

# A Randomized Controlled Trial of the Effect of Real-Time Telemedicine Support on Glycemic Control in Young Adults With Type 1 Diabetes (ISRCTN 46889446)

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**OBJECTIVE** — To determine whether a system of telemedicine support can improve glycemic control in type 1 diabetes.

**RESEARCH DESIGN AND METHODS** — A 9-month randomized trial compared glucose self-monitoring real-time result transmission and feedback of results for the previous 24 h in the control group with real-time graphical phone-based feedback for the previous 2 weeks together with nurse-initiated support using a web-based graphical analysis of glucose self-monitoring results in the intervention group. All patients aged 18–30 years with HbA<sub>1c</sub> (A1C) levels of 8–11% were eligible for inclusion.

**RESULTS** — A total of 93 patients (55 men) with mean diabetes duration (means ± SD) 12.1 ± 6.7 years were recruited from a young adult clinic. In total, the intervention and control groups transmitted 29,765 and 21,400 results, respectively. The corresponding median blood glucose levels were 8.9 mmol/l (interquartile range 5.4–13.5) and 10.3 mmol/l (6.5–14.4) ( $P < 0.0001$ ). There was a reduction in A1C in the intervention group after 9 months from 9.2 ± 1.1 to 8.6 ± 1.4% (difference 0.6% [95% CI 0.3–1.0]) and a reduction in A1C in the control group from 9.3 ± 1.5 to 8.9 ± 1.4% (difference 0.4% [0.03–0.7]). This difference in change in A1C between groups was not statistically significant (0.2% [−0.2 to 0.7,  $P = 0.3$ ]).

**CONCLUSIONS** — Real-time telemedicine transmission and feedback of information about blood glucose results with nurse support is feasible and acceptable to patients, but to significantly improve glycemic control, access to real-time decision support for medication dosing and changes in diet and exercise may be required.

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The incidence of type 1 diabetes in childhood has more than doubled in the past 2–3 decades (1). The proportion of patients with serious complications increases rapidly from late adolescence to early adulthood and has been reported to increase from 3 to 37% over 11 years, follow-up in the age-group 17–25 years (2). Tight glycemic control

and intensive support has been shown to improve control and reduce the risk of retinopathy, neuropathy, and nephropathy by up to 75% (3). One method of improving outcomes in routine practice without substantially increasing resources may be to make use of appropriate technical innovations.

Trials of telemedicine interventions in

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**Abbreviations:** DSN, diabetes specialist nurse; IQR, interquartile range; RCIS, Revised Clinical Interview Schedule.

A table elsewhere in this issue shows conventional and Système International (SI) units and conversion factors for many substances.

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diabetes have demonstrated the feasibility and acceptability of systems for downloading glucose data, although no favorable impact on A1C has been shown consistently (4). Systems for computerized decision support have been evaluated (5,6), and other systems have recorded lifestyle and medication data (7) and provided telephone advice from a clinician (8,9). However, none incorporated real-time transfer of data to a remote computer system for data processing (4). Improved system functionality with real-time data transfer may lead to more effective use and improved control. We therefore conducted in a young adult population a randomized, controlled, clinical trial of a mobile phone-based telemedicine system using real-time data transfer with intensive feedback of results; a phone-based diary of insulin dose, physical activity, and food intake; and nurse-initiated support to determine whether the system would improve glycemic control compared with a system of data transmission of blood glucose results with minimal feedback.

## RESEARCH DESIGN AND METHODS

A randomized, controlled, parallel-group trial design was used, and we invited patients who were registered either with the Pediatric Transition Clinic or the Young Adult Diabetes Clinic in Oxford, U.K., to participate. Inclusion criteria were a diagnosis of type 1 diabetes; age 18–30 years inclusive; twice daily, three times daily, or basal bolus insulin therapy; and suboptimal or poor glycemic control with a lower A1C limit of  $\geq 8.0\%$  and an upper limit A1C limit of  $\leq 11.0\%$  for the last two results. We excluded patients with any contraindication to tight glycemic control, who were unable to give consent, who had other concurrent severe diseases, who were not prepared to undertake blood glucose testing during the study period, or who were with another member of the family participating in the trial.

