



ORIGINAL ARTICLE

An Intervention by a Patient-Designed Do-It-Yourself Mobile Device App Reduces HbA1c in Children and Adolescents with Type 1 Diabetes: A Randomized Double-Crossover Study

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Abstract

Background: Prevention of type 1 diabetes mellitus (T1DM)-related complications is dependent on metabolic control. The recommended glycated hemoglobin (HbA1c) values <7.5% (58.5 mmol/mol) are met only by a minority of diabetic children and especially adolescents. The aim of this study was to evaluate the impact of an intervention comprising the use of *Webdia*, a patient-designed app for smartphones, on metabolic control of T1DM in children.

Methods: Fifty-five patients with T1DM, 10–18 years of age, were included in this single-center, randomized double-crossover study. We tested an intervention consisting of using *Webdia* for 3 months with monthly feedback and adaptation of the treatment. Main outcome was modification of HbA1c. Secondary outcomes were the prevalence of hypoglycemia and quality of life (QoL).

Results: Of the 55 included patients, 33 completed the study, 9 dropped out, and 13 were excluded due to insufficient use of the app. The app was well accepted by the users who completed the study (46.4% rated the program as good and 39.3% as excellent). The intervention led to a reduction of HbA1c by 0.33%, compared to the control group in which HbA1c rose by 0.21% ($P=0.048$) in patients with HbA1c values >8.0% (63.9 mmol/mol) at inclusion, without increasing the prevalence of hypoglycemia (8.52 ± 9.45 hypoglycemic events during last 2 weeks of intervention vs. 7.62 ± 6.37 observation, $P=0.680$). QoL scores were not modified.

Conclusions: The intervention resulted in a significant decrease in HbA1c, without increasing the prevalence of hypoglycemia in patients with initial HbA1c >8.0% (63.9 mmol/mol).

Keywords: Telemedicine, mHealth app, eHealth, Patient-designed applications, Do-it-yourself applications.

Introduction

TYPE 1 DIABETES MELLITUS (T1DM) is one of the most common chronic diseases affecting children and adolescents. Constant technological advances such as fast- and

long-acting insulin types, insulin pumps, continuous glucose monitoring systems (CGMS), and intermittently scanned CGMS (isCGMS) have permitted the development of intensive treatment of the disease and have substantially improved metabolic control over the past decades,¹ thereby decreasing

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This study has previously been presented at the annual meeting of the Swiss Society for Paediatrics in Lausanne, May 2018.

the risk of long-term complications and increasing life expectancy of the concerned patients. However, achieving optimal metabolic control largely relies on self-management by the patient and requires regular self-monitoring of blood glucose, carbohydrate counting, and a strict adherence to the insulin treatment. This represents a challenge in the long term, especially in particular age groups, such as young children and adolescents.² Thus, only a minority of patients meets the treatment goals of maintaining a glycated hemoglobin (HbA1c) level below 7.5% (58 mmol/mol).^{3–5} Diabetes in children has a significant impact on parents and family, leading to higher levels of stress and depressive symptoms than in unaffected families.^{6–8}

Over the last decade, the appearance of smartphones has permitted the development and diffusion of a powerful technology that allows for reliable calculations and constant data exchange with remote servers. Touchscreen technology has led to an improved user interface, thereby permitting large diffusion of these devices, especially among children and adolescents, an age group that easily adopts new technology. Thus, ~88% of American teenagers 13 to 17 years of age are thought to own or have access to a mobile device.⁹ In this context, mobile health applications (mHealth apps) have proliferated, such that hundreds of applications are now available through iOS App Store and Google Play.¹⁰ While this evolution is very positive, it still remains unclear whether these applications have an impact on either metabolic control of T1DM or the quality of life (QoL) of affected patients.

Most applications are simple digital logbooks that allow the collection of data about diabetes management,¹⁰ and only a minority of the applications have been evaluated by randomized controlled trials, in pediatric populations.^{11,12} Overall, systematic reviews show that mHealth apps improve HbA1c in patients with T1DM by ~0.3%. Apps permitting a direct interaction between patients and health care professionals had more impact on metabolic control than apps designed for patient use only.¹²

The objective of this research was to evaluate the impact of a multidisciplinary intervention consisting of using *Webdia*, a patient-designed mHealth app, combined with an educational intervention by specialized nurses and regular insulin dose adaptation by diabetologists on metabolic control of T1DM, QoL, and frequency of hypoglycemia in children 10–18 years of age, followed at the outpatient clinic of the pediatric diabetology unit of the University Hospitals of Geneva, Switzerland.

Methods

Webdia

Webdia is a patient-designed do-it-yourself mHealth app created by J.L.M. after diagnosis of T1DM in his 10-year-old daughter. The mobile application was written with jQuery Mobile (JS Foundation, San Francisco, CA), an HTML5-based user interface system, and interacts with a MySQL (Oracle Corporation, Redwood Shores, CA) database. By creating an application that communicated with a remote server, he wanted to improve his daughter's autonomy and facilitate data exchange within the family.

While all features as well as the design of the application were chosen by J.L.M. based on the needs of his family and input of his daughter, the application was finalized under the medical supervision of P.K. and V.S. The website allowing visualization of patient data was adapted, in particular, to improve communication between the user and the medical team.

