ORIGINAL ARTICLE

Technology Use for Diabetes Problem Solving in Adolescents with Type 1 Diabetes: Relationship to Glycemic Control

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Abstract

Background: This study examines technology use for problem solving in diabetes and its relationship to hemoglobin A1C (A1C).

Subjects and Methods: A sample of 112 adolescents with type 1 diabetes completed measures assessing use of technologies for diabetes problem solving, including mobile applications, social technologies, and glucose software. Hierarchical regression was performed to identify the contribution of a new nine-item Technology Use for Problem Solving in Type 1 Diabetes (TUPS) scale to A1C, considering known clinical contributors to A1C.

Results: Mean age for the sample was 14.5 (SD 1.7) years, mean A1C was 8.9% (SD 1.8%), 50% were female, and diabetes duration was 5.5 (SD 3.5) years. Cronbach's α reliability for TUPS was 0.78. In regression analyses, variables significantly associated with A1C were the socioeconomic status ($\beta = -0.26$, $P < 0.01$), Diabetes Adolescent Problem Solving Questionnaire ($\beta = -0.26$, $P = 0.01$), and TUPS ($\beta = 0.26$, $P = 0.01$). Aside from the Diabetes Self-Care Inventory—Revised, each block added significantly to the model R^2 . The final model R^2 was 0.22 for modeling A1C ($P < 0.001$).

Conclusions: Results indicate a counterintuitive relationship between higher use of technologies for problem solving and higher A1C. Adolescents with poorer glycemic control may use technology in a reactive, as opposed to preventive, manner. Better understanding of the nature of technology use for self-management over time is needed to guide the development of technology-mediated problem solving tools for youth with type 1 diabetes.

Introduction

DURING ADOLESCENCE, SELF-MANAGEMENT to treatment in type 1 diabetes often deteriorates, resulting in higher hemoglobin A1C (A1C) values.¹ In turn, this can increase the risk of long-term complications associated with type 1 diabetes.² The American Diabetes Association recommends problem solving as a critical patient skill for successful self-management and successful glycemic control.³ Problem solving is a cognitive-behavioral process and an interventional focus for behavior change.⁴ The steps of problem solving include (1) problem awareness, (2) barrier identifica-

tion, (3) solution generation, (4) implementation planning, (5) implementation, (6) outcome evaluation, and (7) revision.⁵ The success with which each step is carried out can impact the degree of problem resolution and future generalizability when similar problems are encountered.⁴ Despite recommendations to incorporate problem solving as part of routine diabetes education,³ there are gaps in services to teach and support problem solving skills.⁶

Various technologies are relevant in diabetes problem solving because they provide readily available resources that can help facilitate obtaining knowledge, communicating with adults, connecting with similar others, and/or accessing

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feedback on blood glucose data. These efforts may facilitate adherence to the adolescent's regimen using the technologies and communication channels with which adolescents are now familiar and find acceptable. Problem solving is particularly well suited to technological applications because the foundation of many technological tools is to assist in the process of gathering, processing, analyzing, and communicating data in a way that can be presented in a context that can facilitate decision-making.⁷

Previous interventional studies to improve problem solving in children with type 1 diabetes have demonstrated positive effects on problem solving abilities.^{8–10} Problem solving skills have been associated with improved A1C and self-management^{11–14} and can be assessed using validated patient-report measures.¹³ Readily available technologies such as mobile applications, text messaging, meter software, digital carbohydrate counters, insulin dose calculators, and social networking sites may support self-management problem solving by providing access to resources useful in identifying problems and implementation of solutions. For example, several studies to date provide support for the role of mobile technologies in self-management of diabetes.¹⁵ Additionally, some online health communities for adolescents with type 1 diabetes have been found to have features associated with improved self-management, such as social learning, where teens look to their peers for guidance.¹⁶ However, it is unclear how use of many such tools and applications for problem solving correlates with actual problem solving and glycemic control.

