https://africanjournalofbiomedicalresearch.com/index.php/AJBR
Afr. J. Biomed. Res. Vol. 27 (December 2024); 2442-2449

Research Article

"Evaluating the Effectiveness of Mobile Health (mHealth) Interventions in Managing Type 2 Diabetes"

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Abstract
"Diabetes type 2" is one of the most widespread chronic diseases which is characterized by the necessity to keep the blood glucose level under control and strictly adhere to the medication and diet regimen. This paper assesses the effect of the "mHealth" interventions in the treatment of the disease. The study design used in the study was a randomized controlled trial and the subjects were randomly assigned into the mHealth intervention group and the control group which received routine treatment. The aspects of the intervention were; taking of blood glucose level, administration of the prescription, and the meeting with the doctor. At the end of the study which was after 6 months the mHealth group had reduced their blood glucose level by 1.2 mmol/L and the reduction of HbA1c by 0.8%, $p < 0.01$ compared to the control group while the mHealth group had 85% medication compliance and an improvement of 5 points in the Diabetes Quality of Life (DQOL). Such conclusions imply that there is a great potential for mHealth tools to increase the ability of diabetes care through the effectiveness of treatment and the quality of life of the patient. Further research work is required to determine the sustainability of these interventions and their availability to the target group.

Keywords: Type 2 diabetes, mHealth, glycemic control, medication adherence, quality of life, "randomized controlled trial".

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Received 25/11/2024 *Acceptance 02/12/2024*

DOI: https://doi.org/10.53555/AJBR.v27i3.5654

1. Introduction

"Type 2 diabetes" (T2D) is a long-term illness that primarily affects the metabolic system of the human body and is among the major causes of diseases affecting the global population. Defined by the presence of hyperglycemia for a long period because of insulin resistance or insulin deficiency it is responsible for greater than 90% of diabetes globally (Federation, 2021). T2D is different from Type 1 diabetes (T1D) which is normally diagnosed in childhood or adolescence but it develops slowly and is normally diagnosed in adulthood. Inactivity, growing size, and age have been pointed out as the main factors that lead to T2D as opposed to T1D. As stated by the "International Diabetes Federation" (IDF), the worldwide proportion of diabetic patients reached 10.5% in 2021, with 537 million of the adult population, while in 2030, they are to reach 643 million of the adult population