Security was improved by adding alerts when settings were entered that fell outside usual ranges, and by adding messages sent to the user when settings in his account were changed. Finally, the application was tested by our diabetes team before diffusion and, in collaboration with the University Hospitals of Geneva, a complete external review was performed, to ensure safety and confidentiality of the exchanged personal data.¹³

Webdia is now distributed by the University Hospitals of Geneva, Switzerland, and consists of a simple interface (Supplementary Fig. S1A, B; Supplementary Data available at <https://www.liebertpub.com/suppl/doi/10.1089/dia.2018.0255>), making its use possible for children 10 years of age or more. *Webdia's* main features are summarized in Supplementary Table S1. In addition to the bolus calculator function, the “meals” section comprises a complete list of nutrients and carbohydrate content. Numerous pictures representing different amounts of selected meals are available and permit comparison of the picture with the content of a given plate, to facilitate carbohydrate estimation (Supplementary Fig. S1C). The “favorites” section allows the user to save frequently eaten meals. The “data” section allows the user to review the last entries. All users sharing the same user account can remotely and instantly access the entered blood glucose values or amounts of ingested carbohydrates in the “data” section or on a dedicated secure website (www.webdia.ch, Supplementary Fig. S1D). The app is available worldwide free of charge in English, German, and French on the Apple App Store and on Google Play Store for iOS and Android-powered devices, respectively, and is currently available to all patients.

Study design

We conducted a randomized double-crossover one-center study involving 55 children followed at the outpatient clinic of the pediatric diabetes unit of the University Hospitals of Geneva, Switzerland. The trial was not blind, since both the participants and the diabetology team were aware of the allocation. Clinical outcomes such as HbA1c values were also not blind since they were part of the patient's regular follow-up. The trial was approved by the local ethics committee.

Trial registration

ClinicalTrials.gov NCT02107326.

Enrollment

Patients were recruited between May 2014 and December 2016 during outpatient visits by their usual diabetologist. The study was completed in August 2017. Patients 10 to 18 years of age with a diagnosis of type 1 diabetes (as defined by the American Diabetes Association³) for at least 6 months and who were either treated by pump therapy or multiple daily injections were eligible for inclusion. All patients were familiar with flexible intensive insulin therapy. We excluded patients who had previously used *Webdia*, who did not have the necessary hardware to install the program, or who would not be able to use the program for another reason. All participants provided written informed consent before participation.

Randomization

Patients underwent randomization by means of a computer-generated list that was created independently from the

investigators by the Pediatric Research Platform. The list was available to the physicians when patients were included. No patient categories were created at the time of inclusion.

Study protocol

Patients meeting the inclusion criteria were randomly allocated to group A or B (Supplementary Fig. S2). Baseline data were collected from both groups during visit 1 (V1), just after inclusion. Group A then received a tutorial that consisted of the installation of *Webdia* onto one or several personal mobile devices, setting up the application, an introduction to app functions, and creation of a user account that allowed for remote access to blood glucose data by both the patient and diabetology team. The tutorial lasted ~45 min and was given by only two different specialized nurses (M.C. and L.P.), to ensure similar delivery of the information.

The intervention then consisted of having the participants use *Webdia* as often as possible for a period of 3 months. During this period, the participants were called after 1 month to make sure there were no technical problems and answer questions. Blood glucose values were reviewed every month by the diabetologists (P.K., M.D., and C.G.) on a secure website (www.webdia.ch), and suggestions for treatment adaptation were sent to the participants by e-mail. The content of the e-mail was standardized and always consisted of a comment about the glucose values and, if necessary, a suggestion to adjust the insulin regimen by changing the application's settings. The intervention was followed by a second visit (V2), a 3-month washout period, a third visit (V3), a 3-month control period, and finally a fourth visit (V4).

Group B began with a 3-month control period that was followed by V2, a 3-month washout period, V3, a 3-month intervention period as described above, and V4. Outside the intervention period, the participants were not allowed to use *Webdia*, and the absence of usage was ascertained by the diabetology team. The 3-month control period consisted of usual care of the patients, during which the patient was allowed to contact the diabetology team by usual means (telephone and e-mail), if she/he felt that the insulin regimen needed adaptations.

Primary outcome measures

The primary outcome of the study was a change in HbA1c, between installation of *Webdia* and the end of the 3-month intervention. HbA1c was measured at V1, V2, V3, and V4 during routine outpatient visits, using a Siemens DCA Vantage point-of-care immunoassay analyzer (Siemens Health care Diagnostics Ltd., Frimley, Camberley, UK), which permits measurement of HbA1c values between 2.5% and 14% (4–130 mmol/mol).

Secondary outcome measures

QoL of the participants was assessed by the Diabetes QoL for Youth questionnaire, a questionnaire that was validated in the literature in French and English.^{14,15} The questionnaire comprises 23 questions about the impact of diabetes, where lower scores indicate a lower impact, 11 questions about worries about the disease, where lower scores indicate lower level of worries, and 17 questions about satisfaction with treatment and life, where higher scores indicate higher satisfaction. All questions were scored from 1 to 5, with the

exception of an additional question that asked about general health perception: this question was scored from 1 to 4, with higher scores indicating a better perception of health. The questionnaire was completed by the participants. Parents were allowed to help their child, if the meaning of a question was not clear to the participant.

