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Development and validation of a MHEALTH technology for the promotion of self-care for adolescents with diabetes

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Abstract *Self-care is encouraged in the type 1 Diabetes Mellitus (DM1) setting. Thus, this research aimed to develop and validate a mobile application (APP) to promote self-care for adolescents with DM1. The method was divided into two stages: development and validation, ranging from literature review, benchmarking, prototype construction to validation by specialists. The APP construction was subsidized by the seven steps proposed by the American Association of Diabetes Educators. The screens were designed and possible functions were selected. After the design, the APP prototype was developed and named "DM Agendinha". The content validation process was mediated by the Suitability Assessment of Materials tool, where the percentage obtained was 85.3%, characterizing the APP as "Superior Material". The Smartphone Usability questionnaire was employed for technical validation, and the APP reached a global Content Validity Index of 0.96. We concluded, therefore, that the use of this material by adolescents will favor the acquisition of new knowledge and adherence to healthy practices, considering that it is a highly intelligible electronic technology.*

Key words *Adolescent, Type 1 Diabetes Mellitus, Mobile Technology, Application*

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Introduction

Primary Health Care (PHC) is the gateway to the Unified Health System (SUS) and, as an essential part of it, proposes respect for the principles of Equity, Universality, and Comprehensive Care to individuals. The main activities performed at this level of care are carried out by the Family Health Strategy teams (ESF) comprehensively in care throughout the entire life cycle and in the face of various clinical conditions, among them Diabetes *Mellitus* (DM)[1].

DM is a disease characterized by elevated blood glucose (hyperglycemia) triggered by defects in the secretion or insulin action. This hormone is produced in beta cells of the pancreas and mainly promotes the entry of glucose into the body's cells so that it can be used for various cellular activities[2].

The number of people diagnosed with DM in Brazil has grown by 61.8% in the last ten years, and the Brazilian Northeast has been suffering from this increase. An example is the city of Fortaleza, which ranked second among the capitals with the highest prevalence of this disease[3].

Type 1 Diabetes *Mellitus* (DM1) stands out among the variations of this pathology, which is the most common endocrinopathology among children and adolescents and a severe public health problem[4]. In DM1, the chronic disease results from the autoimmune destruction of insulin-producing cells[2].

Epidemiological data for 2019 estimate that more than 1.1 million children and adolescents worldwide have DM1. Moreover, Brazil ranks third in incidence and prevalence of the disease, second only to India and the U.S. Such data prove that urgent measures must be taken to reverse the situation, prevent new cases and, not least, promote health and self-care in people who are already affected by diabetes[5].

Given this setting, treatment measures are the medications used for diabetes, such as insulin (recommended, mainly, for the cases of DM1). However, it is worth mentioning the incentive of health professionals to patients regarding self-care. The autonomy and empowerment of patients are essential to control the disease and avoid its complications.

The American Association of Diabetes Educators (AADE)[6] emphasizes that self-care can be effective through seven important behaviors, namely: 1) healthy eating (nutrition care); 2) being active (physical activity); 3) controlling blood glucose values; 4) taking medication (using medication at the correct times every day); 5) solving problems (being prepared to face unexpected complications); 6) reducing risks (care for the prevention of chronic complications); and 7) adapting healthily (developing personalized strategies to face daily stress).

However, because it is a disease that primarily affects children and adolescents, self-care and strategies for their empowerment must be directed appropriately to this portion of the population, which has peculiar characteristics.

International literature points to adolescent empowerment as a gradual process that allows individuals to take ownership of knowledge, develop skills and critical sense, directly contribute to health, well-being, and self-confidence[7].

In this sense, it is essential to remember that adolescence comprises individuals aged 12-18 years and is characterized by physical, psychological, and behavioral changes that generate conflicts[6]. Therefore, when receiving the diagnosis of a chronic condition, such as DM1, health promotion actions, such as encouraging self-care, should be carried out for this public to provide a better quality of life and prevent comorbidities.

Health technologies deserve to be highlighted in self-care since they can be considered tools that can be applied to solve or reduce individuals' or populations' health problems of individuals or populations[8]. Among them, mobile applications (APP), software packages with specific functions, can assist individuals in a specific task[9].

As for the use of APP, most adolescents are adept at these technologies[10]. Primarily through smartphones, APPs are intra and interpersonal communication facilitators. They also provide entertainment (games, music, and TV), information (search engines and specialized blogs), and communication, with the use of social networks (Twitter, Facebook, Instagram, Tinder, etc.)[11].