(Sun et al., 2022). T2D is on the rise and this is a concern to people and health care institutions. T2D bears several complications like cardiovascular disease, retinopathy, neuropathy, and nephropathy, this will further affect the quality of life and mortality of the patients (Alam, 2021). T2D is mainly treated by lifestyle intervention which includes diet and exercise and with the help of drugs that focus on glycemic control (Garcia-Molina et al., 2020). However, the effort to manage diabetes to the best level possible in the present day is still daunting because most patients do not stick to their recommended therapy plans strictly, the nature of this disease, and concerns with access to health facilities (Chittem et al. 2022). This is why healthcare providers are always on the lookout for better ways of handling diseases and their effects. The advancement of mobile health (mHealth) has been a very dynamic process and this is making it possible to have new possibilities in the management of chronic diseases such as T2D. mHealth is the utilization of hand-held devices, smartphones, tablets, and wearable sensors in the delivery of healthcare services and surveillance of patients' conditions through real-time data capturing. Smartphones and the increase in the number and kind of mobile applications (apps) have made mHealth interventions more accessible to patients from different socioeconomic backgrounds (Stowell et al. 2018). Therefore, mHealth apps used in the management of T2D should consist of features like; blood glucose records, medication reminders, diet and exercise trackers, and the last one which is the educational feature that will help the patient to manage the disease appropriately. Another advantage of mHealth interventions is that they may reach the patients at the right time and the type of support they need so that they may not frequently visit hospitals/clinics (Mansour et al., 2024). The tools above enable constant assessment and feedback, which will enable the healthcare providers to alter the treatment plans depending on the information obtained (Bashshur et al., 2016). In addition, mHealth interventions are easily available and can be easily modified by the patient; this empowers the latter to manage the disease and do so without having to visit a hospital (Kraus et al., 2021). Since mHealth gives patients control over their health conditions, then it has the potential to offload the burden from the healthcare systems while at the same time enhancing the life of the patient. Several research studies conducted showed that mHealth apps improve patient self-management, glycemic control, and treatment compliance (Veazie et al., 2018). For instance, Kitsiouet al. (2017) reported that mHealth interventions significantly reduced HbA1c levels in patients with T2D by an average of 0.48%, indicating better long-term glucose control. In line with the above findings, Pal et al. (2013) also conducted a systematic review that affirmed the notion that mHealth interventions facilitate behaviors such as increased physical activity and improved diet that are useful in the management of T2D. Other works also demonstrate that the application of mHealth interventions can improve the participation and self-efficacy of a patient. Some of the patient motivation can be sustained by some of the aspects including goals, feedback, and progress which will help the patient uphold the treatment plan (Cucciniello et al., 2021). From the study done by Quinn et al. (2008), it was realized that patients who were under the mHealth apps had a higher level of improvement in medication adherence as compared to the patients under the normal care. These results provide the rationale for the use of mHealth technologies to enhance patient self-management and, therefore, the diseases. Likewise, mHealth interventions may decrease the cost of healthcare services since face-to-face consultations may be less used and complications that may warrant hospitalization may be averted (Holmen et al., 2014). Another study conducted by Quinn et al. (2018) found that patients who adopted the use of mHealth tools for diabetes had fewer ER visits and hospitalization therefore lower costs. This makes mHealth a solution with the potential for cutting on cost hence a solution that can be embraced by care systems that are interested in enhancing the delivery of care without necessarily having to invest in a lot of resources. Therefore, from this research, one can conclude that mHealth interventions are effective in the management of T2D, especially in glycemic control. In the randomized controlled trial conducted by Holmen et al. (2014), patients using mHealth platforms achieved an average reduction of 0.5% in their HbA1c levels after six months, demonstrating better blood glucose regulation. In addition, literature on mHealth interventions has also indicated that the patient's compliance with medication and their level of satisfaction has also improved. More adherence can be explained by the use of reminders concerning the medications and the opportunity to control the process of treatment through the application. Improved compliance not only results in improved control of blood glucose but also decreases the risk of chronic complications (Stratton et al., 2000). Besides, the clinical benefits, mHealth platforms also help in educating the patient about the disease and management of the disease. Some of the apps that offer education on diabetes and its management including details on diet, exercises, and medication use are; (Choi et al., 2020). The mentioned information is given in such a very easy and humorous manner that the patients are in a position to make the right decisions on the best treatment to undertake. Thus, mHealth interventions assist patients in gaining the knowledge and self-efficacy that is required for self-management (Song et al., 2022). Therefore the use of mHealth tools ensures that the patients are satisfied with the care they receive and can follow the long-term disease control measures as recommended (Channi et al., 2022).

1.1 Gaps in Current Research

Nevertheless, there is still limited information on mHealth interventions which has been highlighted despite the growing number of positive results. There is also an issue of the scarcity of follow-up studies that would evaluate the efficacy of mHealth interventions in the long term (Pal et al., 2013). Most of the studies are made about short-term outcomes, which follow up their patients for six to twelve months. However, we cannot be sure if these enhancements in glycemic control, medication compliance, and patient involvement can be sustained for several years. It is necessary to conduct more longitudinal studies to determine the possibility of using mHealth interventions in developing lasting behavior and health changes. One such research limitation is the absence of information on the use of mHealth interventions in "low- and middle-income countries" (LMICs) in which the application of digital technologies may be somewhat restricted (McCool et al., 2022). Most of the studies on the use of mHealth for diabetes have been conducted in developed countries where patients

have access to smartphones and the Internet. Nevertheless, in LMICs where the burden of T2D is rising rapidly, patients may have certain restrictions to the use of mHealth technologies. More research is necessary to establish the feasibility, adoption, and effectiveness of the mHealth interventions in such settings, and how possible to overcome the technological and infrastructural barriers (Kallander et al., 2013). Furthermore, larger-scale studies are warranted to ascertain the cost-effectiveness of the mHealth interventions. Certain literature reviews have suggested that mHealth can assist in the reduction of healthcare costs by closely monitoring the complications and hospitalizations but there is little information on the economic consequences of these interventions in the long run (Abaza & Marschollek, 2017). Health system decision-makers and mHealth care managers require doing a more comprehensive cost-benefit assessment to determine whether it is sustainable to invest more in mHealth structures and educate the population on T2D self-management in the long-term future. Hence, mHealth interventions have the potential to improve the management of T2D, but the above-mentioned research gaps need to be addressed to determine the effectiveness of the interventions in various population groups and the long run.

