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Development of a Mobile Software Tool for Diabetes Diagnosis

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Abstract: *This paper reports on the design and implementation of a mobile diagnostic tool for diabetes. Diabetes is a chronic, often deadly, disease which occurs when the pancreas does not produce enough insulin or when the body cannot effectively use the produced insulin. Globally, at least 422 million people are affected by diabetes in 2014, and it accounted for about 1.5 million deaths in 2012. It is most common to the Pacific and Middle East countries and mostly affects adults between the ages of 35 and 64.*
Lack of early diagnosis of diabetes can lead to many complications and even death, hence the need for low-cost mobile diagnostic tools which could lead to prevention and early management of diabetes. The Formhub platform was used to develop the mobile tool and it was downloaded and tested on Android smartphones with ODKCollect. The developed tool diagnoses diabetes using blood glucose test results, determines the type of diabetes and the likelihood of a person having diabetes in the future, using the risk calculation mechanism.
Keywords:*Diabetes, Diagnostic tool, Mobile, Design*

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I. Background

Diabetes, also referred to as '*Diabetes Mellitus*', is a chronic metabolic disease resulting from the inability of the pancreas to produce enough insulin or the inability of the human body to effectively utilize the insulin it produces (World Health Organization, 2018). Type 1 diabetes occurs when the body does not produce insulin. Type 2 diabetes results from the inability of the body to effectively utilize insulin and usually begins in individuals above 35 years of age; though in practice, there are few exceptions. Type 1 diabetes is believed to occur due to a complex interaction between genetic and environmental factors, while Type 2 diabetes is attributed to the interplay between genetic and metabolic factors. However, both types share some common symptoms which may include excessive urination, fatigue, constant hunger, changes in vision, thirst, weight loss amongst other symptoms.

In 2014, WHO estimates showed that, about 422 million adults were living with diabetes globally. Diabetes also accounted for 1.5 million deaths in 2012. Type 2 diabetes is the most commonly occurring type of diabetes. Type 2 diabetes represents over 90% of diabetes cases in Africa (Piotie, 2010). The International Diabetes Foundation reported in 2013 that Nigeria had the highest number of people living with diabetes in Africa.

In rural communities of Nigeria and other African countries where access to healthcare and services are inadequate, occurrences of diabetes and its complications especially when diagnosed late, often result in serious health complications and death. As much as 85% of cases of diabetes are undiagnosed and remain without treatment due to lack of awareness of early symptoms of this disease, even among healthcare professionals. People with diabetes have a higher risk of developing complications like cardiovascular diseases, circulation problems, lower limb amputations, resulting from neural damage, kidney disease, diabetes foot disease, vision loss and neuropathy (nerve damage) (Diabetes Leadership Forum, 2010; IDF, 2017).

The economic burden of diabetes mellitus in Africa and the world at large cannot be overemphasized. This burden is related to health system costs incurred by society in managing the disease, indirect costs resulting from productivity losses due to patient disability and premature mortality, time spent by family members accompanying patients when seeking care, and intangible costs [psychological pain to the family and loved ones] (Kirigia et al., 2009). In many poor countries, insulin is unavailable and unaffordable, as such people living with insulin dependent diabetes incur huge out-of-pocket personal health expenditures (WHO, 2016). In Nigeria, it was estimated that about 29% of the minimum wage of an insulin dependent individual would be spent on insulin (Ogbera et al., 2014). Nigeria is one of the top five Sub-Saharan Africa countries with the highest cost of diabetes care. The other countries are South Africa, Ghana, Kenya and Zimbabwe (Mbanya et al., 2006).

The WHO has advocated early diagnosis of diabetes as a key determinant of living well and the successful management of diabetes (WHO, 2016). Early detection of diabetes or identification of 'at risk' group of individuals can lead to lifestyle modifications for modifiable factors such as diet and exercise, thus preventing or delaying the onset of diabetes for those at risk, and complications and disabilities for individuals who already have the disease (Herman, 2015).It is asserted that people with prolonged periods of undiagnosed and untreated diabetes, have worse health outcomes.

