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Usability Testing of A Carbohydrate Counting Application designed For and With Young Adults with Type 1 Diabetes

Asmaa Housni, Aidan Shulkin, Alexandra Katz, Giuliana Giannini, Amélie Roy-Fleming, Meranda Nakhla, Courtney South, Anne-Sophie Brazeau

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Preprint
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Abstract

Background: Carbohydrate counting assists people with type 1 diabetes (T1D) adjust mealtime insulin doses, however, it is often burdensome. Mobile applications can simplify this process by automating carb estimation and insulin calculations, yet no comprehensive solution currently combines photo-based carb recognition with an integrated bolus calculator.

Objective: This study aimed to optimize a novel app designed to support young adults with T1D in carbohydrate counting and insulin dosing by incorporating feedback from usability testing.

Methods: We used a think-aloud protocol and conducted four rounds of interviews, each with 3–5 participants, to assess effectiveness of the app and identify areas for improvement.

Results: A total of 18 completed the usability testing. Thematic analysis revealed seven key insights; 1) A person-centered design is important for an individualized experience, addressing the individual as a whole, not just their diabetes; 2) An intuitive user interface is essential to maintain engagement, with clear information presentation and easy interaction; 3) The relevance of information, should be presented in familiar language to enhance identification and inclusion; 4) Personalized features for a tailored user experience; 5) Robust data verification mechanisms and override abilities to avoid human and technological errors; 6) A comprehensive application to improve patient-practitioner communication and reduce manual tracking or the use of multiple apps; 7) Linkage of various factors (exercise, diet, time of injection) to glucose levels could improve self-efficacy and promote personalized learning.

Conclusions: This will be the first Canadian app to combine carbohydrate counting and insulin dosing while involving end users in its development.

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Highlights:

- An app design that allowed linking lifestyle factors (e.g., exercise, diet, insulin timing) to glucose trends was perceived as beneficial for personalized learning and self-efficacy.
- A person-centered design that considered the whole person, not only their diabetes, was viewed as supporting individualized experiences.
- A comprehensive application design that minimized reliance on manual tracking or multiple apps was seen as particularly valuable to facilitate communication with practitioners

Keywords: Type 1 diabetes, mobile application, youth, usability testing

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Background: Carbohydrate counting assists people with type 1 diabetes (T1D) adjust mealtime insulin doses, however, it is often burdensome. Mobile applications can simplify this process by automating carb estimation and insulin calculations, yet no comprehensive solution currently combines photo-based carb recognition with an integrated bolus calculator.

Aims*:* This study aimed to optimize a novel app designed to support young adults with T1D in carbohydrate counting and insulin dosing by incorporating feedback from usability testing.

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Conclusion: This will be the first Canadian app to combine carbohydrate counting and insulin dosing while involving end users in its development.

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Introduction

Type 1 diabetes (T1D) is an autoimmune condition resulting in pancreatic beta cell destruction [1]. People with T1D need daily administration of insulin to regulate glucose levels and prevent acute events and long-term health risks [2, 3]. Intensive insulin therapy through carbohydrate counting (CC) is the recommended treatment for individuals living with T1D due to its association with lowered glycated hemoglobin (HbA1c) levels, and the prevention of diabetes-associated complications [4-6]. Moreover, CC offers dietary flexibility by allowing individuals to tailor their mealtime insulin based on the carbohydrate content of their meals [7]. However, CC adherence can be burdensome and challenging as it requires tracking intake, reading and interpreting nutrition labels, and weighing portions [8, 9]. Additionally, calculations are multifactorial and prone to error, due to the complexities of combining insulin sensitivity factor, insulin-to-carbohydrate ratio, and glucose targets [10].

The transition from childhood to adulthood introduces an additional barrier to CC, namely due to social and developmental changes commonly observed in this age group [11-13], and CC tasks transferred from parent to child. A study by Gurmani *et al*, reported that 43.6% of adolescents inaccurately calculated carbohydrates by 10–20 g from the actual amount [14]. Incorrectly identified meals either lacked nutrition labels or required fiber subtraction to calculate carbohydrates accurately, underscoring the difficulty young adults face estimating carbohydrates in unpackaged foods [14]. This contributes to the broader challenge of achieving glycemic stability during adolescence and young adulthood, as evidenced by the higher HbA1c levels observed in these age groups compared to others [13]. Given the various benefits of CC, strategies are needed to promote its proper use among youth.

A promising solution lies in mobile health (mHealth), a branch of telemedicine that utilizes technology such as mobile devices and tablets to improve healthcare services for both patients and healthcare providers [15]. In the context of diabetes management, mHealth can automate CC as a

novel care approach for individuals living with T1D. In fact, the efficacy of mHealth, i.e. the use of smartphone or tablet applications (hereafter “apps”) in improving diabetes self-management among adults, is well established [16-18]. Despite the large variety of apps able to offer photo recognition powered by artificial intelligence (AI) to quantify meal composition, most are not designed for diabetes management, few have been tested in a clinical setting, and even fewer limit their search to validated food databases only [19]. Additionally, while there are separate apps available for bolus insulin calculations, few have undergone usability testing or been developed using user-centered design approach, raising concerns about the safety of insulin calculation apps [20]. A needs assessment survey was conducted across Canada to identify the needs of people with T1D, including youth, in an app designed to alleviate the burden of CC. The main results of the survey emphasized the need for an app offering nutrient analysis, insulin bolus calculations, app personalization, and support from healthcare professionals [21].

Scientific literature has demonstrated a need for a comprehensive app tailored for individuals living with T1D which integrates accurate CC and bolus insulin calculations. Thus, we collaborated with *Ikigai Development inc.*, a company specializing in app development, to design the *Petit Cactus* app, which involved users in the development process to promote a user-centered design [22]. The *Petit Cactus* app was designed to include four main features: 1) the ability to calculate the number of carbohydrates in meals either through AI-powered photo recognition or through manual selection of food items, with data derived from validated Canadian food databases, 2) bolus insulin dose calculation that incorporates multiple variables (glucose levels, insulin-to-carb ratio, and correction factors), and integrates continuous glucose monitoring (CGM) data to help users visualize how logged events (i.e., meals, stress, sick-days, physical activities) affect glucose levels, 3) an electronic food journal for reviewing logged meals and event history, and 4) a connecting portal to a healthcare provider interface.

The study emphasizes a user-centered design approach by conducting usability testing with

young adults living with T1D [23]. This involves integrating user feedback into app development to enhance the user experience. The objective is to optimize app usability through collaborative design, aiming to better support adolescents with T1D.

Methods

Study Design

Usability testing with young adults involved four iterative rounds, each with a new group of three to five participants testing an updated version of the *Petit Cactus* app refined based on feedback from previous rounds. Individual interviews were conducted, followed by one week of independent use and completion of a feedback questionnaire to capture additional insights (Figure 1). The study was approved by McGill University Research Ethics Board (# 23-04-018).