Besides these traditional possibilities, international studies have shown the increasing use of APPs by health teams as therapeutic guidance facilitators and in managing and monitoring the individual health of patients[12].

Given the importance of the theme addressed, there was a shortage of APPs aimed at adolescents with DM1. As a result, the development of innovative technology helping in the daily lives of these adolescents becomes relevant, with assistance in treatment adherence, preventing health problems, and, consequently, reducing public health expenditure with the complications of not controlling the disease. Also, such technology appears as a tool that allows a better approx-

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imation of the Family Health teams with the target audience. Thus, as a measure of bridging the identified knowledge gap, we aimed to develop and validate an APP for adolescents on DM1, focusing on self-care.

Methods

This is a methodological study based on developing a mobile application (APP) geared to promoting self-care in adolescents with DM1. To this end, three phases were followed, namely: Phase 1 - Literature review related to APPs on DM1 in databases and online stores (benchmarking); Phase 2 - Creation and development of the prototype; Phase 3 - Evaluation of the prototype by judges.

An integrative literature review was carried out to complete Phase 1, through its constituent steps, based on the scholars of this method: a) Identifying the problem and establishing the guiding research question; b) Sampling (selecting databases, controlled descriptors, and defining the inclusion/exclusion criteria for paper, and selecting studies); c) categorizing (establishing the database); d) performing a critical analysis of the included studies; e) analyzing and discussing results; and f) realizing a synthesis of the knowledge evidenced in the analyzed papers or presenting the integrative review[13].

Benchmarking was also carried out in Phase 1, which consisted of reviewing the types of existing applications and comparing their functionality, which is essential since it subsidizes the creation of the developing application. The search occurred in January 2019, in the two leading virtual stores, for each type of Brazilian operating system, namely: a) *Google play* (Android - https://play.google.com/store/apps?hl=pt); b) *Apple store* (iOS - http://www.apple.com/br/).

Thus, a search was conducted within the category "Medicine", using the terms "Diabetes Mellitus", "Diabetes Mellitus type 1" and "Diabetes Mellitus type 1 in adolescence", both in Portuguese and in English.

The inclusion criteria adopted were free APPs, running on the selected platforms (Android and iOS), with content or tools focused on the proposed theme, available in Portuguese or English. The selected APPs were downloaded and installed on two different devices, according to the operating systems. Thus, the Samsung J4 Plus® smartphone was used for the Android system and, iPhone 6S Apple® for iOS.

After identifying the available APPs, the usability evaluation was carried out through the System Usability Scale (SUS) questionnaire, created by John Brooke in 1986 and validated in Brazil by Tenório et al.[14]. The SUS questionnaire can assess products, services, hardware, software, websites, and applications. SUS scores range from 0 to 100 and are interpreted as follows: poor usability (<51 points), good usability (>71 points), excellent usability (>86 points), and best usability achieved (>91 points)[15].

After evaluating usability and based on good usability, the selected applications were also assessed for content, based on the SCAMPER technique, created by Bob Eberle[16] and popularized by Michalko[17]. The name comes from the acronym originated from the initials of seven operators: Substitute, Combine, Adjust, Modify, Put to other uses, Eliminate, and Reverse. This technique uses a set of questions aimed at stimulating new ideas about something that already exists to improve it[18]. Phase 2 was completed with the following steps.

Planning the application

The application was planned before its development, assuming the need to define the theme, the available resources, its objective, the target user of the technology, the actual use, when, where, and what it will be used for, and what is expected from its application[19].

We aimed to provide a tool for promoting self-care of adolescents with DM1 through the seven behaviors highlighted by the American Association of Diabetes Educators[6]. The selected target audience consisted of adolescents with DM1, who had a mobile device compatible with the application (Android system) and the skills to handle it. To this end, we opted to elaborate content with clear language fitted to the public. We were concerned with elaborating attractive, easy loadable images and layout to facilitate user's access regardless of the speed of his mobile network or the device's storage capacity.

An agile software development methodology based on Extreme Programming was used for the technological development of the APP, as advocated by Pressman[9] (Figure 1).