This underscores the need for rapid and cost effective diagnostic tools to aid the activities of healthcare professionals and other cadre of health workers e.g. Community Health Extension Workers (CHEWS), especially in rural hard-to-reach areas and communities where healthcare coverage is poor or inadequate (WHO, 2016).

Diabetes is diagnosed by measuring glucose in a blood sample taken while the patient is in a fasting state, or 2 hours after a 75g oralload of glucose has been taken, or by measuring glycatedhaemoglobin (HbA1c), even if thepatient is not in a fasting state. HbA1c reflects the averageblood glucose concentration overthe past few weeks, rather thanthe blood glucoseconcentrationdepicted by the former. In terms of cost, the HbA1c test ismore expensive than blood glucosemeasurement (WHO, 2011).

II. Literature Review

The use of electronic systems in healthcare management has become very popular across the world. They have been widely accepted in recent times as very useful in disease prevention, management and treatment (WHO, 2012; Kaufman, 2013; Kraschnewski et al., 2013; Sadoughi, 2016; Huang et al., 2018).

More recently, the deployment of mobile technology in the diagnosis, management and treatment of diabetes is growing by leaps and bounds. Mobile devices have been deployed to collect and log blood glucose readings, transmit data wirelessly, provide real-time reminders and alerts and translate and interpret data over time (Chavez et al., 2017; Garg et al., 2017;Muralidharan et al., 2017; NEHI, 2012, Quinn et al., 2018;).

O'Connor et al. (2011) conducted a clinical trial on 2,556 patients with diabetes to investigate the impact of an electronic health record-based diabetes decision support system on the control of glycated haemoglobin, cholesterol levels and blood pressure in adults with diabetes. They reported an improvement in glucose and blood pressure control in adults with type 2 diabetes who were in the intervention group.

Shaheen (2009) developed an Intelligent Decision Support System (IDSS) which acts as an expert system for diabetic patients by providing information on homecare supervision, self-treatment and preparation before face-to-face diagnosis through a mobile network communication platform. Healthcare providers are granted access to view patient data through the same communication platform and are informed when an alarming condition occurs. The IDSS was designed to improve the quality of daily life for diabetic patients, as healthcare providers are better equipped to manage the disease by monitoring patients' health over a computer network. Ajay & Prabhakaran (2011) have reported the use of custom-made applications on mobile phones which can aid health workers in computing risk scores to predict Asian people with diabetes or those at high risk for developing diabetes. Diabetes Manager System mobile app developed by WellDoc (http://www.welldoc.com/) helps diabetic patients and healthcare providers to manage diabetes by allowing users to track their blood glucose levels and share the data with healthcare providers (NEHI, 2012).

In most other approaches in the development of mobile diagnostic tools, diagnosis is mainly based on clinical data gotten from the use of glucose metresintegrated with such mobile devices, such as phones and tablets. An example of such a device is the iGlucose smart glucose metredeveloped by PositiveID (NEHI, 2012). However, such approaches are expensive to use and maintain.

Some attributes to consider when making a selection of a mobile data collection platform include a high degree of interoperability, cost effectiveness, ease of setup, ease of use, skip logic, language, web portal entry, GIS and mapping, ability to collect images, off-line data collection, SMS integration, data security and privacy compliance.

The use of free and open source platforms for developing simple, low-cost applications is becoming increasingly popular among Information Technology (IT) and other computer users, including people in the healthcare sector (Aminpour et al 2013; Ingram, 2013; Kiah et al., 2014). A number of platforms exist for developing mobile data collection applications. Some of these platforms are Formhub (www.formhub.org), Magpi (www.magpi.com), Nokia Data Gathering (https://projects.developer.nokia.com/ndg), etc.

