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Text-message responsiveness to blood glucose monitoring reminders is associated with HbA_{1c} benefit in teenagers with Type 1 diabetes

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Abstract

Aims—To evaluate an 18-month text-messaging intervention in teenagers with Type 1 diabetes and to assess factors associated with text responsiveness and glycaemic benefit.

Methods—Teenagers with diabetes ($N=147$), aged 13–17 years, received two-way text reminders at self-selected times to check blood glucose levels and reply with blood glucose results.

Results: At baseline, the participants (48% boys, 78% white, 63% pump-treated) had a mean $\pm$ SD age of 14.9 ± 1.3 years, diabetes duration of 7.1 ± 3.9 years and HbA_{1c} concentration of 69 ± 12 mmol/mol ($8.5 \pm 1.1\%$). The mean proportion of days with ≥ 1 blood glucose response declined over time (0–6 months, $60 \pm 26\%$ of days, 7–12 months, $53 \pm 31\%$ of days, 13–18 months, $43 \pm 33\%$ of days). Over 18 months, 49% responded with ≥ 1 blood glucose result on $\geq 50\%$ of days (high responders). Regression analysis controlling for baseline HbA_{1c} revealed no significant change in HbA_{1c} from baseline to 18 months in high responders ($P=0.54$) compared with a significant HbA_{1c} increase in low responders ($+0.3\%$, $P=0.01$). In participants with baseline HbA_{1c} ≥ 64 mmol/mol ($\geq 8\%$), high responders were 2.5 times more likely than low responders to have a clinically significant [≥ 5.5 mmol/mol ($\geq 0.5\%$)] HbA_{1c} decrease over 18 months ($P<0.05$). In participants with baseline HbA_{1c} <64 mmol/mol ($<8\%$), high responders were 5.7 times more likely than low responders to have an 18-month HbA_{1c} <58 mmol/mol ($<7.5\%$; $P<0.05$).

Conclusions—Teenagers with Type 1 diabetes who responded to text reminders on $\geq 50\%$ of days over 18 months experienced clinically significant glycaemic benefit. There remains a need to tailor interventions to maintain teenager engagement and optimize improvements.

Introduction

As teenagers with Type 1 diabetes become increasingly independent in self-care behaviours, they are at risk of decreased adherence and deteriorating glycaemic control [1]. To protect

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Competing interests
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against glycaemic decline, teenagers may benefit from increased support and innovative ways to improve self-care. Given the busy schedules and significant amount of time teenagers spend apart from families, they may need a remote means of support. Text messaging is a natural option given the prevalence of mobile phone and short message system (SMS) use amongst teenagers [2].

A variety of educational and behavioural interventions for adolescents with Type 1 diabetes have demonstrated some benefit in terms of glycaemic control; however, the feasibility of incorporating such interventions into clinical practice may be limited by healthcare resources and time, thus limiting scalability [3–7]. Text-messaging interventions have been studied in young people with Type 1 diabetes, and remain a practical and promising strategy [8–10]. One meta-analysis of mobile phone interventions showed a 3.3-mmol/mol (0.3%) reduction in HbA_{1c} in those with Type 1 diabetes receiving the mobile intervention [9]. An intensive intervention, the Novel Interventions in Children's Healthcare (NICH) programme, which targeted high-risk young people with Type 1 diabetes and included a text-messaging component, demonstrated a reduction in diabetic ketoacidosis-related emergency department visits [11]. There may also be additional, non-glycaemic, benefits of text-messaging interventions. In teenagers with baseline HbA_{1c} of ~10% who were treated with two to three daily injections of pre-mixed insulin, those who received a supportive text-messaging intervention, Sweet Talk, had improved diabetes self-efficacy and self-reported adherence compared with those who did not receive Sweet Talk [12].