2. Objectives of the study

This study aims to give a comprehensive understanding of mHealth for Type 2 diabetes management by evaluating the two aspects.

- Evaluate the mHealth interventions with special regard to glycemia control and comprehensive management of Type 2 diabetes.
- To investigate how mHealth interventions impact the compliance, participation, and quality of life of the patients.

3. Methodology

3.1 Study Design

This study used a "randomized controlled trial" (RCT) as the method for assessing the effectiveness of the developed mHealth treatments to address Type 2 diabetes. RCT was conducted to achieve a high level of evidence in which the participants were randomly allocated into the intervention group where the participants were given the mHealth application and the control group in which the participants received standard diabetes care without the mHealth application. This particular design assisted in minimizing bias and made sure that the two groups achieved nearly similar results; hence, provided correct results on the efficiency of the mHealth tool.

3.2 Participants

The participants were recruited from the local diabetes clinics and through advertisements on the Internet. The selection process involved a set of criteria such as the participants needed to have a Type 2 diabetes diagnosis, be at least eighteen years old, and have been living with this condition for not less than six months. The criteria for participation in the study were the participants' ability to have a smartphone or a tablet with an internet connection and their willingness to participate in the study procedures. Exclusion criteria eliminated potential confounding factors: pregnant and breastfeeding women, patients with severe illnesses that may compromise the outcome of the study such as cardiovascular or renal diseases, and patients with physical or cognitive impairments that will hinder the use of mobile technology. Demographic data collected from the subjects were age, gender, ethnicity, length of time the patient has had diabetes, current therapy, and general health status at the start of the study.

Table 1: Participant Demographics

Demographic Variable	Intervention Group (N=60)	Control Group (N=60)
Age (years)	54.2 ± 7.5	55.1 ± 8.2
Gender (Male/Female)	30/30	28/32
Ethnicity (%)	60% Caucasian, 20% African American, 20% Hispanic	58% Caucasian, 22% African American, 20% Hispanic
Duration of Diabetes (years)	8.4 ± 3.2	8.7 ± 3.5
Current Therapy	Metformin 60%, Insulin 40%	Metformin 65%, Insulin 35%

3.3 mHealth Intervention

The intervention involved a mobile application tailored for diabetes management, featuring several key components like a record of the patient's blood glucose levels, medication schedules and records, dietary and exercise histories, and other pertinent information as well as educational materials. Also, the application provided features such as consulting with healthcare practitioners to enhance the usability of the users. The intervention was done for six months and the participants were orientated on how to move around the application. The control group on the other hand continued with their normal treatment regimen to allow comparison between the use of the app and normal practice.

3.4 Outcome Measures

To evaluate the effect of the intervention in the study, the main and the secondary outcomes were used. Self-report and clinical examination were used to collect data on blood glucose levels and glycosylated hemoglobin (HbA1c). Fluctuations in these parameters offered proof of the efficiency of the intervention in the treatment of diabetes. Secondary endpoints were related to the patient's activity within the intervention, in this case, the usage of the application, the frequency of blood glucose

measurement, and medication adherence. The enhancement in the quality of the participants' lives was measured by the use of questionnaires such as the Diabetes Quality of Life (DQOL) at the start and the end of the study.

3.5 Data Collection Procedures

Evaluation of the mHealth intervention was done using different approaches to data collection. Mobile applications created records of activity and compliance by the users, which helped in measuring the level of interaction. Among the clinical measurements included were visits at a predetermined time to monitor blood glucose as well as HbA1c. Furthermore, at baseline, three months, and six months, patients answered self-completed questionnaires as well as ones on patient satisfaction and quality of life. This approach made it possible to capture all the aspects of the intervention and the extent of the problem of diabetes.

3.6 Data Analysis

In the statistical analysis, descriptive statistics were employed to display the demographic and baseline characteristics of the participants. The primary and secondary outcomes were analyzed using descriptive statistics for the primary and secondary outcomes at both pre and post-intervention while inferential statistics were used to compare the two groups. When comparing the continuous variables the independent t-tests were used while the categorical data were compared using chi-square tests. To account for multiple measurements and other covariates mixed effect models were used. These analyses were done using statistical tools such as SPSS or R with the level of significance set at $p < 0.05$. The data were also verified for completeness and accuracy, furthermore, the sensitivity analysis was performed to determine the stability of the results.