The diabetes diagnostic tool discussed in this paper was developed on the Formhub platform, which is downloadable onto phones using a middleware called ODKCollect (www.opendatakit.org). Formhub was chosen as the platform for the development of the diagnostic tool because it is free, safe, open-source and extensible application (www.formhub.org).

The approach used in the development of the mobile diabetes diagnostic tool as presented in this paper, is similar to previously-developed tools, but unique for the following reasons:

- Since the tool runs on mobile devices, the clinical staff can move from one ward to another collecting the necessary data.
- The tool is more cost-effective as users only need an Android phone to use it.
- It facilitates data analysis and reporting, as data can be collated at the end of the diagnostic exercise.
- In addition to diagnosing patients, the tool can also be used to check for people at risk of developing type 2 diabetes in the next five years, thereby ensuring early detection and management of the disease.

III. Methodology

Faced with the problem of developing a cost-effective tool for the diagnosis of diabetes, there was the need to get some background knowledge on the subject matter from healthcare professionals. They helped to understand what kind of health conditionis diabetes, its types and symptoms, effects, treatments and so on.

The use of tests is widely accepted as an important element in the diagnosis of diabetes. These tests include the Blood Glucose Test which determines the level of glucose in the blood and sometimes the Oral Glucose Tolerance Test (OGTT), depending on whether the person has an unequivocally elevated Fasting Plasma Glucose (FPG) or Random Plasma Glucose (RPG). FPG and RPG are both types of oral glucose tolerance test. As their names imply, FPG checks the level the glucose in a person's blood plasma after a period of fasting for at least 8 hours before the test while RPG checks the glucose level at a random time (any time of the day) when a person has severe symptoms of diabetes (American Diabetes Association, 2014).

If the FPG or RPG result is less than 5.5mmol/L, it implies the presence of diabetes is unlikely. When the FPG result is greater than or equal to 7.0mmol/L or the RPG result is greater than or equal to 11.1mmol/L, then the person likely has diabetes. Otherwise (that is, if a person has an equivocal blood glucose test result), it means the presence of diabetes is uncertain and OGTT is administered. If OGTT result is less than 7.8mmol/L, then presence of diabetes is unlikely; if it is greater than 11.1mmol/L, then the person is likely to have diabetes. Otherwise, the person is said to have Impaired Glucose Tolerance (IGT) which was originally considered as the pre-diabetes stage and exposes its victims to an increased risk of future diabetes (Diabetes Australia, 2012). Figure 1 is a flow diagram showing the glucose test levels that guide the diagnosis of diabetes.