Hypoglycemic events were reported by the patients themselves, during the last two weeks of the intervention and of the observation periods. A questionnaire was sent to the patients during these periods and was collected by the diabetology team at the end of the period. According to the recommendations of the American Diabetes Association Workgroup on Hypoglycemia,¹⁶ the patients were asked to record the frequency of mild (little or no interruption of activities), moderate (some interruption of activities, no need of assistance), and severe (needing assistance of others) hypoglycemia.

Satisfaction of the participants with *Webdia* was assessed with a questionnaire that was composed of five items assessing the following: (1) the usage frequency of the program as a whole (possible answers were never, once per month, twice per month, once per week, less than four times per week, four times per week or more, and every day) and (2) the usage frequency of the four main features of the program: bolus calculator, meals, favorites, and data sections (possible answers were never, once per month, twice per month, once per week, and several times per week). One item assessed the implication of the patient's parents during program use. For this item, participants had to estimate how often their parents had assisted them in using the program during the study period (possible answers were 0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100% of the time). A last item assessed global satisfaction with the program that could be rated as insufficient, sufficient, good, or excellent.

Usage data

Usage data were reviewed by P.K. at the end of the experimental intervention, based on the participant's entries that were available to the medical team. Participants were considered "noncompliant" to the protocol if the application was used less than 4 days per week.

Sample size

Sample size was estimated based on a nominal two-sided type I error rate of 5% and 80% power. We considered a change in HbA1c of $\geq 0.5\%$ as clinically relevant. Assuming a standard deviation for HbA1c, a sample size of 33 was needed for a power of 80% in detecting a difference in HbA1c of 0.5% or more between two paired groups. With a potential 20% dropout rate, the sample size was 55.

Statistical analysis

t-Tests and Pearson chi-square tests were used to assess whether there were significant differences between groups A and B, and between patients having completed the study versus noncompliant patients for the demographic characteristics, as well as for the primary outcome at baseline. *t*-Tests for paired samples were used to compare the change in HbA1c, QoL scores, and frequency of hypoglycemia before and after each intervention, and between the intervention "use of program" and "usual care." The proportion

of patients with an improved perception in their general self-rating of health, before and after the intervention, as well as the proportion of patients reporting a severe hypoglycemic event, was compared between the intervention “use of program” and “usual care” using a McNemar test. Results were considered statistically significant at P -values less than 0.05 and all tests were two sided. All tests were performed using the Statistical Package for Social Sciences version 22.0 (SPSS; IBM, Armonk, NY).

Results

Study participants

A total of 55 patients were included between May 2014 and December 2016. The baseline demographics are shown in Table 1. Mean age at inclusion was 13.6 ± 2.4 years, 56.4% were male, and 52.7% of the patients were treated by pump therapy (CSII). Mean HbA1c at inclusion was $8.1\% \pm 1.1\%$.

Compliance of the participants

Of the 55 included patients, 33 completed the study, 9 dropped out, and 13 were excluded from further analysis due to insufficient use (less than 4 days per week) of the application (Fig. 1). The reasons for dropout were a technical problem preventing the loading of *Webdia* for one patient, while eight participants decided to retract consent before installing and using the application.

Patient characteristics according to completion of the study are shown in Table 2. Patients who were excluded from further analysis due to noncompliance were significantly older and had a longer duration of diabetes. Other characteristics such as sex, mode of insulin delivery, previous use of a bolus calculator, and mean HbA1c at inclusion were not significantly different between excluded patients and the participants who completed the study. Most noncompliant participants indicated that they stopped using the application because they were not willing to change their habits for the purpose of the study. One participant complained about the responsiveness of the application, which he considered too slow.

Issues reported 1 month after *Webdia* installation

Only one participant indicated, when called after the first month, that he did not trust the insulin doses suggested by the application. The settings and calculations of the application were checked and found to be correct. Despite this, the participant quit using the application.

Effect of the intervention on HbA1c

Paired comparison of the change in HbA1c between installation of *Webdia* and the end of the intervention versus the control period failed to demonstrate a significant impact of the program in the whole study population ($P=0.632$, Supplementary Fig. S3). However, selecting patients with HbA1c values $>8.0\%$ (63.9 mmol/mol) at inclusion revealed a significant 0.33% reduction in HbA1c after a 3-month use of *Webdia*, while HbA1c rose by 0.21% during the control period ($P=0.048$, Table 3). This subpopulation consisted of 16 participants with a mean HbA1c of $8.8\% \pm 0.7\%$ at inclusion.

Effect of the intervention on the frequency of hypoglycemia

The frequency of patient-reported hypoglycemic events during the two last weeks of *Webdia* use versus usual care was compared by paired t -tests; 8.52 ± 9.45 mild, moderate plus severe events during *Webdia* use were not significantly different from 7.62 ± 6.37 events during usual care ($P=0.68$), neither in the whole patient population nor in the subgroup of patients with HbA1c values $>8.0\%$ (63.9 mmol/mol) at inclusion.

