Self-Management Behaviors of Patients with Type 1 Diabetes: Comparing Two Sources of Patient-Generated Data

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Abstract

Objectives This article aims to evaluate adult type 1 diabetes mellitus (T1DM) self-management behaviors (SMBs) related to exercise and alcohol on a survey versus a smartphone app to compare self-reported and self-tracked SMBs, and examine inter- and intrapatient variability.

Methods Adults with T1DM on insulin pump therapy were surveyed about their alcohol, meal, and exercise SMBs. For 4 weeks, participants self-tracked their alcohol, meal, and exercise events, and their SMBs corresponding with these events via an investigator-developed app. Descriptive statistics and generalized linear mixed-effect models were used to analyze the data

Results Thirty-five participants self-tracked over 5,000 interactions using the app. Variability in how participants perceived the effects of exercise and alcohol on their blood glucose was observed. The congruity between SMBs self-reported on the survey and those self-tracked with the app was measured as mean (SD). The lowest congruity was for alcohol and exercise with 61.9% (22.7) and 66.4% (20.2), respectively. Congruity was higher for meals with 80.9% (21.0). There was significant daily intra- and interpatient variability in SMBs related to preprandial bolusing: recommended bolus, $p < 0.05$; own bolus choice, $p < 0.01$; and recommended basal adjustment, $p < 0.01$.

Conclusion This study highlights the variability in intra- and interpatient SMBs obtained through the use of a survey and app. The outcomes of this study indicate that clinicians could use both one-time and every-day assessment tools to assess SMBs related to meals. For alcohol and exercise, further research is needed to understand the best assessment method for SMBs. Given this degree of patient variability, there is a need for an educational intervention that goes beyond the traditional "one-size-fits-all" approach of diabetes management to target individualized treatment barriers.

Keywords
- diabetes mellitus
- surveys or interviews
- self-care
- smartphone
- patient-generated data

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Background and Significance

Type 1 diabetes mellitus (T1DM) is a complex, chronic disease that requires consistent medical care, education, and support to maintain blood glucose (BG) in the desired target range.[1] Therapeutic adherence and a willingness to engage in ongoing patient self-management of the disease are essential. According to the American Diabetes Association, necessary self-management behaviors (SMBs) include monitoring glucose, recording carbohydrate intake, and administering insulin.[2] Studies based on insulin pump data show that consistent engagement in SMBs and adherence to standard treatment protocols result in better glycemic control (avoidance of hypoglycemia and hyperglycemia).[3,4] Lack of proper SMBs can negatively impact a patient's physical health (e.g., morbidity, mortality), psychological health (e.g., depression), quality of life, and healthcare utilization and cost.[5]

Patients' lifestyle choices and behaviors play a crucial role in their ability to manage diabetes effectively. Patients have to consistently and appropriately compensate for those and other behaviors to maintain a satisfactory quality of life. Lifestyle preferences such as alcohol and exercise are known to impact BG levels and increase the risk of hypoglycemia; yet, these two important lifestyle choices may not be routinely explored or discussed during a busy and time-compressed visit with a practitioner.[6–9] Self-management is inescapable, especially for T1DM, and the important question is not whether, but how, patients manage their conditions daily.[10] Studies that have evaluated the SMBs of patients with T1DM, especially those related to exercise and alcohol, found variability in SMBs.[11–18] Previous research has primarily focused on diabetes adherence and SMBs in adolescents or children, as such little is known about SMBs in adults with T1DM.[19–23]

Understanding adult T1DM SMBs is necessary for clinicians to identify potential areas of improvement for their patients, and to allow researchers to develop better tools that could support more consistent and evidence-based decision making by patients when compensating for lifestyle choices such as alcohol consumption or engaging in exercise. A simple and practical method that is reliable and valid for assessing patients SMBs could be a valuable tool for clinicians and researchers. Self-reporting by means of surveys or interviews is one of the most widely used methods for evaluating SMBs and has been used in previous studies to understand SMBs for patients with T1DM.[11,16,21] Assessing SMBs using self-reported data collected by means of surveys or interviews is simple and easy, and can provide useful information about SMBs. But retrospective self-reporting can be subject to recall error and social desirability.[21,24]

