2-28-2013

Importance of New Technologies for Diabetes Monitoring

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Abstract

Diabetes and its ramifications and treatments are presented, followed by discussion of the importance of communication between patient and clinician. Improved communication approaches, including telephone consultations, blood glucose communications to a provider with feedback, and active electronic diaries on smartphones for both type 1 and type 2 diabetes mellitus, are reviewed.

What Exactly Is Diabetes?

Diabetes is a metabolic disease: a disorder of how the body uses food. Most of the food eaten is digested into glucose, which enters into the bloodstream, where cells use it for growth and energy. Insulin, a hormone produced by the pancreas, must be present for glucose to be absorbed into cells. Normally, when people eat, the pancreas produces the proper amount of insulin necessary for glucose to be moved from the blood stream into the cells. In individuals with diabetes the pancreas produces either insufficient or no insulin, or the body's cells do not respond correctly to the insulin which is produced. The net result: the body loses its fuel source even though the bloodstream contains more than sufficient glucose.

Three types of diabetes mellitus exist: (1) type 1 diabetes (formerly called juvenile diabetes); (2) type 2 diabetes (formerly called adult onset diabetes); and (3) gestational diabetes. Type 1 diabetes accounts for about 5-10% of diagnosed diabetes in the U.S. and occurs mostly in children and young adults but can appear at any age ("Types of Diabetes", 2012). It occurs because the body's immune system attacks and destroys the insulin-producing cells in the pancreas. If not diagnosed and treated with insulin, an individual with type 1 diabetes can lapse into a life-threatening coma, called diabetic ketoacidosis. Most people who develop type 1 are otherwise healthy (Kasper et al., 2005).

About 90-95% of diabetics have type 2 diabetes, which is most often associated with older age, obesity, family history of diabetes, previous history of gestational diabetes, physical inactivity, and certain ethnicities. About 80% of people with type 2 diabetes are overweight or obese. In 2010, type 2 diabetes was diagnosed in more than 25.8 million adults over the age of 20 in the U.S., while another 7.1 million went undiagnosed; 81.5 million had prediabetes (Roger et al., 2011). The prevalence of type 2 diabetes in all age, gender and ethnic groups in the U.S. is expected to more than double (from a prevalence of 5.6% to a prevalence of 12%) between 2005 and 2050 (Narayan et al., 2006).

Type 2 diabetes is increasingly being diagnosed in children and adolescent. When type 2 diabetes is diagnosed, the pancreas is usually producing sufficient insulin, but for unknown reasons the insulin cannot be used effectively by the body and eventually a decrease in insulin production occurs. The result is the same as for type 1 diabetes: glucose increases in the blood and the body cannot use of its main source of fuel efficiently. Clearly, type 2 diabetes is a significant and growing medical problem in the U.S.

Some women develop gestational diabetes during pregnancy. Although gestational diabetes usually disappears postpartum, women who have had it have a 40-60% likelihood of developing type 2 diabetes within 5 to 10 years. Maintaining a reasonable body weight and being physically active may help prevent development of type 2 diabetes.

Whatever the type, diabetes is associated with multiple long-term complications affecting virtually all parts of the body. The disease often leads to blindness, heart and blood vessel disease, stroke, kidney failure, amputations, and nerve damage (American Diabetes Association, 2010). Uncontrolled diabetes can complicate pregnancy, and birth defects are more common in babies born to women with diabetes. Before the discovery of insulin in 1921, a diagnosis of type 1 diabetes was a death sentence – all patients died within a few years after diagnosis. Insulin, while not a cure, was the first major breakthrough in the treatment of diabetes.

Basic therapies for type 1 diabetes include healthy eating, physical activity, and taking insulin; basic treatment for type 2 diabetes are the same as for type 1, except that oral medication may be substituted for insulin. Blood glucose levels should be closely monitored through frequent blood glucose checking; patients with diabetes should also monitor blood glucose levels several times a year with a laboratory test called the HbA1c, results of which reflect average blood glucose levels over a 2-3 month period. This entire monitoring procedure has been characterized by many diabetics as complex (Kouris et al., 2010)

People with diabetes should see a health care provider who will help them learn to manage their diabetes and who will monitor and assist in their diabetes control. Most people with diabetes receive care from primary care physicians—internists, family practitioners, or pediatricians but occasionally a team of providers is necessary to manage diabetes care successfully. The goal of diabetes management is to keep levels of blood glucose, blood pressure, and cholesterol as close to the normal range as safely possible.