Several recommendations related to behavioural and mobile health interventions have emphasized the importance of measuring engagement with the intervention, as this often influences the effect of the intervention [10,13]. In a systematic review of 22 mobile device studies, the duration of the mobile diabetes interventions ranged from 3 to 12 months (mean 6.0 ± 3.7 months); attrition rates among those receiving interventions varied widely, ranging from 0% to 56% [10]. Attrition occurs even in shorter-duration studies. For example, in one 8-week pilot study of a text-messaging intervention designed to promote positive effect, response rate waned from 87% in week 1 to 62% in week 8 [14]. Another short-term pilot study of a text-messaging intervention in teenagers with Type 1 diabetes showed drop-off in responsiveness to messaging from an average of 27 responses per user in month 1 to an average of six responses per user in month 3 [15].

On the one hand, text messaging offers the opportunity to engage teenagers with Type 1 diabetes in self-care; on the other hand, there appears to be substantial drop-off in teenagers' attention to text messaging over time. We therefore sought to minimize the burden of a text-messaging intervention for teenagers with Type 1 diabetes by slowly escalating the frequency of text reminders to check blood glucose (BG) levels. Given the expectation that teenagers would probably decrease their engagement with text reminders over time [14,15], we defined responsiveness according to the proportion of days with text replies by the teenagers. In the present study, we evaluated an 18-month text-messaging intervention in teenagers with Type 1 diabetes in order to assess factors associated with any text-message responsiveness and glycaemic benefit.

Participants and methods

This study analysed 18 months of data from teenagers with Type 1 diabetes ($N=151$) receiving a text-messaging intervention aimed at increasing BG monitoring frequency to improve glycaemic control. Eligibility criteria included age 13–17 years, diabetes duration of at least 6 months, daily insulin dose ≥ 0.5 units/kg, HbA_{1c} 48–97 mmol/mol (6.5–11.0%), and possession of a mobile phone with text-messaging ability. The research was conducted at two sites. Institutional review boards at both sites approved the study protocol. Teenagers/parents provided written informed assent/consent before beginning any study procedures.

Study visits occurred concurrently with clinic visits every 3 months. Demographic and clinical data were obtained by parent–teenager interview and chart review. BG monitoring frequency was calculated from a meter download reflecting the 4-week period preceding the study visit and reviewed by the clinical provider. HbA_{1c} was measured centrally every 6 months [reference range 20–42 mmol/mol (4–6%); Roche Cobas Integra analyser (Roche Diagnostics, Indianapolis, IN, USA)]. For participants with missing HbA_{1c} at 18 months ($n=5$), we used the 12-month value carried forward for three participants, and the 6-month value carried forward for two participants.

The text-messaging intervention used a two-way SMS texting system (CareSpeak® Communications). Participants received \$5 per month to cover costs of unlimited text messaging. The participants received text-message reminders to check BG at self-selected times and to reply with their BG level. If they did not respond within 10 minutes, they would receive a second reminder. After each text response, the participants would receive a single congratulatory text for providing a BG response. Initially, the participants received one text per day on weekend days at self-selected times, with a gradual increase to a maximum of four texts daily, with text reminder frequency increasing every 1 to 2 months. Any time a participant did not reply for 2 weeks, the number of daily text reminders was reset to one.

In each 6-month period (0–6, 7–12, 13–18 months), we calculated the proportion of days each participant provided ≥ 1 BG response to text-message reminders; the denominator was the total number of days in that 6-month period when at least one reminder was sent. For an integrated assessment of text-message responsiveness, we calculated the proportion of days with ≥ 1 BG response for the entire 18-month period. Participants with ≥ 1 BG response on $<50\%$ of days over the 18 months were considered low responders and teenagers with ≥ 1 BG response on $\geq 50\%$ of days over the 18 months were considered high responders. Participants who had some text-message data but lacked full 18-month data ($n=10$) were categorized as low or high responders based on their available data.