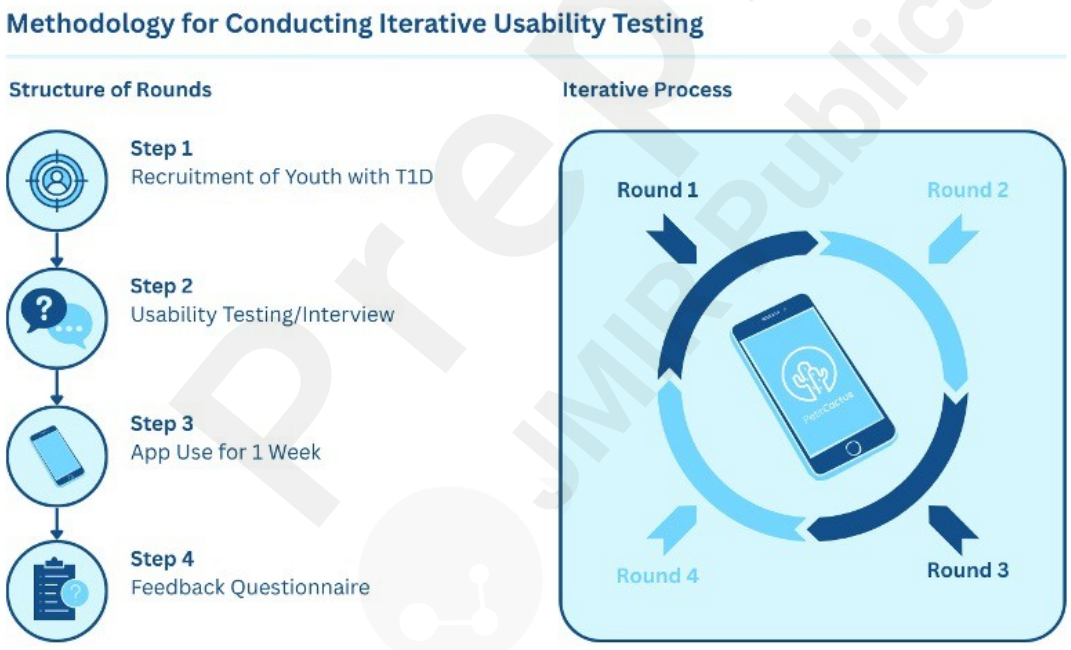


Figure 1. Methodology for conducting iterative usability testing.

Eligibility Criteria

Young adults aged 14 to 24 years, with a T1D diagnosis >1 year, using intensive insulin therapy (i.e., basal-bolus injections or insulin pump therapy), and residing in Canada, were eligible to participate

in the usability testing.

Participant Recruitment and Consent

Recruitment was conducted using convenience sampling from the BETTER registry, a volunteer registry of individuals living with T1D in Canada [24]. Canadian diabetes organizations, social media, and word of mouth. Prior to enrolment in the study, each participant provided an informed consent and completed a demographic and background questionnaire on Limesurvey (LimeSurvey GmbH, Hamburg, Germany) hosted on secure servers. Adults aged ≥18 years provided their own consent, and parents or legal guardians provided consent for participants aged 14-17 years.

Procedures

Following consent, participants were contacted by email to schedule an interview. Subsequently, a link to a Microsoft Teams meeting was sent. One or two days preceding the interview, participants received a user guide to the app with access and log in information. Interviews were 60 to 90 minutes in length, and included the participant, the interviewer, and an observer who took notes to complement verbatim transcripts, when necessary. Prior to commencing the interview, participants were reminded of the objective of the usability testing and their role in the co-design process: to provide feedback on their impression of the app and necessary changes required to improve its functionality. Users were encouraged to interact with the app in a sequential order, starting with completing their user profile and dashboard, and then later trialing the various features (i.e. meal entry, the bolus insulin calculator) (**Appendix A**). Participants were asked to verbalize their thoughts while navigating the app, and when necessary, were asked probing questions from the discussion guide to gather more details on their opinion of the app (i.e. functionality, design, ease of use). Following the interview, participants used the app for one week and were then requested to complete a final questionnaire including 8 open-ended questions focusing on potential barriers to app use,

usability of the different features (i.e., the food journal, meal entry and CC, readability of glucose graphs, desired support from healthcare providers), as well as their motivations for trying the app, and ideas for enhancing engagement (**Appendix B**). Upon completion of the interview and questionnaire, participants were provided a $50 CAD gift card of their choice from a selection of retailers as a compensation for their time and participation in the study.

Data Collection

The interviews were recorded and transcribed using Microsoft Teams. Three members of the research team (A.H., A.S., G.G.) verified the accuracy of the transcripts and anonymized all identifiable information. The transcripts were then translated from French to English using a forward-backward translation method [25], when necessary.

Data Analysis

The transcripts were open coded independently by three researchers (A.H., A.S., G.G.) , using MAXQDA (version 24, VERBI GmbH, Berlin, Germany), to develop a preliminary code book [26]. Interviews were conducted in four rounds, with thematic saturation reached within each round, and overall saturation achieved by the fourth round. Two researchers then independently coded all transcripts using the finalized codebook. To ensure consistency, two transcripts were initially co-coded, and discrepancies were discussed until consensus was reached, leading to refinement of code definitions. The remaining transcripts were coded independently, with regular meetings held to compare coding decisions and resolve any discrepancies through discussion. An inductive thematic analysis was conducted to interpret the data [27], during which established codes were clustered into broader themes.

Results

Participants

Twenty participants were recruited and provided consent. However, two participants were excluded due to not meeting the inclusion criteria for age and T1D diagnosis, despite self-reporting eligibility in the initial online survey. A total of 18 eligible participants completed the interview and the questionnaire. About two thirds of the participants identified as women (n=12, 66.7%), and Caucasian (n=11, 61.1%). The median [IQR] age was 23 [19-24] years and a diabetes duration of 9 [6-12] years. Almost all participants (n=17, 94.4%) used CGM systems. The majority used an insulin pump to administer insulin (n=14, 77.8%), and 12 (66.7%) used an automated insulin delivery system. Participants' characteristics are outlined in **Table 1**.

Table 1. Participant Characteristics

	n (%) or median [IQR]
Demographics	n=18
Age, years	23 [19 - 24]
Gender, women	12 (66.7%)
Country of birth,[a] Canada	15 (83.3%)
Ethnicity[b]	
White/Caucasian	11 (61.1%)
Black (African, Afro-American, Caribbean)	3 (16.7%)
Arab	1 (5.6%)
Indigenous (First Nation)	1 (5.6%)
Currently studying[c]	13 (72.2%)
Highest level of education acquired	
Highschool level	7 (38.9%)
Cegep, Vocational or Community College	6 (33.3%)
University level	5 (27.8%)
Medical history and diabetes management	
Diabetes duration, years	9 [6 - 12]
Had at least one diabetes-related consultations in the last year with:	

Medical specialist (Endocrinologist, Pediatrician, Internist)	17 (94.4%)
Family doctor/General practitioner	15 (83.3%)
Registered Dietitian	12 (66.7%)
Registered Nurse	12 (66.7%)
Use continuous glucose monitoring systems	**17 (94.4%)**
Dexcom G6	10 (55.6%)
Freestyle Libre	1 (5.6%)
Freestyle Libre 2	1 (5.6%)
Guardian Sensor 3	2 (11.1%)
Guardian Sensor 4	3 (16.7%)
Use insulin pens or syringes exclusively	**4 (22.2%)**
Use an insulin pump	**14 (77.8%)**
Use of pump features in the last week[d]	
Use an integrated bolus wizard/calculator function	14 (100%)
Use an automated insulin pump	12 (86%)

[a]Participants (n=3) born outside of Canada became landed immigrants in Canada in 2003, 2015, and 2022. [b]n=2 don't know. [c]n=1 prefers not to answer. [d]Proportion among the 14 pump users only.