### Interventions

Patients from both groups were given a blood glucose monitor (One Touch Ultra) and a general packet radio system mobile phone (Motorola T720i) that incorporated the option of recording their insulin dose, food intake, and activity levels in an electronic patient diary. The glucose self-monitoring results were automatically transmitted by the phone to a remote server with data processing facilities.

### Intervention group

The experimental intervention consisted of clinical advice and structured counseling from a diabetes specialist nurse (DSN) in response to real-time blood glucose test results. Immediate graphical feedback of results was provided with blood glucose readings displayed as a time series for the previous 24 h and as a color-coded histogram to indicate proportion of values within target ranges during the previous 2 weeks (intensive feedback). The DSN checked the readings fortnightly or more often and had access to summaries and graphical displays of data via a secure webpage for each patient. Patients also had the option to access their own webpage. The DSN telephoned the patients to identify concerns and problems, and possible solutions were discussed collaboratively. Realistic goals were agreed upon, and patients were encouraged to develop an action plan to address them. The treatment plan encouraged patients to adhere to a multiple insulin injection basal bolus regimen, unless it was contraindicated.

### Control group

The results were transmitted to the server for data storage but were not available to the DSN. Feedback presented on the phone screen consisted of a graphical time series of blood glucose readings for the previous 24 h only (minimal feedback), and access to the data were available only in plain diary format on the patient's personal webpages.

### Measures

The primary outcome measure was A1C measured blind to group allocation by a high-performance liquid chromatography method using a Biorad Diamat automated glycosylated hemoglobin analyzer (Biorad Laboratories, Hemel Hempstead, Hertfordshire, U.K.). Baseline data on duration of diabetes, weight, BMI, and the Revised Clinical Interview Schedule (RCIS) were also collected. The RCIS is a standardized, semistructured interview to

assess symptoms associated with anxiety and depression (10). It has been widely used and applied to the assessment of young adults with diabetes (11) and has a case threshold of  $\geq 12$  (12). We also recorded the frequency and results of blood glucose readings taken by each participant, time spent in telephone contact with the nurse, and any technical problems.

### Trial procedures

**Ethics and consent.** The Oxford Research Ethics Committee approved the study. Patients were invited to participate in the trial on attendance at a routine clinic appointment or by a written invitation. They received an information leaflet explaining the trial, and at least 48 h elapsed before those agreeing to participate attended a research clinic appointment where the nature of the trial was further explained. They were given the opportunity to have any questions about the trial answered before being asked to provide written informed consent using a standard form.

### Assessment

After giving their consent, participants completed study questionnaires and were assessed for psychiatric morbidity using the RCIS. A venous blood sample was taken for measurement of A1C, creatinine, total cholesterol, and nonfasting triglycerides. Patients were instructed in the use of the blood glucose monitor and the mobile phone. The DSN negotiated appropriate times of the day to contact by telephone patients in the intervention group.

### Randomization

Randomization was carried out centrally by the trial administrator following the assessment visit. A computer program (MINIM; Evans, Day and Royston, University of London, London, U.K.) was used to perform a minimization procedure that adjusted the randomization probabilities to balance sex and psychiatric score between the intervention and control groups. Earlier work had indicated that significant psychological distress was common in young adults with diabetes (11). We therefore wanted to ensure that these individuals were evenly distributed between the two randomized groups. Randomization was conducted independently of the DSN.