Application layout

High-fidelity functional prototyping of the app was performed using the Adobe® XD toolset, a software dedicated to developing graphical in-

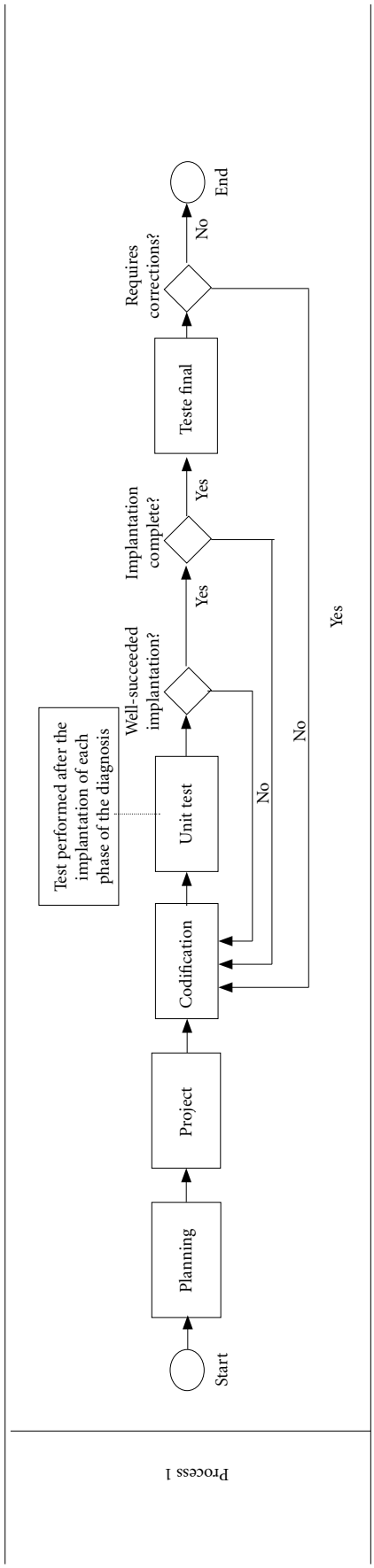

Figure 1. Test performed after the implantation of each phase of the diagnosis.

Source: Extreme Programming (Adapted from Pressman and Maxim[9]).

terfaces and user experience, as a first step in the application layout development process. The first screen artifacts were produced with the definition of data visualization areas, insertion of figures, click areas, and the generation of micro-interactions between the application's components, screens, and buttons.

With the composition of the set of screens, the graphical user interface (GUI) was therefore developed with the ion-components of the Ionic Framework, available in the documentation on the tool's website. The ChartJS library components (https://www.chartjs.org/docs/latest/) were also used.

The button action component was used in the layout composition and was the main action part of the application. It is responsible for summoning the methods that perform the calculations and the new screens and inserts them in the execution stack. The initial screen of the application is a Line Chart-type chart from the ChartJS library to facilitate the user's visualization of the inserted data.

We opted for the Android operating system, as recent research indicates that it predominates the Brazilian market[20]. The collaboration from an Information and Communication Technology (ICT) professional, emphasizing the web designer, was required.

The promotion of self-care of adolescents with type 1 Diabetes Mellitus was strictly observed through the following topics: healthy eating; physical exercises; blood glucose control; medication adherence; coping with complications or unexpected situations; prevention of complications and strategies for coping with stress.

Phase 3 included the prototype's validation by different judges' instruments, divided into two groups: content judges (researchers/teachers and care professionals with experience on the subject) and technical judges (professionals with experience in ICT or APP).

Content judges and technicians were selected by searching the Lattes Platform website in the Lattes Curriculum tab, signaling the option "Search Lattes Curriculum", and third-party referrals (snowball technique) were also accepted. These judges should meet at least two of the criteria described by Jasper[21] to participate in the validation so that they can be considered theme or technical specialists (e.g., experience-acquired skill/knowledge, specialized skill/knowledge, which make the professional an authority on the subject and unique skill in a particular type of study).

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The Suitability Assessment of Materials (SAM) instrument developed by Doak et al.[22], Portuguese version by Sousa et al.[23], was employed to validate content. The SAM instrument contains a list to check attributes related to the content, writing style, appearance, motivation, and cultural adequacy of the educational material.

The technical validation process was mediated by version (1.0) of the Smartphone Usability Questionnaire (SURE), built and validated by Von Wangenheim et al.[24], which consists of 31 items and measures the usability of smartphone applications. Technical validity was assessed by calculating the Content Validity Index (CVI). An CVI value higher than 0.78 was stipulated as the desired parameter, as recommended by Alexandre and Coluci[25].

This study observed the human research ethical precepts. Initially, the research protocol was submitted to Plataforma Brasil and was then analyzed and approved by the Human Research Ethics Committee (CEP) of the State University of Ceará (UECE).

