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IoT framework of telerehabilitation system with wearable sensors for diabetes mellitus patients

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ABSTRACT

Physical activity is commonly used as a treatment for diabetes patients, although its effectiveness in improving cognitive functions such as learning, thinking, remembering, and decision making is not clear. Regular exercise can gradually improve metabolic abnormalities associated with pre-diabetes and assist patients with type-2 diabetes (T2D) in managing their pharmacological treatment. The usage of mobile health (mHealth) as a tool to help diabetes patients with their diabetes self-management have been demonstrated in previous studies and it can lead to reductions in glycosylated hemoglobin (HbA1c) levels. Heart rate readings during physical activity is beneficial for healthcare professionals (HCP) to ensure appropriate intensity levels for their patients is achieved. Additionally, the list of the tailored physical activities is long, and it is quite challenging for the T2D patients to remember. Therefore, Tele-DM is proposed, consisting of a smartwatch and mobile application that enable remote physiotherapy sessions for T2D patients. The smartwatch transfers the heart rate data to Tele-DM through Google Fit database. The system provides tailored exercise programs to help patients reduce their weight and HbA1c levels. With the ability to facilitate two-way communication between HCP and T2D patients, the Tele-DM system is designed to enable an effective remote rehabilitation process.

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1. INTRODUCTION

Diabetes mellitus (DM) is a group of metabolic diseases where it is caused by the inability of the pancreas to produce enough insulin which results to persistently high blood glucose levels [1]. It also can be referred as hyperglycemia. Type 1 diabetes (T1D), type 2 diabetes (T2D) and gestational diabetes are the three main types of diabetes mellitus [2]. T1D occurs when pancreatic ß-cells are destroyed and pancreas produces less insulin while T2D is caused by muscle that are unable to respond to insulin correctly, also called as insulin resistance [1]. The autoimmune reaction that prevents the body from producing insulin eventually leads to lifelong dependency on insulin intake for T1D patients. Meanwhile, gestational diabetes mellitus (GDM) is defined as glucose intolerance which only affects during their pregnancy [3]. It is only temporary, and the condition usually ends when the pregnancy is over. However, they are at a higher risk of developing type 2 diabetes later in life [2], [3].

T2D is the most common form of diabetes where there have been 460 million people affected by the disease and it is expected to rise to 700 million in the next 25 years [4]. T2D is develops over the years from younger age and in most cases of people diagnosed with T2D are adults. Some of the factor that lead to T2D are insulin secretion, genetic component, obesity, incretins, increased glucose uptake, and circadian rhythm [5]. According to world population review, as of 2022, Malaysia is now ranked at number 16 in the world with 19.0% (6.3 million) of prevalence rate diagnosed with diabetes [6]. Diabetes is not only incurable, but it also increases the chance of various health problems and microvascular compilations such as heart disease, nerve damages (neuropathy), strokes, hearing loss, hypertension, blindness (retinopathies), amputations, and kidney failure (nephropathies) [4], [7]–[9].

The mentioned health problems also cause considerable premature deaths, productivity losses, and poor quality of life [10]. Glycosylated haemoglobin (HbA1c) is a biochemical measurement used to monitor diabetes. Diabetes patients that practice sedentary condition (inactive in physical activities) will increase the HbA1c and it could worsen the glycaemic control and diabetes condition [11], [12]. A normal HbA1c level for people who does not diagnose with diabetes is below than 5.7%, while when the levels are between 5.7% to 6.4%, they are called pre-diabetes, and levels higher than 6.4% indicates diabetes. There is evidence that has been proven to show that physical activity, weight control and timing of feeding can improve the condition of T2D or delay the development of diabetes.

A research has been found that high intensity interval training (HIIT) has a positive impact on the condition of diabetes where HIIT could improve the glycaemic control or reduce the HbA1c [11]. A recent meta-analysis study shows that HIIT and moderate intensity have reduced the HbA1c of the diabetes participants, compared to low intensity training, and control training [13]. Moreover, a study also has found that males who diagnosed with diabetes, showed more significant result in the reduction of HbA1c when they follow the aerobic training, resistance training, and flexibility training program plan [14]. Finally, diabetes patients who only relying on drugs intake will be having difficulties in achieving better curative effect. They have to include health education such as performing physical activities, and healthy lifestyle to have better improvement of diabetes treatment [15].