### Follow-up for the intervention group

Participants assigned to the intervention group were contacted by the DSN within a week of their assessment visit. They were told that they would be contacted fortnightly and that they would be able to receive feedback via the mobile phone and, if they had access, via the internet. Personalized objectives were set by patients following discussion with the DSN with the aim of establishing 1) regular blood glucose monitoring at appropriate times, 2) optimization of the basal insulin dose, 3) optimization of short-acting insulin dose, and 4) appropriate adjustment of short-acting insulin dose with food and physical activity. The DSNs supported behavior change by encouraging participants to identify their own objectives and goals based on a patient-centered model of care (13). A follow-up visit was made to the regular clinic 4 months after assessment. Information on diabetes management was recorded together with a record of the frequency of hypoglycemia and hospitalization for any causes.

### Follow-up for the control group

Participants assigned to the control group were contacted by the DSN within a week of their assessment visit and told that they would be able to contact a DSN by telephone as required for the duration of the study. A follow-up visit was made to the regular clinic 4 months after assessment, and the same information was recorded as for the intervention group.

### Final study visit

At the final 9-month clinic visit ( $\pm 1$  month) a further blood sample was taken for measurement of A1C. Questionnaires were again administered. If participants were not seen within the specified time interval, any subsequent A1C results were also recorded.

### Standardization of the intervention

The trial used intervention protocols to support the DSNs in adopting a consistent approach to telephone contacts with patients. A sample of contacts with participants was tape recorded and reviewed by the investigators to confirm use of patient-centered techniques.

### Power calculations

Using a two-sided test at a 5% level of statistical significance, the trial was designed to have a 80% statistical power to detect a difference in the mean change in A1C from baseline to end of trial between

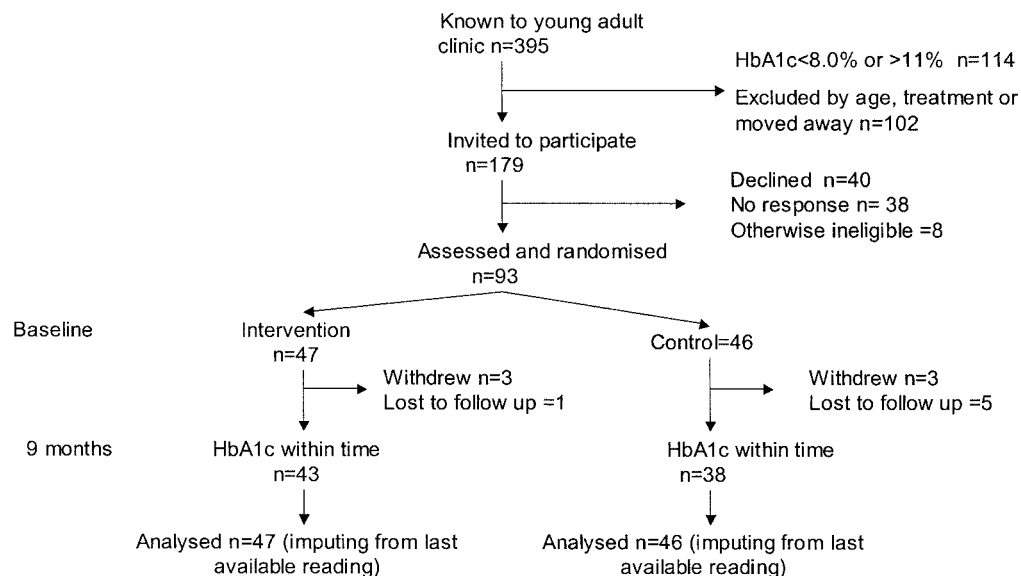


Figure 1—Trial flow diagram.

the intervention and control groups of 0.7% based on baseline mean A1C of  $9.0 \pm 1.2\%$ . We aimed to recruit 100 patients, allowing for 6% drop-out.