People with diabetes must take responsibility for their day-to-day care, much of which involves keeping blood glucose levels from going too low or too high. When blood glucose levels drop too low a person can become nervous, shaky, and confused. Judgment can be impaired, and if blood glucose falls too low, fainting can occur. A person can also become ill if blood glucose levels rise too high.

Uses of Communication Technologies in Diabetes

The healthcare industry is slowly adopting new strategies to deal with the swelling prevalence of chronic disease, including diabetes, due largely to market dynamics. Healthcare organizations constrained by revenues and less than adequate tools to manage chronic care patients systematically are changing from being centered on the provider to more centered on the patient. Unfortunately, traditional forms of patient communication have not been particularly effective in improving patient adherence to lifestyle and medical lifestyle changes (Boland, 2006). However a host of new communication and remote monitoring technologies are becoming available so that providers can interact with patients virtually “anywhere, anytime” (Boland, 2007).

Health authorities seem to have high expectations for telemedicine (Brown, et al., 2007; Franc et al, 2011), which addresses several major challenges: improved access to healthcare (especially for patients in remote or underserved areas); assistance in overcoming the scarcity of qualified clinicians in the face of a diabetes epidemic; and the reduction of costs while improving (or, at least, maintaining) quality. The aims of telemedicine in the field of diabetes differ according to the type of diabetes. In type 1 diabetes which is associated with relatively complex insulin regimens, the goal of telemedicine is to assist patients in achieving better blood glucose control via more accurate adjustment of insulin doses. In type 2 diabetes there are two basic goals of telemedicine: (1) accurate and timely adjustment of insulin dosage and (2) improvement in blood glucose control by means of dietary and/or physical activity changes. Currently, there appear to be two promising approaches (Franc et al, 2011):

(1) hand-held communication devices, especially smartphones, have been shown to improve blood glucose control. These systems can provide immediate patient assistance (e. g., insulin-dose calculation for specific meals and/or food choices), and all data stored in the device can be transmitted to authorized caregivers, enabling remote monitoring and even teleconsultation. Although these systems were initially developed for type 1 diabetes, they also appear to offer many possibilities for type 2 diabetes as well.

(2) systems combining an interactive Internet system (or a mobile phone coupled to a remote server) with a system of communication between the patient and the healthcare provider (e.g., by e-mail, texting or telephone calls) have also been demonstrated to be beneficial for blood glucose control. Primarily aimed at patients with type 2 diabetes, these systems generally provide patient motivational support as well.

Type 1 Diabetes Studies

Telephone Consultations

Several studies (Ładyzynski and Wójcicki, 2007; Lehmkuhl et al., 2010) reported on use of traditional (i.e., landline) telephone contacts to better manage type 1 diabetes. Despite somewhat different protocols, both reported that both experimental and control groups demonstrated decreased mean HbA1c levels at the program, but neither group's decrease was statistically significant.

Another study (Thompson, Kozak, and Sheps, 1999) did yield significant results. Regular telephone contacts were proposed for patients with poorly controlled type 1 diabetes (HbA1c > 8.5%). Patients in the experimental group had 15 minute telephone contacts three times a week. After 6 months, the mean HbA1c in this group had decreased from 9.6% to 7.8% while in the standard-care control group, the decrease in mean HbA1c was from 9.4% to only 8.9%. This difference in mean improvement in HbA1c levels between the two groups was statistically significant ($P < 0.01$) and clinically relevant, and therefore the system was considered effective, as (the researchers noted) would any system involving close management of diabetic patients. However, patient follow-up was expensive: nurses spent an average of 17.25 hours per week calling patients, the equivalent of an almost half-time employee to cover 23 patients.

