English or Spanish	54.5	124	124	12 months	Teleminder automated telephone messaging computer	Self-monitored blood glucose, self-care, perceived glycemic control, symptoms of poor glycemic control, foot problems, chest pain, breathing problems	Biweekly automated assessment and self-care education calls, and follow-up by nurse educator	No face-to-face contact with health professional; follow-up visits in the control group were at the providers' discretion
Tsang <i>et al.</i> (2001) [27]	China	Diabetic patients	32.5	Group 1: 10 <sup>+</sup> Group 2: 9	Group 1: 10 <sup>+</sup> Group 2: 9	Pre: 3 months Post: 3 months	Hand-held electronic diary connected to a telephone line, Email.	Meal portions and blood glucose	Once every 2 days	-
Bellazi <i>et al.</i> (2002) [29]	Finland, Italy and Spain	Diabetic patients	35	11	-	-	Two modules (Patient Unit and Medical Unit) connected over Internet via telephone network	Blood glucose, diet, insulin therapy, ketonuria and glycosuria	Periodically, every 7–10 days	-
Biermann <i>et al.</i> (2002) [16] once a month or upon	Germany	Diabetic patients on intensified insulin therapy	30	27	16	4–8 months	BG-meter connected to a telephone modem	Blood glucose	Before each visit or telephone consultation, at least every 2 weeks	Regular personal visits for all patients every 2 months (e.g. lab controls). Personal visits for demand.
Gomez <i>et al.</i> (2002) [15]	Spain	Type 1 diabetic patients	-	10	10	6 months	Hand-held computer with blood glucometer. E-mail.	Blood glucose, insulin changes, diet modifications	At least once every 2 weeks	Three visits at the hospital
Chase <i>et al.</i> (2003) [23]	USA	Adolescent with type 1 diabetes for at least 1 year	17	30	33	6 months	Accu-Check Complete meter (both groups <sup>§</sup> ) and Acculink modem for blood glucose transmission (intervention group)	Blood glucose	Every 2 weeks for 6 months	Twice for the modem group (at 0, 6 months; quarterly for the control (0, 3, 6 months))
Lavery <i>et al.</i> (2004) [24]	USA	Diabetic foot risk category 2 or 3	55	44	41	6 months	Hand-held infrared skin thermometer	Foot skin temperature	Twice a day	Once every 10–12 weeks
Montori <i>et al.</i> (2004) [18]	USA	Type 1 diabetes (>1 years) on intensive insulin therapy & HbA <sub>1c</sub> ≥ 7.8%	43	13	15	6 months	Glucometer connected to phone line**	Blood glucose	Daily monitoring of blood glucose and data transmission at least every 2 weeks	Contact with nurse as necessary and clinic visits every 3 months

**Table 1** Continued

Study	Country	Type of patients	Average age	Size of the experimental group	Size of the control group	Study duration	Technology used	Type of transmitted data	Frequency of data transmission	Planned meetings with healthcare professionals
Vahatalo <i>et al.</i> (2004) [30]	Finland	Diabetic patients	56	102	101	12 months	Cellular phone	Blood glucose	Average 1.25 transferred measurements/day; more frequent among patients with higher education or working in IT-related occupation (1.4 measurements)	Routine clinical visit every 3–4 months
Chumbler <i>et al.</i> (2005) [28]	USA	Veterans with diabetes	64 69	GR 1: 197 <sup>††</sup> GR 2: 100	–	12 months	Hand-held messaging device with disease management catalogues; telemonitor with two-way audio-video connectivity; videophone	Blood glucose, vital signs, patient's symptoms, behaviours and knowledge related to his disease	Daily or weekly	Weekly teleconsultations

\*The study consisted of 11 pairs of patients who were randomly assigned to two successive 3-month periods; either start using computerized self-monitoring glucose and then manual recording on booklets, or vice versa.

<sup>†</sup>Group 1 used the system for reporting glucose values for 6 months and then used a paper diary for 9 months; Group 2 used a paper diary for 6 months and then used the system for 9 months.

<sup>††</sup>Group 1 used the monitoring system for 12 weeks and then had a control period of 12 weeks; Group 2 had a control period of 12 weeks and then used the system for 12 weeks.