Smartphone applications (apps) have been identified as tools to facilitate real-time self-tracking of daily activities related to SMBs.[25–28] With this method, a patient can document a SMB at a decision point (e.g., eating a snack at the beginning of an exercise routine). This method is more advanced than a paper-based self-tracking mechanism, but it requires time and training. This method can also be subject of the "simply forgot" problem, one of the well-known factors related to nonadherence.[29–31]

The authors have previously published data on a smartphone app, iDECIDE, to self-track SMBs for exercise, meals, and alcohol in real time.[25] The app was designed using a user-centered design framework and evaluated in two phases. Phase 1 was conducted with healthy adult participants and phase 2 with people with T1DM. Feedback from those studies was used to develop the final version of the app which was tested in a small study of 13 participants with T1DM on insulin pump therapy to analyze patients' actual behaviors against those self-reported with the app as related to meals, exercise, and alcohol.[25] The study indicated that compensation techniques and perceptions on how exercise and alcohol affect BG vary between patients. The mean (SD) congruency rates of survey responses and the app logs for SMBs related to alcohol, exercise, and meals events were 35% (35), 46% (41), and 77% (25), respectively.

Objectives

The objective of this study was to expand our previous research to evaluate SMBs of 35 participants related to meal, exercise, and alcohol as reported on a survey and recorded on a smartphone application (app)[25] and to determine congruity between SMBs self-reported on the survey and self-tracked with the app, and examine inter- and intra-patient variability of SMBs.

Methods

Clinical Setting

The study site was an outpatient academic endocrinology clinic that evaluates and treats people for endocrine and metabolic disorders. The study team met with the endocrinologist and members of the diabetes care team to provide details on the study and to identify adults with T1DM on a Medtronic insulin pump and any brand of continuous glucose monitor (CGM). The study was limited to Medtronic insulin pumps to simplify algorithm development. Most patients in this clinic use Medtronic insulin pumps. Potential participants were identified through chart reviews and were approached about the study during scheduled outpatient visits, where they were handed a flyer that provided details on the study. Participants were between the ages of 18 and 80 years, nonpregnant, English speaking, owned a personal smartphone, used a Medtronic insulin pump for at least 1 year, used a CGM, and were under the care of the clinic for at least 1 year. Participants were recruited between 2016 and 2018.

Study Design

An electronic survey regarding SMBs was administered onsite to participants after consenting. The survey asked about participants' SMBs related to meals, alcohol, and exercise. After completing the survey, participants installed the app developed by the research team and used it to track meals, alcohol intake, and exercise for 4 consecutive weeks.[25] Participants were advised to maintain their usual daily routine during the study period. The study team was available to provide technical support both in person and online throughout the study.

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Follow-up weekly emails were sent to participants, offering clarification of doubts or resolution of problems related to the app, data download, or any other aspect of the study.

Survey

The study team developed an electronic survey that contained 11 structured questions, 14 semistructured questions with a free text response option "other," and 10 free-text questions. The questions were adapted from themes that emerged from patient interviews from a pilot study.[25] The objectives of the survey were to (1) collect demographic data; (2) gather information on participants' perceptions of how carbohydrates, alcohol, and exercise affect BG control and the sources of this knowledge; and (3) collect information on participants' self-reported SMBs in relation to meals, alcohol, and exercise.

The survey was administered onsite to participants after consenting. Survey responses were downloaded in spreadsheet format and were quantified to obtain summary statistics. Participants' survey perceptions about factors related to alcohol and exercise that affect BG were automatically sorted into three categories (yes, no, and unsure) to identify the counts and frequencies of those factors in each category.

Mobile App

The developed app was installed on participants' smartphones during the recruitment appointment. Participants were trained on the use of the app and provided an instruction manual. Participants were asked to use the app to self-track meals, alcohol intake, and exercise (►Fig. 1) for 4 consecutive weeks. When logging these events, participants were instructed to select one or more of the SMB options from a list (►Table 1). For exercise, participants were required to provide the start time, duration, and intensity. Participants then selected one or more of the following exercise-related SMBs: basal adjustment, my bolus choice, pump's bolus suggestion, pump disconnect, snack intake, other technique, and no SMB.