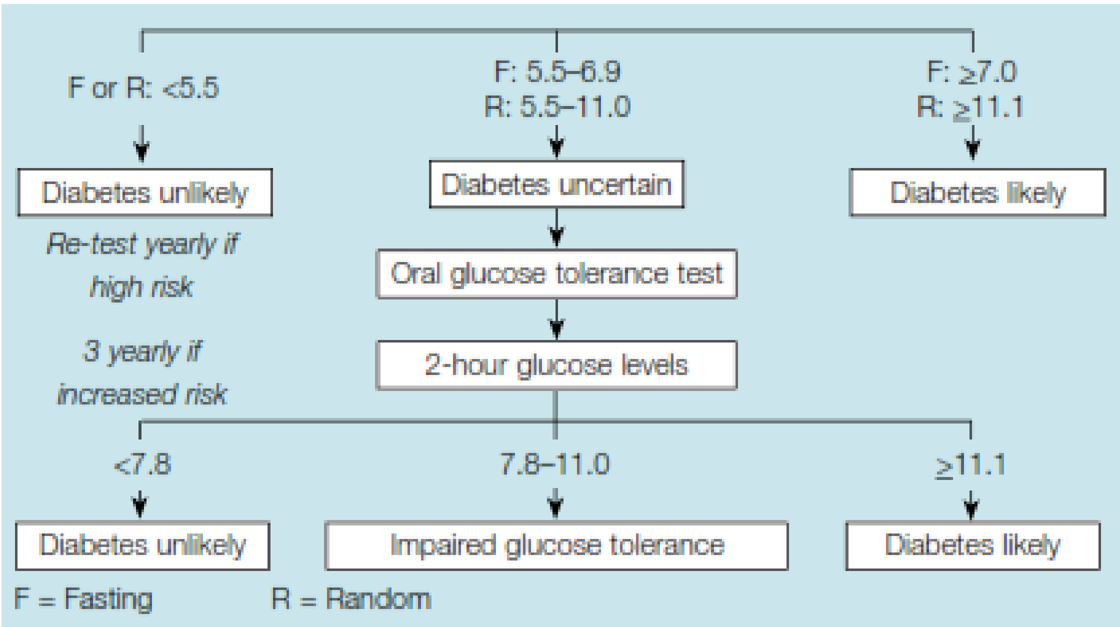

Figure 1: Glucose levels (in mmol/L) guiding the diagnosis of diabetes
(*Source: Diabetes Australia (2012)*)

An algorithm was developed as a tool for the diagnosis of diabetes. The tool was primarily developed for use in Nigeria; as such the design of the algorithm was based on the clinical guidelines for the management of diabetes in Nigeria as documented by Diabetes Association of Nigeria (2013). The algorithm was developed as outcome from consultations with health professionals. The pseudocode describing the diagnostic process is shown in the Appendix. Figure 2 is an activity diagram for the diabetes diagnostic tool which outlines the activities involved in the diagnostic process. Figure 3 is a use case diagram describing the scenarios performed by different actors with the diagnostic tool. Figure 4 is a less-detailed flowchart of the diagnostic process.

