

Refereed papers

A real-time, mobile phone-based telemedicine system to support young adults with type 1 diabetes

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ABSTRACT

Telemedicine systems have been proposed as a means of supporting people with diabetes in the self-management of their condition. Requirements for monitoring parameters of care, including glycaemic control, extent of analysis and interpretation of data, patient–clinician contacts, and involvement of a multidisciplinary care team with effective communication, can be addressed by telemedicine systems. We describe the development and implementation of an innovative real-time telemedicine system based around transmission and feedback of data to and from a mobile phone. Proprietary Java-based programs were used to link a blood glucose meter to a mobile phone. In addition to immediate transmission of blood glucose data, information about insulin dose, eating patterns and physical exercise were collected. Immediate feedback to the phone included a colour histogram to draw attention to levels of control over glycaemia over the previous two weeks. Clinicians supporting patients had access to summary screens identifying users not testing, and those with levels of blood glucose outside pre-defined limits. More detailed graphical displays of data were used to provide data about control of insulin dose and the degree to which it was modified in response to diet and exercise. The system has been evaluated in a clinical trial conducted in secondary care and is now being adapted for use in a trial in primary care, which is designed to assess its effectiveness in providing integrated management for the patient, general practitioner and pharmacist.

Keywords: diabetes, medical care, monitoring

Introduction

Telemedicine systems have been proposed for nearly two decades as a means of supporting people with diabetes to achieve improved outcomes. However, there is limited evidence that systematic transmission of patient data, including blood glucose results, with patient feedback and support is effective. A recent systematic review described over 20 different systems evaluated in trials. Despite good evidence for their acceptability to patients, there was no overall evidence of improvement in glycaemic control.[1] The majority of these systems relied on two weekly downloads of blood glucose readings from meters with transmission of data by modem, which does not provide the required frequency of support for the day-to-day adjustment of therapy necessary for optimal control.

Care of patients with diabetes provides an exemplar for the management of people with chronic disease. Integration of management between primary and secondary care, encouragement of self-management of disease, and systematic monitoring of measures of disease progression and control are complex issues and may lead to problems that are difficult to resolve. Telemedicine systems can incorporate innovative approaches that may address these problems.

Mobile phones using GPRS technology offer a technically attractive solution to establishing data transfer between patients and clinicians. The majority of the population now have a mobile phone, and use in the young adult group is high. Recent GPRS mobile phones possess a range of features that make them particularly suitable for such use. They can transmit and receive data in real time, they have a screen for the graphical display of data, and they have a small keyboard to allow entry of additional data. In addition, the computing power within a phone provides an additional resource for analysing data.

One of the major requirements of an adequate telemedicine system is to ensure that the proposed technical solutions address specific problems experienced in providing effective support for disease management. Previous trials to provide telephone support to young adults with diabetes have not consistently shown improved glycaemic control. A randomised trial in Scotland providing telephone support demonstrated that young adults felt more in control of their disease, but no changes in HbA_{1c} were noted.[2] A second randomised trial providing up to six 15-minute phone calls weekly demonstrated an improvement in HbA_{1c} in the intervention group compared with the control group.[3] Support and education in interpretation of test results, and developing personalised approaches to improve control, are therefore key elements in system design. Providing this information in the context of self-management is important in supporting behaviour change, but the facility to provide specific information and decision support may also be required to achieve sufficiently large changes in insulin dose to improve glycaemic control.[4]

We have developed a real-time telemedicine system based around the use of mobile phone technology. This paper describes the way that the system has been implemented and the way that it has been used in a group of young adults with type 1 diabetes.

Methods

The system was developed at the Department of Engineering Science, University of Oxford in collaboration with e-San Ltd, and implemented on a Motorola T720i phone and a One Touch Ultra® blood glucose meter. Proprietary programs were written in Java for the mobile phone to enable data transfer from the meter, transmission of these and other data (including the answers to questions in a phone-based diary) to a secure server, and the display of graphical summaries of glycaemic control on the phone's colour screen (see Figure 1). Additional software was developed to allow analysis of the incoming patient data on a server and display of the information on a secure web page for each patient. The connection between mobile phone and blood glucose meter was made with a proprietary cable and subsequently a wireless Bluetooth® connection has been developed.