The purposes of this study were (1) to assess the use of technologies for self-management problem solving in adolescents with type 1 diabetes, (2) to identify associations between frequency of technology use for problem solving and adolescent characteristics, and (3) to determine the unique contribution of the new Technology Use for Problem Solving in Type 1 Diabetes (TUPS) scale to A1C, while taking into account previously established correlates such as diabetes problem solving, self-management, demographics, and clinical factors. We hypothesized that use of technology for problem solving would be negatively correlated with A1C—specifically, that higher frequency of technology use would correspond with lower A1C. Additionally, we expected that TUPS would contribute unique variance beyond other factors in modeling A1C.

Subjects and Methods

This study was conducted at a pediatric diabetes clinic at a large tertiary-care medical center. Inclusion criteria were as follows: adolescent age of 12–17 years, diagnosis of type 1 diabetes, Internet access to complete an online survey, ability to read and understand survey content as reported by parents, and duration of diabetes greater than 6 months. An exclusion criterion was a diagnosis of type 2 diabetes. Informational letters were sent to parents of potential adolescent participants, identified in electronic health records, with diagnoses of type 1 diabetes. Study data were collected and managed using the Research Electronic Data Capture (REDCap).¹⁷ REDCap is a secure, Web-based application designed to support data capture for research studies. Parents were provided a URL to the study Web site. Online informed consent was obtained from parents, and assent was obtained from

adolescents, before data collection procedures began. Study procedures were approved by the Vanderbilt University Medical Center Institutional Review Board.

Measures

Demographic and clinical data other than A1C (such as duration of diabetes) were obtained through parent report. All other measures were completed by the adolescent. Socio-economic status (SES) was measured using the education level of the parent completing the survey, as well as the median household income.¹⁸ Parent education level and household income were then summed to provide a composite SES score. Education level was categorized as one of the following: less than high school, high school or GED, 2-year college, 4-year college, masters degree, or doctoral/professional degree. Median household income was obtained by using patient addresses and data from the U.S. Census American Community Survey. Household income was categorized as <\$20,000, \$20,001–\$40,000, \$40,001–\$70,000, or >\$70,000. Composite SES scores could range from 2 to 8.

The 15-item Diabetes Self-Care Inventory—Revised (SCI-R)^{19,20} was used to assess self-management to the prescribed treatment regimen. This measure uses Likert-type items to assess the frequency of completing 15 self-management tasks. Scores could range from 15 to 75, with higher scores indicating better self-management. In previous research, this measure had a Cronbach's α internal reliability coefficient of 0.87 and negatively correlates with A1C.¹⁹

Problem solving was assessed using the 13-item self-report Diabetes Adolescent Problem Solving Questionnaire (DAPSQ).¹³ Items assess the frequency of problem solving for diabetes self-management. The total score could range from 13 (low problem solving skills) to 65 (high problem solving skills). In previous research, this measure had a Cronbach's α internal reliability coefficient of 0.92 and correlated negatively with A1C.¹³

The new TUPS scale was created for this study to assess use of commonly available technologies for diabetes problem solving. The items of the TUPS scale were created based on literature review of common uses of technology for problem solving in adolescents with diabetes. Scale items were reviewed for content validity through an iterative consulting process with experts, including a pediatric endocrinologist, pediatric psychologists, and a certified diabetes educator/nurse practitioner, and with teenagers with type 1 diabetes. Iterative changes ceased when no new recommendations were made from stakeholders. The TUPS scale has nine items and measures the frequency that diabetes-specific and commonly available technologies are used to address problems with diabetes self-management, including use of (1) meter software to log glucose data, (2) meter or pump graphing software for following trends, (3) online resources to search for problem solving information or support, (4) text messaging for communication about diabetes problems, (5) social networking resources, (6) diabetes mobile applications, (7) digital resources and applications for information reference (for example, I use a carbohydrate counter application or Web site to help me figure out how many carbohydrates are in the food I eat), (8) alarms and reminders, and (9) patient portal sites to access personal health information and communicate with providers. Likert-type responses could range