The frequency of patients reporting at least one severe hypoglycemic event was compared by a McNemar test and was not statistically different between arms: 4 patients out of 23 (17.4%, 95% confidence interval [CI]: 5.0–38.8) reported a severe hypoglycemia during *Webdia* use and 6 patients out of 27 (22.2%, 95% CI: 8.6–42.3) during usual care ($P>0.99$). In these patients, the mean number of severe hypoglycemic events was 2.0 during *Webdia* use and 3.2 during usual care. We therefore conclude that lower HbA1c was not associated with an increased risk of hypoglycemia.

TABLE 1. BASELINE DEMOGRAPHICS OF THE STUDY POPULATION AT RANDOMIZATION

	All (n=55)	Group A (n=28) (50.9%)	Group B (n=27) (49.1%)	P Group A vs. B
Age (years)	13.6 ± 2.4	13.6 ± 2.4	13.7 ± 2.4	0.846 ^a
Sex				
Male	31 (56.4%)	21 (75.0%)	10 (37.0%)	0.005 ^b
BMI (kg/m ²)	20.0 ± 3.7	20.1 ± 3.1	21.6 ± 4.0	
BMI Z score	0.54 ± 0.91	0.34 ± 0.94	0.74 ± 0.86	0.105 ^a
Duration of diabetes (months)	63 ± 43	90 ± 48	66 ± 39	0.655 ^a
Insulin dose (IU/kg/day)	0.91 ± 0.27	0.94 ± 0.24	0.89 ± 0.30	0.451 ^a
Insulin delivery				
Pump therapy	29 (52.7%)	14 (50.0%)	15 (55.6%)	0.680 ^b
Multiple daily injections	26 (47.3%)	14 (40.0%)	12 (44.4%)	
Previous use of bolus calculator	15 (27.3%)	8 (28.6%)	7 (25.9%)	0.826 ^b
HbA1c (%)	8.1 ± 1.1	8.1 ± 1.4	8.1 ± 0.9	0.942 ^a

Data are number (%) or mean \pm standard deviation.

^a t -Test (two tailed).

^bPearson chi-square (two-tailed).

BMI, bodymass index; HbA1c, glycated hemoglobin.