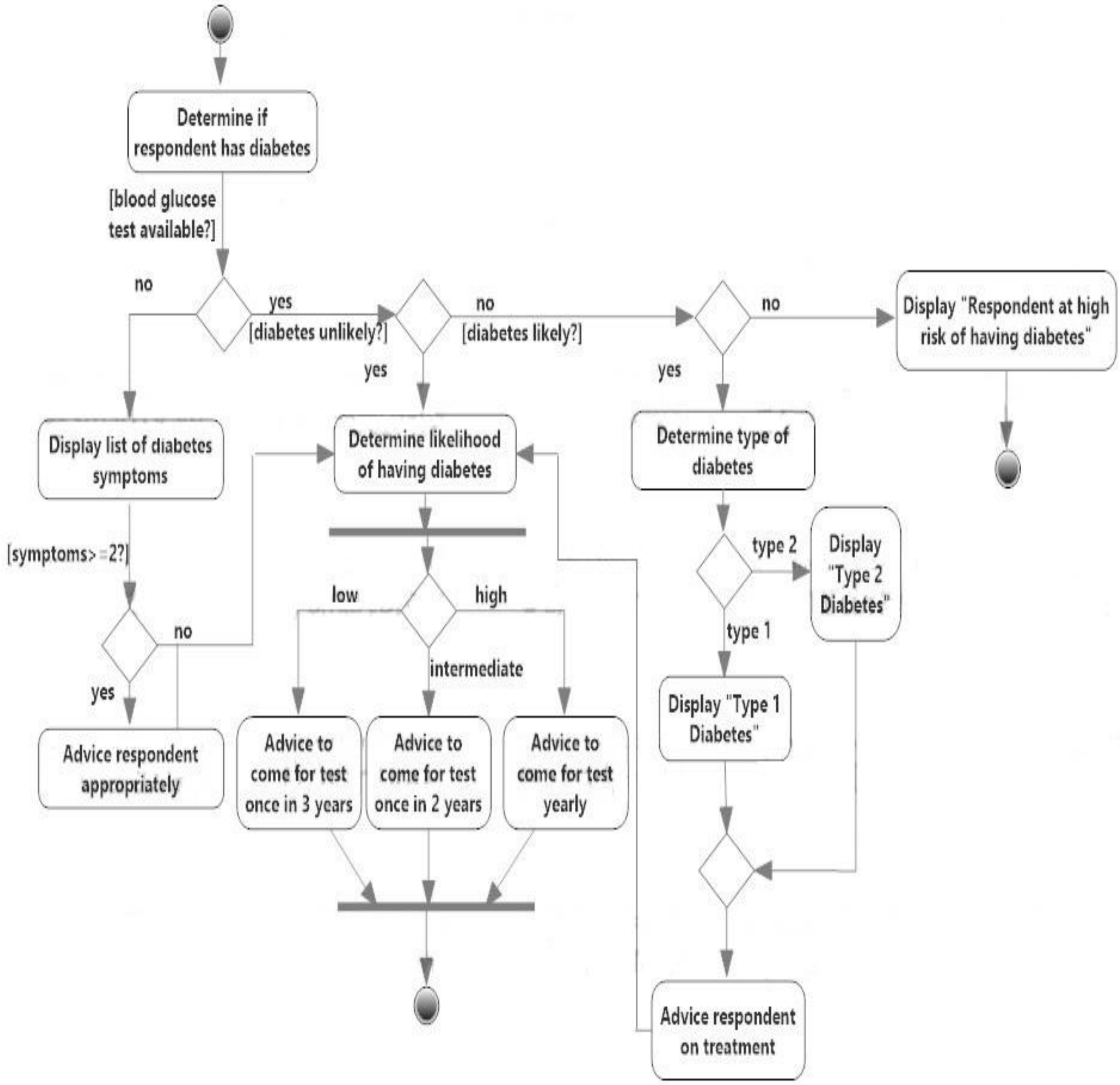

Figure 2: Activity Diagram for the Diabetes Diagnostic Tool

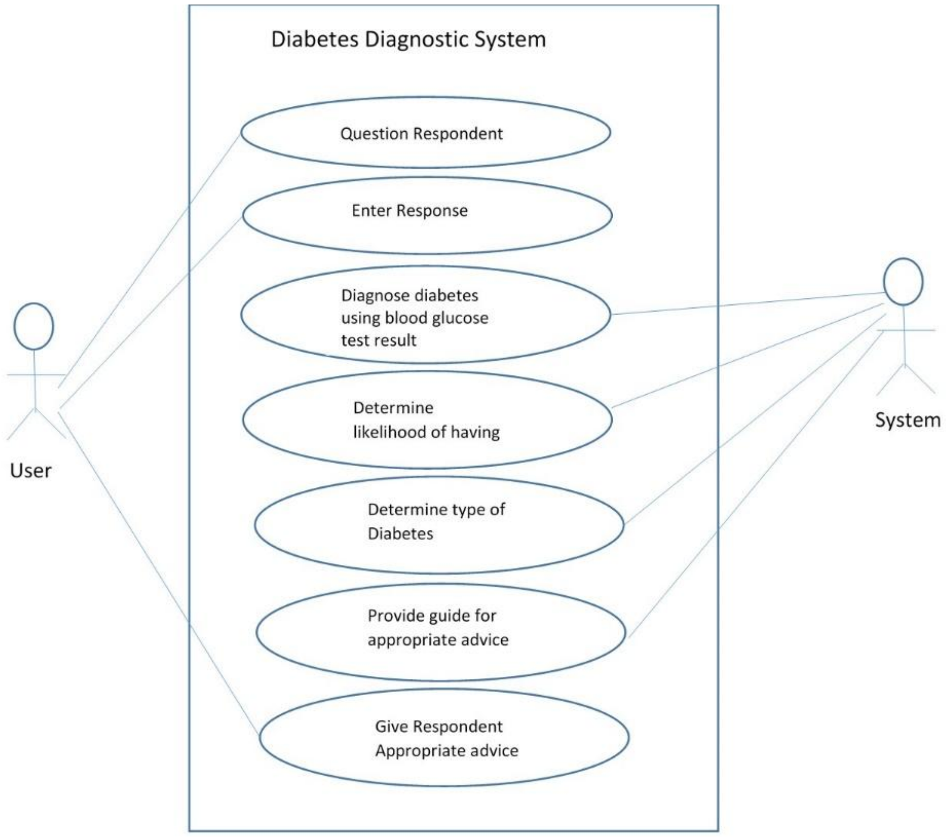

Figure 3: Use Case diagram for the Tool

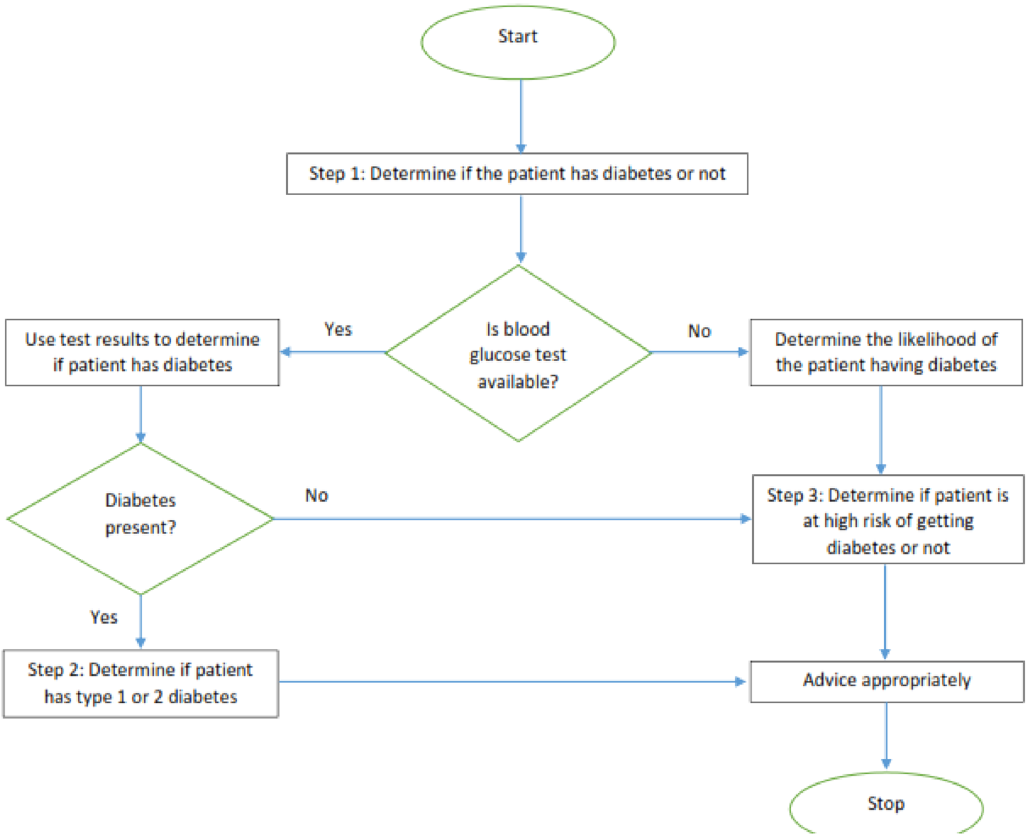

Figure 4: Flowchart for the Diabetes Diagnostic Tool

IV. Implementation

Results

The mobile diagnostic tool was developed for type 2 diabetes. This tool can determine if a patient has diabetes or not. If a person is diagnosed with diabetes, it can also determine if the person has Type 1 or Type 2 diabetes. However if a person is not diagnosed with diabetes, the tool can determine if the person is at low, intermediate or high risk of having diabetes in the next five years. This tool was tested on a TECHNO D7 Android smartphone. Figure 5 displays a snapshot of the ODKCollectmenuinterface, while Figure 6 shows a presentation of one of the risk factorsduring user interaction.