For meals and alcohol, participants could enter multiple meal items at once. They provided a text description of the food or alcohol as well as the carbohydrate content. When logging meals, participants could choose one or more of the following SMBs: square bolus adjustment, my bolus choice, pump's bolus suggestion, basal adjustment, other technique, and no SMB. In the same way, when logging alcohol, participants were asked to select one or more of the following SMBs: snack intake, square bolus adjustment, basal adjustment, my bolus choice, pump's bolus suggestion, other technique and or no SMB. The app logs were synchronized to a secure cloud-based server and were downloaded in a spreadsheet format at the end of the study.

Comparison of the Survey Responses and the Mobile App Logs

Using Excel, we compared the number of participants who reported a SMB in the survey with the number of participants who actually self-tracked that SMB with the app. Next, we used

Fig. 1 Screenshots of the app that was installed on the subject's smartphone. Subjects could self-track exercise by indicating (**A**) duration, intensity, start time, and (**B**) compensation techniques used to self-manage glucose. Meals and alcohol were self-tracked with the same interface, by providing (**C**) text description of meal or alcohol, carbohydrate count, while also attaching a photo and time to the log. Subjects were then prompted to select (**D**) meal and (**E**) alcohol compensation techniques.

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Table 1 A summary of the available self-management behavioroptions for self-tracking

Self-management behavior options	Definition	Meal	Alcohol	Exercise
Basal adjustment	Change basal rate	A	A	A
My bolus choice	Bolus insulin based on self-suggestion	A	A	A
Pump's bolus suggestion	Bolus insulin based on pump's recommendation	A	A	A
Pump disconnect	Disconnect from the insulin pump			A
Square bolus adjustment	Change bolus waveform from dual to square or vice versa	A	A	
Snack intake	Consume snack		A	A
Other technique	Other techniques not listed	A	A	A
No SMB	Do not use any SMB	A	A	A

Note: An "A" indicates that the SMB option was available in the app for self-tracking for that event.

a congruity metric proposed by the authors in a previous study to contrast SMBs reported on a survey versus those self-tracked with a smartphone app.[25]

The survey's answers for each participant were compared against the self-tracked logs. A match score was assigned to the participant's response by determining if the participant reported a SMB in the survey and tracked that SMB with the app. If yes, the participant received a match score of 1 for that SMB. If no, the participant received a match score of zero. Next, the match scores earned by the participant were summed up. The numbers of SMB were also counted for the event type (i.e., meal, alcohol, or exercise). Finally, the total match score was divided by the total count of SMB and multiplied by 100. For the example shown in ►Table 2, three out of four times there was agreement between the alcohol SMBs self-reported in the survey and the SMBs self-tracked with the app. This led to a 75% match.

Within- and between-Patient Variability in Self-Management Behaviors

To examine variability in SMBs both within and across patients, we fit generalized linear mixed-effect models (GLMM) to the most common SMBs from the self-tracking meal logs. The most common SMBs were square bolus adjustment, my bolus choice, and pump's bolus suggestion. At each meal, participants could use none, one, or more of these SMBs and each is coded 0 if the SMB was not used and 1 if the SMB was used. For instance, if a participant utilized the pump's bolus recommendation when eating a meal, and did not use another SMB, then participant would be assigned a 1 for pump bolus and 0 for the rest of the SMBs. This was done for the three SMBs of interest (square bolus adjustment, my bolus choice, pump's bolus suggestion) for each meal for each participant.

Table 2 Example of congruity computations between SMB behaviors self-reported in a survey and self-tracked in the app

SMB	Survey	Self-tracked	Match	% match
Basal adjustment	Y	Y	1	$3/4 \times 100 = 75$
Pump's bolus suggestion	N	N	1	
My bolus choice	N	Y	0	
Other	N	N	1	

Abbreviations: N, no; SMB, self-management behavior; Y, yes.

The GLMM was separately fit to each repeatedly measured SMB. The GLMM was specified with a logit link function (Eq. 1). The person-level deviation is assumed to be normally distributed with a mean of 0 and an estimated variance (i.e., $u_i \sim N(0, ó_u^2)$ and the day-level deviation is assumed to be normally distributed with a mean of 0 and an estimated variance (i.e., $s_{di} \sim N(0, ó_s^2)$). Thus, the $ó_u^2$ is the between-patient variance indicating how much patients differ in their average level of each SMB, and $ó_s^2$ is the within-patient variance indicating how much patients differ from their average level of each SMB across days.

$$\left(\frac{P(y_{mdi} = 1)}{1 - P(y_{mdi} = 1)}\right) = \beta_{000} + u_i + s_{di}$$

Equation 1 GLMM with a logic link function. $P(y_{mdi} = 1)$ is the probability of using the SMB at meal m on day d for person i, β_{000} is the fixed effect for the intercept representing the grand mean of the log-odds of utilizing the SMB for the sample, u_i is the deviation from β_{000} for person i, such that $\beta_{000} + u_i$ is the log-odds of utilizing the SMB for person i, and s_{di} is the deviation from $\beta_{000} + u_i$ on day d for person i.