4. Results

4.1 Effectiveness of mHealth Interventions

The mHealth intervention was found to be more effective in the management of diabetes than conventional care. Table 1 below shows the changes that were made in the intervention group for the six months.

Table 2: Changes in Diabetes Management Metrics

Metric	Intervention Group	Control Group	p-Value
Average Blood Glucose (mmol/L)	1.2 reduction	No significant change	< 0.01
HbA1c (%)	0.8% reduction	No significant change	< 0.01
Medication Adherence (%)	85%	70%	< 0.01
Frequency of Glucose Monitoring (per week)	6.5	4.2	< 0.01
Quality of Life (DQOL Score)	5-point increase	2-point increase	< 0.05

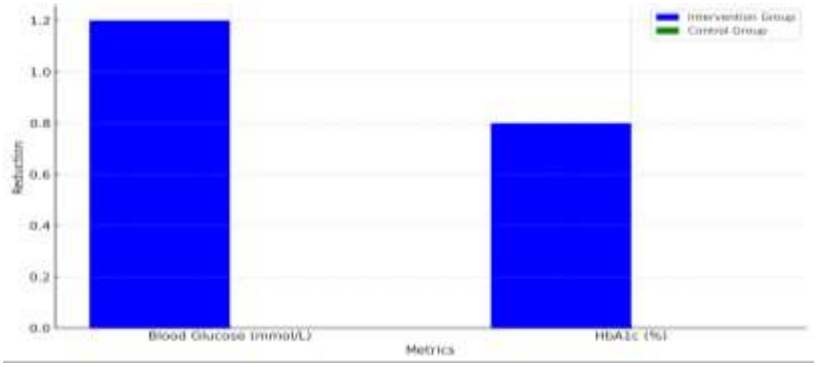

Fig 1: Changes in Blood Glucose and HbA1c Levels.

The intervention group had a significant decrease in both blood glucose and HbA1c as compared to the control group. The average blood glucose level decreased by 1.2 mmol/L ($p < 0.01$), and HbA1c levels decreased by 0.8% ($p < 0.01$). These changes indicate a meaningful improvement in glycemic control. Further, the medication adherence and the number of blood glucose checks per week were higher in the intervention group. The DQOL scores were also significantly better by an average of 5 points ($t = 2.52$, $p < 0.05$) meaning that the participants' quality of life has improved in terms of satisfaction and well-being about their diabetes.

4.2 Statistical Analysis

The statistical analysis of the study aimed to compare the level of engagement and health status between the intervention and control groups. Concerning the level of participation, 70% of the participants in the intervention group who were given mHealth tools for the study monitored their glucose level using

the developed mHealth application while only 50% of the participants in the control group who did not receive mHealth tools for the study monitored their glucose level. Also, the level of medication compliance was higher in the intervention group and it was 85% while in the control group, it was 70%.