Mobile telephone communications allow interaction with individuals more frequently and while those individuals' behavior is actually occurring, making potential interventions more effective (Hitman, 2011; Riley et al., 2011). As of December 2011, there were over 331.6 million wireless telephone subscribers in the US, a 39% increase in 5 years (CITA Advocacy, 2012), and an estimated 78% worldwide owned cell phones in 2010, the latest data available (Sanou, 2011). The vast use of cellular phones should make this type of communication system a very viable option (Brown, et al., 2007), as cellular phones have been demonstrated to be especially suited for engaging the self-care of patients while leveraging providers' the expertise and time (Boland, 2006, 2007). Measurable improvements, however, have not been demonstrated.

The combination of a glucose meter combined with the battery pack of a cell phone to make the determination of blood glucose easier has been reported (Carroll, Marrero and Downs, 2007; Malasanos, 2008). Although this approach sounds promising, significant improvements in blood glucose control using it have not been demonstrated (Carroll et al., 2011).

<u>Blood Glucose Data Transmission to a Provider with Feedback</u>

Numerous studies have been published using different systems to transmit blood glucose data. These may be subdivided into three categories. The first consists of simple teletransmission of blood glucose values from a glucose meter with a memory function. Many such studies have been published, most sponsored by firms that market blood glucose meters. In one study (Montori et al., 2004), patients with type 1 diabetes who were poorly controlled despite receiving intensive insulin therapy sent their blood glucose data to the care team regularly over a 6-month period using a modem. The experimental group received telephone "feedback" from a nurse within 24 hours of each transmission, and these patients' mean HbA1c levels decreased significantly ($p = 0.03$). Reduction in mean HbA1c in the control group did occur, but was thought to be potentially related to a possible study effect. In another study, patients with type 1 diabetes and poorly controlled blood sugar transmitted their data regularly by telephone from a glucose meter (Jansà et al., 2004). After 6 months, both the experimental and control groups results were similar, but the experimental group's costs were considerably higher than those of the control group.

Nevertheless, more sophisticated systems have been developed. For example, in the Telematic Management of Insulin-Dependent Diabetes Mellitus (T-IDDM) project, patients were provided with desktop computers, allowing them to send data in addition to blood glucose values. Unfortunately, the preliminary results did not demonstrate significant changes in HbA1c (Bellazzi et al., 2002; d'Annunzio et al., 2003).

Overall, the results of transmission of blood glucose values with retrospective feedback have been disappointing, regardless of the technology employed. One meta-analysis (Montori et al., 2004) included 7 randomized trials of type 1 diabetic adults showed statistically significant, but very limited (0.4%), improvement in HbA1c in the telemedicine group compared with controls, but this improvement was obtained only after one of the seven studies examined was excluded. These systems generally failed to incorporate truly effective feedback from the caregiver other than an increase in frequency of telephone contact with the patients, which is infeasible in routine practice in the long term. As a number of other studies (Lawson, 2005; Nunn, 2006; MacLean et al., 2012) have also failed to demonstrate a significant difference in HbA1c levels between experimental and control groups when telephone coaching alone was used, it appears safe to conclude that this approach is not particularly useful or cost-effective.

Active Electronic Diaries on Smartphones

There is a growing interest in self-management of diabetes via mobile health applications. Chomutare et al. (2011) found 60 diabetes applications for iPhones; within a year and a half, the number had increased to 260 (over a 40% increase). Other mobile platforms reflect a similar trend.

Complex systems can transmit data such as insulin intake, blood glucose, dietary consumption, and physical activity in a readily available format for the clinician, allowing more rapid help for patients in determining their appropriate insulin dose

(Kouris et al., 2010). A secure website coupled with a smartphone can easily do this (Gammon et al., 2005; Rossi et al., 2009), and is probably more attractive (as well as more prompt and accurate) than the traditional paper diary for patients with diabetes. Such a system has no autonomy or responsibility, but merely puts the data into an electronic format, with the insulin prescription remaining the physician's sole responsibility. A number of researchers (Rami et al., 2006; Benhamou et al., 2007; Istepanian et al., 2009) have demonstrated that mobile communication tools can potentially enhance the cost effective self-management of diabetes and improve HbA1c levels.