Critical Issues and User Feedback Across Rounds: A Thematic Analysis

Usability testing of the CC app with young adults with T1D was analyzed using thematic analysis, revealing seven key themes that highlighted usability priorities for engagement and satisfaction across four rounds (**Figure 2**). Evaluations and suggestions for the app's features were compiled to illustrate how the features evolved across the usability testing rounds (**Appendix C**).

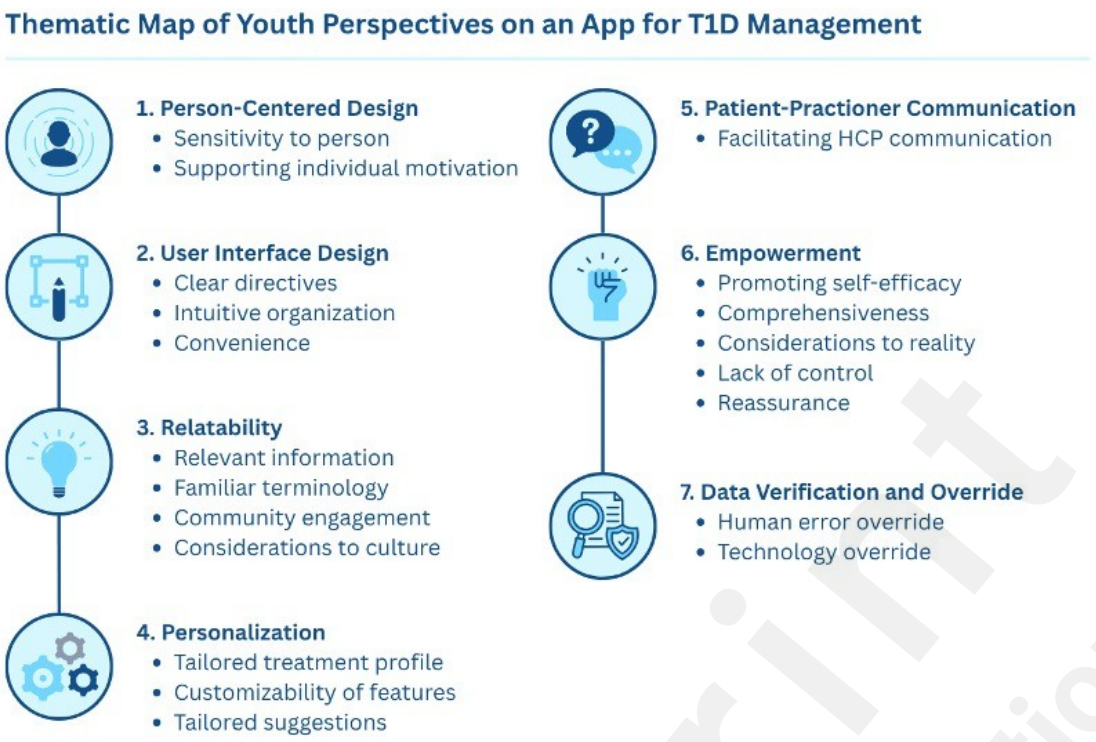


Figure 2. Themes identified through usability testing of a T1D management app with youth.

Theme 1: Person-Centered Design

Participants consistently emphasized the need to focus on the person living with T1D rather than solely on the condition itself, even though the app is designed to support T1D management. This theme evolved across the four rounds to reflect a progression and growing interest in personalization, emotional well-being, and sensitivity to stigma in the app's design.

In Round 1, participants highlighted the importance of prioritizing profile settings (e.g., name, gender, day of birth) before treatment parameters during onboarding. This approach was appreciated for making the app feel more personal.

> "*I like the order; how first it's your name, your gender, your birthday... And then the last thing is to put in your diabetes [information]. It's not like 'oh, right away, put your bolus before your name'.*"

- Woman, 20 years old, 13 years living with T1D

By Round 2, this focus expanded to emphasize designing for personal relevance by incorporating features that reflected the individuality of each user's diabetes management journey and intuitive functionality. Participants suggested organizing features in a way that aligned with their unique routines and preferences, allowing them to feel in control of their experience.

"I'd prefer to go to the dashboard first [rather than the profile when logging in] and make it my homepage, so everything I need is in one place and I can access it the way I want."

- Woman, 24 years old, 8 years living with T1D

In Round 3, participants shifted to distinguishing information relevant to healthcare providers from that intended for T1D users. Participants suggested the ability to customize dashboard displays, such as hiding HbA1c levels, which some found stress-inducing. They also recommended avoiding design elements that could unintentionally reinforce negative perceptions (e.g., a thumbs down for late insulin administration) and replacing red and green indicators with neutral colors to classify food choices.

"*Especially when you're a young teenager and you see your HbA1c's high, it can stress you out. Maybe it could be an option to hide it on your dashboard.*"

- Woman, 20 years old, 13 years living with T1D

The final round added features to support individual motivation. For instance, participants suggested integrating challenges and objectives that align with users' preferences for managing their diabetes, focusing not just on what they need to do but on how they want to experience and engage

with the process. This also included offering peer support and the option to send encouragement messages to others within the app, if they consent to it.

> *"Maybe add some challenges or objectives, then we could see whether we've reached them or not. I think it would be a good idea to involve friends [...], you can look up their profiles, see their trends, and send them encouragement, like a 'send encouragement' button. When you visit their profile, you can interact with them."*
>
> - Woman, 17 years old, 5 years living with T1D

Theme 2: User Interface Design

During Round 1, users identified foundational problems. They reported significant challenges with navigation, struggling to locate key elements such as the photo recognition feature, the dashboard, the settings and treatment profile, and the help menus. There was a lack of clear directives, leaving users uncertain about what needed to be entered and unclear about the descriptions of what was displayed. Prompts, descriptors, and visual cues were suggested to optimize the user's comprehension of entry requirements.

> *"I think for people who are newly diagnosed, it would be better to guide them on how to find [ratios and correction factors to enter into the app] in the pump, if there's some kind of video or something to tell them. Because it's very easy to find on the pump, but still for someone who's newly diagnosed, it might be little [overwhelming]. So that would be a recommendation."*
>
> - *Woman*, 22 years old, 11 years living with T1D

By Round 2, navigation improvements reduced these challenges; however, multi-step

processes remained cumbersome. For instance, meal logging required navigating through multiple pages (first to confirm food items recognized by the AI algorithm, then confirm the detected quantities, and finally to confirm bolus calculations), whereas users suggested a streamlined approach using a list or drop-down menu in the same page. Another important aspect is intuitive organization, ensuring that the order of information display is practical. For example, users instinctively clicked on their profile picture to navigate back to their profile.

> *"All the meal log steps should be on the same page [rather than navigating multiple pages], with the save button at the bottom.*
> - Woman, 24 years old, 8 years living with T1D

In Round 3, critical navigation issues were resolved, and only minor refinements were suggested to improve convenience, such as faster photo upload and quicker analysis of the photos. Participants also highlighted the value of automatic logging of meals in the food journal, when a photo is used to estimate carbohydrate content, along with glucose trends and insulin dosing. They further requested simple data extraction for the food journal and the ability to filter and sort information efficiently. This was further reinforced in the feedback questionnaire (**Appendix D**).