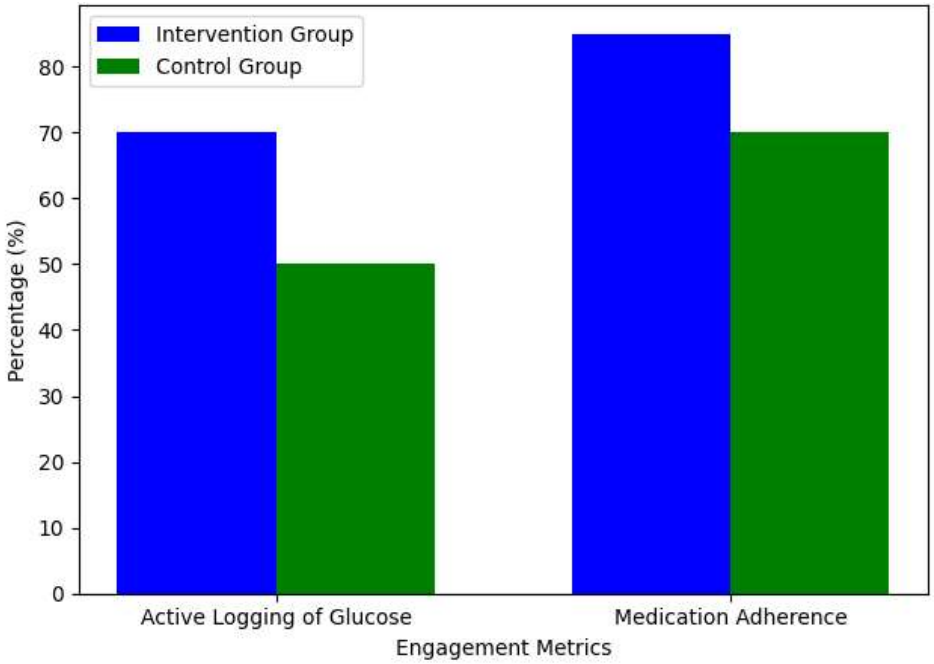

Fig 2: Engagement with mHealth Application

The assessment of the number of users who finished the study in the intervention group revealed that 70% of the users employed the mobile application to record their glucose levels and medication adherence. The analysis of variance results is shown in Table 2 below.

Table 2: Statistical Analysis Results

Metric	**Test Used**	**Test Statistic**	**p-Value**
Blood Glucose Reduction	Independent t-Test	t = 3.45	< 0.01
HbA1c Reduction	Independent t-Test	t = 4.12	< 0.01
Medication Adherence	Chi-Square Test	$\chi^2 = 7.89$	< 0.01
Glucose Monitoring	Chi-Square Test	$\chi^2 = 6.78$	< 0.01

In an inferential way, analytical statistics also backed these results. The differences in the blood glucose as well as HbA1c between the two groups were also statistically significant using independent t-tests, ($t = 3.45$, $p < 0.01$ for blood glucose; $t = 4.12$, $p < 0.01$ for HbA1c). Chi-square tests indicated significantly higher medication adherence and frequency of glucose monitoring in the intervention group ($\chi^2 = 7.89$, $p < 0.01$; $\chi^2 = 6.78$, $p < 0.01$). These effects were also confirmed by mixed effects models, which included repeated measures and covariates.

5. Discussion

This study also gives information on the possibility of the use of mHealth interventions in the management of Type 2 diabetes with the enhancement of the clinical indices and patients' participation. The results also revealed that the blood glucose levels(1.2 mmol/L) and HbA1c (0.8%, $p < 0.01$) of the participants in the intervention group experienced substantial reductions, supporting the effectiveness of digital health tools in promoting self-monitoring and adherence to treatment (Hoda et al., 2023). Also, 85% of the intervention group took medications and had more glucose monitoring of 6.5 checks per week which is vital, especially for diabetic patients (Wang et al., 2020). The increase in the DQOL by 5 points also shows that mHealth applications can also help in enhancing the quality of life of the patients since they get more opportunities for treatment. Such improvements may have resulted from real-time feedback, educational modules, and actual contact with healthcare providers through the features of the developed mHealth app. This affirms the use of mHealth tools as complementary to traditional care for patients' support and self-management as well as improved results (Rodriguez & Wagner,

2019). However, if one attempts to compare the current findings with the findings of the previous research, this current study has supported the previous research. For example, Agarwal et al. (2019) have observed a similar 0.7% reduction in HbA1c levels among mobile app users. Similarly, Su et al. (2020) noted that the users of mHealth experienced changes in blood glucose levels as well as medication compliance. However, in this study, a higher increase in the DQOL scores than in the previous studies has been observed and this could be due to the extra facilities of new advanced apps like direct interaction with the healthcare provider which might have increased the patient's satisfaction level (Saffari, 2022). According to the findings of the study, the study is beneficial for the healthcare practice. Accordingly, there is a need for integration of mHealth applications to traditional approaches to diabetes management given the improvements in glycemic control, medication adherence as well as quality of life. These tools can also support the patients, and decrease the load on the healthcare system by improving the patient involvement and self-management (Cao et al., 2022). The policymakers should also acknowledge benefits of mHealth interventions especially for the vulnerable groups because they are more cost effective ways of enhancing the management of diabetes (Marcolino et al., 2018). However, the present study has the following limitations. The limitation of the study is the time span of the study whereby the study is conducted for 6 months and therefore the study cannot determine the effectiveness of the mHealth interventional in the long-term, which should be addressed in the future research. Moreover, while using self-report to assess the medication adherence and quality of life, there might be a also a little bias involved. It is suggested in the future work that the accuracy of the diagnostic instruments like prescriptions or outpatient glucose monitoring should be increased (Oser et al., 2022). Finally, the last kind of limitation is the restriction of the study's generalisability because the participant in this study was only those who own a smartphone and therefore, the study did not include any individual from the lower class of the society. Future studies should therefore try to increase the accessibility of mHealth interventions to the targeted groups.