<sup>‡</sup>The study consisted of two parallel 6-month phases. Patients were switched to the other part of the trial half way through the study.

<sup>‡‡</sup>All patients were able to assess the level of blood glucose and fax the results as often as needed.

<sup>†††</sup>Both intervention and control groups were offered modem transmission of glucometer data; patients in the intervention group feedback within 24 hours, while patients in control group were not given unsolicited feedback.

<sup>††††</sup>Patients in group 1 were monitored weekly, with more intensive evaluations, while those in group 2 were monitored daily, but less intensively.

patients for glycemic control [8]. Liesenfeld *et al.* involved 54 adolescents in a telemedical care program at the end of which they evaluated their glucose levels and frequencies of hypoglycemia [14]. Bellazi *et al.* conducted a small demonstration of the telemedicine management system that they developed (using Internet) on 11 patients who were heterogeneous, and different at the clinical level and the time of participation in the demonstration [29]. Lastly, Vahatalo *et al.* involved a control group (101 patients) in their study, but did not provide patients with cellular phones as was the case with the intervention group [30].

Interestingly, the technologies used in the experiments significantly evolved over the years. The technologies involved in earlier studies consisted of glucometers that were connected to a telephone network and modem [19,25,26]. In the late 1990s and early 2000s, the technologies used in telemonitoring studies also evolved around telephone systems to communicate data and provide feedback for patients in some cases [21,22]. Around the same period, the first attempts to research the use of more advanced technologies (e.g. electronic case manager system and electronic hand-held diary) for diabetes home telemonitoring started emerging [8,27]. Finally, in the more recent studies, hand-held devices became more popular such as a computer with glucometer [15], an infrared skin thermometer [24], cellular phones [30], and an advanced messaging device with disease management catalogues [28]. In short, it is evident through the review of the literature that the development of technologies used for telemonitoring of diabetic patients was significant over the years, with a transition from a simple transmission of glucometer readings via telephone [19,25,26] to advanced two-way audio-video connectivity [28].

In parallel to the development of technologies, there was also advancement in the type of transmitted data using these technologies. While blood glucose remained an essential indicator for diabetes [8,14–16,18–23,25–30], it became possible to capture more parameters, which are also important in the care of diabetic patients, using new technologies. For example, the appearance of electronic hand-held diaries and computer systems supported the e-mailing process and allowed patients to enter information about their lifestyle events (e.g. meal portions and diet) and medications (e.g. Meneghini *et al.* [8]; Liesenfeld *et al.* [14]; Gomez *et al.* [15]; Edmonds *et al.* [21]; Tsang *et al.* [27]) and it became possible to capture patients' vital signs and symptoms (e.g. fever, chest pain, foot problems) as well as their behaviours and knowledge using advanced hand-held devices [8,22,24,28].

### Observed effects of diabetes home-telemonitoring systems

As shown in Table 2, the experiments involving telemonitoring of diabetic patients presented significant impacts at various levels, namely, informational, clinical, behavioural, structural and economical. First, the quality of data is an important aspect that should be examined when assessing telemonitoring studies. Any follow-up on patients' medical conditions through telemonitoring necessitates having successful transmission of valid and reliable data. Otherwise, decisions and conclusions based on this approach for patient care become erroneous and invalid. Monitoring the quality of data was explicitly reported in several diabetes telemonitoring studies. Shultz *et al.* explained that error checks were performed by the system [26]. Edmonds *et al.* recognized that few

double data entries were observed during their study [21]. Marrero *et al.* [20] and Meneghini *et al.* [8] performed periodical comparison of values obtained by the system to the patient's glucometer memory log. And Gomez *et al.* acknowledged improvement in the quality and volume of information available for clinicians via the telemonitoring system [15], which ultimately provides detailed accurate information needed to support their decision-making process (e.g. therapy planning and therapy changes). Problems with data transmission were minimal as reported by Billiard *et al.* [25], Marrero *et al.* [20] (<1% in both cases), and Biermann *et al.* [16] (<5%). No technical problems were noted by Vahatalo *et al.* [30] when patients used cellular phones for data exchange. Nevertheless, almost half of the studies that were examined did not report any checking or assessment of the quality of data being considered. In short, data and information quality are critical issues to examine, especially when the data are not automatically transferred from medical equipment. Only Vahatalo *et al.* reported low activity in transferring glucose values using cellular phones [30], which might indicate selectivity in measurements by patients. And Marrero *et al.* recognized the potential for problems in the accuracy of the data and the ability to handle very large information volume [20].