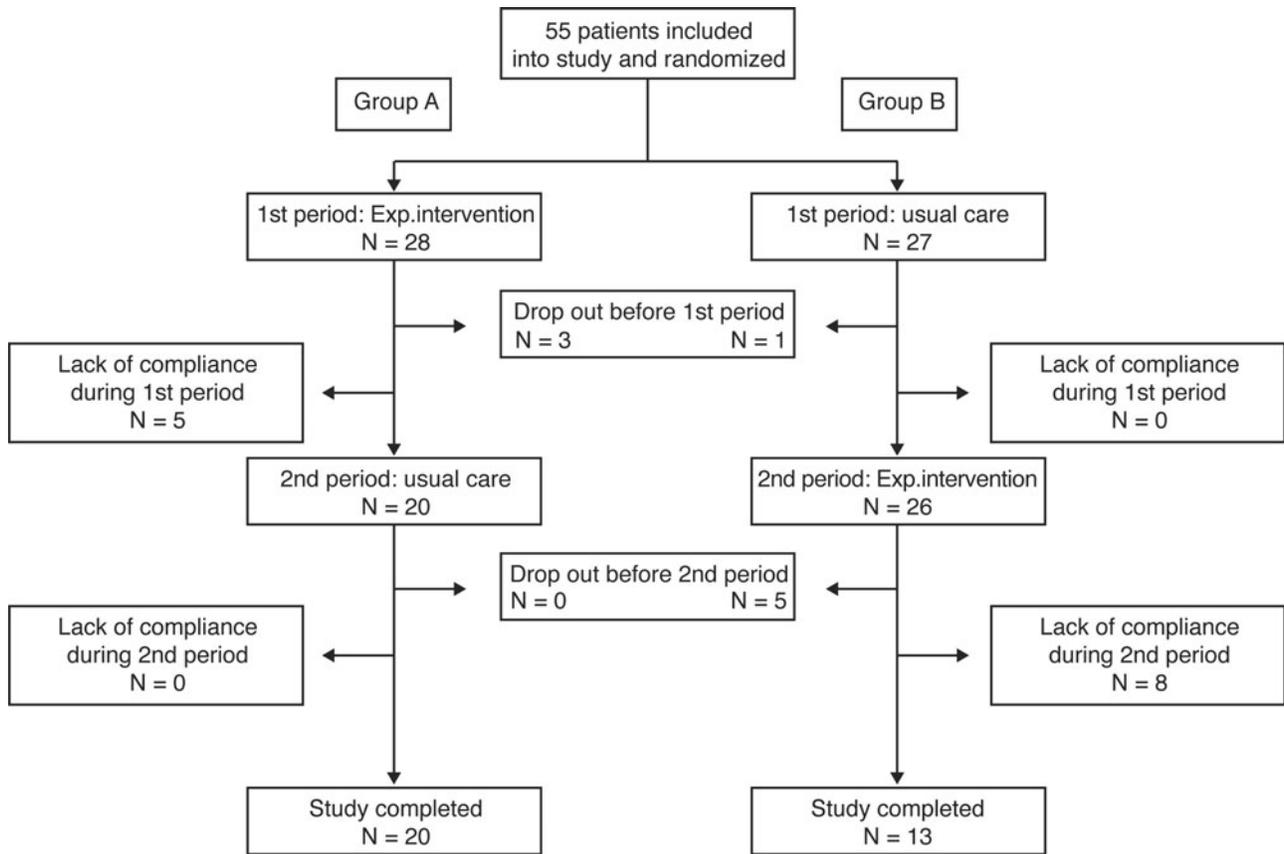


FIG. 1. Participant enrollment and follow-up. A total of 55 children were included and underwent randomization into groups A and B. Four participants dropped out before the first period and five before the second period. One dropout was due to a technical problem related to the smartphone of the participant and eight were due to withdrawal of the consent before the installation of *Webdia*. A total of 13 participants were considered noncompliant to the protocol due to insufficient use of *Webdia* and were excluded from further analysis. Thirty-three participants completed the study.

TABLE 2. PATIENT CHARACTERISTICS ACCORDING TO COMPLETION OF THE STUDY

	Completed study (n = 33) (60.0%)	Dropped out (n = 9) (16.4%)	Noncompliant (n = 13) (23.6%)	P noncompliant vs. completed
Age (years)	13.3 ± 2.3	12.8 ± 1.8	15.1 ± 2.4	0.024 ^a
Sex				
Male	19 (57.6%)	6 (66.7%)	6 (46.2%)	0.484 ^b
BMI (kg/m ²)	20.1 ± 2.9	19.7 ± 1.9	23.5 ± 4.9	
BMI Z score	0.40 ± 0.92	0.55 ± 0.56	0.88 ± 1.06	0.127 ^a
Duration of diabetes (months)	52 ± 35	70 ± 48	86 ± 52	0.014 ^a
Insulin dose (IU/kg/day)	0.93 ± 0.28	0.86 ± 0.31	0.91 ± 0.24	0.876 ^a
Insulin delivery				
Pump therapy	17 (51.5%)	5 (55.6%)	7 (53.8%)	0.887 ^b
Multiple daily injections	16 (48.5%)	4 (44.4%)	6 (46.2%)	
Previous use of bolus calculator	7 (21.2%)	2 (22.2%)	6 (46.2%)	0.091 ^b
Randomization				
Group A	20 (60.6%)	3 (33.3%)	5 (38.5%)	0.175 ^a
Group B	13 (39.4%)	6 (66.7%)	8 (61.5%)	
App use per day	2.47 ± 1.17			
HbA1c (%)	8.0 ± 1.0	7.8 ± 0.5	8.6 ± 1.6	0.085 ^a

Data are number (%) or mean ± standard deviation.

^at-Test (two tailed).

^bPearson chi-square (two tailed).

TABLE 3. EFFECT OF *Webdia* USE ON HbA1c IN PATIENTS WITH INITIAL HbA1c >8.0%

	Experimental intervention (n = 16)	Usual care (n = 16)	P ^a
HbA1c change during observation (%)	-0.33 ± 0.75	+0.21 ± 0.79	0.048

Data are mean ± standard deviation.

^aPaired samples *t*-test (two tailed).

Effect of the intervention on QoL scores

Comparison of the change in QoL during *Webdia* use versus usual care was also assessed by paired *t*-tests and showed no significant effect of the intervention on the scores analyzing the impact of diabetes, worries about diabetes, and satisfaction of the patients with their treatment and with life. General health perception improved in 15.2% of the patients during use of the program, versus 9.1% during usual care—a nonsignificant difference (Supplementary Table S2).

Use of *Webdia* and satisfaction with the application

Eighty percent of the participants reported using *Webdia* every day (Fig. 2A). Participants further reported to be highly satisfied when using the application. Thus, 39.3% rated the program as “excellent” and 46.4% as “good” (Fig. 2F). The bolus calculator was most often used (Fig. 2B), followed by the “meals” and the “data” sections (Fig. 2C, E). The “favorites” section was rarely used (Fig. 2D). The presence of the parents when the participant was manipulating the application was also investigated and was dependent on the age group: most (64.3%) participants 14–18 years of age reported that their parents were not implicated in the use of the application, versus 7.1% in participants 10–13 years of age (data not shown).

Discussion

The aim of this randomized double-crossover study was to test the effect of using the patient-designed do-it-yourself mHealth app *Webdia* in combination with an active multidisciplinary intervention on HbA1c, QoL, and frequency of self-reported hypoglycemia in children 10 to 18 of age followed at the outpatient clinic of the pediatric diabetology unit of the University Hospitals of Geneva in Switzerland.

We show that the 3-month-long intervention lead to a reduction of HbA1c by 0.33% in patients with an HbA1c >8.0% (63.9 mmol/mol) at inclusion compared to the control period, during which HbA1c rose by 0.21%. This patient subpopulation representing 16 (48.5%) patients is of special interest, since it reflects those patients struggling with diabetes control and for whom additional tools could be of use to meet treatment goals. We also show that the improved metabolic control in this patient group was not related to an increased rate of hypoglycemia and thus probably also reflects less glycemic variability.