Several such systems are under development. One, the "Diabetes Interactive Diary" (DID) (Rossi et al, 2009) meets the above description, and also features an electronic illustrated food list, which allows patients to simply select the quantities and types of foods they intend to eat, and the software automatically calculates the equivalent amount of carbohydrates and insulin required (Rossi et al., 2011). Unfortunately, a weakness of the DID system is poor interaction with the doctor via text messages. Also, results have been mixed. Rossi et al. (2010) found little difference between control and experimental groups, with no significant difference in terms of decreased HbA1c levels ($p = 0.68$).

Another system is the Diabeo system, which also incorporates the features previously discussed using a Personal Digital Assistant, but adds insulin doses for both basal and prandial blood glucose, and also for patients whose blood glucose falls regularly outside a predetermined range ("Multi-Technology Solutions", 2012). Evaluations of the Diabeo system (Franc et al., 2009) showed good results for mean blood glucose values, which were quite similar pre- and post-meals. Excellent patient satisfaction was observed, with a large majority expressing the wish to continue using the system even at their own expense, rather than continuing to use a traditional passive glycemic diary. A 6-month multicenter randomized study using 80 adults with poorly controlled type 1 diabetes clearly showed marked metabolic improvement with the Diabeo system (Charpentier et al., 2011), and a follow-up study involving 700 patients and 100 healthcare professionals is planned for 2012 in France, where it will be the largest telemedicine study ever conducted in that country ("Clinical Results", 2012).

Type 2 Diabetes Studies

As the prevalence of type 2 diabetes far exceeds that of type 1 diabetes, studies involving telemedicine for these patients have been done on a somewhat larger-scale. In addition to the studies previously described for type 1 diabetes which also used apply to type 2 diabetes, studies designed to inform and deliver an educational message to patients at a lower cost also exist. These systems generally allow patients to transmit a variety of additional useful data, in addition to blood glucose and HbA1c values, for diabetes management. Literature is reviewed using the following typology: Internet-based blood glucose control systems, systems using a cellphone connected to a remote server, and active electronic diaries on smartphones.

Telephone Consultations

Early studies (Weinberger et al., 1995; Aubert et al., 1998) showed nurses' telephone follow-up of diabetic patients improved patients' blood glucose. However, these early interventions proved expensive and time-consuming. Telephone interventions using a call center manned by non-medical staff have also been tested. One such study was conducted in England. Using a call center to monitor a large population of type 2 diabetes patients with limited resources (Young et al., 2005) yielded a 0.31% reduction in HbA1c in the intervention group compared with the control group (P = 0.003).

Other studies generally support the earlier findings. A 2000 study (Piette et al., 2000) involving 280 English- or Spanish-speaking adults with diabetes who were treated in a county health care system found that blood glucose levels were significantly (P = 0.002) lower among intervention patients than patients receiving traditional care; a 2001 study by Piette et al. (2001) of 272 diabetic VA patients, found that an intervention by telephone nurses resulted in a statistically significant (P = 0.04) reduction of HbA1c at one year. More recently, (Walker et al., 2011) conducted a study involving a low-income insured minority population with type 2 diabetes and poor blood glucose control. They showed modest results of a telephone compared to a printed intervention, with a small but statistically improvement in HbA1c (p = 0.009) between the two groups at 1 year.

Unfortunately, the above results are not always seen. Krein et al. (2004) conducted a randomized controlled trial at two VA Medical Centers involving 246 veterans with poorly controlled diabetes. Two nurse practitioner case managers worked with patients and their primary care providers, monitoring and coordinating care for the intervention group through the use of telephone contacts, collaborative goal setting, and treatment algorithms. Control patients received educational materials and usual care from their primary care providers. After 18 months, the difference in HbA1c levels between the experimental and control groups was not statistically significant (P = 0.65), although the intervention patients were substantially more satisfied with their diabetes care.

The combination of a glucose meter combined with the battery pack of a cell phone for the determination of blood glucose for type 1 diabetes was discussed earlier, and negative results were noted (Carroll et al., 2011). Interestingly, when this same approach was used for patients with type 2 diabetics, statistically significant (P = 0.01) improvements in blood glucose were observed (Cho et al., 2009). There are now 3 such Smartphone apps available on the market (Lieberman, 2012).