Second, abundant research has examined the effect of telemonitoring on clinical outcomes of diabetic patients. A significant decrease in HbA<sub>1c</sub>, an indicator of how well diabetes is being managed, was observed in several studies as a result of telemonitoring [8,14,15,18,19,22,25–27]. Nevertheless, other studies did not find significant effects of telemonitoring intervention on glycemic control [16,20,23,28,30]. For example, Chumbler *et al.* [28] did not find any significant clinical impact of using telehealth monitoring of veterans' diabetes when comparing patients monitored on a daily basis versus patients monitored weekly. Their study, however, was observational in nature and did not involve randomization of patients who were not comparable at baseline in terms of demographic characteristics (e.g. age, marital status) and clinical characteristics (e.g. blood pressure, body mass index). An examination of change in complications rates was also noted in four studies. Meneghini *et al.* [8] and Liesenfeld *et al.* [14] found a significant reduction in the prevalence of complications (e.g. hypoglycaemia) when using the Electronic Case Manager system and hand-held glucometer, respectively. Lavery *et al.* also reported a significant decline in the number of diabetic foot complications in the group using hand-held infrared skin thermometers [24]. These findings were not consistent however, with the results by Chase *et al.* [23] who did not find significant differences in diabetes complications (e.g. ketoacidosis and hypoglycaemia) in their sample of adolescent diabetic patients. It is important to note that there was no evidence reported by Montori *et al.* [18] indicating that telecare, which is defined as 'the transmission of glucometer data followed by nurse-mediated feedback and support', presented major impact when compared to the transmission of data alone.

Third, at the behavioural level, telemonitoring systems had a noticeable impact on both patients and clinicians. All studies, except for the ones conducted by Shultz *et al.* [26], Liesenfeld *et al.* [14], and Chumbler *et al.* [28], reported various behavioural effects as a result of using telemonitoring of diabetic patients. In four studies, doctors were able to get used to the new system [25], access its functionalities [29], and use it to perform changes in patients' therapies during the intervention period [15,18].

**Table 2** Summary of the results of telemonitoring studies of patients with diabetes

Study	Types of observed effects	Clinical	Behavioural	Structural	Economic
	Quality of data				
Billard <i>et al.</i> (1991) [25]	Telematic transmission were successful (<1% failure rate)	HbA <sub>1c</sub> slightly declined during the telematic period compared with the booklet period. Such decline was not counterbalanced by weight gain or increased insulin dosages.	Patients found the access procedures easy to perform. 81% wanted to remain on the telematic system. Doctors also became accustomed to the system.	–	–
Ahring <i>et al.</i> (1992) [19]	–	HbA <sub>1c</sub> significantly decreased after 6 and 12 weeks for the experimental group only but with no significant weight reduction. Insulin doses did not change significantly. Patients (34–54) years had best results.	Almost all of the patients suggested that their understanding of blood glucose control and motivation for self-management was improved.	–	–
Shultz <i>et al.</i> (1992) [26]	Error checks were performed by the system for the transmitted data.	Significant improvement in glucose control; using the system was more effective in reducing the level of glycohemoglobin.	–	–	–
Marrero <i>et al.</i> (1995) [20]	Reliable system with <1% transmission error. Gucometer data were downloaded during clinic visits and compared with transmission records.	No significant difference between the two groups on metabolic control although there was a worsening in glycemic control in both groups (hormonal changes and puberty).	No significant effect of the system at the psychological level, and on the quality of life of the intervention group. Reported feeling of security among intervention group and increase in responsibility (health) in both groups.	No significant differences between the two groups on hospitalizations and emergency room visits. Significantly less time spent by nurses per phone call in the experimental group.	–
Edmonds <i>et al.</i> (1998) [21]	Few double entries were observed.	–	Overall, good acceptability of the system by patients who found it helpful and practical for diabetic management.	–	–
Meneghini <i>et al.</i> (1998) [8]	Reconfirmation of inputted data by patient in the system. Periodical comparison of the values obtained by the ECM with the glucometer memory log and HbA <sub>1c</sub> results.	Significant decrease in the prevalence of complications (hypoglycemia, hyperglycemia) by threefold. Significant reduction in HbA <sub>1c</sub> by 0.8% at 6 months and 0.9% at 12 months.	Significant system usage by patients and adherence to the process of care. System empowers case managers to increase intervention and improve metabolic control.	Significant reduction in annual clinic visits by twofold (50%). Time saving and support for decision making of providers.	No additional cost on patients (e.g. computer devices); only medical fees covered by third party insurance. Cost of running ECM system is \$1000/month with \$50 per patient per month.
Liesenfeld <i>et al.</i> (2000) [14]	Four patients manipulated their data and were not included in the analyses.	Improvement in metabolic control with significant reduction in HbA <sub>1c</sub> and hypoglycaemic events end of the program. No significant relationship between glucose levels and frequency of hypoglycaemia.	–	No hospital admissions were reported during the program. The rate of severe adverse events was not different after the program.	–