> "*Overall, it seems quite easy, quite simple. For me, I love the simplicity of it, like how simple it is to navigate. Nothing too [overwhelming]. If something's overwhelming, people will just be like 'Ok, I don't care, I don't want to do this'.*"
> - Woman, 22 years old, 11 years since diagnosis.

By Round 4, no major issues were identified. Participants did not report any usability problems or preferences.

> "*I tried both functions, searching for items and then taking a photo. I found it works well*."
>
> - Woman, 14 years old, 4 years since diagnosis.

Theme 3: Relatability

This theme focused on enhancing relatability by providing relevant and accessible information while minimizing complexity. In Round 1, participants emphasized the need to streamline the food journal feature by avoiding overly detailed descriptions in the database and instead prioritizing a simple, comprehensive list of commonly used items. The importance of using familiar terminology was highlighted to improve user comprehension. For instance, participants suggested accommodating synonyms (e.g., correction factor vs. insulin sensitivity factor) and quantifying measurements in familiar terms (e.g., 1 cup vs. 250 ml) to align with user preferences.

> "*For instance [when I enter the word banana in the food item search bar], I feel like the propositions are too specific. [...] The first thing is: Dessert, pudding, banana. It doesn't offer me the fruit banana first, but it offers many things made of bananas.*"
>
> - Woman, 23 years old, 10 years living with T1D

In Round 2, a sense of community was introduced as participants suggested adding an in-app peer messaging feature, allowing them to connect with someone going through a similar process and foster a feeling of understanding, relatability, and shared experience.

> *"I'd like to be able to connect and communicate with peers my age using the app."*
>
> - Man, 24 years old, 6 years living with T1D

By later rounds, fostering community engagement became a key focus. Participants proposed

adding features like a *Frequently Asked Questions* section to promote peer feedback and provide actionable insights while maintaining ongoing users' collaboration.

> "*It can be practical to have [an FAQ section]. Sometimes there are people who think they have a "silly" question but not everyone knows about it. So, if there was [an FAQ section], people would be able to get a precise answer quicker, [without feeling ashamed]*."
> - Woman, 19 years old, 10 years living with T1D

Additionally, participants stressed the importance of cultural inclusivity by ensuring that the app's content, such as food items in the database, is relevant and accessible to users from diverse backgrounds. Together, these adjustments would enhance the app's relatability, making it more intuitive and user centered.

> *"I think that the different cultures and cultural foods might be something to take into consideration. [...] In the future, if it's possible to collaborate with people from different cultures, that would be helpful. In Canada, just using Western food might be a bit limiting, especially considering the different cultures even within Canada. So we really need to make sure there are many different people and many different cultures represented."*
> - Woman, 22 years old, 11 years living with T1D

Theme 4: Personalization

In earlier rounds, participants emphasized the importance of tailoring the treatment profile to individual needs, including options for CGM connection, weight tracking, injection reminders, and specifying insulin treatment types (e.g., pen/injections vs. pump). This was particularly relevant when discussing the dashboard and the types of statistics users wanted displayed, depending on their insulin delivery methods and glucose level monitoring preferences. They also stressed the need to

recognize the individuality of T1D management by offering options to differentiate between physiological and perceived hypoglycemia.

> *"Not all of the information on glucose levels would be useful [for me], but it would maybe be useful for injection users or people with a CGM that want to have the data in this app. But I know I wouldn't use this information."*
>
> - Woman, 23 years old, 10 years living with T1D

> *"If your glucose levels is high for a long period of time, once it goes down, you can feel [as if you're in a hypoglycemic episode], but it may not actually be a physiological [hypoglycemic episode]. That would be nice to add [...] and make it an event to be able to associate it with a glucose reading"*
>
> - Man, 24 years old, 9 years living with T1D

Beyond diabetes management, customizability of the app itself is important. Participants expressed a desire to personalize the general aesthetics, such as colors and app design, as well as practical features like language settings, glucose units of measurement, custom tags, and data visualization. These options were seen as essential to making the app feel more user centric.

> "*Since kids are using [the app] [...] if there was a way to put an avatar like a soccer ball or a flower [...] I think that would be a cute [way] for children to be able to personalize their account.*"
>
> - Woman, 20 years old, 13 years living with T1D

By later rounds, the need for advanced personalization became more refined, with

participants suggesting the incorporation of AI technology to provide tailored diabetes management recommendations. They emphasized the value of having these personalized suggestions based on user trends and status, particularly after a week of consistent app use.

> "*If the AI would be able to give you a suggestion… If, say you've had too many [hyperglycemic episodes] and it's dinner time. [..] Maybe if the AI could give suggestions based on your statistics for the day*."
>
> - Man, 18 years old, 12 years living with T1D

Theme 5: Patient-Practitioner Communication

Participants highlighted the potential for the app to enhance patient-practitioner communication, facilitating more effective diabetes management. In the first round of usability testing, the focus was on addressing critical issues, such as tracking and simplifying the retrieval of key data, including the frequency of hypoglycemic events. Participants reported that these features could empower users to take charge of their management during appointments with their healthcare team, fostering more productive discussions.

> *"It would be useful for [the app] to tell you how many [hypoglycemic episodes] you have had. Because often, let's say when you go see your endocrinologist, they ask you how many [hypoglycemic episodes] you have had and you're like thinking in your head*."
>
> - Woman, 20 years old, 13 years living with T1D
>
> "*This morning, I went to see the dietitian, and I had to provide a dietary recall, but trying to remember everything I'd eaten, it's definitely more tedious. But to see that [the food journal] is accessible, to have it on hand all the time, and to be able to enter it as I go*

along, I find it really practical."

- Woman, 19 years old, 10 years living with T1D

By later rounds, the emphasis shifted to refining and expanding these features. Participants suggested the ability to generate downloadable reports that combine detailed data, such as dietary information linked to glucose levels, to share with healthcare professionals. This functionality goes beyond what existing CGM or insulin apps offer, which rely on manual entry of carbohydrate values or meal notes, by providing not only glucose trends and hypoglycemic events, but also broader contextual information, including automatic tracking of meal composition, physical activity, menstrual cycle patterns, stress levels, and illness, offering a more comprehensive and less burdensome way to understand factors influencing glucose trends. These enhancements foster bidirectional assistance, ensuring that both patients and healthcare professionals have access to comprehensive, actionable insights. This collaborative approach would support more informed decision-making and ultimately benefit both parties in achieving optimal diabetes management.

"I already have separate downloads from my pump and [CGM]. Having everything in one place, like a single document, could make it easier for the medical team."

- Woman, 19 years old, 10 years living with T1D

" I think having [the coverage vs correction dose] split up is a great way to look at it. Like when I go to like the diabetic nurses, they're always trying to figure out, is it a carb ratio thing, or do we need to adjust the insulin correction factor."

- Man, 23 years old, 21 years living with T1D

Theme 6: Empowerment

The theme of empowerment focuses on how the app can enhance users' confidence and ability to manage T1D effectively, while addressing concerns about over-reliance on technology. In Round 1, participants emphasized how a CC app could empower young adults with T1D by promoting self-efficacy. The app's ability to centralize tools and information into a single platform was highlighted as essential for simplifying diabetes management. Features like long-term tracking and trend analysis allowed users to understand factors influencing glycemia, such as physical activity, stress, and timing of insulin injections.