Mobile applications have become an increasingly popular tool in the health sector over the past decade. These apps are designed to provide users with a wide range of health-related services, from tracking their physical activity [16] and calorie intake to monitoring chronic conditions, providing access to medical advice control assistive devices [17]. Mobile health apps come in a variety of forms, including fitness and wellness, chronic disease management, telemedicine, and medication management apps. The mHealth has been used as a tool for diabetes treatment and self-management. The first example of mHealth is called Glycoleap [18]. The mobile application offers features such as tracking of blood glucose levels, food intake, physical activity, and medication adherence. It also provides personalized feedback and support to help users make healthier lifestyle choices and improve their diabetes self-management. The program consists of a hundred (100) patients diagnosed with T2D that possess the HbA1c levels of ≥7.5%. The study suggested that the Glycoleap app has potential to improve diabetes self-management and glycemic control in people with type 2 diabetes.

A mobile application called D'Lite [19]. There are 2 groups for the program, intervention group and control group. The intervention group consists of 72 adults that uses the mobile application, while the control group consists of 76 adults that uses the standard approach of the physical activities and diet counselling. The authors stated that the program of the intervention group was effective in improving participants' lifestyle behaviours, including diet and physical activity, which resulted in improved glycemic control and weight loss. These findings suggest that the use of a smartphone app in promoting lifestyle changes can be beneficial for individuals with prediabetes.

A study on the intervention of DSMES app found that it had a positive impact on medication adherence in individuals with type 2 diabetes [20]. The mobile application is designed to help individuals with type 2 diabetes improve their medication adherence through education and support. The DSMES app includes features such as reminders for taking medication, tracking medication adherence, and providing educational materials on diabetes self-management.

The Time2Focus mobile app is designed for patients diagnosed with T2D. It aims to improve behavioural engagement and clinical outcomes by providing educational and interactive resources related to managing the condition. The participants of the program were from the age of eighteen to eighty-nine years old and possess the HbA1c levels between ≥8% and <12% for the past three months. The study showed that the mobile application led to improved general behavioural engagement and positive changes in clinical and cognitive outcomes of the T2D patients [21]. Based on the previous studies, mHealth has been proven that it can help improve glycemic control, self-management of diabetes, medication adherence, lifestyle behaviours, and clinical outcomes in patients with T2D.

Another study of mHealth [22], the study aimed to examine the effect of a mobile health intervention on patients with hypertension and T2D. The program consists of participants from the age of forty to seventy years old, and the HbA1c levels of >6.0% for the last four months. The authors concluded that the mobile health intervention had a positive impact on patients with hypertension and diabetes. However, it failed to show clinical improvement, and the authors stated that the medicine intake could significantly lower the HbA1c levels of T2D patients.

A BlueStar mobile application [23], the aim of the paper is to evaluate the effectiveness of a mobile app, BlueStar in improving self-management of T2D. The participant in the program is T2D patients with HbA1c levels of more than 8.0%. The program also was divided into 2 groups, with one group uses the mobile application while the other uses the standard method. The authors stated that there is no difference in the outcomes of HbA1c levels between the 2 groups. Other than that, the authors also mentioned that the low usage of the mobile app from the intervention group impacted the outcomes of HbA1c levels.

Tele rehabilitation is a rapidly growing field that leverages modern technology to provide rehabilitation services to patients in the comfort of their own homes. The goal of tele rehabilitation is to deliver high-quality care and improve patient outcomes by using telecommunication technology to remotely connect patients with rehabilitation specialists [24]. The physical activities in the Tele-DM mobile application are tailored and validated by the expert panels such as physiotherapists, diabetes educators, and academicians in the exercise and sport science to increase the positive outcome on the HbA1c levels. Measuring the heart rate during the physical activities is suggested to ensure an appropriate intensity of physical activities is achieved and the T2D patients can take necessary actions if they are experiencing symptoms such as irregular heart rate or chest discomfort during exercises. Therefore, a smartwatch is required to measure the heart rate of T2D patients during exercises. Based on the previous studies, they do not include this feature in their mHealth.

Even though mHealth has been proven its effectiveness in handling glycaemic control, it can be quite challenging due to the difficulties for T2D patients to remember the long list of the tailored exercises or to follow the activity schedule in a long period. This can lead to the decrease in motivation of the T2D patients. Additionally, without the telerehabilitation system, patients would require spending more time and money to come to the physiotherapy session at the hospital for their routine exercises. Healthcare professionals facing difficulties to promote, provide guidance, and to monitor on physical activities generally for their diabetes patients [25], children with special needs [26], strokes patients and many more. Therefore, telerehabilitation monitoring system is needed where patients can perform physical activities at home, while HCP can monitor their patients remotely.