We then separately evaluated teenagers with baseline $HbA_{1c} \geq 64$ mmol/mol ($\geq 8\%$) and those with baseline $HbA_{1c} < 64$ mmol/mol ($< 8\%$). For each HbA_{1c} group, we defined a clinically meaningful improvement in glycaemic control. For those with baseline $HbA_{1c} \geq 64$ mmol/mol ($\geq 8\%$), a meaningful improvement was a decline in HbA_{1c} of ≥ 5.5 mmol/mol ($\geq 0.5\%$) from baseline to 18 months. For those with baseline $HbA_{1c} < 64$ mmol/mol ($< 8\%$), we defined clinical success as achieving an $HbA_{1c} < 58$ mmol/mol ($< 7.5\%$) at 18 months, which is the American Diabetes Association target HbA_{1c} for this age group [16].

Statistical analyses were performed using SAS 9.4 (SAS Institute, Cary, NC, USA). Descriptive data are presented as means $\pm$ SD values or proportions. Statistics based on distribution and sample size included *t*-tests, ANOVA, chi-squared test, and regression models. Regression models were adjusted for potential confounding factors such as baseline HbA_{1c}. *P* values <0.05 were considered statistically significant.

Results

Study sample

A total of 151 participants received the text-messaging intervention. Of these, four [75% girls, age 15.0 ± 1.5 years, diabetes duration 5.3 ± 2.4 years, HbA_{1c} 77 ± 13 mmol/mol [$9.2 \pm 1.2\%$)] became inactive (two transferred care and two withdrew) after the first study visit, providing no follow-up data, and thus were excluded from analyses, leaving 147 in the study sample. Five additional participants withdrew or were lost to follow-up during the first 6 months, and five more withdrew or were lost to follow-up between study months 7 and 12. Based on the available text-messaging data during their study participation, six were low responders and four were high responders.

Baseline characteristics

Roughly half (48%) of the total number of participants ($N=147$) were boys, the majority (78%) were white, and nearly two-thirds (63%) were receiving pump treatment at baseline. They had a mean age of 14.9 ± 1.3 years, with diabetes duration of ~ 7 years (7.1 ± 3.9 years). Their mean baseline HbA_{1c} concentration was 69 ± 12 mmol/mol ($8.5 \pm 1.1\%$), and the median (range) HbA_{1c} concentration was 67 (49 to 98) mmol/mol [8.3 (6.6 to 11.1%); Table 1].

Text-message responsiveness

Text-message responsiveness (proportion of days with one or more BG responses) declined over time (months 0–6: $60 \pm 26\%$; months 7–12: $53 \pm 31\%$; months 13–18: $43 \pm 33\%$; $P < 0.0001$) as shown in Fig. 1. Over the 18-month study, 49% of participants ($n=72$) were classified as ‘high responders’, defined as those who replied with one or more BG response on $\geq 50\%$ of days.

Characteristics of high vs low responders

At baseline, high responders and low responders were similar with respect to age, Type 1 diabetes duration, sex distribution, race, and family demographic factors, but high responders had higher baseline daily BG monitoring frequency (5.1 ± 2.3 vs 4.3 ± 1.6 ; $P=0.016$), and lower baseline HbA_{1c} [66 ± 11 mmol/mol ($8.2 \pm 1.0\%$) vs 73 ± 12 mmol/mol ($8.8 \pm 1.1\%$); $P=0.004$ (Table 1)]. Over the 18-month study period, high responders performed significantly more BG checks at 6 and 12 months, and had significantly lower HbA_{1c} at all time points compared to low responders (Fig. 2).

Association between text-message responsiveness and glycaemic control after 18 months

Change in HbA_{1c} over time was assessed according to text-message responsiveness after adjusting for baseline HbA_{1c}. In a significant linear regression model ($R^2=0.20$, $P<0.0001$) controlling for baseline HbA_{1c}, text-message responsiveness predicted change in HbA_{1c} over 18 months ($P=0.03$). In low responders, HbA_{1c} increased by 3.3 mmol/mol (0.3%) from baseline to 18 months ($P=0.01$). In high responders, there was no significant change in HbA_{1c} from baseline to 18 months ($P=0.54$; Fig. 3).