Results

The study on-screen is nested in a Master's dissertation. The results of the three phases of the research are shown below, prioritizing the data related to the development of the application.

In Phase 1 of the study, 41 publications were initially collected for the integrative review. From this number, papers that were not available in full and those that did not address the theme of promoting self-care for adolescents with DM1 were excluded. Thus, the final sample resulted in five papers. The research was conducted in Canada, Norway, Australia, and Brazil and published from 2012 to 2017. Their main results showed that the tools are of paramount importance for the self-monitoring of adolescents with DM1, and the creation of new applications for this purpose should be encouraged.

Sixty-five applications were analyzed for benchmarking, 28 of which scored 71 points or higher in the SUS questionnaire (classified as good usability), and 37 applications failed to achieve a sufficiently good usability level. The use of the SCAMPER technique in the 28 applications that obtained good usability showed that some applications could improve their language (making it more accessible to the adolescent public), provide the sharing of data to health professionals who accompany patients, make the handling of the APP's functionalities simpler, and jointly address the components for promoting self-care in diabetes.

Presentation of the application

The name chosen for the application was "*DM Agendinha*", as an abbreviation for *Diabetes Mellitus Agendinha*. The user's first layout corresponds to the design of the application (logo), which is made available on the menu screens of the devices with the APP icon. Figure 2 shows an illustration of the login and main menu screens.

Starting from the initial menu, the user has eight icons, seven of which correspond to the behaviors highlighted by the AADE[6] and one icon to register the results of various tests related to the monitoring of Diabetes *Mellitus*. The description of the items is shown below, as they are arranged in the application.

Food

In this topic, the application has a recipe guide, divided into four categories (Figure 3): a) Children's recipes: chayote croissant, banana popsicle, and colored jelly; b) Sweets: pineapple and cashew nut cake, passion fruit mousse cake, condensed milk chocolate cake, the delicacy of the gods, and guava paste with cheese roulade; c) Snacks: onion soup, watermelon refreshment, and ham quiche; d) Meals: rump skirt with herb sauce, chicken stroganoff, and countryside stuffed roll.

Exercises

For this item, the application encourages the adolescent's adherence to regular physical exercise. Thus, this habit's advantages to his health are highlighted, along with eight tips to make this activity pleasurable.

Blood glucose

The application addresses blood glucose control through an appropriate space in which adolescents record their capillary blood glucose values. When recording these values (in mg/dl), the application absorbs the data and can show their history through charts. Their charts are self-explanatory and, when generated, they can reveal whether the values are above the recommended parameters (Figure 4).

Medicines

The application provides a register for the teenager to record the name of the medication, the dosage, and administration time. Thus, the application will issue an audible alarm as a medication time reminder at the scheduled times.

Tips for coping with complications

This topic aimed to set questions for adolescents to recognize the factors that triggered the change in their blood glucose value and provide them with tips to avoid the recurrence of these complications (Figure 5).

Prevention of complications

Other essential measures were considered concerning the prevention of complications, such as avoiding tobacco use; going to the ophthalmologist at least once a year; going to the dentist regularly; and being careful with own feet, aiming to avoid chronic complications – heart attacks, strokes, damage to the kidneys and nerves, feet amputation and vision loss. This information is provided in an explanatory manner.

Music (Stress-coping strategies)

As a stress-coping tool, the application brings a playlist with instrumental songs to promote relaxation.

Tests

The application has a function to record the results of the primary laboratory tests requested from patients with a diagnosis of diabetes. The results are stored and serve as a reference to compare values over time (history).

Content validation

Eight judges participated in the content and technical validation, according to the criteria mentioned above, with five content judges (researchers or professors in the health field, with experience in caring for adolescents diagnosed with DM1) and three technical judges (professional experience in APP design or development).

The content judges answered the 21 items of the SAM instrument, distributed into six evaluative aspects (1. Content; 2. Literacy requirement; 3. Illustrations; 4. Layout and presentation; 5. Learning stimulation/motivation; 6. Cultural

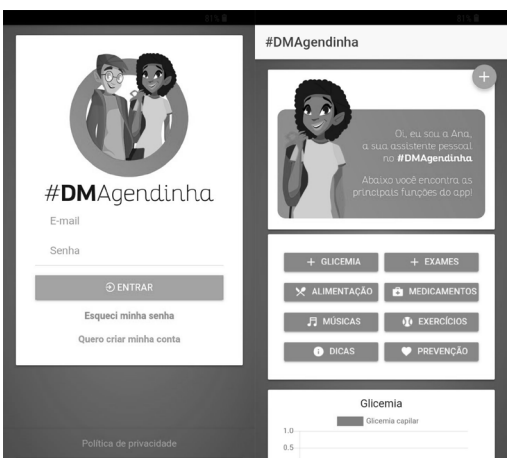

Figure 2. APP Screens 1 and 2.