The format for the patient diary, phone and web-based graphical feedback was developed following initial discussions with clinicians. A 'user group' of five young adults with type 1 diabetes was assembled to test the equipment and provide regular feedback on its usability and to suggest changes to the system. As a result, changes were made in the sequence of actions required to send data, the way the diary was used, data entry items and the screen display of results.

The technology used to transmit data was a GPRS system (2.5 G) with an 'always on' connection to a central server with secure encoded links (mobile access to the internet). The formats of graphical feedback, both on the phone screen and the web pages, were developed in consultation with the patient user group and clinicians.

Results

Transmission of data

Before injecting insulin the patient was asked to link the blood glucose meter to the mobile phone by cable (see Figure 2). Connection of the meter to the phone

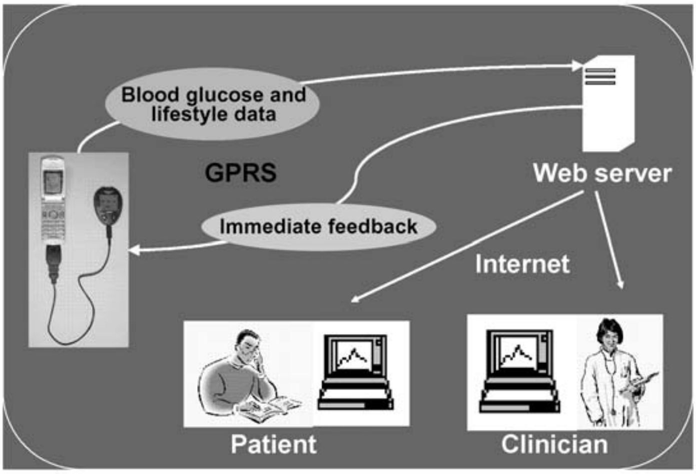


Figure 1 Schematic of the phone/server/web/clinician/patient system

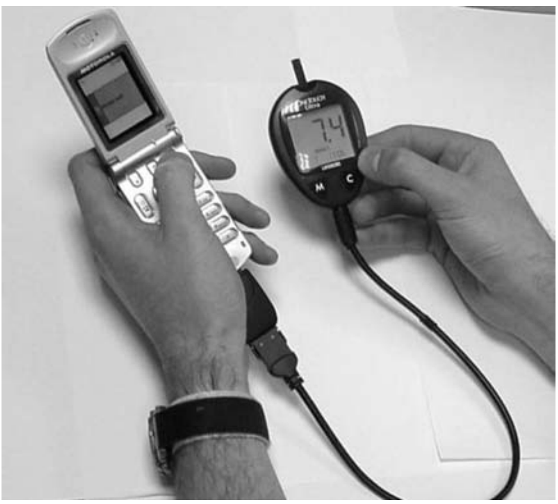


Figure 2 Picture of phone and meter linked by cable

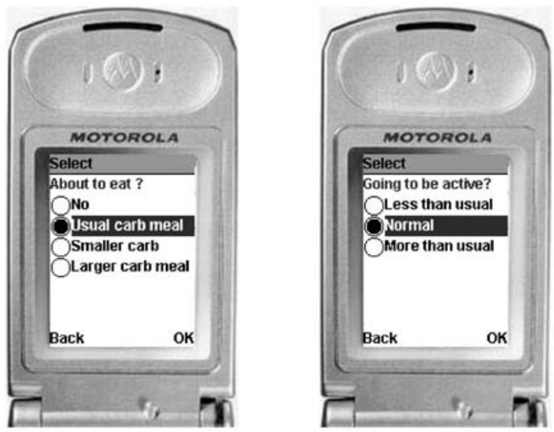


Figure 3 Picture of diary screen implemented on the phone

activated the phone software. Instructions for blood glucose testing were then displayed on the phone screen. After the blood glucose result had been displayed, the patient was asked to record planned food intake, exercise and the number of units of insulin being injected (see Figure 3). Responses to the questions could be completed by most patients within 15 seconds. Additional recording of problems with hypoglycaemia could also be made using the phone-based diary.

Phone-based feedback

Following transmission of blood glucose results and patient diary entries, the server relayed to the phone a summary of blood glucose results measured within the previous 24 hours for display on the screen. The next screen displayed a colour-coded histogram of blood glucose values for the previous two weeks (see Figure 4).