TABLE 1. SAMPLE CHARACTERISTICS

<i>Variable</i>	<i>Value</i>
Patient characteristics	
Age (years)	14.5 (1.7)
Female	56 (50%)
Race	
White	100 (89%)
Black	9 (8%)
Asian	2 (2%)
Other	1 (1%)
Pump user	71 (63%)
Duration of diabetes (years)	5.5 (3.5)
A1C	8.9% (1.8)
Parent characteristics	
Household income	
<\$20,000	3 (3%)
\$20,001–\$40,000	23 (20%)
\$40,001–\$70,000	54 (48%)
>\$70,001	32 (29%)
Education	
Less than high school	1 (1%)
High school or GED	31 (28%)
2-year college	20 (18%)
4-year college	36 (32%)
Masters degree	20 (18%)
Doctoral or professional degree	3 (3%)
Socioeconomic status score	5.4 (1.2)
Marital status	
Single	10 (9%)
Married	93 (83%)
Long-term relationship	4 (4%)
Separated	4 (4%)

Data are mean (SD) values or number (%) as indicated.
A1C, hemoglobin A1C.

from “never” to “everyday.” The total score could range from 9 to 54.

Adolescent A1C was measured (range, 2.5–14%) by the DCA Vantage Analyzer (Siemens Healthcare Diagnostics Inc., Malvern, PA). A1C was obtained from the participants’ medical records. The A1C value used for the analysis was from the date closest to the survey completion.

Statistical analyses

Descriptive statistics and frequencies were calculated for variables as appropriate, and normal distributional properties were assessed. Bivariate nonparametric correlation was used. Hierarchical multiple regression analyses were conducted to examine the contribution of demographic and clinical variables, SCI-R, DAPSQ, and TUPS to predicting A1C. Analyses were conducted in SPSS version 22.0 software (IBM Corp., Armonk, NY). Based on the hypothesized contribution to prediction of A1C in a hierarchal model, predictor vari-

ables were entered in blocks, as follows: (1) SES variables (parent education and income), (2) disease duration, pump status, and age, (3) SCI-R, (4) DAPSQ, and (5) TUPS. All tests were two-tailed with a minimum $P < 0.05$ level of significance.

Results

Sample characteristics

Table 1 shows demographic and clinical characteristics of the sample. In total, 112 adolescents and their parents participated in the current study. Mean age was 14.5 (SD 1.7) years. Half (50%) of the participants were female. Mean A1C was 8.9% (SD 1.8%). The majority ($n = 108$) of patients had A1C values documented within 3 months before or after completing the survey. Three patients with A1C values documented within 4 months before or after completing the survey were also included in the analyses for a total of 112 participants in the analyses. Duration of diabetes ranged from 10 months to 16 years, with a mean of 5.5 (SD 3.5) years. The majority of adolescents (89%) were white, 8% were black, 2% were Asian, and 1% were categorized as other. Use of subcutaneous insulin infusion pumps was 63%. Mean household income was \$60,000 (SD \$28,000). Mean SES score was 5.4 (SD 1.2). The majority (93%) of the participants’ parents were married and had completed some college (71%).

Measure characteristics

Table 2 shows the characteristics of the measures used in this sample. The mean of the SCI-R was 58.59 (SD 5.25) with a Cronbach’s α of 0.79. Mean score for the DAPSQ was 52.03 (SD 9.15) with a Cronbach’s α of 0.90. The mean score for the TUPS scale was 24.34 (SD 9.34) with a Cronbach’s α of 0.78.

Relationship of technology use for problem solving with adolescent characteristics

Table 3 shows that in the bivariate correlation among the adolescent characteristics, the composite score for the TUPS scale correlated significantly with SCI-R (self-management, $r = 0.49$; $P < 0.001$), duration of diabetes ($r = -0.19$; $P < 0.05$), and problem solving ($r = 0.27$; $P < 0.05$). TUPS score did not correlate significantly with SES ($r = 0.12$; $P > 0.05$), pump use ($r = 0.16$; $P > 0.05$), age ($r = -0.08$; $P > 0.05$), or A1C ($r = 0.14$; $P > 0.05$) in the bivariate correlation.