Captions: E-mail, Password, Enter, Forgot my password, I want to create an account, Privacy policy. Hello! I am your #DMAgendinha personal assistant. The App's main functions are found below! Blood glucose, Tests, Diet, Drugs, Music, Exercises, Tips, Prevention, Blood glucose, Capillary blood glucose.

Source: Own elaboration (2020).

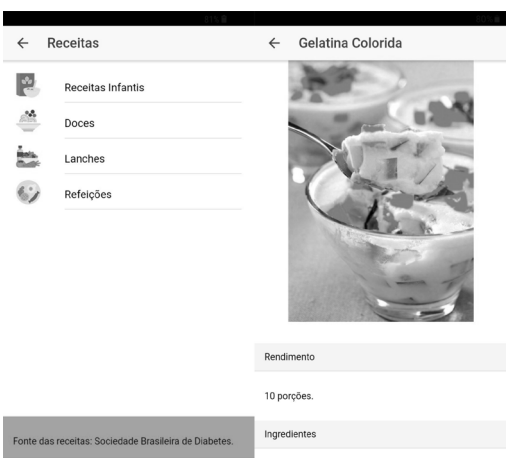

Figure 3. Screens 3 and 4 - Healthy Eating and Children's Recipe.

Captions: Recipes, Children's recipes, Sweets, Snacks, Colored jelly, Yield, 10 portions, Ingredients, Source of recipes: Brazilian Diabetes Society.

Source: Own elaboration (2020).

Figure 4. Screens 9 and 10 - Glycemic Control and Glycemic Curve.

Captions: The App's main functions are found below! Blood glucose, Tests, Diet, Drugs, Music, Exercises, Tips, Prevention, Blood glucose, Capillary blood glucose, Update chart.

Source: Own elaboration (2020).

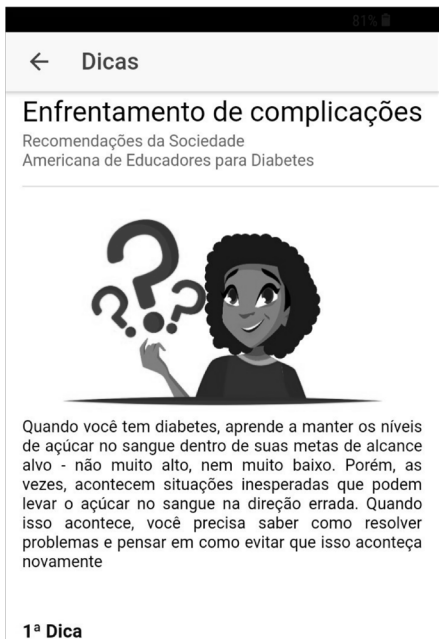

Figure 5. Screen 12 - Coping with complications.

Captions: Tips, Coping with complications, Recommendations of the American Association of Diabetes Educators. When you have diabetes, you learn to keep blood glucose levels within your targeted goals – not very high, nor very low. However, some unexpected situations occur sometimes and they can lead blood glucose to the wrong direction. When this happens, you must need to know how to solve problems and think about avoiding this from happening again. First tip.

Source: Own elaboration (2020).

suitability), indicating: partially adequate, adequate, or excellent. In turn, the technical judges answered the 31-item SURE questionnaire, pointing out: 1=strongly disagree; 2=disagree; 3=agree; 4=totally agree. The results showed that the *DM Agendinha* app was positively evaluated by the judges, with superior educational technology, obtaining a measured score percentage of 85.3% in the instrument (SAM) and an overall CVI of 0.96 in the technical validation of the questionnaire (SURE).

Discussion

Developing and validating a technology to promote self-care for adolescents with DM1 is of paramount importance, as these technologies are scarce in the primary virtual stores and not widely published in the leading health journals. We aimed to create another app on diabetes and develop a technology aligned with patient self-care, as we believe that the empowerment of these adolescents is essential to keep the disease under control, avoiding the primary complications.

However, the development of tools such as the APP *DM Agendinha* requires the appropriation of rigorous methods to achieve the proposed objective and the desired results. Translating scientific and reliable content to the digital medium with accessible language becomes a challenging task, both due to the chosen digital device's properties (screen size, keyboard, and processing performance) and differences in data use in the new format[26].