"*I feel like they should integrate automatically. So, for example, there should be a way of taking all that information, [from other apps] , and importing them into this app. But I feel like the app is great and it's s something that I've been waiting for for a long time*"
- Man, 24 years old, 9 years since diagnosis.

"*If I look at my graph later and see that one day I was trending high all day, but then I look back at the food diary and remember what I ate, I'll understand better*."
- Woman, 19 years old, 10 years since diagnosis.

"*Let's say one night you take your insulin and [your glucose] spikes, then that's your indication that you need to give insulin earlier. [...] You could say 'Oh, that's why it went super high versus low'. To me, it could make a big difference.*"
- Woman, 20 years old, 13 years since diagnosis.

Additionally, the app reassured users by validating daily behaviors, even those deviating from guidelines, providing a realistic and supportive approach to condition management.

> *"I really liked [the feature of inputting insulin before or after a meal]. I sometimes forget to give myself insulin before I eat. I think it's important to see the trend."*
>
> - Man, 18 years old, 12 years living with T1D

In later rounds, participants expressed appreciation for these empowering features but raised concerns about the potential trade-off between reliance on technology and their sense of control. Some users noted skepticism regarding the accuracy of the app's recommendations, which they felt could undermine their self-efficacy.

> *"I'd rather input [the carbohydrates] manually. Especially with the fact that I have to give myself insulin, I don't think it's a good idea to let the AI guess. I'd rather just put in the little effort and just calculate it myself to know exactly how much I need."*
>
> - Man, 24 years old, 7 years since diagnosis.

Discussions emphasized the importance of building user trust to address these concerns. Participants suggested that transparent mechanisms to verify the app's outputs and ensure accuracy would help mitigate doubts. This evolution across rounds demonstrates the balance needed between empowering users and maintaining their confidence in the app as a reliable support tool for diabetes management. This is further highlighted in the feedback questionnaire, where participants expressed reluctance to rely on AI-driven photo recognition if the carbohydrate content of meals is already known (**Appendix D**).

Theme 7: Data Verification and Override

Participants highlighted the importance of data verification and override capabilities within the app to ensure accurate diabetes management. In earlier rounds, the focus was on addressing

critical issues, such as implementing mechanisms to override technological errors. Participants emphasized the need for the ability to accept or reject automated suggestions made by the app, ensuring recommendations were accurate and relevant. They also stressed the importance of addressing human error by incorporating prompts that encourage users to verify and correct data entries, enhancing accuracy and reliability.

> *"You could choose to accept [the suggestions provided by the AI through photo recognition] or not [...] Like, if it's wrong, then you still have the option to dismiss it."*
> - Woman, 20 years old, 13 years living with T1D
>
> "*My pump does it for me, but let's say you calculate 44 grams of carbohydrates but you [input it] quickly and add a 0 at the end, it will give you a bolus that is too high. My pump won't let me do this. There needs to be a level of security [in the app]. The app should inform you to check it.*"
> - Woman, 19 years old, 7 years living with T1D

By later rounds, the emphasis shifted to refining these features, including streamlining the verification process to avoid unnecessary disruptions during app use. Participants suggested simplifying error notifications to ensure they were clear but not intrusive and incorporating an option to review and confirm CGM readings. These minor improvements aimed to strike a balance between maintaining user control and creating a seamless experience. Together, these features would enhance users' confidence in the app's data and recommendations, building trust and improving its overall effectiveness.

> "*To have the option to enter it manually if you want to override that even if you have a*

> *CGM connected. For example, if someone is skeptical about their [CGM] reading and they measure with the typical finger prick and it's a different value, they can input it [manually].*"
>
> - Man, 24 years old, 9 years living with T1D

This evolution across the rounds reflects an increasing demand for features that align with users' unique needs and preferences, enhancing both usability and engagement (see **Appendix C**). This was also emphasized as a suggested feature after one week of using the app (**Appendix D**).

Discussion

Usability testing

The usability testing revealed seven major themes highlighting the app's areas for improvement. These themes focused on young adults empowerment, enhancing patient-practitioner communication, data verification and override for accuracy in diabetes management, an intuitive user interface design, and the relatability of the information provided. While both the person-centered design and personalization themes reflect participants' desire for individual relevance, they differ in scope and intent. Person-centered design represents a broader guiding principle emphasizing empathy and how the app acknowledges the person behind the condition. In contrast, personalization refers to the practical and technological implementation of this principle i.e., how the app's content, settings, and recommendations adapt to the user's specific needs and data.

Clinical guidelines recommend adjusting meal-time insulin dose to manage glucose variability due to different meal compositions [28, 29]. However, there is no consensus as to which insulin strategies to use. Significant inter-individual differences in insulin dose requirements exist, necessitating personalized advice based on postprandial glucose monitoring for several hours afterwards [30]. This highlights a major theme: empowering users to gain control over their T1D

management by understanding personal trends and factors affecting glycemia. While users appreciated receiving personalized AI-generated recommendations based on their trends, the sense of empowerment mainly came from accessing personal statistics and tracking various factors (e.g., physical activity, stress levels, sick days, time of insulin injection). This aligns with their need to remain in control and avoid full reliance on the app, which could hinder self-efficacy. Some users were skeptical about the accuracy of AI-generated information, emphasizing the need for safety mechanisms for data verification and the ability to override when necessary. This aligns with previous research on the lag between interstitial and capillary glucose levels, which led to data distrust and prompted some CGM users to rely on capillary glucose to clarify high and low readings [31].

The sense of empowerment was further emphasized in the context of patient-practitioner communication. While the app facilitated the simple retrieval of relevant information for healthcare providers, it also empowered users to take charge of their diabetes management by sharing important details and tracking topics they wish to discuss. This empowerment is particularly crucial during adolescence, a time when young people are striving to gain independence and shape their personal and social identities [32]. This is especially important when the perceptions of youths' needs differ from those of healthcare professionals [33].

The need for a person-centered design arises from the necessity to address the various factors impacting the daily life of individuals with T1D and to consider their individuality. This approach may help bridge the gap often left during appointments with healthcare providers, where the focus is typically on glucose control rather than on addressing the person as a whole, due to time constraints [34]. Additionally, the app should reflect the lived experience of T1D to avoid setting unrealistic expectations. It should incorporate features that accommodate users' day-to-day habits, such as tracking whether insulin was administered before or after meals, despite guidelines recommending injecting before meals [35].

Participants emphasized the need for a comprehensive app that consolidates all necessary information for diabetes management, avoiding the need to juggle multiple sources. However, some felt that repetitive information, such as glucose readings or insulin doses, was redundant since it is already available through CGM and insulin pump reports. Customization options for tracking factors, data visualization, and trend analysis can help maintain user interest and avoid excessive exposure to information that may be deemed irrelevant or less useful by some. In fact, anxiety tends to be higher in adolescents, raising concerns about CGM data overload potentially negatively impacting their quality of life. This suggests that CGM data may feel overwhelming to adolescents [36]. Participants emphasized this point by indicating a preference to 'hide' glucose data, focusing instead on trend analysis, understanding glucose level variations and factors influencing glycemia.

Good graphic design and an intuitive interface are crucial for an effective tool. Simplicity also reduces technical difficulties that may discourage user engagement [37]. A study on the co-design of a digital mental health platform for young adults highlighted the importance of relatability, with participants emphasizing that the platform should be one they can identify with [38].