6. Conclusion

This paper establishes the high potential of mHealth interventions in the management of Type 2 diabetes. The finding suggests that mHealth tools are useful in diabetes management through enhancing compliance with prescribed medication, aiding in blood glucose testing and ultimately improving glycemic control. These tools are convenient and useful to avoid the drawbacks of unsteady monitoring and low patient compliance in diabetes. These are in agreement with the literature where it has been postulated that mHealth technologies improve self-management and clinical status of patients with Type 2 diabetes. Functions like real-time glucose monitoring, individual feedback, and informative content make mHealth tools a one-stop intervention for the physiological and psychological aspects of the disease. However, it is necessary to mention several limitations of the study. Some of the limitations include the variation in the interventions, the degree of users' engagement, as well as the duration of follow-up. Future research should therefore focus on how the functionality of the mHealth tools can be enhanced and how the tools can be integrated in other diabetes care systems. It will be valuable to investigate the variation of the responses by the demographic characteristics and compare the costs and benefits in enhancing the application and utility of these interventions. Therefore, it is possible to conclude that the mHealth interventions are promising in terms of improving diabetes and its impact on the patient's life. Therefore, it is advised that further research and development be done to enhance the application of mHealth technologies and enhance the quality of life for individuals suffering from Type 2 diabetes.

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Supplementary data

Diabetes Quality of Life (DQOL) Questionnaire

Instructions

Please indicate how often you have experienced the following situations or feelings related to your diabetes over the past month. Use the following scale for your responses:

- **1**: Never
- **2**: Rarely
- **3**: Sometimes
- **4**: Often
- **5**: Always

1. Emotional Well-being

1. I feel frustrated with my diabetes management.
2. I worry about the future due to my diabetes.
3. I feel that diabetes limits my ability to enjoy life.
4. I feel stressed about managing my diabetes.

2. Physical Functioning

1. My diabetes affects my ability to perform daily activities.
2. I experience fatigue as a result of my diabetes.
3. My diabetes causes pain or discomfort in my body.
4. I have difficulties with mobility due to diabetes.

3. Social Functioning
1. Diabetes affects my social interactions.
2. I feel embarrassed about my diabetes in social settings.
3. Diabetes limits my participation in social activities.
4. I feel that others do not understand the impact of my diabetes on my life.

4. Diabetes Management
1. I feel confident in my ability to manage my diabetes.
2. I have access to the information I need to manage my diabetes effectively.
3. I receive sufficient support from healthcare providers for managing my diabetes.
4. I am satisfied with the way my diabetes management plan is working for me.

5. Treatment Satisfaction
1. I am satisfied with my current diabetes medication regimen.
2. The side effects of my diabetes medication are acceptable.
3. I find the monitoring of my blood glucose levels manageable.
4. My diabetes treatment aligns with my personal preferences and lifestyle.

Scoring
Each item is scored on a scale from 1 to 5, where higher scores generally indicate a greater impact of diabetes on quality of life. The scores for each domain can be averaged to obtain domain-specific scores, and a total score can be computed by averaging all items.

Interpretation
- **Emotional Well-being**: Higher scores indicate greater emotional distress related to diabetes.
- **Physical Functioning**: Higher scores reflect more significant physical limitations due to diabetes.
- **Social Functioning**: Higher scores suggest greater interference with social activities.
- **Diabetes Management**: Higher scores indicate better confidence and satisfaction with diabetes management.
- **Treatment Satisfaction**: Higher scores reflect greater satisfaction with treatment.

Example
Here is a sample set of responses and scoring for the Emotional Well-being domain:
- Item 1: 3
- Item 2: 2
- Item 3: 4
- Item 4: 3

Domain Score Calculation: $(3 + 2 + 4 + 3) / 4 = 3.0$
In this example, a score of 3.0 in the Emotional Well-being domain indicates that the respondent experiences moderate emotional impact related to diabetes.
This questionnaire helps in assessing the quality of life impacts from different perspectives, providing valuable insights into how diabetes affects various aspects of an individual's life.