Relation of technology use for problem solving to A1C

We explored the relationship between each technology represented by an item on the TUPS scale and its relationship with A1C using nonparametric bivariate correlation. None of the items were significantly related to A1C separately.

TABLE 2. MEASURE CHARACTERISTICS

<i>Measure</i>	<i>Mean score</i>	<i>SD</i>	<i>Sample range</i>	<i>Survey range</i>	<i>Cronbach’s α</i>
Diabetes Self-Care Inventory—Revised	58.59	5.25	37–73	15–75	0.79
Diabetes Adolescent Problem Solving Questionnaire	52.03	9.15	28–64	13–64	0.90
Technology Use for Problem Solving	24.34	9.34	9–54	9–54	0.78

TABLE 3. BIVARIATE CORRELATIONS BETWEEN TECHNOLOGY USE FOR PROBLEM SOLVING AND PATIENT CHARACTERISTICS

Characteristic	Correlation with TUPS
A1C	0.14
SES	0.12
Duration of diabetes	−0.19 ^a
Pump use	0.16
Age	−0.08
SCI-R	0.49 ^b
Problem solving	0.28 ^a

^a $P < 0.05$, ^b $P < 0.001$.

A1C, hemoglobin A1C; SCI-R, Self-Care Inventory—Revised; SES, socioeconomic status; TUPS, Technology Use for Problem Solving.

Results for the hierarchical regression model are summarized in Table 4. The overall $R^2 = 0.23$ in modeling A1C was significant ($F = 4.40$, $P < 0.001$; df of 7, 104). Each block, with the exception of the SCI-R, added significantly to the model R^2 . Significant variables in the final hierarchical regression model included SES ($\beta = -0.26$, $P < 0.01$) and DAPSQ ($\beta = -0.26$, $P = 0.01$), which were both negatively correlated to A1C, and the TUPS scale ($\beta = 0.26$, $P = 0.01$), which was positively correlated with A1C. Nonsignificant variables were the SCI-R ($\beta = 0.09$, $P = 0.46$), duration of diabetes ($\beta = 0.16$, $P = 0.11$), pump use ($\beta = -0.07$, $P = 0.36$), and patient age ($\beta = 0.17$, $P = 0.09$). Overall, in the hierarchical regression analysis, higher scores on the TUPS scale were associated with higher A1C, suggesting that increased frequency of use of the selected technologies was associated with higher A1C.

Discussion

In this study, we sought to assess use of technologies for self-management problem solving, to identify associations between frequency of technology use for problem solving and adolescent characteristics, and to determine the contribution of the use of technologies for diabetes problem solving

in modeling A1C. Previously established predictors, such as diabetes problem solving, self-management, demographics, and clinical factors, were taken into consideration in the model.

Analyses were conducted to relate study variables to the TUPS technology use measure and to estimate the unique variance that technology use for diabetes contributes to the prediction of glycemic control. Overall, adolescents reported modest use of technologies for diabetes problem solving. Using bivariate correlation, self-management and problem solving were related to the TUPS score. It is notable that there was no association between age and the TUPS scale and no relationship between SES and the TUPS scale. Younger adolescents used these technologies for problem solving at the same frequencies as older adolescents.

There have been mixed results in the literature regarding various associations between SES and participation in technology-based diabetes studies. Some studies have indicated that lower SES individuals are less likely to participate in technology-mediated diabetes programs,^{21,22} whereas others identified large proportions of participants with lower SES amenable to technology-based programs to prevent diabetes.²³ Many technologies, such as text messaging and online access, are essentially ubiquitous.²⁴ Given the near-universal access to some technologies, SES may play a less important role today in predicting technology use than when access to technologies was relatively more dependent on family economic resources. Additional research is needed to determine if there is a socioeconomic disparity in the access to common technologies that may be used to help with diabetes self-management.