Strengths and Limitations

These results should be interpreted in light of the study’s limitations. A major limitation is that most participants were AID users, relying on systems that automate insulin delivery and integrate CGM data, thereby reducing the need for manual calculations or tracking. While some app functions may overlap with AID features, the app serves a complementary rather than redundant role. AID systems focus on insulin automation but provide limited insight into the behavioral and contextual factors influencing glucose stability. In contrast, the proposed app supports self-awareness, education, and behavioral reflection by linking glucose trends with meal composition, stress, physical activity, and other lifestyle factors. It also facilitates communication with healthcare providers through integrated reports that combine these contextual data. Finally, its relevance extends

to individuals on basal–bolus injection therapy, who continue to make daily dosing decisions manually, and to those without access to AID systems due to cost, eligibility, or access limitations. Other limitations include the potential selection bias arising from the non-random sample, which may affect generalizability. However, the users represented various ethnicities, genders, education levels, and insulin treatment modalities. Researcher bias was mitigated by using the same interviewer throughout, ensuring consistency in questioning style, tone, and data collection procedures across rounds. In addition to having an observer present during the interviews, subjectivity in data analysis was addressed by having three coders reach consensus through discussions. Observer bias was minimized by adhering to a pre-set questionnaire and having no prior relationships with participants. Due to the potential for authority and response bias, the interviewer mitigated their impact by establishing rapport with participants to create a comfortable and non-judgmental environment, used neutral language and tone to avoid perceived authority, and encouraged openness by reassuring participants that their honest opinions were valued.

A key strength of the study is that end-user needs directly informed the app's development, with participant input integrated iteratively across all design rounds. This co-design approach ensured that the resulting features were grounded in lived experience and reflected the priorities of young adults with T1D. By continuously refining the app based on user feedback, the design process enhanced relevance and usability, laying a strong foundation for future pilot testing and real-world engagement.

Conclusion

Petit Cactus represents the first mobile app to integrate CC and insulin dosing, in a single, user-informed platform. Through its co-design process, the study identified design principles that extend beyond this specific application; emphasizing person-centered, intuitive, and emotionally sensitive interfaces that align with users' daily routines and language. Participants also underscored the

importance of personalization, data accuracy, and effective communication tools to support self-efficacy and meaningful interaction with healthcare providers. These insights can inform the design of future digital health tools aimed at improving diabetes self-management and user engagement across diverse technological contexts. Usability testing has refined Petit Cactus accordingly, and a pilot trial will next evaluate its impact on engagement and glycemic outcomes among young adults with T1D.

Declarations :

Ethics approval and consent to participate:

The study was approved by the McGill University Research Ethics Board (#23-04-018). Written informed consent was obtained from participants aged ≥18 years and from parents or legal guardians of participants aged 14–17 years. The study was conducted in accordance with the principles of the Declaration of Helsinki for research involving humans and/or human data.

Consent for publication:

Not applicable

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Availability of Data and Material:

The datasets used and analysed during the current study available from the corresponding author on reasonable request.

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Author contributions and guarantor statement:

A.H.: Conceptualization, methodology, project administration, protocol - original draft, protocol - review & editing, participation recruitment, interview facilitation, formal analysis, visualization, writing - original draft, writing - review & editing. A.S.: Interview observation, writing - original draft, writing - review & editing. A.K.: writing - original draft, writing - review & editing. G.G.: Interview observation, writing - original draft, writing - review & editing. A.R.F.: Writing - review & editing. C.S.: Interview observation, writing - review & editing. M.N.: Writing - review & editing. AS.B.: Conceptualization, protocol - review & editing, writing - review & editing, supervision. AS.B. is the guarantor of this work and, as such, has full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

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Appendix A: Interview guide and questions

I. Tasks requested during the interview:

- Complete your profile setting
- Enter a meal
- Calculate the insulin bolus dose
- Consult the food journal
- Consult the dashboard
- Read the glucose level and event graph
- Ask a question to the AI chatbot

II. Probing questions:

- What was the user experience like in using the app to perform this task?
- Was it easy or difficult to navigate this task?
- What do you think of the design of the steps to follow?
- Why did you navigate to [Page A] instead of [Page B]?
- What prompted you to click on [a specific interaction]?

III. General concluding question:

- What features are most important to you?
- What features are least important to you?
- What features were you expecting to find but did not?
- What features did not work as expected?

Appendix B: Feedback questionnaire

1. What factors would make you not reuse this application?
2. How could the food journal be better organized?
3. If applicable, which parts made meal entry and/or carbohydrate calculation unnecessarily complicated?
4. What would make the blood sugar level graphs easier to read?
5. What kind of support from healthcare professionals would you like to receive through the application?
6. What interested you in trying the application?
7. What features would make PetitCactus more engaging? (e.g., having characters, challenges and rankings, progress bar, maintaining a streak, earning points for groceries, travel giveaways...)
8. Have you seen other applications do something similar?

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9. Please leave any other suggestions or comments you may have.

Appendix C: Feature Development Through Usability Testing Rounds

Features	Round 1	Round 2	Round 3	Round 4
Photo Recognition for Carb Suggestions	The photo capture feature for carb estimations was presented unclearly, leading some participants to mistake it for a tool to simply add pictures of meals.	User feedback was incorporated to improve the presentation of the photo recognition feature, which was clarified by adding prompts to explain its function. Photo uploading remained slow.	Ease of use was enhanced by adding simple options to edit food items incorrectly recognized by AI.	The algorithm was optimized for accuracy, with faster photo uploading.
Meal Logging	Meal logging was designed with step-by-step navigation instead of showing everything on one page. However, it was overly complex, unintuitive, and too lengthy. The food database also had issues with irrelevant items and inaccurate search results.	The food database was subsequently improved by adding a better search function that presents key food items first, while retaining a large database.	The next iteration addressed this by displaying everything on the same page with streamlined manual entry and dropdown features. The food database was refined to prioritize commonly used items, but estimating quantities remained challenging.	The final iteration enhanced functionality by allowing users to copy or edit previously logged meals, offering more units of measure and options to determine food quantities. It also included options to add notes or assign meal tags (e.g., high fat, high protein, pre/post-workout, or injection timing).
Event Logging	The feature was not included in this round, but users suggested it to track events other than meals that could impact glucose levels.	Initial concept presented.	The full feature was added, allowing users to track various events beyond meals, such as glucose and insulin (independent of meals), and physical activity.	More events were added, such as the menstrual cycle, medication, and a customizable event, to enable more comprehensive event tracking.

Insulin Dosing Calculator	Basic model for dosing recommendations.	No changes were made.	The feature now presents an added safety measure. Users are shown their glucose levels and ratios and must confirm entries before calculations.	No changes were made.
Dashboard	The dashboard featured a basic design with limited functionality, presenting statistics on the number of meals, units of insulin, and glucose levels, all compiled over the course of the day.	User feedback was incorporated, resulting in a clearer visual presentation and the addition of adjustable timeframes for compiling statistics.	The final design included a personalized data display with the addition of a graph to show glucose levels alongside logged events (meals, activity, stress, and others).	When the CGM is connected, glucose levels are displayed in real time, and the cactus avatar dynamically changes to reflect these levels.
Profile Settings	Basic settings included name, age, date of birth, gender, target glucose levels, insulin modality, glucose monitoring preferences, and app language.	Settings were expanded to enable users to enter multiple correction factors, input their basal insulin regimen, as well as the option for users to remove information irrelevant to their diabetes management.	Further refinements were made, including the option to add a profile picture or an avatar.	No changes were made.
Connection to a Healthcare Provider Portal	Not available. Participants recommended a direct method to share data with the healthcare team.	Initial concept of provider connection presented.	The prototype was tested with basic integration, including an option to link the account with a healthcare team portal.	No changes were made.
AI Chatbot	The AI chatbot was presented unclearly, often mistaken for a help center.	Prompts and examples of queries were added to clarify its use.	In the final iteration, the AI was integrated to provide personalized feedback based	No changes were made.