Piette <i>et al.</i> (2000) [22]	-	Significantly better glycaemic control (lower HbA <sub>1c</sub> , higher normal haemoglobin, better glycaemic control) and fewer diabetic symptoms in the intervention group.	Significantly better self-care (glucose self-monitoring, weight monitoring, foot inspection and medication adherence) in the intervention group.	No significant differences between the two groups on hospitalization, emergency services use, podiatry, ophthalmology and outpatient visits. Nurse used time more efficiently by focusing on patients needing more assistance.	-
Tsang <i>et al.</i> (2001) [27]	-	Significant improvement in glycaemic control for both groups (decrease in HbA <sub>1c</sub> during the experiment).	95% of patients found the technology easy to use while 63% found it useful. Most patients found the system useful in evaluating their eating habits	-	-
Bellazi <i>et al.</i> (2002) [29]	-	Reduction in HbA <sub>1c</sub> and insulin requirement among some of the patients.	Increase in patient-doctor communication. Patients found the system efficient and easy to use. Doctors also found the system reliable and helpful.	-	-
Biermann <i>et al.</i> (2002) [16]	Problems in data transmission occurred in <5% of data transfers.	Decrease in HbA <sub>1c</sub> (metabolic control) but no significant difference between the two groups.	85% of intervention patients found the telecare system easy to use and better than conventional care (feeling of security, faster intervention, less waiting and travel time). One-third of patients reported that using daily log book and pen is 'bothersome'.	20% more time consumption for healthcare professionals with telecare because of more contacts.	Savings of 650 EURO per year per patient with optimal telemanagement (hypothetical).
Gomez <i>et al.</i> (2002) [15]	Increase in the quality and volume of the information collected by patients ensuring better decision-making process for clinicians.	Significant decrease in HbA <sub>1c</sub> after the DIABTEL study. The system improved the metabolic control of patients.	Improvement in patient empowerment and education. Doctors performed more therapeutic changes during the intervention period.	Increase in doctors' workload (reply to patients' messages). Similar number of phone calls to the diabetes center in both periods.	-
Chase <i>et al.</i> (2003) [23]	-	No significant differences in glucose control and acute diabetes complications (e.g. hypoglycaemia) between the intervention and control groups.	No significant differences between the two groups on testing compliance and satisfaction with care. Fewer days of school and work lost when using the modem.	-	Significant difference in cost of care. Using the modem is more cost-effective than standard care; \$305 for a clinic visit and \$173 for a 6-month modem transmission.
Lavery <i>et al.</i> (2004) [24]	-	The experimental group had significantly fewer diabetic foot complications.	Patients were able to use the device and modify their activity, or contact the nurse for advice, or schedule a clinical evaluation.	-	-