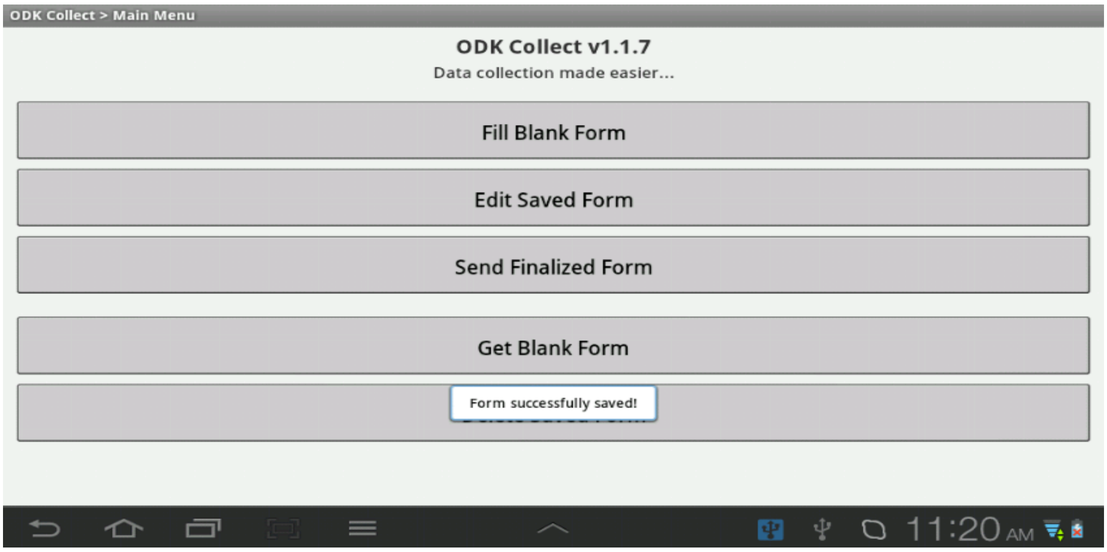

Figure 5:ODKCollect Menu Interface

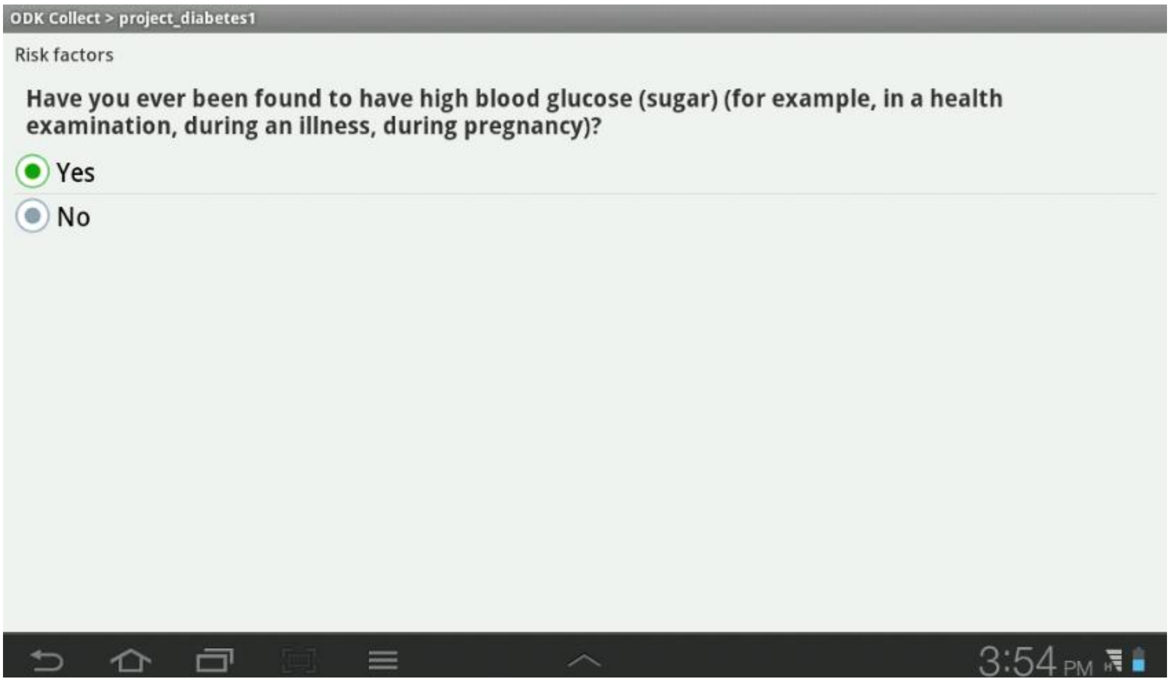

Figure 6: One of the risk factors questions

Challenges and Future Work

The major challenge encountered in the course of developing the diabetes diagnostic tool is the difficulty of designing an accurate mechanism for determining the type of diabetes. This was because there are no practical or specific markers for differentiating the two types of diabetes. However, the challenge was overcome with the best possible solution.

The major limitation of the tool is the fact that the form only works on Android phones. It could be used on Java-enabled smartphones. This limitation restricts the scope of use of this tool. A walk around this limitation is being explored for future development.Further research can also be focused on the expansion of the tool to accommodate the diagnosis, treatment and prevention of diabetes. This will make the tool more useful in the management of diabetes. The use of other form hosting sites and development platforms can be explored in order to make the design of forms that can run on Java-enabled phones possible.

V. Conclusion

There is a lot of promise in the use of mobile technology in the diagnosis, treatment and management of diabetes amongst other diseases. Early diagnosis of diabetes is vital to the prevention of complications and deaths arising from the disease. Also, populations at risk of developing diabetes can be readily armed with adequate information via the use of mobile technology, thus resulting in lifestyle modifications. It is hoped that advancements in mobile technology and continuous development of this mobile tool will eventually result in proper diagnoses of diabetes and a drastic reduction in the incidences of preventable deaths and complication resulting from this disease in Africa and around the world.

APPENDIX

Pseudocode for the Diabetes Diagnostic System:

```
Step 0: Start
Step 1: Determine if respondent has diabetes
    Step 2: Is blood glucose test result available?
        Step 3: If yes, is FPG or RPG < 5.5?
            Step 4: If yes, print “Diabetes unlikely”
            Step 5: Determine likelihood of having diabetes in next 5 years
            Step 6: Is likelihood low?
            Step 7: If yes, print “Come for blood glucose test once every 3 years”
            Step 8: If no, is likelihood intermediate?
            Step 9: If yes, print “Come for blood glucose test once every 2 years”
            Step 10: If no, print “Come for blood glucose test yearly”
        Step 11: If no, is FPG >= 7.0 or RPG >= 11.1?
            Step 12: If yes, print “Diabetes likely”
                Step 13: Determine type of diabetes
                Step 14: Is respondent insulin-resistant?
                Step 15: If yes, did diabetes symptoms progress slowly?
                Step 16: If yes, print “Type 2 diabetes”
Step 17: Advice respondent on appropriate treatment
Step 18: If no, print “Type of diabetes uncertain”. Go to step 5
                Step 19: If no, did diabetes symptoms progress rapidly?
                Step 20: If yes, print “Type 1 diabetes”. Go to step 17
        Step 21: If no, print “Diabetes uncertain”
            Step 22: Is OGTT < 7.8?
            Step 23: If yes, print “Diabetes unlikely”. Go to step 5
            Step 24: If no, is OGTT > 11.1?
            Step 25: If yes, print “Diabetes likely”. Go to step 13
            Step 26: If no, print “Respondent at high risk of having diabetes”
    Step 27: If no, display list of diabetes symptoms
Step 28: Is respondent experiencing at least 2 symptoms?
Step 29: If yes, advice to go for blood glucose test as soon as possible. Go to step 5
Step 30: End
```

Note:

OGTT: Oral Glucose Tolerance Test

RPG: Random Plasma Glucose

FPG: Fasting Plasma Glucose

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