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			on previous discussions.	

Appendix D: Appreciations and suggestions from the feedback questionnaire after one week of app use.

App features	Appreciations	Suggestions
Profile	Appreciation for bilingualism of app (English/French)	Ability to enter multiple correction factors, Remove feature of naming ratios, Ability to input insulin regimen (i.e. basal vs bolus), Personalizing profile (i.e. creating an avatar, adding background photos), Ability to start inputting information and modify later (during the onboarding).
Meal entry	Photo recognition facilitates carb counting and insulin dosing, especially for those newly diagnosed with T1D	Indicate that associating tags to meals is optional Prioritize “basic foods” first in database Inaccurate AI-photo recognition, specifically of mixed meals Limited units of measurement (e.g. grams but not millilitre) No added benefit of meal entry when user already knows carbohydrate content of meal. Photo recognition of meals is slow. Add a video tutorial for first time users.
Journal	Well organized Clear to see past data and trends Ability to sort for data by events (i.e. exercise)	Adding a notes tab to complement food entry Filter entries by: Date (day, week, month) Characteristic (i.e. insulin requirement) Alphabetical order Manually uploading images is slow and does not accurately detect carbohydrate quantity Add ability to personalize display of journal
Graph	Ability to relate blood sugar levels with meals	Color-coordinate different variables on the graph (i.e. fasting blood sugar, target range) Ability to turn

	Comprehensive app that includes all features for managing T1D rather than using multiple apps	phone and see graphic in a landscape view
Chatbot	N/A	Add email address or phone number to provide feedback in addition to AI feedback Ability to provide personalized suggestions using data from food journal
Suggested Features	Ability to send information (i.e. graph) from app to healthcare professionals Allow the app to be self-improving based on user input Including progress tracking for personal T1D-related goals (i.e. habit streaks) Collaborating with healthcare professionals through the app to provide user-specific recommendations Integrate app with other devices (i.e. smart watches, computers) Ability to earn points with engagement for groceries, travel giveaways, gift cards. Add games related to diabetes. More customizability of the avatar. Ability to link a child's account to a parent's version of the app.	

Appendix E: Themes and codes description

Themes	**Codes**	**Description**
Person-centred design	Sensitivity to person	Considering the impact of information on the wellbeing of the user, which involves discerning information relevant to the healthcare professional versus relevant to the user's ability to manage T1D. Finding a balance between encouraging users to self-manage T1D all the while not discouraging or causing undue stress.
	Supporting individual	Adding challenges and objectives for the app to align

	motivation	with how individuals prefer to engage with their diabetes management, focusing not just on what they need to do, but on how they want to experience and interact with the process.
User interface design	Clear directives	Prompts, descriptors and visual cues optimize user's understanding of entry requirements.
	Intuitive organization	The order in which information is displayed (i.e. app design) is practical, and the ability for users to perform intuitive behaviours (i.e. intuition to click on profile picture to return to profile) is met.
	Convenience	Ease of use of app functions including data entry (i.e. photo recognition), data extraction (i.e. insulin dose), data export (i.e. food journal), and ability to filter and sort information.
Relatability	Relevant information	Prioritizing pertinent information for the user's T1D management while minimizing exposure to unnecessary and complex information.
	Familiar terminology	Considering the interchangeability T1D terminology (i.e. correction factor vs insulin sensitivity factor) and synonymous langugae (1 cup vs 250 ml) with the goal of being inclusive to all possible terminology used by users.
	Community engagement	Continuous end-user collaboration and engagement for the purpose of peer support and app feedback.
	Consideration to culture	Diversifying food database to include food products from various cultures with the goal of the app being relevant to all users.
Personalization	Tailored treatment profile	Relating to user's ability to optimize T1D management through various features such as CGM

		connection, weight tracking, injection reminders, inputting insulin therapy (i.e. pen vs pump).
	Customizability of features	Personalizing app design such as the general aesthetic, language settings, available units of measurement, custom tags, custom data visualization.
	Tailored suggestions	Using trends and status of user to generate diabetes-specific management suggestion through AI technology.
Patient-practitioner communication	Facilitating healthcare professional communication	Facilitate T1D-related information transfer between patient and practitioner: assist the user to retrieve and share pertinent information from the app to healthcare professionals (i.e. # of hypoglycemia in the past 3 months), and allowing healthcare professionals to easily retrieve information on their own as well.
Empowerment	Promoting self-efficacy	Ability for the user to gain control over their T1D management by understanding the impact of various factors (i.e. physical activity, stress levels, sick days, time of insulin injection) on glycemia.
	Comprehensive	Encompassing all necessary features deemed useful to users within one app (i.e. note taking, food journal, CGM graph) to improve the practicality of T1D management.
	Considerations to reality	App functionalities consider the lived experience of T1D to avoid setting unrealistic expectations. The app incorporates features that considers the day-to-day habits of users (i.e. ability to track whether insulin was administered before or after meals despite the guidelines being to inject before meals).

	Control	The ability to rely on technology while not hindering self-efficacy. This may be hindered by an underlying skepticism of the accuracy of technology-provided information.
	Reassurance	Relating to the security of T1D management (i.e. insulin administration, pump malfunctioning) and ability to validate previous actions (i.e. logging insulin injection)
Data verification and override	Human error override	Technology-driven data verification to discern human error.
	Technology override	Manual user verification and correction of AI generating information.