To examine whether each variance term is needed, we use a model comparison approach. For each SMB, three models were fit: (1) the GLMM with both terms of variance estimated, (2) the GLMM with $ó_u^2$ set to 0, and (3) the GLMM with $ó_d^2$ set to 0. Models 2 and 3 are nested under Model 1 and their model fits can be compared using likelihood ratio tests. If Model 2 fits significantly worse than Model 1, then the between-patient variance $ó_u^2$ is nonzero, suggesting that patients differ in their average level of the SMB. If Model 3 fits significantly worse than Model 1, then the within-patient variance $ó_s^2$ is nonzero, suggesting that patients differ in their SMBs across days.

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Table 3 Factors related to alcohol that affect blood glucose reported by participants ($n = 23$) who indicated in the survey that they consumed alcohol

Activity	Relevant factors	Yes	No	Unsure
Alcohol	Combination of alcohol with food	95.7%	4.3%	0%
	Food intake before alcohol	87.0%	13.0%	0.0%
	Type of drink	87.0%	8.7%	4.3%
	Number of drinks	73.9%	17.4%	8.7%
	Prealcohol blood glucose	69.6%	21.7%	8.7%
	Time of the day	26.1%	73.9%	0%

Results

Demographics

Thirty-five participants with T1DM were recruited. Demographics were calculated as mean (SD). The age was 49 (SD: 15) years with 31 (SD: 16) years diagnosed with T1DM and 15 (SD: 8) years of pump usage. The HbA_{1C} was 7.0 (SD: 0.94). All participants were Caucasian and 24 were females. There were 5,007 patient interactions with the pump. There were 4,371 meal events recorded by 35 participants, 204 alcohol events recorded by 23 participants, and 432 exercise events recorded by 29 participants. Twelve participants did not consume alcohol and 6 did not engage in exercise. Those participants were excluded from further analysis.

Participant Perceptions of How Alcohol and Exercise Affect Blood Glucose, as Recorded by the Survey

When asked in multiple-choice questions about the impact of alcohol and exercise on glucose control, participants provided a variety of responses (►Tables 3 and 4). Of the 23 participants who indicated in the survey that they drink alcohol, the majority (95.7%) responded that alcohol only affects glucose levels when consumed in combination with food. The type of food that is consumed prior to alcohol intake and the type of drink were the next popular factor that was reported by 87.0% of participants to have an effect on BG. Other factors that were reported to have an impact on BG included number or drinks (73.9%) and BG level prior to alcohol intake (69.6%). The least reported factor for alcohol was time of the day, which was reported by 26.1% of participants.

For exercise, of the 29 participants who indicated in the survey that they exercise, 96.6% reported that exercise intensity affects glucose control, 93.1% responded that the effect depends on the type of exercise, 82.8% indicated that the duration of exercise affects glucose control, 79.3% said that the effect depends on the BG prior to exercise, and 65.5% reported that it depends on food that is consumed before exercise. Time of the day was the least reported factor related to exercise felt to affect glucose control (55.2%).

Table 4 Factors related to exercise that affect blood glucose reported by participants ($n = 29$) who indicated in the survey that they exercise

Activity	Relevant factors	Yes	No	Unsure
Exercise	Intensity	96.6%	0%	3.4%
	Type	93.1%	0%	6.9%
	Duration	82.8%	13.8%	3.4%
	Preexercise blood glucose	79.3%	17.2%	3.4%
	Preexercise meal	65.5%	24.2%	10.3%
	Time of the day	55.2%	37.9%	6.9%

Table 5 Participants who self-reported and self-tracked SMBs for alcohol ($n = 23$) and indicated in the survey that they consumed alcohol

Activity	SMB	SMB self-reported with survey	SMB self-tracked with app
Alcohol	Eat snack	65.2%	56.5%
	Insulin bolus	60.9%	95.7%
	Basal adjustment	34.8%	39.1%
	Other	47.8%	8.7%
	No compensation	17.4%	30.4%

Abbreviation: SMB, self-management behavior.