**Table 2** Continued

Study	Types of observed effects Quality of data	Clinical	Behavioural	Structural	Economic
Montori <i>et al.</i> (2004) [18]	-	HbA <sub>1c</sub> significantly lower in the telecare group after 6 months.	No difference between the two groups in the change (after 6 months) for adherence to insulin doses, smoking status, general diet, specific diet, exercising and foot care. Telecare patients had significantly more dosage changes than control patients. Dosage changes were significantly correlated with greater nurse feedback.	More health professional time spent in the telecare group. Nurses spent additional 50 minutes/patient on the phone with the telecare group. The nurse spent 30 minutes and the clinical endocrinologists 0 minute reviewing data transmitted from each patient in the control group; they spent 2.4 hours and 9 minutes, respectively, in the intervention group.	-
Vahatalo <i>et al.</i> (2004) [30]	No technical problems in the transfer of glucose values were observed.	No significant difference in HbA <sub>1c</sub> between the two groups.	Cellular system was easy to learn and acceptable by patients. Low activity in transferring glucose values, limiting the ability to assist in management of diabetes. Selective measurements might have occurred, which are misleading.	-	-
Chumbler <i>et al.</i> (2005) [28]	-	No significant differences between the two groups in any of the clinical outcome measures.	-	Change in diabetes hospital admission rates was 53% lower in the daily monitoring group vs. weekly monitoring group. Change in the average number of hospital bed days of care was nine days lower in the daily monitored group. Diabetes-related ER visits were not significantly different between groups.	-

ECM; Electronic Case Manager; DIABTel; Diabetes Telemonitoring system.

Meneghini *et al.* [8] also reported that the system used in their study empowered case managers to perform changes in the intervention, when needed, and improve metabolic control. With respect to the patients, a positive attitude towards telemonitoring systems was observed in several studies, and was evident through patients' behaviours and feedback. This attitude was facilitated by the reported ease of use [16,25,27,29,30], perceived usefulness [21,27] and practicality [21] of the respective telemonitoring system. Yet, the most important behavioural implications for patients are reflected through their education and empowerment [15,19,24,27]. The ability of patients to understand their illness (e.g. blood glucose control, long-term complications), perform self-management and self-care, assume responsibility related to health, and take the necessary measures when needed (e.g. change activities/habits, contact providers only when appropriate) represent important implications of telemonitoring systems at the patient level [15,19,20,22,24,27]. Patients' acceptance of a system originates from their appreciation of its contribution to their medical condition as a supportive and helpful tool during their treatment. Such appreciation is certainly catalysed by the improvement in the user-friendliness of telemonitoring systems that have been easy to use by patients (e.g. Ahring *et al.* [19]) who might not have advanced technological background to operate complicated systems. In addition, the ability of telemonitoring systems to support patients' autonomy and feeling of security while maintaining the needed medical supervision have also contributed to patients' acceptance of such systems [15,16,20]. It is also important to note that patients' time savings associated with using telemonitoring systems (e.g. travel distance, days lost from school and work) remain attractive features of such technologies, especially in areas where patients need to travel long distances to reach their healthcare providers [16,23].

Fourth, with respect to the structural effects of using telemonitoring systems, an increase in doctors' workload was observed in three studies as a result of the ability of patients to communicate easily with their providers and the need for continuously reviewing the transmitted data [15,16,18]. Meneghini *et al.* who examined the impact of using an electronic case manager system for glycemic control on the utilization of services [8], reported time savings and support for the decision making of providers because of the system, with a resulting 50% reduction in annual clinic visits [8]. The study by Chumbler *et al.* also reported changes in the utilization of services for patients monitored on a daily basis as compared with those monitored on a weekly basis [28]. Although patients monitored on a daily basis did not receive intensive evaluations of their cases, they were more frequently assessed than the patients monitored on a weekly basis, and as such had a significant decrease in hospital admission rates, length of stay and unscheduled clinic visits [28]. Only two studies reported non-significant differences on hospitalizations and emergency visits because of telemonitoring [20,22]. Piette *et al.* also noted that there were significant differences in outpatient visits (e.g. podiatry, ophthalmology) between the intervention group using biweekly automated assessment and self-care education calls, and the control group [22], which did not have systematic monitoring or reminders of appointments.