This paper aims to develop an mHealth, Tele-DM mobile application. Tele-DM is a remote monitoring telerehabilitation system, where T2D patients can perform physical activities at home with professional guidance and for healthcare professionals can remotely monitor their patients progress and performance. The system consists of a smartwatch where it is used to measure the heart rate of T2D patients when performing the routine physical activities. Moreover, the aims of this paper also to develop a user-friendly interface of mobile application to ease the T2D patients to perform the tailored physical activities.

2. METHOD

Figure 1 depicts a system architecture for Tele-DM mobile application that comprises three main components. The first component is a patient system in Tele-DM and a wearable device, smartwatch designed for T2D patients. The smartwatch is connected to the mobile application via Bluetooth and can monitor their vital signs such as heart rate, calories, and steps. A smartwatch, Xiaomi Mi Band 7 is chosen for this project due to the low cost. The second component is a database management system (DBMS) that stores all the user's data including patients and HCPs. The third component is an HCP system in Tele-DM designed for healthcare professionals that allows them to access the patient's data, monitor patient's exercise, analyse it, and provide personalized care based on the data. Finally, the users require an internet connection on their mobile devices to access the Tele-DM system.

A flutter framework is used to develop the Tele-DM mobile application. Flutter uses Dart as its programming language, and it enables developers to create native applications for both iOS and Android in a fast and creative way. Based on a survey [27], Flutter is the most popular cross-platform framework used by global developers from 2019 to 2021 with 42% of developers used Flutter in 2021. DBMS is one of the important aspects when developing a mobile and web-based application. A non-relational database NoSQL, MongoDB is used as the DBMS of Tele-DM system. Developers can design apps faster, handle many different types of data, and manage application more organized because MongoDB employs JSON-like documents with schema. Finally, Tele-DM using technologies such as Nodejs, Express and Heroku as the back end of the system that helps to communicate with the DBMS.

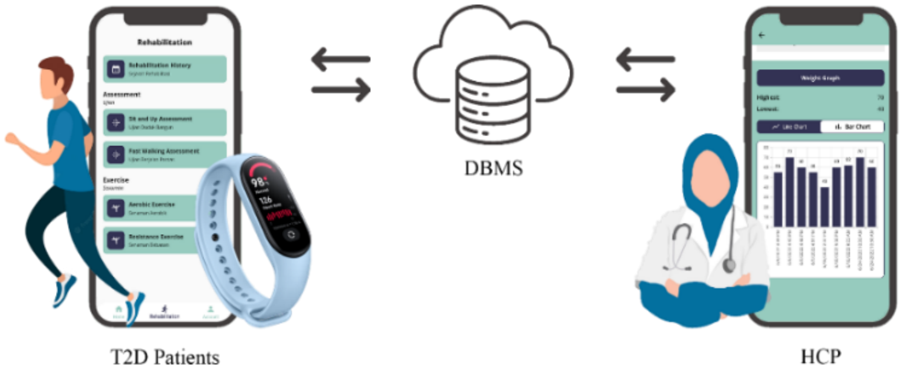

Figure 1. System architecture of Tele-DM

2.1. Features in Tele-DM mobile application

Table 1 describes features that are implemented in the Tele-DM mobile application. The features are designed to help T2D patients in performing routine physical activities at home and HCP can monitor their patients remotely. The chat function is useful for communication between T2D patients and HCP within the application. The application also includes a calendar to help patients schedule tasks and exercises, as well as daily objectives for physical activity. The application stores a patient's history of completed physical activities and vital signs, which can be monitored by patients and their HCPs. Additionally, the system includes an exercise module that tracks time and vital signs data during exercise sessions.

Furthermore, Tele-DM also provides a weight logging and progress monitoring function, as well as the ability for patients to monitor their daily heart rate, walking steps, and calorie intake. Furthermore, blood glucose monitoring must be done using hospital equipment, but patients can log their results in the system during their monthly follow-up appointments. The application also includes patient and HCP information, such as identification numbers, names, genders, birthdates, blood types, heights, weights, and HCP contact information. Finally, Tele-DM supports both English and Malay languages. Overall, these features aim to support diabetes patients in managing their condition and communicating with their healthcare providers more effectively.