### Analysis

Case report forms were entered onto computer and checked for range and consistency. The primary analysis was planned as intention to treat. For any patients randomized but lost to follow-up, the results were imputed from the last appointment. Results are presented as means  $\pm$  SD. Changes in A1C from baseline are presented as the mean change of the individual values with 95% CIs. An exploratory analysis was conducted to investigate the difference between the two groups in change of proportion of participants achieving a reduction in A1C  $\geq 0.7\%$  and value of  $\leq 8.0\%$  by the end of the trial. The level of 8.0% was chosen as one of the entry criteria for the trial representing the difference between good and moderate-to-poor control, and a reduction in A1C of 0.7% was the protocol-specified difference that the trial was designed to detect.

Statistical analyses were carried out using the Statistical Package for the Social Sciences Version 11.0 (SPSS, Chicago, IL). We examined the difference between groups in the mean individual changes in A1C from randomization to the end of the trial using an unpaired *t* test. We also conducted an analysis of the within-group mean change from baseline to the 4-month visit and from baseline to the end of the trial, using paired *t* tests. *T* tests were also used to examine differences in the mean numbers of blood glucose re-

sults transmitted. The Mann-Whitney test was used to compare mean blood glucose results recorded between allocated groups. A  $\chi^2$  test was used to examine the proportion of participants with both a fall of A1C of  $\geq 0.7\%$  and a final A1C of  $\leq 8\%$ . Associations between number of weeks of monitoring and the telephone contact time spent by the study nurse were analyzed with a Pearson correlation coefficient. We set the level of statistical significance at  $P = 0.05$  for the main pre-specified study outcome analysis and  $P < 0.01$  for other analyses.

**RESULTS**— Of 395 young adults known to the young adult clinic, 102

were excluded on the grounds of age, treatment, or having moved away. A further 114 were not eligible on the basis of A1C results (Fig. 1). A total of 179 patients were invited to participate, of whom 93 (52%) were subsequently assessed and randomized between September 2003 and March 2004. Forty-seven were assigned to the intervention group and 46 to the control group. At 9 months, 43 (91%) subjects of the intervention group and 38 (83%) of the control group had been followed-up.

The baseline characteristics of the two groups were similar (Table 1). The proportions of people using different formulations of long-acting insulin were also

Table 1—Clinical and demographic characteristics of participants

	Intervention group	Control group
<i>n</i>	47	46
Age (years)	$24.5 \pm 4.2$	$23.2 \pm 4.2$
Sex (men/women) (% men)	28/19 (59.6)	27/19 (58.7)
Duration of diabetes (years)	$13.3 \pm 6.8$	$11.6 \pm 6.8$
Weight (kg)	$77.0 \pm 11.2$	$73.2 \pm 11.1$
BMI ( $\text{kg}/\text{m}^2$ )	$25.8 \pm 3.4$	$24.6 \pm 3.5$
Number of blood glucose tests in the week prior to trial entry	$19.3 \pm 12.1$	$18.3 \pm 14.9$
Number of injections a day	$3.9 \pm 0.6$	$3.8 \pm 0.6$
Total insulin dose	$63.1 \pm 16.3$	$65.5 \pm 25.4$
Using ultra long-acting insulin in basal bolus regimen	31 (66.0)	28 (60.9)
A1C at baseline	$9.2 \pm 1.1$	$9.3 \pm 1.5$
Proportion of participants with RCIS score above threshold $\geq 12$ for significant symptoms	8 (17.0)	11 (23.9)

Data are means  $\pm$  SD or *n* (%).

Table 2—A1C within-group changes and differences between intervention and control groups

	Mean A1C at baseline (%)	Mean A1C at 4 months (%)	Change in A1C from baseline to 4 months (%)	Mean A1C at 9 months (%)	Change in A1C from baseline to 9 months (%)
Intervention group (n = 47)	9.2 ± 1.1	8.6 ± 1.4	0.57 (0.25–0.89), P = 0.001	8.6 ± 1.4	0.62 (0.27–0.98), P < 0.001
Control group (n = 46)	9.3 ± 1.5	8.9 ± 1.5	0.34 (0.09–0.59), P < 0.01	8.9 ± 1.4	0.38 (0.03–0.73), P < 0.04
Between-group differences in change in A1C			0.23 (–0.17 to 0.63), P = 0.26		0.25 (–0.25 to 0.74), P = 0.33