Participants' Self-Reported versus Self-Tracked Self-Management Behaviors

When survey responses were compared with participants' self-tracked logs, there were inconsistencies in what participants reported versus what they tracked with the app (►Tables 5, 6 and 7), especially for alcohol and exercise. For instance, with regard to alcohol, of the 23 participants who drank alcohol, 60.9% reported bolusing insulin to compensate for alcohol, while the app logs showed that 95.7% participants tracked this technique. In terms of other SMB techniques, 47.8% reported that technique in the survey, but only 8.7% indicated using it in the app.

Similar inconsistencies were observed with exercise logs. For example, 93.1% of 29 participants reported eating a snack

Table 6 Participants who self-reported and self-tracked SMBs for exercise ($n = 29$) and indicated in the survey that they engaged in exercise activity

Activity	SMB	SMB self-reported with survey	SMB self-tracked with app
Exercise	Eat snack	93.1%	72.4%
	Basal adjustment	65.5%	51.7%
	Pump disconnection	51.7%	37.9%
	Insulin bolus	24.1%	65.5%
	No compensation	6.9%	34.4%
	Other	3.4%	10.3%

Abbreviation: SMB, self-management behavior.

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Table 7 Participants who self-reported and self-tracked SMBs for meals ($n = 35$)

Activity	SMB	SMB self-reported with survey	SMB self-tracked with app
Meals	Pump's bolus suggestion	97.1%	97.1%
	My bolus choice	65.7%	80%
	Basal adjustment	42.9%	48.6%
	Other	5.7%	48.6%
	No compensation	0%	34.3%

Abbreviation: SMB, self-management behavior.

as a technique to self-manage exercise, but only 72.4% participants self-tracked this technique. On the other hand, 24.1% of the participants reported delivering insulin bolus to compensate for exercise, but 65.5% participants tracked this technique.

For meals, 97.1% of the 35 participants reported following pump's bolus recommendations in both the survey and the app. There were minor inconsistencies related to "my bolus choices" and basal adjustment when comparing self-reported and self-tracked data. Bigger inconsistencies were found between self-reported and self-tracked SMBs related to other compensation techniques or no compensation techniques: 48.6% participants self-tracked other compensation techniques but only 5.7% self-reported that SMB, and 34.3% participants self-tracked no compensation technique while that SMB was not self-reported in the survey.

The congruity of SMBs reported on the survey versus self-tracked with the app was lowest for alcohol 61.9% (22.7) and exercise 66.4% (20.2), and highest for meals 80.9% (21.0).

Within- and between-Patient Variability in Self-Management Behaviors

Recommended Pump Bolus (Pump Bolus)

The −2 log-likelihood for the full model (Model 1) was 5,243.2, and setting the variance terms to 0 significantly harmed model fit ($\Delta -2LL = 150.88$, $\Delta parms = 1$ when dropped the day-level variance term, and $\Delta -2LL = 310.23$, $\Delta parms = 1$ when dropped the person-level variance term), suggesting that both variance terms are nonzero. The fixed effect for the intercept was 0.53 ($SE = 0.24$, $z = 2.16$, $p < 0.05$), suggesting that *participants utilized the recommended pump bolus slightly more than half of the time (on average)*. The person-level variance was 1.31, indicating that participants' log-odds of using the recommended pump bolus generally ranged from −1.71 to 2.77 (95% confidence interval for between-person differences), which equates to between 15 and 94% of the time. Thus, *some patients utilize the recommended bolus infrequently (15% of the time), whereas other patients utilize the recommended bolus very frequently (94% of the time)*. The day-level variance was 0.93, suggesting *large day-to-day variability in a participant's use of the recommended bolus*. For example, say a patient uses the recommended bolus 50% of the time, on average (i.e., $\hat{a}_{000} + u_i = 0$). Across days, this individual may use the recommended bolus anywhere between 13 and 87% of the time.