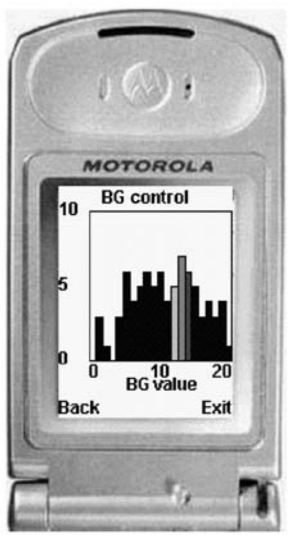


Figure 4 Picture of feedback histogram on phone screen

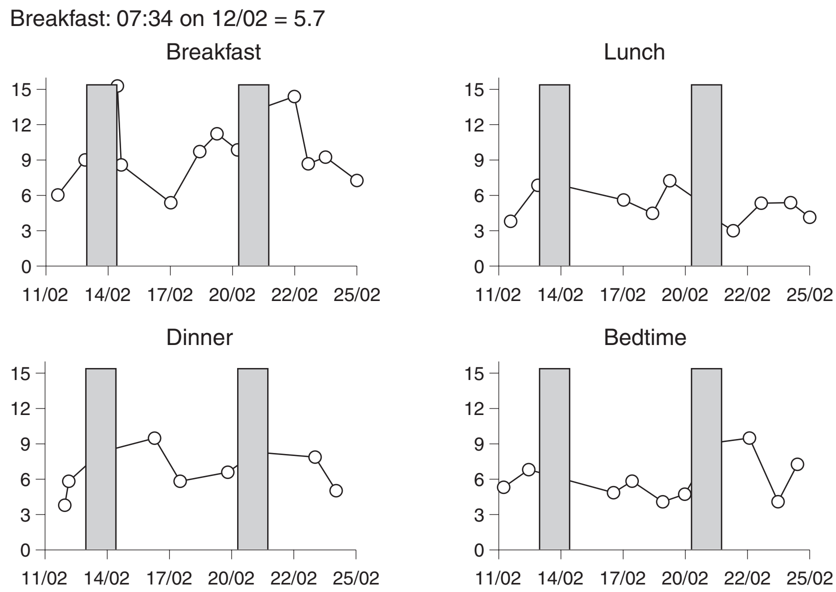


Figure 5 Modal displays by time of day (shaded bars represent weekends)

Individual thresholds could be set to determine the colouring of the histogram bars, with blue representing low levels and red representing high levels. By aiming to increase the proportion of test results shown in green and minimise the number of blue and red readings, the phone display provided the user with a reminder of overall progress which could then prompt attention to adjust the insulin dose.

Web-based feedback

Access to data held on the secure server was available through a standard web browser with password protection. Different levels of access were set for technical staff, clinicians and patients. The web page provided time-series displays of all blood glucose readings together with displays of blood glucose data at set time points during the course of the day (pre-meal and bedtime) (see Figure 5). The mean blood glucose and insulin doses were also displayed with the standard deviation.

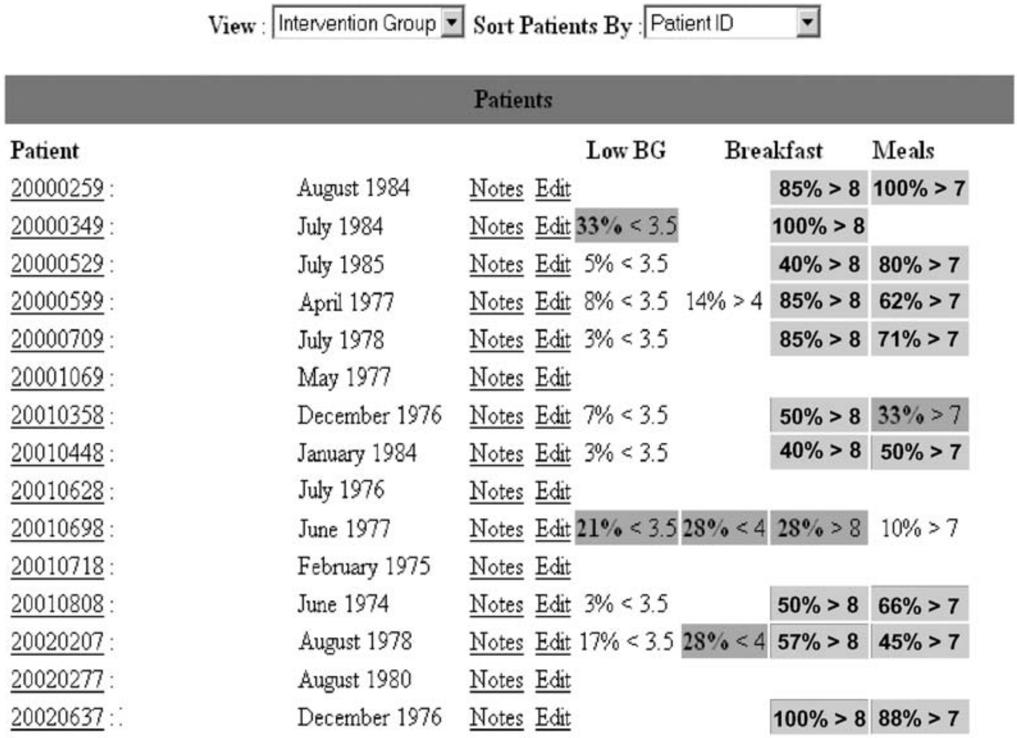
Nurse support using the web-based feedback