Participants with baseline HbA_{1c} ≥ 64 mmol/mol

Among participants with baseline HbA_{1c} ≥ 64 mmol/mol (≥ 8%), high responders ($n=42$) were significantly more likely than low responders ($n=58$) to have a ≥ 5.5-mmol/mol (≥ 0.5%) decrease in HbA_{1c} from baseline to final follow-up HbA_{1c} after controlling for baseline HbA_{1c} [odds ratio 2.5 (95% CI 1.02, 5.98); $P=0.046$].

Participants with baseline HbA_{1c} <64 mmol/mol

In participants with baseline HbA_{1c} <64 mmol/mol (<8%), high responders ($n=30$) were significantly more likely to have a final follow-up HbA_{1c} in the target range of <58 mmol/mol (<7.5%) compared with low responders [$n=17$; odds ratio 5.7 (95% CI 1.1, 29.6); $P=0.03$]. The proportion of those with baseline HbA_{1c} <58 mmol/mol (<7.5%) was not different in high vs low responders (57% vs 41%; $P=0.31$) among those with baseline HbA_{1c} <64 mmol/mol (<8%).

Discussion

The present study showed that responsiveness to text-message reminders was associated with glycaemic benefit. Some shorter-duration studies of text-messaging interventions have also shown glycaemic benefit [9,17,18], but the present 18-month study showed that responding to text-message reminders ≥ 50% of the time (days) over 18 months was associated with glycaemic benefit for teenagers with Type 1 diabetes. HbA_{1c} increased in low responders, as it often does in this age group [1], while HbA_{1c} remained stable in the high responders. Furthermore, we found clinically significant glycaemic benefit after 18 months in those with low as well as high baseline HbA_{1c} values. High responders were 2.5 times more likely than low responders to have a ≥ 5.5 mmol/mol (≥ 0.5%) drop in HbA_{1c} when baseline HbA_{1c} was ≥ 64 mmol/mol (≥ 8%). Additionally, high vs low responders were nearly six times more likely to achieve target HbA_{1c} of <58 mmol/mol (<7.5%) after 18 months when baseline HbA_{1c} was <64 mmol/mol (<8%).

Disappointingly, we observed a significant drop in text-message responsiveness over time; however, this is quite consistent with other studies of text messaging and mobile health [10,14,15], highlighting the need to consider innovative ways to maintain engagement in interventions involving mobile platforms. This may be especially true for adolescents who may be easily distracted or who may require more dynamic devices to maintain interest. Indeed, it may be difficult for diabetes mobile platforms to keep up with the pace of advancement of general mobile applications.

In general, BG monitoring frequency and baseline glycaemic control remain potent predictors of long-term glycaemic control in young people [19,20]. Similarly, we found that baseline BG monitoring frequency and HbA_{1c} predicted text-message responsiveness over time in our teenage sample. Thus, we strived to assess whether text-message responsiveness uniquely contributed to follow-up glycaemic control in our sample. Indeed, we confirmed that text-message responsiveness was associated with a clinically meaningful HbA_{1c} benefit, as noted above, independent of baseline HbA_{1c}.

The present study offers an opportunity to preserve or improve glycaemic control in the vulnerable group of teenagers with Type 1 diabetes, but some limitations should be noted. Because of the graduated nature of the text-message reminders (with resetting to one reminder per day after 2 weeks without response), we reported the percentage of days with responses, which we believe is the most meaningful way to demonstrate ongoing and consistent engagement of the adolescents with the text-reminder intervention. We did not focus on the mean number of responses per day, therefore, we cannot recommend an ideal frequency for text-message reminders. Another limitation relates to the incomplete follow-up of some participants; however, sensitivity analyses that excluded the 10 participants with incomplete 18-month text messaging data revealed similar results. Additionally, in a separate sensitivity analyses that excluded the five participants without 18-month HbA_{1c} data, the results were again the same.