Table 1. Description of features available in Tele-DM mobile application

Features	Description
Chat function	Diabetes patients can communicate with their HCP through chat function. HCP also can remind their patients of future meeting.
Calendar	Schedule of tasks or exercises to be performed by patients.
Daily objectives	Daily objectives on what physical activities must be done by patients.
Rehabilitation	Guidance videos and instructions of each assessment and exercise.
Assessments progress loggin	Tele-DM mobile application provide a logging function on certain assessments where patients can manually enter their results of the assessments and store the results in database.
History of rehabilitation	The system will store all completed physical activities with its vital signs in database. Data can be monitored by patients and their personal HCPs.
Weight logging and progress monitoring	Diabetes patients can measure their own weight and manually record their weight in the Tele-DM mobile application. They can monitor the progress of their weight loss journey.
Vital signs monitoring	Patients can monitor their daily heartrate, walking steps, and calories.
Blood glucose logging and monitoring	Blood glucose measuring must be done using hospital equipment. They must come to the hospital for their monthly follow up and they will log their results in the system.
Information of patient and HCP	Patient's information such as identification (ID) number, name, gender, birthdate, age, blood type, height, and weight. This information will be displayed in the mobile application.
Multi-language	English and Malay are the available languages in Tele-DM.

2.2. Physical activities for T2D patients

As mentioned before, the physical activities in the Tele-DM mobile application are tailored and validated by the expert panels. This includes guidance videos, instructions, and health lessons on every physical activity. The health lessons aim to educate T2D patients on the benefits of physical activity and how it can positively impact their overall health. The main activities that are available in Tele-DM are sit up assessment, fast walking assessment, aerobic exercise, and resistance exercise. These physical activities are ensured to have a positive impact on the condition of T2D patients. Specifically, regular exercise has been linked to improvements in HbA1c levels and weight loss, both of which are important factors in managing T2D.

2.3. Connection of smartwatch to Tele-DM

Figure 2 illustrates how the smartwatch is connected to Tele-DM mobile application to transfer the recorded heart rate after completing the physical activities. While T2D patients are performing exercises, Zepp Life mobile application collects the vital signs data such as heart rate, steps, and burned calories from the smartwatch. The data is then uploaded to the Google Fit cloud database. Google Fit cloud allows users to securely store and access health and wellness data from a variety of sources, including smartwatches, fitness trackers, and mobile apps. Finally, Tele-DM fetches the vital signs data from the Google Fit mobile application and uploads it into its own database (MongoDB).

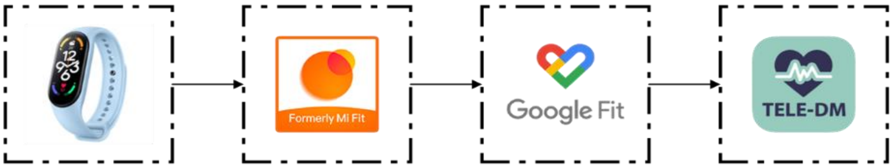

Figure 2. Connection process from smartwatch to Tele-DM

2.4. Effectiveness evaluation of Tele-DM

The effectiveness of mobile application on T2D patients in terms of HbA1c and weight loss can be determined by performing physical activities. HCPs can use the system and the period and flow of the program can be decided according to HCPs preference to ensure the patients can utilize the system effectively and reduce their HbA1c levels. The Tele-DM application is also expected to help improve the condition of the diabetes in the T2D patients and to help them learn about diabetes self-management. Feedback from the participants in terms of user-friendliness, graphical user interface, rating of the system, and improvement ideas of the system will be collected from the participants from time to time. These are important to ensure the system will grow in the right direction and to make sure the system is suitable to be used by T2D patients, especially for the elderly.

3. RESULTS AND DISCUSSION

The results for this research project, containing screenshots of completed framework of Tele-DM mobile application, and descriptions of features implemented in the application which has been showed previously in Table 1. Figure 3 displays the home page of Tele-DM, which features a chat function that allows patients to interact with their healthcare providers (HCPs) frequently. Patients can also monitor their daily vital signs (steps, calories, and heart rate) on the home page. Additionally, patients can create, read, update, and delete (CRUD) operations for their tasks or objectives, and their daily objectives will be displayed on the home page.