The nurse could make contact with patients in a number of ways. Short Message Service (SMS) text messages could be sent to draw attention to particular problems. Regular SMS messages could also be set up to provide reminders. The mobile phones could also be used to ring the patient directly or to leave voice messages. These features were demonstrated by the nurse at an initial meeting with the patient.

A range of techniques was used to help support patients in self-management of their diabetes and their attempts to improve glycaemic control. Strategies included providing factual information (for instance, how to calculate the amount of insulin required to reduce blood glucose by a given number of units), providing education about diabetes, supporting problem solving, and helping to enhance motivation to change behaviour through reinforcement of positive ideas.

Patients were initially encouraged to use their blood glucose monitor at least four times a day – before each meal and at bedtime – to provide the results needed to optimise the insulin dose for the basal-bolus regimen. Review of records could identify those who were not transmitting results, and a summary screen of all patients indicated those who were not transmitting results regularly (see Figure 6). Although technical problems occasionally accounted for failure to transmit results, more often the problem was related to difficulties in fitting the measurement into daily routines, or failing to remember to follow the procedure.

Once regular testing was established, most patients then moved to establishing the optimal dose of the basal insulin therapy. The facility for displaying time-sequence data at bedtime and pre-breakfast allowed the overnight change in blood glucose to be established. The concept of adjusting the long-acting component to attain a fall of 3 to 4 mmol/l from a level of around 8 to 9 mmol/l at bedtime was explained. The nurse used the time-sequence displays to guide their discussions with the patient. The patients also had the option to access these displays. Reasons for fluctuation


View : Intervention Group Sort Patients By : Patient ID

Patients

Patient			Low BG		Breakfast	Meals
20000259 :	August 1984	Notes Edit			85% > 8	100% > 7
20000349 :	July 1984	Notes Edit	33% < 3.5		100% > 8	
20000529 :	July 1985	Notes Edit	5% < 3.5		40% > 8	80% > 7
20000599 :	April 1977	Notes Edit	8% < 3.5	14% > 4	85% > 8	62% > 7
20000709 :	July 1978	Notes Edit	3% < 3.5		85% > 8	71% > 7
20001069 :	May 1977	Notes Edit				
20010358 :	December 1976	Notes Edit	7% < 3.5		50% > 8	33% > 7
20010448 :	January 1984	Notes Edit	3% < 3.5		40% > 8	50% > 7
20010628 :	July 1976	Notes Edit				
20010698 :	June 1977	Notes Edit	21% < 3.5	28% < 4	28% > 8	10% > 7
20010718 :	February 1975	Notes Edit				
20010808 :	June 1974	Notes Edit	3% < 3.5		50% > 8	66% > 7
20020207 :	August 1978	Notes Edit	17% < 3.5	28% < 4	57% > 8	45% > 7
20020277 :	August 1980	Notes Edit				
20020637 :	December 1976	Notes Edit			100% > 8	88% > 7

Figure 6 Reminder and prompt summary screen

in the pre-breakfast blood glucose level, such as variation in bedtime glucose, additional overnight food or nocturnal hypoglycaemia, could be explored using the systematically displayed data. Once a stable basal regimen had been achieved, the level of blood glucose before each meal was explored using the information provided by the graphical displays. Discussion of initial blood glucose levels for the day, eating and exercise patterns were used to explain variations between days.