The regression model demonstrated that after controlling for demographic and clinical variables and including other established behavioral predictors of A1C, the use of technologies for diabetes problem solving was significantly correlated with A1C and contributed significantly to the overall model R^2 . However, although higher problem solving skills were associated with lower A1C, we found that higher technology-facilitated problem solving use scores were associated with higher A1C. In a bivariate nonparametric analysis, no individual item on the TUPS scale was found to correlate significantly with A1C. We had hypothesized that increased use of technology for problem solving would be associated with lower (better) A1C, but the results indicate a counterintuitive relationship between use of common technologies for diabetes and A1C.

Previous research has documented a U-shaped relationship between adolescent health and Internet use.²⁵ In this sample it is possible that adolescents who already practice good self-management behaviors may not find the need to use additional tools or technology to maintain self-management, and it is conceivable that adolescents with poorer glycemic control may use technology in a reactive manner after problems have arisen. Alternately, if a tool or technology is used excessively, the highest-frequency users may create a distraction from self-management. This may be particularly true of social technologies. In order to address these questions, the nature and the frequency of use of these technologies need to be assessed longitudinally.

The cross-sectional design of this study precludes causal inferences regarding associations between technology use for diabetes and glycemic control. Because Internet access was a

TABLE 4. HIERARCHICAL REGRESSION MODEL PREDICTING HEMOGLOBIN A1C

Model block, factor	β	R^2	ΔR^2
Block 1			
Socioeconomic status	−0.26 ^b		
Block 2		0.13 ^b	
Disease duration	0.16		
Pump status	−0.07		
Age	0.17		
Block 3		0.14 ^b	0.01
Self-Care Inventory—Revised	0.09		
Block 4		0.18 ^b	0.04 ^b
Diabetes Adolescent Problem Solving Questionnaire	−0.26 ^a		
Block 5		0.23 ^b	0.05 ^a
Technology Use for Problem Solving	0.26 ^a		

^a $P < 0.05$, ^b $P < 0.01$.

requirement to participate in the survey, the population of adolescents without Internet access is not represented in this sample. Finally, because median household income was obtained by using family addresses and data from the U.S. Census American Community Survey, there is a risk that the contribution of income to the SES index was not sensitive to participants' individual circumstances.

Conclusions

The findings of this study raise interesting questions about our understanding of the importance and role of technology use for diabetes problem solving and self-management. This is the first study to associate commonly available technologies with diabetes outcomes in adolescents with type 1 diabetes. Research has also shown that focused use of specific technologies within an intervention, such as text messaging and the Internet, can improved outcome.^{26,27} In this sample, the unguided use of available tools had a negative relationship with glycemic control. It is likely that more appropriate direction and guidance regarding how and when to leverage elements of these technologies in problem solving could provide opportunities for expanding support for adolescents with diabetes. To date, no research exists on the integration of these technologies in routine pediatric diabetes care.

A limitation of this study is that a single A1C value, measured from the date closest to the survey completion, was used in analyses. Considering the variation of A1C that may occur between clinic visits, as well as the time it can take for new technologies assessed at one point in time to lead to changes in behaviors, future studies evaluating the impact of technology exposure over time may reveal interesting relationships between quantity and duration of technology use and impact on A1C.

In order to advance this research, qualitative aspects of how and when technologies are used or not used to solve diabetes self-management problems need to be identified. Longitudinal studies are called for to ascertain causal relationships among use of technologies, self-management, and A1C. Better understanding of the nature of technology use for diabetes self-management will provide insights regarding how to improve integration of technology into everyday patient problem solving. Finally, further research is essential to determine the way technologies best fit into an adolescent's particular problem solving needs, and how such tools could be adapted over time as those needs change.

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Author Disclosure Statement

No competing financial interests exist.

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