Last, only three studies reported some sort of economic analysis of the impact of using diabetes telemonitoring systems. Meneghini *et al.* estimated the cost of running the Electronic Case Manager

system that was used for telemonitoring in their study to \$1000/month; the cost per patient was estimated at \$50 per month and hence the monthly cost of the system would be returned if at least 20 patients used the system [8]. Biermann *et al.* performed a hypothetical scenario for estimating savings associated with 'optimal' usage of a telemanagement system for blood glucose transfer [16]. In this case, approximate savings of 650 EURO per year per patient were estimated [16]. Chase *et al.* also compared the cost involved in data transmission to the cost of clinic visits [23]. They found that using the glucometer and modem for blood glucose transmission is more cost-effective than regular clinic visits (\$173 for 6-month usage of the modem as compared with \$305 for a clinic visit) [23].

## Discussion

Telemonitoring has advanced over time to cover a variety of medical conditions (e.g. cardiovascular, hematologic, respiratory, neurologic, metabolic and urologic) that can be successfully supervised from home [12]. The continuous increase in healthcare costs and the shift towards outpatient care have triggered the search for alternative techniques that can keep the patient away from the hospital, without being put at risk, while closely monitored. As a result, telemonitoring systems have become an important progressive approach in health care, which involves creative user-friendly technologies that empower patients and support monitoring of their health status from home. This study was focused on telemonitoring, which differs from other types of remote provider-patient communications that are also commonly used in relation to chronic diseases (e.g. teleconsultation, telediagnosis). As such, studies involving healthcare providers in the capture and transmission of patient information (e.g. a visiting nurse monitoring vital signs) or focusing on patient education (e.g. Horan *et al.* [31]) were excluded.

Diabetes represents one of the major chronic illnesses that can be associated with acute and long-term complications leading to disability and death [3,5,9,15]. As such, it is a burden on the patients as well as the healthcare system of any country. The development in therapies and clinical guidelines for the treatment of diabetes has necessitated timely capturing of patient data related to his or her medical condition (e.g. clinical, physiological, behavioural) [15]. Such data can now be easily and reliably recorded with the advancement in information and communication technologies used for telemonitoring. For example, it is possible to regularly monitor the blood glucose level of a diabetic patient using a glucometer connected to a telephone network (e.g. Biermann *et al.* [16]; Ahring *et al.* [19]; Marrero *et al.* [20]; Billiard *et al.* [25]) or a hand-held computer with a glucometer (e.g. Liesenfeld *et al.* [14]; Gomez *et al.* [15]). Similarly, electronic diaries, messaging devices and cellular phones can now support timely transmission of data on a patient's diet, vital signs and symptoms as needed, sometimes several times during the day. And the use of diabetes telemonitoring has shown significant clinical and behavioural effects on the patient as well as the provider.

At the clinical level, the close management and monitoring of diabetes patients have resulted in significant decrease in HbA<sub>1c</sub>, as reported in several studies (e.g. Gomez *et al.* [15]; Ahring *et al.* [19]; Piette *et al.* [22]; Billiard *et al.* [25]; and Tsang *et al.* [27]), which indicates good management of the medical condition.

Maintaining blood glucose control implies success in the management and treatment of the diabetes condition and minimizing of long-term complications [8]. Similarly, the close monitoring of patients' temperatures has shown a significant decrease in foot complications [24], which is also an indicator of good management of the medical condition. And in instance, evidence has demonstrated a reduction in overall complications associated with diabetes (e.g. Meneghini *et al.* [8]). Yet, the magnitude of the effect of telemonitoring and telecare at the clinical level remains debatable, especially with the variation between patients in vulnerability, background and ability for self-management [18]. Although abundant literature has examined the effect of telemonitoring on clinical outcomes of diabetic patients, the differences in samples selection (e.g. different age groups, random vs. non-random samples), characteristics of patients (e.g. degree of illness, aggressiveness of treatment, level of education and technological knowledge) as well as the approach for treatment of the control group [16] makes the comparison across studies difficult. Nevertheless, it is evident through this review that the ability of telemonitoring systems to provide timely supervision for diabetic patients who certainly need consistent and repetitive monitoring can ensure glycemic control and reduction in HbA<sub>1c</sub>, even if varying in magnitude and not always significant.