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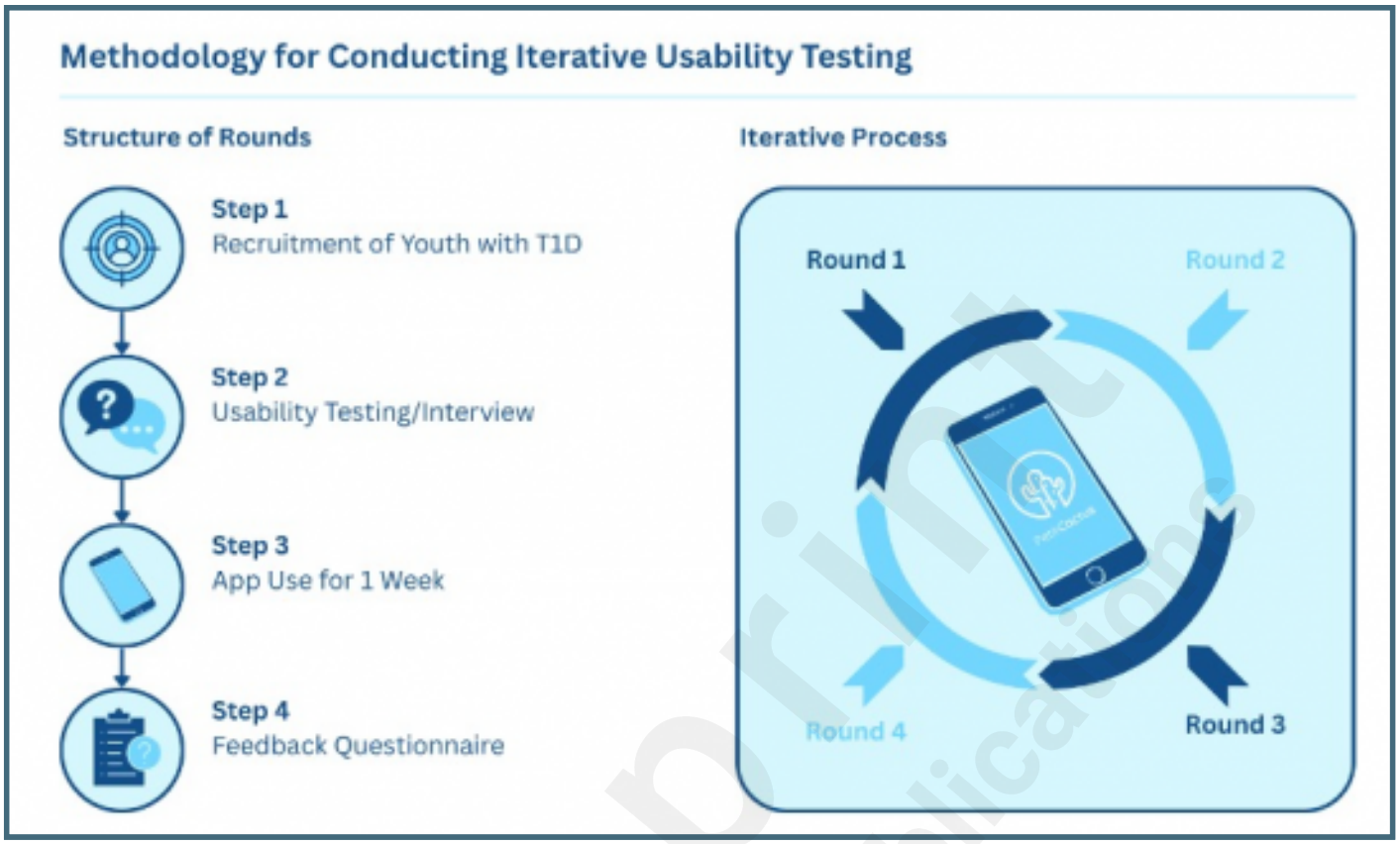
Supplementary Files

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Figures

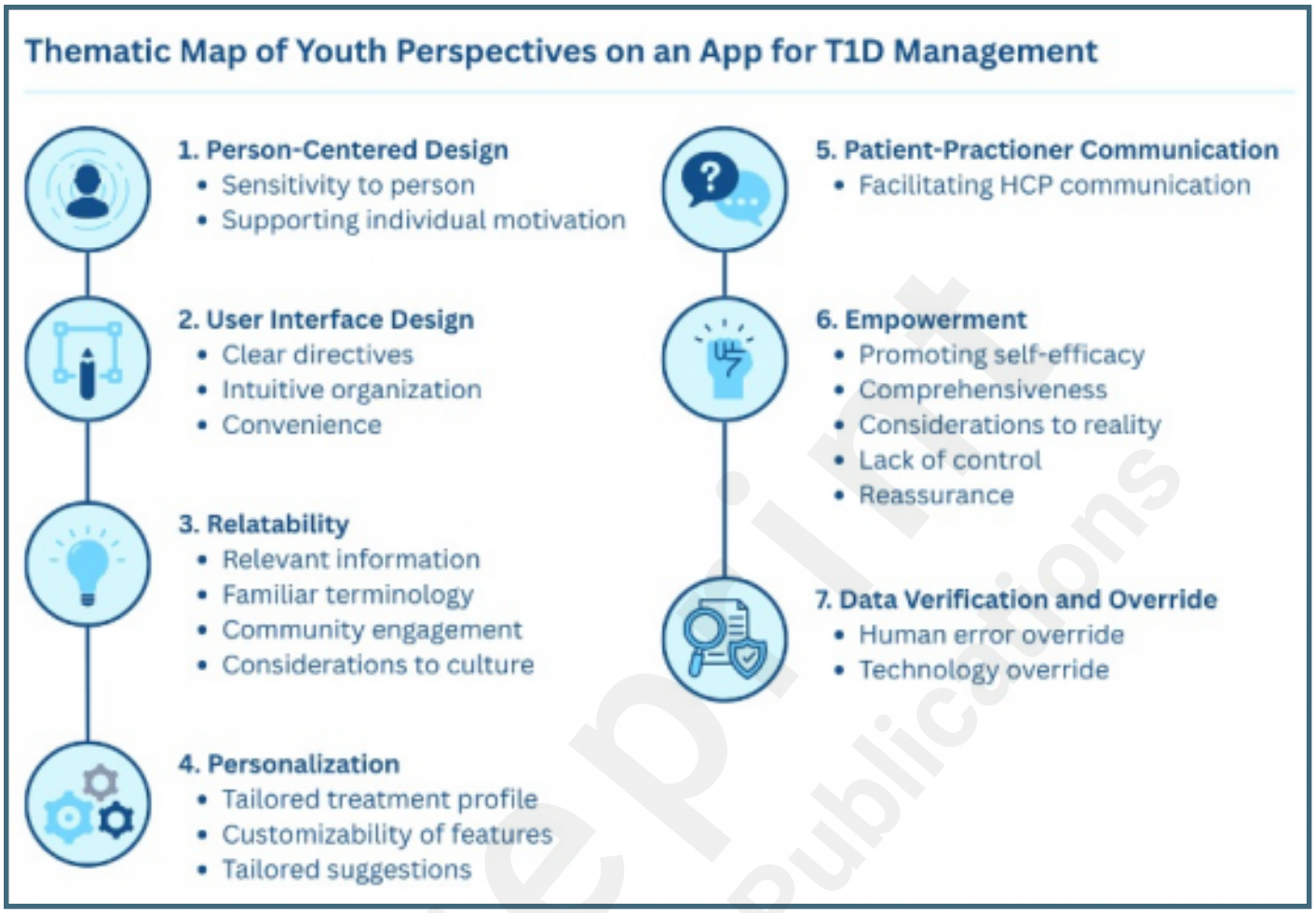
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Methodology for conducting iterative usability testing.



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Themes identified through usability testing of a T1D management app with youth.



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Multimedia Appendixes

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Interview guide and questions.
URL: http://asset.jmir.pub/assets/219115a88e3bcb29d2693234b158d749.docx

Feedback questionnaire.
URL: http://asset.jmir.pub/assets/81f0fa863a563f4a6ff1a67fe40ff0de.docx

Feature Development Through Usability Testing Rounds.
URL: http://asset.jmir.pub/assets/58ce2707c33def28865f02906dc14e09.docx

Appreciations and suggestions from the feedback questionnaire after one week of app use.
URL: http://asset.jmir.pub/assets/c88febb392e742fc0a9172c4c10ebc88.docx

Themes and codes description.
URL: http://asset.jmir.pub/assets/7d3642f4ea3890950057197c0f90c67e.docx

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