Figure 4 displays the rehabilitation page where the T2D patients can perform the four main physical activities which are sit up assessment, fast walking assessment, aerobic exercise, and resistance exercise. Patients can click on the activity's name to begin their routine physical activities. Figure 5 shows the profile page in the system. The page displays patient's personal information and their personal healthcare professionals. The settings page can be opened by clicking the gear icon on the profile page. The settings page provides patients to change the system's language between Bahasa and English, and they can also change their personal information. The multi-language feature will help Tele-DM reach wider audience and will help the elderly patients who prefer a Malay language only.

Figure 6 displays the page of rehabilitation history where patients can see their completed physical activities. Additionally, patient's personal HCP have access on this page to monitor their patient's progress of physical activities. The data is displayed on a vertical scrollable calendar as shown on top of the page. The calendar in the application is easy to navigate, and the user interface is user-friendly. The calendar uses coloured dots to indicate the number of completed physical activities on a specific date. If there are no dots on a particular date, then no physical activities were completed on that date. When the user clicks on a specific date, such as August 23rd, 2022, the results of completed physical activities are displayed below the vertical calendar. This feature allows users to view their completed physical activities for a particular day easily.

Figure 7 and Figure 8 show the example user interface of the completed aerobic exercise and resistance exercise respectively. The pages can be opened by clicking on the exercise's name on the rehabilitation history as shown in Figure 6. Every completed exercise saved in the database has a unique ID that can be used to identify the specific exercise. The ‘summary and feedback’ pages for both aerobic and resistance exercises are divided into three parts: summary, vital signs, and feedback. The summary part records the time taken by the user to complete each exercise, from warm-up to cool-down, date of completion, start time, and end time of the exercise.