Further subgroup analysis showed that age (10–13 years versus 14–18 years), gender, duration of diabetes (6 months–5 years versus >5 to 16 years), treatment modalities (CSII versus multiple daily injections), frequency of app use (≤ 3 versus >3 times per day), and previous use of a bolus calculator did not influence the effect of the intervention. However, as the study was not powered to look at subgroups,

possible influence of one of these factors could not be revealed through our analysis.

Knowing that most pediatric patients 10 to 18 years of age own or have access to a smartphone and that patients ask for optimal communication with the diabetology team,¹⁷ we have used the mHealth app as a basis for our intervention. To integrate patients into the design of the intervention, we have used a patient-designed mHealth app that was developed by the father of a 10-year-old patient followed at our outpatient clinic, as described above.

As interventions offering direct communication with the patient are more effective in reducing HbA1c,¹² we have chosen to use *Webdia* as a basis to improve communication with our patients between standard consultations and to use monthly e-mails to give feedback to the participant about the blood glucose values entered into the application. As the identified health care providers, we also had access to the participant’s settings and could have directly modified them—the participant would then have got a message and summary of the new settings through the application. Nonetheless, direct communication by e-mail seemed more adequate in our context, since it allowed us to comment on the values observed and to explain the suggested changes. This approach increased the amount of time needed to give feedback, but the diabetologists appreciated the idea of involving the participants in the process of treatment adaptation.

Finally, we chose to involve specialized nurses in these interventions, to reflect the usual collaboration within the team and to not only ensure proper installation and configuration of the app but also to optimize the use of the new tool by the participant. Involvement of all members of the team was thought to allow for long-term use of the app, even beyond this trial.

Despite the interventions mentioned above, we had to exclude 13 (23.6%) participants during the study, due to insufficient use of the application. This postrandomization attrition rate is comparable to other eHealth studies¹⁸ and also behavioral interventions for children with chronic conditions.¹⁹ Risk factors for noncompliance were older age and longer duration of diabetes. This confirms previous findings that show that adherence to treatment in adolescents is particularly difficult to obtain.² In this context, it is important to note that *Webdia* was designed by the father of a 10-year-old girl. The emphasis was thus put on a simple and easy-to-use interface, more than on features, such as reward systems or challenges, which might be more appealing to adolescents.²⁰ This observation may set the basis for future improvements.

Nonetheless, among the 33 participants who used the application regularly, the satisfaction with the program was high. While the bolus calculator was the feature that was most used, the favorites section was hardly ever used. This function required several steps to create “favorite meals” and will be eliminated from the program and replaced in a future