These results, based upon quite different population types, suggest that a simple inexpensive telephone intervention by non-clinical health educators can be useful.

Blood Glucose Data Transmission with Feedback from a Provider

Internet-Based Blood Glucose Control Systems

The use of computers by the public continues to increase, and many patients use this medium to find information about healthcare (Noh et al., 2010). The most frequently used technology in diabetes management is the Internet, which has been shown to increase patients' knowledge, support their engagement with treatment, increase patients' self-efficacy, and facilitate behavior change (Brown, Lustria, and Rankins, 2007).

Some approaches have been aimed at indirect control of blood glucose levels; e.g., through weight reduction or increased physical activity. An Internet-based supplement to traditional diabetes care used the remote intervention of coach in an attempt to increase patients' physical activity. This system was evaluated in 78 sedentary type 2 diabetes patients over 8 weeks. A moderate increase in physical activity was found in the experimental group as opposed to the control group, but the lack of objective measures of blood glucose or HbA1c made evaluation of the true effectiveness of this approach impossible (McKay et al., 2001). Examining effects of diet, Tate, Jackvony, and Wing (2003) showed that Internet-based behavioral counseling significantly ($P = 0.04$) improved weight loss in overweight and obese adults at risk of type 2 diabetes. Patients received weekly counseling and feedback via e-mail after submitting calorie and exercise information. Unfortunately, as with the McKay et al. (2001) study, objective measures of improvement of type 2 diabetes were not reported.

Systems Using a Cell Phone with a Remote Server

The ubiquitous spread of cellphones among the US population has already been discussed. Krishna and Boren (2008), in a review of the literature, found that 9 out of 10 studies that examined the use of a cell phone for health information for persons with diabetes or obesity reported significant improvement in HbA1c levels of experimental groups. Quinn et al. (2008), in a small study (30 patients), found that patients receiving real-time cellphone feedback regarding blood glucose levels analyzed by WellDoc proprietary software had significantly decreased ($P < 0.02$) decreased HbA1c levels compared with patients not receiving such feedback. In a study involving cell phone use and the internet for overweight patients with type 2 diabetes, Yoo et al. (2009) found statistically significant reduction of HbA1c in their experimental group, but as the study was short (only 12 weeks), it could not be determined if the effects observed were long-term ones or not. The combination of mobile behavioral coaching and lifestyle behavior, blood glucose data, and patient self-management data individually analyzed and presented with evidence-based guidelines to providers significantly ($P = 0.001$) reduced HbA1c levels over 1 year (Quinn et al 2011).

Other systems have been tested using dedicated computers allowing patients to transmit more complex data from their homes. The Informatics for Diabetes Education and Telemedicine (IDEATel) study (Shea, 2007; Shea et al., 2009) was a large (1665 participants) randomized trial involving older, ethnically diverse, medically underserved, Medicare beneficiaries with type 2 diabetes. Participants in the intervention group received a computer with Internet access via modem to an existing telephone line and videoconferencing capabilities. The patients' existing primary care physicians were contacted when a case managed determined that a change in patient management was indicated. The intervention group had a statistically significant decrease in HbA1c relative to usual care ($P = 0.001$), but the decrease was not deemed to be clinically significant. Unfortunately, no Medicare cost savings were observed (Moreno et al., 2008)

Other Internet-based systems for the management of patients with poorly controlled type 2 diabetes showed more favorable results. In one (McMahon et al., 2005), all patients attended a half-day diabetes educational meeting, and the interventional group patients met with a team of educators consisting of a pharmacist, a nurse, and a nutritionist. This group also received an electronic notebook, and a system for the home monitoring of their blood glucose. They had access to a secure website from which data from the monitoring system could be viewed (by both patients and caregivers), and provided diabetes educational modules, and the capability for patients to communicate with caregivers. A statistically significant reduction in HbA1c was achieved in both groups ($P < 0.001$) at 3, 6, 9 and 12 months from baseline, and was greater at 12 months in the interventional group compared with the control group ($P < 0.05$). Unfortunately, results in a more recent study (Fonda et al., 2009) were not impressive. Fonda et al. (2009) used a small sample (52 each in experimental and control groups) where the experimental group received a notebook computer, a glucose meter, training in the use of these devices, toll-free dial-up Internet service, and secure access to the study website. Subjects interacted with the study's advanced practice nurse (a certified diabetes educator) both via the internal messaging system of the computer and occasionally through telephone contact. The Web site accepted electronic transmissions from the glucose monitoring devices and displayed these data in graphic and tabular form for both the subject and the nurse to review. Subjects could send and receive secure messages to and from the care manager. Web-enabled diabetes educational modules and links to other Web-based diabetes resources were provided. After 12 months, decreases in HbA1c in the experimental group, although observed, were not statistically significant (P = 0.25).