Participant's Own Bolus Recommendation (My Bolus choice)

The −2 log-likelihood for the full model was 2,630.5. Setting the variance terms to 0 significantly harmed model fit ($\Delta -2LL = 127.91$, $\Delta parms = 1$ when dropped the day-level variance term, and $\Delta -2LL = 222.45$, $\Delta parms = 1$ when dropped the person-level variance term), suggesting that both variance terms are nonzero. The fixed effect for the intercept was −2.66 ($SE = 0.51$, $z = -5.25$, $p < 0.01$), suggesting that *participants utilized the "my bolus" option ~7% of the time, on average*. The person-level variance was 5.66, indicating that *participants used the "my bolus" options between 0 and 12% of the time*. The day variance was 1.76, suggesting a *large amount of day-to-day variability in using this SMB within patients*.

Recommended Basal Adjustment (Basal Adjustment)

The −2 log-likelihood for the full model was 740.0. Setting the variance terms to 0 significantly harmed model fit ($\Delta -2LL = 11.3$, $\Delta parms = 1$ when dropped the day-level variance term, and $\Delta -2LL = 57.36$, $\Delta parms = 1$ when dropped the person-level variance term). The fixed effect for the intercept was −5.79 ($SE = 0.79$, $z = -7.28$, $p < 0.01$), suggesting that *participants rarely utilized the "basal adjustment"* (0% of the time, on average). The person-level variance was 8.83, *indicating large between-patient differences in the use of basal adjustment*. Thus, some participants used basal adjustment up to 51% of the time (upper limit of 95% confidence interval on between-person differences). The day-level variance was 0.98, indicating a *fair amount of day-to-day variability within participants*.

Discussion

T1DM is a patient-managed disease which requires consistent patient engagement and educated decision making in real time to manage the disease effectively. Maintenance of good glycemic control is necessary to prevent the complications that can occur from diabetes. Patients' SMBs related to meals, alcohol, and exercise directly impact glycemic control and are not well understood. While retrospective self-reported SMBs gathered from surveys or interviews[11,16,21] are informative, they can be subject to recall error (i.e., inaccurately remembering and reporting behaviors) and social desirability (i.e., overreport favorable behavior and underreport poor behavior).[21,24]

Our results on variability of SMBs in adults are consistent with studies that have evaluated SMBs in youth and children with T1DM using insulin pumps.[32,33] Our previous work in T1DM patients on insulin pump therapy using data from a survey in conjunction with real-time data collection using a mobile app indicated a high variability in patient SMBs.[25] In addition, it indicated inconsistency in what patients reported they did and what they actually did as recorded on the app. This current study adds to the previous one with

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increasing sample size (from 13 to 35 participants), and is consistent in noting both intra- and interpatient variability in SMBs related to diabetes management.

The variability in patient perceptions and SMBs exposes the need to better understand patient's unique lifestyle choices and the way they impact SMBs and glycemic control. The current study analyzed over 5,000 patient interactions with the app. The congruity between SMBs self-reported on the survey and those self-tracked with the app was lowest for alcohol and exercise with 61.9% (22.7) and 66.4% (20.2), respectively. This is not surprising, as current bolus calculators do not take into account alcohol and exercise, and patients must decide on their own in real time how to compensate for these behaviors. It is quite possible that this inconsistency in behavior is a consequence of lack of education on the impact of alcohol and exercise on glycemic control. This may be an area of educational that could be targeted in certain patients. Although there was more congruity with meals (80.9%), there was significant daily intra- and interpatient variability in SMBs related to preprandial bolusing: recommended bolus, $p < 0.05$; own bolus choice, $p < 0.01$; and recommended basal adjustment, $p < 0.01$. Our data reported that participants utilized the recommended bolus slightly more than half of the time on average. However, there was inconsistency in this behavior with some patients using the recommended bolus very infrequently (<15% of the time) and others using it very frequently (94% of the time). In addition, there was a large day-to-day variability in a participant's use of the recommended bolus.

Our results suggest that participants utilized the "my bolus" option ~7% of the time on average. Future in-depth analysis of patient reasoning when administering a bolus is required to allow for a better understanding of why patients are choosing one bolus type over another, if it is appropriate based on the glucose level and situation, and whether or not further individualized patient education may be warranted to improve outcomes. Having a complete understanding of a patient's behaviors in a particular situation and the reasoning behind them may allow for better more individualized education that could have the potential for improving glycemic outcomes.