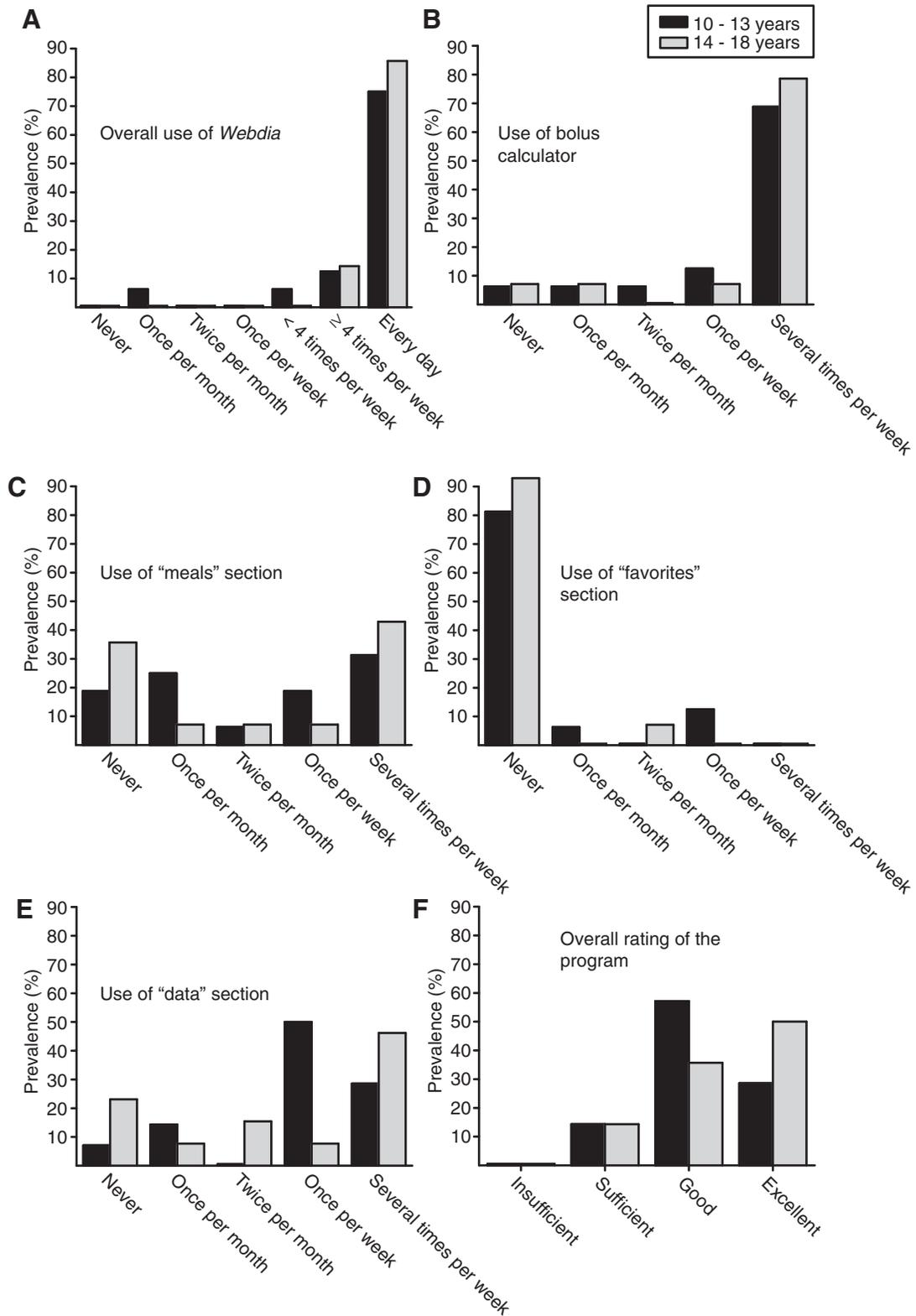


FIG. 2. Use and rating of *Webdia*; (A) 80% of the participants reported using *Webdia* every day. (B) The bolus calculator was most often used, followed by the "meals" (C) and the "data" (E) sections. The "favorites" section was rarely used (D); (F) 39.3% of the participants rated the program as "excellent" and 46.4% as "good."

version by the possibility to take pictures of a particular meal and store them within the application, together with its carbohydrate content, for repeated future use.

The need for manual entry of data into the application may also represent an obstacle to its regular long-term use. Alternative ways to integrate data should be sought: most glucose meters communicate through Bluetooth and most (is) CGMS devices make their data available in clouds to which mHealth apps should have access. Some CGMS devices are approved for glucose management decisions without the need for confirmatory capillary blood glucose measurements. These devices have increased the amount of data available to the patient and health care providers. It will therefore be particularly interesting in the future to combine CGMS data with apps that will give advice to patients, not only based on glucose values but also on the predicted trend of these values.

As for QoL, the scores concerning impact of diabetes, worries about diabetes, and satisfaction with treatment and life are comparable to those initially published by Ingersoll and Marrero,¹⁴ with most (84.4%) of the patients rating their health as excellent or good. No significant impact of the intervention was found.

The strengths of this study are the systematic analysis of the effect of a multidisciplinary intervention on metabolic control of T1DM in children. The fact that the application used during this trial exchanges data with a remote server allows health care teams to remotely monitor their patient's glucose values, and thus makes the application particularly interesting for geographical regions where patients have difficulties meeting their health care provider on a regular basis. The application is available free of charge on the Apple App Store and on Google Play Store, which makes it also affordable to countries with limited resources, where patients often have long distances to travel to reach a diabetologist.

Overall, the study integrated well into everyday practice of the multidisciplinary team. Thanks to its simple interface, few technical problems occurred and the diabetologists who gave feedback to the patients on a monthly basis appreciated the standardized display of glucose values that permitted an efficient review of the values. The positive feedback of the participants has led to the integration of the application into routine practice. Thus, specialized nurses present the application to new patients; and several of them, as well as patients who had participated in the study in the past, use it on a regular basis. Thanks to its compatibility with all mobile devices and its simple interface, we believe that its implementation would be easily feasible in other settings.

Some potential weaknesses of the study must be acknowledged. First, a significant difference in terms of gender existed between group A and group B, with significantly more boys in group A, who used the application before the washout and observation period. We do not, however, believe that this difference affected the results of the trial, thanks to its crossover design, which meant that every participant has undergone both phases of the study. Second, the duration of the intervention and observation periods was limited to 3 months, a short duration given the chronicity of the disease.

Further analysis should be performed to determine the percentage of patients who continue using *Webdia* after completion of the study and whether the mere use of the application (without regular feedback by the health care team) allows improved glucose control on a longer term.

Finally, with manual data entry into the app, there was no possibility to make sure that the glucose values that were used by the health care team to give feedback to the participants corresponded to real glucose readings obtained from a glucose meter. As connectivity of glucose meters and CGMS has improved in the meantime, further trials should be based on the automatic upload of measured data into the app. In addition, the application will have to evolve by considering frequent use of isCGMS or CGMS.

Future versions of *Webdia* should thus integrate suggestions that consider additional parameters such as past values and tendencies. Further analysis is also needed to understand whether the time invested by the health care team to give a monthly feed back to patients could be compensated, by less frequent outpatient visits, for example.

Conclusion

In conclusion, we have demonstrated that the use of *Webdia*, a free of charge patient-designed do-it-yourself mHealth application, in combination with a multidisciplinary intervention by specialized nurses for the installation of the application and regular review of blood glucose values and adaptation of the insulin regimen, leads to a significant reduction of HbA1c in patients with initial HbA1c values >8.0% (63.9 mmol/mol), without increasing the risk of hypoglycemia. Insufficient use of *Webdia* by adolescents suggests that the app may have to be redesigned to make it more attractive to this age group.