At the behavioural level, studies have consistently reported good receptiveness by patients to the technology, and an increase in perceived empowerment and education of patients with respect to their health condition [15,19,25,27]. Therefore, although the primary goal of telemonitoring is the close management of a medical condition, this approach seems to have significant positive impact on patients' attitudes and behaviours towards their illness. The feeling of security projected by the ability to regularly communicate indicators of their physical illness and being monitored, have positive impacts on patients who are usually more vulnerable than the rest of the population.

The evaluation of the economic and structural impacts of telemonitoring is still at early stages. Savings associated with telemonitoring would certainly depend on several factors such as patients' travel distance and proximity to providers – rural/urban location [16], availability of specialists [23], stage of illness and degree of severity [16]. Hence, more development in the area of cost-benefit analysis research associated with telemonitoring is needed before being able to draw firm conclusions on its economic effect. Several studies in the literature have examined cost of certain illnesses taking into consideration the services utilized, medications, days lost from work, etc. A similar approach can be used with telemonitoring provided large samples of patients are available. This would involve however, higher cost in relation to the equipment used as well as the time spent by healthcare providers involved in the monitoring of patients. The increase in time spent by providers in telemonitoring scenarios has been reported in the literature [15,16,18]. Yet, no study has compared the increase in short-term time spent by the providers in telemonitoring settings with the long-term time spent with the diabetic patients when complications arise.

Assessment of the progress in diabetes telemonitoring and its impacts has been limited to small scale studies over short periods of time. As mentioned earlier, the experiments found in the literature ranged between 3 and 15 months, and the size of the experiment groups did not exceed 124 patients [22]. Only Chumbler

*et al.* examined, in an observational study, veterans in groups of 197 and 100 patients [28]. Therefore, in order to be able to generalize the findings of telemonitoring studies and experiments, it is essential to extend the follow-up period for these studies (i.e. check if the benefits persist) and involve larger samples of patients. Before being able to state that diabetes telemonitoring reduces hospital admission rates or hospital length of stay, it is important to have a strong experimental design with minimal threats to the validity of the results that can lead to generalizable findings. For example, randomization of patients in telemonitoring studies need to accommodate large samples with different demographic characteristics (e.g. age, gender, education, ethnicity) representing the population at large and involving diabetic patients with various levels of illness severity. Differences between urban and rural settings should also be taken into consideration when assessing the impact of telemonitoring at each of the structural, behavioural and economic levels. Successive studies in this area will allow building strong evidence on the effects of diabetes telemonitoring, which may ultimately lead to change in the practice and management of diabetes.

Nevertheless, improving the design would certainly come at the expense of higher costs (e.g. installing and maintaining systems) and more difficulty recruiting patients. And with the current lack of information in the literature on the economic impact of diabetes telemonitoring or any thorough cost-benefit analysis in this area, it is difficult to benchmark or indicate a range as to the magnitude of the cost that might be incurred over a longer period of study and larger samples. Hence, our review shows the importance of conducting cost-benefit analyses for diabetes telemonitoring, an area that is missing in the extent literature. Such studies would give us a better idea of the economic impact of this technology in relation to its benefits, and either validate or suggest modifications, in the current body of knowledge in this area.

Diabetes telemonitoring has witnessed significant technological advancement over years. With the continuous increase in the number of diabetic patients worldwide and the need for effective management of the disease and timely transmission of data, there is pressure to further develop this approach in order to better support patient care. The shortage in healthcare providers in some geographic areas certainly creates the need to optimize on the benefits of this approach. Development in diabetes telemonitoring is expected as new telecommunication technologies are emerging (e.g. wireless networking, mobile computing). So far, a small number of studies have examined in details the various effects of telemonitoring at the informational, clinical, behavioural, structural and economic levels. Most of these studies presented diabetes telemonitoring as an effective approach for glycemic control, and patient empowerment and education. Nevertheless, before being able to provide strong conclusions as to the impact of this promising patient management approach, there is need for further investigation of its efficacy and cost-effectiveness over longer periods of time, and larger diversified samples. Until now, little evidence is available for clinicians and policy makers related to the efficacy of telemonitoring and telecare [18]. Further assessment of the attitude of providers and willingness to use this technique, although it may present an increase in their workload [15,16] and a problem of licensing and reimbursement [12,16,23], is also important in order to better understand the limitations and potential challenges that might arise in the future.

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