The telemedicine system was used in a randomised controlled clinical trial with 94 young adults with type 1 diabetes, of whom 46 used the system with full functionality. Over 57 000 date-stamped readings were collected. The majority of problems were associated with failure to transmit data because of local GPRS problems. There were also a number of instances of the cable between the blood glucose meter and mobile phone breaking. Among the intervention group, the provision of feedback led to maintenance of regular blood glucose monitoring throughout the trial, and to increased numbers of patients achieving HbA_{1c} targets of <8% with falls of 0.7% or more. There was a substantial fall in the intervention group compared to the control group in the level of blood glucose among the transmitted tests.

Discussion

This paper describes the development and implementation of a real-time, mobile phone-based system to support young adults in the management of their diabetes. The system has been tested in over 100 young adults with encouraging results.

The system described in this paper has a number of advantages compared to previous systems in which data have either been collected intermittently, or which have relied on patient-reported data rather than data downloaded from a meter. Real-time transmission of data means that feedback is instant and relevant to the circumstances at the time of doing the reading. Young adults with diabetes are familiar with both mobile phones and the blood glucose meters, and so the system is likely to be at hand and acceptable. The Bluetooth® connection that is now available is convenient and user-friendly, and should further encourage use. The system can identify patients who are not testing or have poor control, and if necessary, alert a clinician. It allows detailed examination of control prior to contacting the patient, and permits a telephone discussion with the patient with both clinician and patient reviewing the relevant data on a web server.

A number of recent attempts have been made to implement diabetes telemedicine systems using different technical solutions. Telephone support from a nurse facilitator has now been trialled in the UK and has been shown to improve HbA1c.[5] However, the system was used largely among people with type 2 diabetes, and no systematic transmission of blood glucose results was used. Another system has used motivational text messages to support young adults.[6] Blood glucose data were entered manually and motivational messages (unrelated to the blood glucose values) were automatically sent by a server to the phone using SMS. A third system in France is currently using a combination of a personal digital assistant (PDA) and mobile phone, but again download of data is weekly or bi-weekly and not contemporaneous. The telemedicine system described here provides a platform that has the advantage, compared to other systems, of basing management on real-time data transfer, shared information between clinician and patient, and the potential for immediate data analysis to provide advanced decision support.

One of the principles underlying the system is to support diabetes self-management. One possible avenue through which to develop systems is the provision of 'expert advice'. The large datasets of clinical data and blood glucose measurements accumulated in the course of the recent trial are currently being analysed and modelled to improve our understanding of how changes in eating patterns, physical activity and insulin use affect changes in blood glucose. The results of this analysis may provide the basis to further improve the system by providing decision support modules. Recommendations to patients need to be carefully formulated and the resulting changes in behaviours need to be seen as active choices, since proscriptive goals may often conflict with other important goals and lead to discomfort rather than improve performance.[7,8] However, improvements in the level of decision support provided through the system will be needed to help patients target the increased doses of insulin necessary to achieve optimised levels of HbA_{1c}.

This system addresses the issue of co-ordination of care between multiple clinicians and medical facilities. The patient has control over transmission of data and so the extent to which others have access to the information is determined by negotiation. Previous attempts to co-ordinate care using hand-held paper records have been popular among patients, but have not been shown to improve the processes of care.[9] However, some of the disadvantages of paper records overcome by this system are the immediate capture of data without need for transcription, immediate access to the information by all involved in care through a web browser, and availability of the record at any patient contact. Integration of these data into the patient's electronic health record will further decrease the duplication of data held in different systems and increase the accuracy of the data that are accessible. The current system has already been used by a wide range of healthcare staff, including pharmacists, diabetes nurses, primary care teams and hospital teams.

Conclusions

The GPRS mobile phone diabetes telemedicine system described here takes an innovative approach to implementing transmission of blood glucose results to clinicians and providing decision support and patient feedback. The potential of this system to maintain blood glucose testing behaviour and to bring about reduction in blood glucose has been demonstrated in a recent trial. With further experience this system offers the possibility of extending the approach to type 2 diabetes, and other chronic diseases where regular monitoring and support might be helpful.

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CONFLICTS OF INTEREST

LT is a Director of e-San Ltd providing e-health software and services. OG has received consultancy fees from e-San. AF and AN have no competing interests.

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