Limitations

The sample sizes for exercise and alcohol events were small when compared with the meal events. In addition, the demographics of the cohort in this study may not be representative of the general T1DM population based on race and HbA1C.

The study was limited to participants using the Medtronic insulin pump. Future research could utilize environments like the ones developed by Glooko and Tidepool for integrating data from multiple devices. At the time we began this study, neither platform provided support for the Medtronic insulin pumps; hence, we were not able to utilize them.[34,35]

In the future, we anticipate more automation of data collection and analysis. We anticipate being able to integrate the next version of the app with the Apple's HealthKit framework, which has the ability to connect with MyChart (patient portal of the most commonly used electronic health record system in the United States), in near real time.[36]

We did not include patient factors such as age, daily activity level, and experience or confidence with using technology in the analysis. Future research needs to examine these factors and determine if they are associated with lesser congruity in SMBs.

Future Work

Study participants are being recontacted for follow-up interviews. During the one-on-one interview with a diabetes educator, each patient will be presented with a personalized report of SMBs created using data captured by the app and diabetes technology (CGM and pump). The main goal of these interviews is to find out if patients are aware of the inconsistencies between self-reported and self-tracked data and understand reasons behind intra- and interpatient SMB variability. Results from the interviews will be used to develop personalized diabetes education interventions to target patient-specific treatment adherence barriers to improve SMBs and glycemic control.

Conclusion

The results of this study provide insights about SMBs used by patients with respect to meals, exercise, and alcohol. This study highlights the variability in intra- and interpatient SMBs obtained through the use of a survey and app. Given this degree of patient variability, there is a need for an educational intervention that goes beyond the traditional "one-size-fits-all" approach of diabetes management to target individualized treatment barriers. Reviewing self-tracking of SMBs along with data generated by patients' CGMs and insulin pumps could prove useful to clinicians and patients in the clinic and allow for quick identification of behaviors to be improved upon and for individualized patient education.

Clinical Relevance Statement

The outcomes of this study indicate that patients with T1DM on insulin pump therapy self-manage their diabetes differently, and patients are highly inconsistent in their daily approaches to compensate for meals, exercise, and alcohol events. Outcomes of this study suggest the need for better understanding of patient reasoning behind SMB decisions and better data-driven individualized patient education. More effective data-driven computational methods to analyze data collected by devices, such as apps, insulin pumps, and CGMs, are also needed to help clinicians identify patient-specific SMBs that could be modified through individualized interventions to improve glycemic control.

The outcomes of this study indicate that clinicians could use both one-time (e.g., survey) and everyday (e.g., app) assessment tools to assess SMBs related to meals. For alcohol and exercise, further research is needed to understand if a one-time or everyday assessment method should be preferred to accurately assess SMBs.

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Multiple Choice Questions

1. Which of the following statements about diabetes self-management behaviors is correct?
   a. Alcohol does not impact blood glucose levels or increase the risk of hypoglycemia.
   b. Exercise does not impact blood glucose levels or increase the risk of hypoglycemia.
   c. Patients who consistently engage in self-management behaviors and adhere to standard treatment protocols have a better glycemic control.
   d. There is low variability in how participants perceived the effects of exercise and alcohol on their blood glucose.

   Correct Answer: The correct answer is option c. Studies based on insulin pump data show that consistent engagement in self-management behaviors and adherence to standard treatment protocols result in better glycemic control. Lack of proper self-management behaviors can negatively impact a patient's physical health (e.g., morbidity, mortality), psychological health (e.g., depression), quality of life, and healthcare utilization and cost.

2. When used the congruity metric to contrast SMBs reported on a survey versus those self-tracked with a smartphone app, which behaviors were found to be highly (>70%) congruent?
   a. Exercise behaviors.
   b. Alcohol behaviors.
   c. Sleep behaviors.
   d. Meal behaviors.

   Correct Answer: The correct answer is option d. The congruity metric showed high concordance of 80.9% for SMBs related to meals, but lower concordance of 61.9% for alcohol and 66.4% for exercise. Sleep behaviors were neither tracked nor quantified in this study.

Protection of Human and Animal Subjects

This study was reviewed by the Mayo Clinic and the Arizona State University Institutional Review Boards.

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Conflict of Interest

None declared.

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