Data are means ± SD or means (95% CI).

similar between the groups, with 31 in the intervention and 28 in the control groups using an analog long-acting insulin, 12 and 14, respectively, using isophane insulin (e.g., Insulatard or Humulin I), and 4 and 4, respectively, using biphasic isophane insulin (e.g., Mixtard). Nearly one-fifth of the participants reached the threshold for significant symptoms of ≥12 with the RCIS score.

In total, 51,165 blood glucose results were transmitted over the course of the study, with 29,765 taken by the intervention group and 21,400 by the control group. The number of weeks in which at least seven blood tests (at least one a day) were taken was significantly different between intervention and control groups (27.3 ± 11.8 and 18.8 ± 11.1, difference 8.4 [95% CI 3.7–13.1], P < 0.001). During week 36 of the trial, the median number of readings sent by participants in the intervention group was 11 (interquartile range [IQR] 1–28) compared with 0 (0–7) for those in the control group (P < 0.0001). The median blood glucose level for the intervention group over the 9-month trial was 8.9 mmol/l (5.4–13.5) vs. 10.3 mmol/l (6.5–14.4) for the control group (P < 0.0001).

The A1C fell in both groups from baseline to 9 months (Table 2). There was a reduction in A1C in the intervention group after 9 months from 9.2 ± 1.1 to 8.6 ± 1.4% (difference 0.6% [95% CI 0.3–1.0], P = 0.001) versus a smaller reduction in the control group from 9.3 ± 1.5 to 8.9 ± 1.4% (difference 0.4% [0.03–0.7], P = 0.04). There were similar reductions at 4 months (Table 3). The difference in change in A1C between groups was not statistically significant at 9 months (0.2% [–0.2 to 0.7], P = 0.3).

The proportion of people achieving an A1C reduction of ≥0.7% and an A1C ≤8.0% at 9 months was 29.8% in the intervention group (14/47) and 8.7% (4/46) in the control group (difference 21.1% [95% CI 5.7–36.5]). The fre-

quency of blood glucose testing in the week before entry into the trial was significantly correlated with the number of weeks in which at least seven blood glucose results were transmitted in both the intervention (r = 0.60, P = 0.002) and in the control (r = 0.45, P = 0.002) groups. Other baseline demographic and clinical characteristics, including sex, were not associated with the subsequent number of weeks in which participants tested blood glucose. There was no association between the number of weeks recording at least seven blood glucose results and the reduction in A1C (intervention group r = 0.28, P = 0.054 vs. control group r = 0.22, P = 0.14). Over the 9-month study, the A1C of men dropped 0.2 ± 1.0% compared with a fall of 1.0 ± 1.2% among women (t = 3.6, P < 0.001). Apart from sex, baseline demographic and clinical characteristics were not associated with change in A1C.

There was a significant difference in the proportion of transmitted blood glucose tests that were in the hypoglycemic range (<3.0 mmol/l) between the two groups (intervention 1,650/29,765 [5.3%] compared with 739/21,400 [3.5%], P = <0.0001). During the course of the trial, there was one recorded grade 3 hypoglycemic episode in the control group and two recorded episodes of ketoacidosis in participants assigned to the intervention group. Each of these episodes resulted in a hospital admission.

#### Nurse contact

There were 601 phone contacts initiated by nurses to participants allocated to the intervention group, representing an average of 13 per patient or a rate of 1 every 2.5 weeks. The duration of these phone calls was on average 7 min 9 s (±4 min 15 s). There was no association between the total nurse contact time and change in A1C over the course of the study (P = 0.6).