Recently, an Internet-based patient monitoring system which involves no active clinician input has been noted (Lim et al., 1022), relying instead on a "rule engine" based on the clinical guidelines of the American and Korean Diabetes Associations. Patients were send weekly directions based upon their weekly and monthly blood glucose and HbA1c levels. The mean HbA1c and fasting blood glucose levels during the study decreased significantly in experimental group compared with the control group (P = 0.007). Because this system allows patients to make self-adjustments to their treatment based on automatic algorithms, it enhances patient empowerment in diabetes care.

The preponderance of evidence seems to support the use of mobile telephones combined with web-based electronic communications for better control of blood glucose for type 2 diabetics. Based upon a meta-analysis of English-language articles published between January 2002 and March 2012, (Liu and Ogwu, 2012, 17) concluded that "overall, significant improvements were observed in blood glucose and/or HbA1c concentration" when mobile telephone interventions and mobile telephones were used.

Results

The effect of patients using blood glucose monitors alone has shown to have little improvement of diabetes health, but does improve patient education of overall health and what factors may be necessary for successful improvements. As new technologies have been developed in the self-management of diabetes, these devices can help to achieve and maintain blood glucose targets by improving the overall capability of monitoring glucose levels (Boyle, 2008).

Telemedicine shows great promise in the monitoring and treatment of diabetes patients (Brown, et al., 2007; Franc et al, 2011). Telemedicine allows the physician to monitor a patient via the web, without having to make a trip to the doctor's office. The total cost of these monitoring systems can be quite variable, ranging from five dollars per patient to $6,340 (Jackson et al., 2006).

Results for effectiveness of diabetes technology varied with the different comparisons of monitoring systems and technological preventative tools; improvements in HbA1c were often significant, albeit relatively small.

Discussion

This study reviewed new technological approaches to the monitoring and control of blood glucose. The results demonstrated that using technologies such as cell phones, wireless blood glucose monitoring devices, and the internet to monitor blood glucose may be beneficial to both the patient and the physician. The patients benefit from these technologies was by allowing for continuous and real time monitoring of their blood glucose levels. Physicians benefited by improving the quality and productivity of their care giving. New technologies have been demonstrated to have had a positive effect on diabetes monitoring, and new applications continue to be developed.

The Ford Motor Co. and Medtronic have developed a blood glucose monitoring system that can be worn by the driver or passenger, and monitors the blood glucose levels of the person by using Bluetooth technology to link up to the very popular Sync system developed by Microsoft which is installed in many Ford vehicles. The program can place glucose levels, signs and symptoms of confusion, blurry vision and lightheadedness for passengers wearing the device when levels become too low alerting one to take proper action at the appropriate time reducing the risk hypoglycemia and dangerous risk factors for driving. Ford has even recently released a prototype automobile app featuring both a Bluetooth-enabled in-dash continuous glucose monitoring device and a voice controlled cellphone-based diabetes monitoring service which could potentially decrease risks, accidents or deaths (Tenderich, 2011).

Current systems for continuous glucose monitoring (CGM) are the result of progressive technological improvement, and beneficial effects on glucose control have increasingly been demonstrated. Developing and as yet unknown technologies should only be more exciting and potentially effective in patients' contribution to diabetes self-management in the future.

Conclusions

The utilization of current and future HIT have been shown to have a positive effect on both type 1 and type 2 diabetes monitoring. Specifically, smartphones and telemedicine have also been shown to be effective in blood glucose monitoring.

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