Acknowledgments

P.K. wrote the research project, wrote the article, and researched data. C.B., M.C., C.C., M.D., C.G., L.P., and V.S. reviewed/edited the research project and article. P.K. is the guarantor of this work and had full access to all the data, and takes responsibility for the integrity of the data. Our research as well as the development of *Webdia* was supported by the Swiss Diabetes Foundation, the "Fondation Romande pour la Recherche sur le Diabète" and the "Fondation de bienfaisance du groupe Pictet." The authors thank Dr. Marianne Caffisch for her constructive advice and Dr. Rachel Aronoff for further review of the article.

Author Disclosure Statement

No competing financial interests exist.

References

1. Diabetes Control and Complications Trial Research Group, Nathan DM, Genuth S, et al.: The effect of intensive treatment of diabetes on the development and progression of long-term complications in insulin-dependent diabetes mellitus. *N Engl J Med* 1993;329:977–986.
2. Clements MA, Foster NC, Maahs DM, et al.: Hemoglobin A1c (HbA1c) changes over time among adolescent and young adult participants in the T1D exchange clinic registry. *Pediatr Diabetes* 2016;17:327–336.
3. American Diabetes Association: Standards of Medical Care in Diabetes 2017. *Diabetes Care* 2017;40(Supplement 1): S1–S135.
4. Miller KM, Foster NC, Beck RW, et al.: Current state of type 1 diabetes treatment in the U.S.: updated data from the T1D Exchange clinic registry. *Diabetes Care* 2015;38:971–978.

5. Rosenbauer J, Dost A, Karges B, et al.: Improved metabolic control in children and adolescents with type 1 diabetes: a trend analysis using prospective multicenter data from Germany and Austria. *Diabetes Care* 2012;35:80–86.
6. Nieuwesteeg A, Hartman E, Emons W, et al.: Paediatric parenting stress in fathers and mothers of young children with type 1 diabetes: a longitudinal study. *Diabet Med* 2017;34:821–827.
7. Patton SR, Dolan LM, Smith LB, et al.: Pediatric parenting stress and its relation to depressive symptoms and fear of hypoglycemia in parents of young children with type 1 diabetes mellitus. *J Clin Psychol Med Settings* 2011;18: 345–352.
8. Whittemore R, Jaser S, Chao A, et al.: Psychological experience of parents of children with type 1 diabetes: a systematic mixed-studies review. *Diabetes Educ* 2012;38: 562–579.
9. Lenhart A: Teens, social media & technology overview 2016. Washington DC, USA, Pew Reserch Center, 2015.
10. Bellei EA, Biduski D, Cechetti NP, De Marchi ACB: Diabetes mellitus m-Health applications: a systematic review of features and fundamentals. *Telemed J E Health* 2018 [Epub ahead of print]; DOI: 10.1089/tmj.2017.0230.
11. Garabedian LF, Ross-Degnan D, Wharam JF: Mobile phone and smartphone technologies for diabetes care and self-management. *Curr Diab Rep* 2015;15:109.
12. Kitsiou S, Pare G, Jaana M, et al.: Effectiveness of mHealth interventions for patients with diabetes: an overview of systematic reviews. *PLoS One* 2017;12:e0173160.
13. Lee JM, Hirschfeld E, Wedding J: A patient-designed do-it-yourself mobile technology system for diabetes: promise and challenges for a new era in medicine. *JAMA* 2016;315: 1447–1448.
14. Ingersoll GM, Marrero DG: A modified quality-of-life measure for youths: psychometric properties. *Diabetes Educ* 1991;17:114–118.
15. Skinner TC, Hoey H, McGee HM, et al.: A short form of the Diabetes Quality of Life for Youth questionnaire: exploratory and confirmatory analysis in a sample of 2,077 young people with type 1 diabetes mellitus. *Diabetologia* 2006;49:621–628.
16. Workgroup on Hypoglycemia ADA: Defining and reporting hypoglycemia in diabetes: a report from the American Diabetes Association Workgroup on Hypoglycemia. *Diabetes Care* 2005;28:1245–1249.
17. Boogerd EA, Maas-van Schaaijk NM, Noordam C, et al.: Parents' experiences, needs, and preferences in pediatric diabetes care: suggestions for improvement of care and the possible role of the Internet. A qualitative study. *J Spec Pediatr Nurs* 2015;20:218–229.
18. Boogerd E, Maas-Van Schaaijk NM, Sas TC, et al.: Sugarsquare, a web-based patient portal for parents of a child with type 1 diabetes: multicenter randomized controlled feasibility trial. *J Med Internet Res* 2017;19:e287.
19. Karlson CW, Rapoff MA. Attrition in randomized controlled trials for pediatric chronic conditions. *J Pediatr Psychol* 2009;34:782–793.
20. Bishay LC, Sawicki GS: Strategies to optimize treatment adherence in adolescent patients with cystic fibrosis. *Adolesc Health Med Ther* 2016;7:117–124.

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