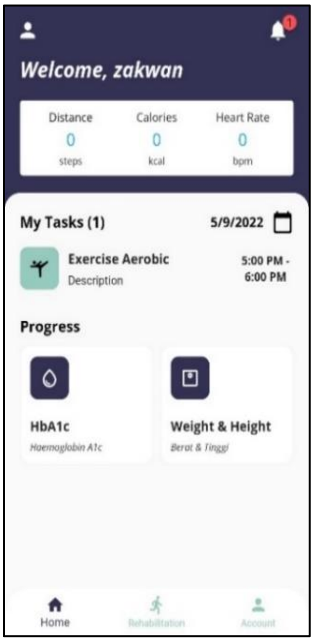

Figure 3. Home page

Figure 4. Rehabilitation page

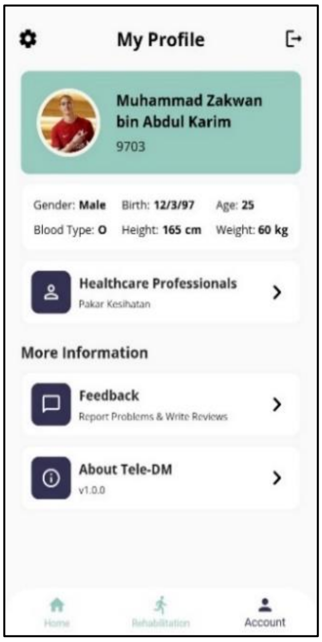

Figure 5. Profile page

Figure 6. Rehabilitation history

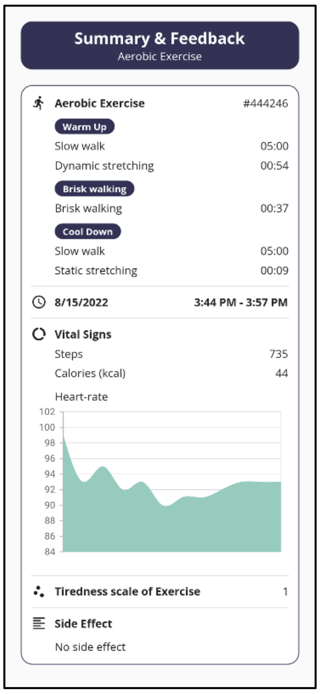

Figure 7. Completed aerobic

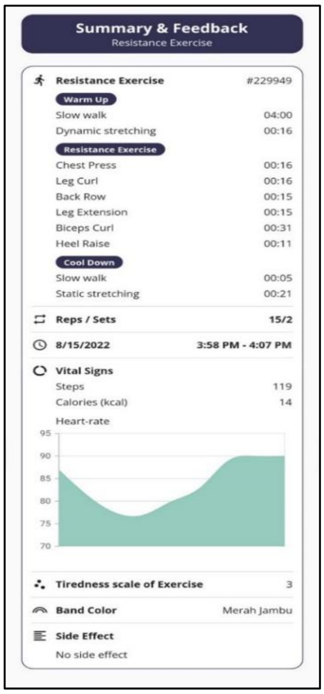

Figure 8. Completed resistance

The vital sign's part displays the recorded vital signs, steps, burned calories, and heart rate fetched from smartwatch at the of the exercises. HCP can monitor the heart rate of every patient's physical activity to ensure an appropriate intensity of physical activities is achieved. Other than that, HCP can also monitor if there are any irregular heart rates during patient's activities. Finally, the feedback section allows the user to provide feedback at the end of each exercise. This section enables the user to give input on their experience with the exercise, including their tiredness scale, and the encountered side effect such as chest discomfort. The resistance exercise involves the usage of a band, and the patient can provide feedback on the color of the band used for the exercise as shown in Figure 8.

Figure 9 and Figure 10 show an example of HbA1c and weight data logging and monitoring respectively. The graph shows the variation in patient's HbA1c levels and weight over a period of time. The x-axis represents the time in months, while the y-axis shows the HbA1c levels and the weight data. To ensure the scalability of the application, the chart will only display 10 data at a time, and the rest of the data can be seen by scrolling the charts vertically. The HbA1c levels and weight charts provides a useful tool for HCP to determine the effectiveness of the tailored physical activities in the Tele-DM mobile application. The charts also allowing HCP to identify trends and make necessary adjustments to their patient's treatment plan to make sure patients can have a positive outcome on their diabetes.

Figure 11 shows a page where T2D patients can send reports on any encountered bugs or problems and provide feedbacks about the application. The page displays a form where patients can enter information about any problems they have encountered while using the application, such as errors or crashes. Additionally, patients can provide feedbacks, reviews, or star rating on the mobile application, such as suggestions for improvements or features they would like to see added. This information will be saved in the database and can be monitor by their HCP. This page provides an essential tool for developers to receive feedback from patients, allowing them to improve the application and provide a better user experience.

Figure 9. HbA1c logging and monitoring

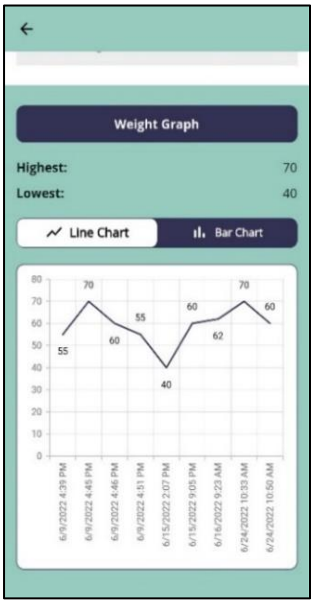

Figure 10. Weight logging and monitoring

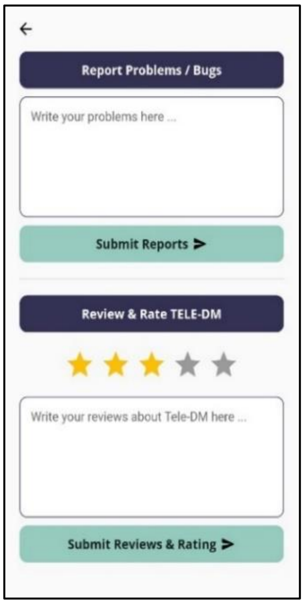

Figure 11. Reports and feedback page

4. CONCLUSION

The aim of Tele-DM is to help T2D patients to perform physical activities at home with professional guidance. Moreover, the mobile application is expected to be an aid tool for T2D patients to be easily monitored their progress and performance by their personal healthcare professionals. Thus, making their rehabilitation process more effective. Tele-DM includes the usage of wearable device, smartwatch to measure patient's heart rate while they are doing their tailored physical activities. The heart rate reading helps HCP to ensure that the intensity of physical activities is at appropriate level. Additionally, HCP can measure the effectiveness of the Tele-DM mobile application by the results of HbA1c levels and weight. Finally, by using the tailored physical activities and the user-friendliness of the application, the system is expected to help T2D patients to improve their diabetic self-management, reducing glycaemic control, and weight loss.

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