#### Technical problems

The most frequent problem reported was the inability to transmit results because of temporary general packet radio system problems (48 occurrences in intervention and 11 in control group). Other technical problems included difficulties with the cable linking the meter and phone, damage or theft of mobile phones, and the need to replace batteries. These problems were recorded on 51 occasions in the intervention group and 43 occasions in the control group.

**CONCLUSIONS**— This study is the largest rigorously conducted randomized controlled trial of telemedicine conducted in adults with type 1 diabetes. We have demonstrated the feasibility of using a telemedicine system with real-time transmission of blood glucose test results and intensive feedback to support young adults with type 1 diabetes, but we found no significant difference in change of A1C between the intervention and control groups. Nevertheless, the median transmitted blood glucose level over the course of the trial was significantly lower in the intervention group, with a significantly higher proportion achieving a reduction in A1C of ≥0.7% and value of ≤8.0% by the end of the trial. Furthermore, nearly 40% more blood glucose results were transmitted by patients in the intervention than the control group. These findings strongly suggest that the system was valued and acceptable to users.

The trial had a number of strengths. We took care to ensure that the groups were matched using a minimization schedule incorporating measures of anxiety and distress. We also tried to ensure that a standardized intervention was delivered by the DSNs using a range of techniques to promote adherence to the intervention program specified in the protocol. These included the use of a detailed training manual and analysis of a random sample of the telephone contacts

to make certain advice given to patients complied with the protocol. However, some care is needed in interpreting the results of the trial. We deliberately excluded patients with good control and recruited a representative population of those remaining, but delivering an effective intervention to this patient group is likely to be difficult. High levels of psychological and behavioral disturbance have been documented in this age-group (2,11,14), and a fifth of our patients were classified by their RCIS score as having clinically significant symptoms associated with anxiety or depression. Nevertheless, we achieved surprisingly high rates of follow-up.

A key element of our intervention was the telephone support offered by the DSNs. One previous smaller trial (15) has shown benefits from nurse telephone support, but their intervention involved three 15-min telephone calls each week compared with our intervention of one 7-min call every 2.5 weeks. Another study used both a home visit and telephone calls every 3 weeks to provide negotiated telephone support and, although A1C deteriorated over the period of the study in all groups, there were significant improvements in self-efficacy (16).

Our finding of a significant within-group reduction in A1C in both the intervention and control groups is a common but inconsistent finding in trials of this type (8,17). It does not, however, necessarily imply that the intervention was responsible for the within-group improvement in glycemic control. Other possible explanations include chance and regression to the mean, although this seems unlikely as patients in the trial were selected on the basis of the two A1C measurements preceding the trial baseline reading.

In common with two earlier studies (18,19) that used telephone modems rather than real-time transfer of data, we did not observe a significant between-group difference in change of A1C. One explanation may be that we recruited patients without establishing whether they were motivated to achieve better glycemic control, whereas clinical practice interventions may best be targeted to patients contemplating better control. It is also possible that, despite giving minimal feedback to the control group, the use of a phone and meter provided an incentive for these patients to focus on their glycemic control, and it may have encouraged alterations in insulin dose, physical activ-

ity, and diet. A longer trial might possibly have shown a significant effect, since the proportion of patients testing regularly in the control group fell steadily over the 9-month trial period but remained constant in the intervention group. Another explanation for the lack of significant effect may be the relatively low intensity of the intervention that focused on encouraging self-adjustment, based on the interpretation by patients of trends in their results rather than providing proscriptive advice about the insulin dose. More intensive interventions may be needed to help people change their health behavior more effectively, using computerized decision support systems to consistently ensure that large enough changes in insulin dose are made (20). The observed success in maintaining monitoring with intensive feedback suggests that our platform could deliver such interventions in the future.

In summary, we have shown that real-time transmission of blood glucose results for young adults with type 1 diabetes with feedback of information about results over the previous 2 weeks and nurse support using a telemedicine system is feasible and acceptable to patients. The system may lead to improved glycemic control, but to achieve this real-time decision, support for medication dosing and changes in diet and exercise may be needed.

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