We were concerned with the language used throughout the process of building the *DM Agendinha* application. The technical terms were

identified and transformed into a popular language to facilitate the adolescents' understanding. Care regarding language adequacy to facilitate its understanding is vital in works related to health education and promotion. Thus, popular use words should preferably be employed. The use of technical terms should be limited to what is strictly necessary[22].

When seeking to develop technology for diabetic adolescents, we should not forget that such individuals bring about the peculiarities of their complex life cycle. Thus, health professionals should be free to expose the main difficulties, needs, and skills developed throughout the disease to identify possible strategies that improve supported self-care[27].

When effectively approaching diabetic adolescents, knowing their needs, and educating them to take care of their health, the possibility of choosing healthy lifestyle habits is transferred to them, given their chronic condition. As a result, they will become responsible for their health. However, this responsibility is a cross-sectional process for all adolescents to maintain healthy lifestyles (universal self-care). However, the responsibility should focus on self-care[28] in adolescents with DM1.

Adolescents must have access to reliable sources of information about DM1 and acquire knowledge about the disease for the correct attitude in favor of self-care. This becomes relevant since their knowledge about the disease is crucial in the adopted behaviors. However, learning is directly influenced by the adolescents' social and cultural beliefs, positively or negatively affecting the disease's control[29]. Noteworthy is that influencing environments also includes virtual environments, such as the use of educational APPs.

In this sense, *DM Agendinha* was concerned with being an environment that could positively influence adolescents with DM1. We defined figures that would adequately express the theme after elaborating the content. Illustrations must be intended to explain or emphasize essential ideas in the text, presenting high quality and familiarity with the target audience. Illustrations are essential to the legibility and understanding of a text, as they will attract readers and awaken and maintain their interest in reading[30].

The literature already brings scholars who have developed applications for adolescents, in other themes, such as human papillomavirus (HPV) and head and neck cancer, to instigate the importance of health and body care[31]. Furthermore, as a health promotion tool, the development of applications is known to be something debated in the academies and elaborated on different themes for a variety of audiences[32]. However, in the *DM Agendinha*, the content is aligned with seven primary behaviors, namely: healthy eating (nutrition care); being active (physical activity); controlling blood glucose values; taking medications (using medications at the correct times every day); solving problems (be prepared to face unexpected complications); reducing risks (care for the prevention of chronic complications); and adapting healthily (developing personalized strategies to face daily stressors)[6].

The relevance of each behavior mentioned above for the control of diabetes is undeniable. As a differential, the application adapted the adolescent public guidelines, always supported by literature relevant to the theme and prominent organizations and institutions. For example, all recipes in the APP are derive from the Brazilian Diabetes Society (SBD), ensuring a low-carb diet. Adequate nutrition is vital to adolescent health promotion and well-being, contributing to their growth and healthy development, and avoiding diseases and complications[33].

Regular physical exercise and blood glucose control are also reported in the literature as essential for the control of diabetes[34]. Thus, the APP *DM Agendinha* encourages adolescents to be physically active and contributes to controlling blood glucose levels.

As in DM1, drug treatment is anchored in the subcutaneous use of insulin, and adherence deserves to be highlighted. Thus, the audible alarm that the application emits is another tool to promote self-care since the literature confirms that medication adherence is closely related to the control of diabetes and prevention of complications[35].

Finally, the APP brings about essential tips for managing the disease and music to stimulate relaxation and relieve the disease's stress to cope with complications. We are aware of the limitations in this specific criterion since the number of music tracks is reduced, and it is not yet possible to import a large number of tracks from other platforms. It is believed that a future update of *DM Agendinha* will allow integration with another specific APP to listen to music.

The Family Health Strategy is one of the ideal settings to encourage the use of this type of tool since the team's health professionals (doctors, nurses, and dentists) must maintain the bond with their assisted patients and families to maximize self-care of these patients, keep the disease under control, ensure good medication adherence, and prevent diseases and complications.

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Conclusion

We can conclude that the *DM Agendinha* is a valid mobile application to promote self-care for adolescents with type 1 DM. The application can be a viable tool for ESF professionals since they are responsible for monitoring these PHC patients.

Collaborations

LFPA Alves, MM Maia, MFM Araújo, MMC Damasceno and RWJF Freitas participated in the design, planning, and data collection, analysis, and interpretation. They also contributed to the elaboration, review, and approval of the final version of the paper.

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