Future research into mobile health interventions in teenagers with Type 1 diabetes may consider incorporating teen-selected designees, such as parents, friends or providers, to receive text responses. A recent large meta-analysis showed that mobile health interventions that involved young people's caregivers in mobile health interventions produced larger effect sizes compared with those that did not include caregivers, although most interventions were 3 to 6 months in duration [21]. We recognize, however, that the expectation for increasing adolescent self-care may be counter to the inclusion of others. Future interventions may also benefit from the use of actionable feedback to young people based on the data they provide, and some form of active clinician monitoring. While both of these characteristics have been associated with glycaemic benefit [10], longer-term studies are needed. Further, such interventions probably involve greater cost, which could impact their scalability. Finally, text messaging may not be the ideal option for engaging teenagers because of the cost of messaging (in comparison to free mobile apps) and because of adolescents' changing preferences and interests as new technologies become available. Investigation of the effectiveness of such interventions will require ongoing assessment of teenagers' needs and preferences.

In summary, text messaging may offer an acceptable means to engage teenagers with Type 1 diabetes in self-care behaviours, potentially preventing the expected deterioration in glycaemic control during this vulnerable developmental period. There remains a need to tailor such interventions over time for teenagers to maintain their engagement, while extending the reach of such interventions.

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What's new?

- As teenagers with Type 1 diabetes become increasingly independent in self-care behaviours, they are at risk of decreased adherence and deteriorating glycaemic control.
- This study of a text-messaging intervention in teenagers with Type 1 diabetes demonstrated clinically significant glycaemic benefit in participants who responded to reminders on 50% of days over 18 months. The benefit was present in participants with baseline HbA_{1c} ≥ 64 mmol/mol (≥ 8%), and in those with baseline HbA_{1c} < 64 mmol/mol (< 8%).
- Teenagers who engaged with a mobile health intervention, such as text messaging, experienced improvement in glycaemic control. Such interventions should be tailored to maintain teenager engagement and optimize benefit.

FIGURE 1.

Decline in text-message responsiveness over time. The mean $\pm$ SD percent of days with ≥ 1 blood glucose (BG) response declined over time, $P < 0.0001$. Month 0–6, $n = 147$; month 7–12, $n = 142$; month 13–18, $n = 137$.

FIGURE 2.

Blood glucose (BG) monitoring and HbA_{1c} over time. (a) Mean $\pm$ SD frequency of BG monitoring was higher in high responders than in low responders at baseline, 6 and 12 months. (b) Mean $\pm$ SD HbA_{1c} was lower in high responders than in low responders at each time point. * P <0.05 for difference between groups, ** P <0.01 for difference between groups.

FIGURE 3.

Impact of text messaging on HbA_{1c}. In a linear regression model controlling for baseline HbA_{1c}, text-message responsiveness predicted change in HbA_{1c} over 18 months ($P=0.03$). In low responders, HbA_{1c} increased by 0.3% from baseline to 18 months ($P=0.01$). In high responders, there was no significant change in HbA_{1c} from baseline to 18 months ($P=0.54$).

Table 1

Baseline characteristics

	All participants N=147	Low responders n=75	High responders n=72	P*
Age, years	14.9±1.3	14.7±1.2	15.1±1.3	0.05
Diabetes duration, years	7.1±3.9	7.1±3.6	7.2±4.2	0.89
Boys, %	48	43	53	0.22
Race/ethnicity: white, %	78	80	75	0.47
Family structure: two-parent, %	82	81	83	0.75
Household income \$100,000, %	53	54	53	0.88
Parental education: college level or higher, %	72	76	68	0.28
BMI z-score, SDS	0.79±0.77	0.86±0.69	0.70±0.85	0.21
Pump use, %	63	69	56	0.08
CGM use, %	13	12	14	0.73
Daily insulin dose, units/kg	0.95±0.24	0.96±0.24	0.94±0.24	0.61
BG monitoring, times/day	4.7±2.0	4.3±1.6	5.1±2.3	0.016
HbA _{1c}				0.004
mmol/mol	69±12	73±12	66±11	
%	8.5±1.1	8.8±1.1	8.2±1.0	

BG, blood glucose; CGM, continuous glucose monitoring; SDS, standard deviation score.

*P-value for *t*-test or chi-squared test for difference between low vs high responders.