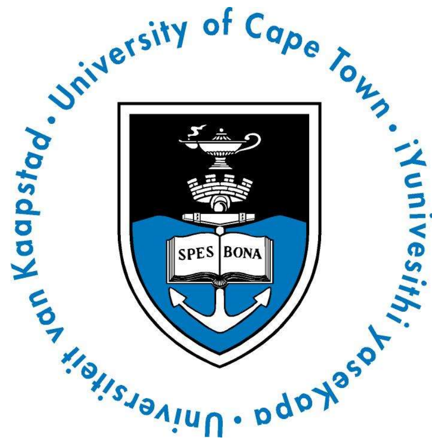

Division of Biomedical Engineering

Department of Human Biology

University of Cape Town

Project Title

Gestational Diabetes Self-Management and Remote Monitoring Mobile Platform

Research Thesis

In fulfilment of the requirements for the degree:

MSc in Biomedical Engineering

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Date: 12 January 2020

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Abstract

There is a high prevalence of gestational diabetes (GD) in South Africa, which is continually growing. South African women with GD are not effectively managed or educated about self-care, do not self-monitor frequently enough and, therefore, often succumb to various GD induced complications. The ineffective management of GD is largely due to financial and time constraints caused by the regularly required outpatient services. On the other hand, healthcare professionals do not monitor their patients frequently enough because of accessibility issues, which means they cannot intervene timeously to prevent diabetes complications.

The aim of this project was to develop a mobile health (mHealth) platform for GD self-management and for remote monitoring to improve the GD cycle of care in South Africa. The objectives were to assess the current GD management practices in South Africa, to assess the existing mHealth solutions for GD and to design, develop and test a GD mHealth platform.

The existing GD management practices and current GD mHealth solutions were investigated. The results of the investigation informed the design of low-fidelity and high-fidelity mock-ups of the platform. The high-fidelity mock-up underwent usability testing and the insights gained were used to develop a working prototype of the new mHealth platform, which was then ready for in-lab testing.

It was found that GD had a prevalence of up to 25% in parts of South Africa. Over 70% of patients in both private and public healthcare sectors did not meet their diabetic goals, which directly correlated with diabetes induced complications. However, previous research found that using mHealth as an intervention caused a statistically significant decrease of 0.38 mmol/L (95% confidence interval (CI) 0.52 mmol/L to 0.23 mmol/L) in overall blood glucose levels during pregnancy when compared to a control group. There was a higher probability of vaginal deliveries in the intervention group than in the control group (risk ratio = 1.18). It was less likely for new-borns from the intervention group to be diagnosed with hypoglycaemia than new-borns from the control group (risk ratio = 0.67).

Based on the research and usability studies conducted, an alpha version of the GD mHealth platform was developed, including a mobile app used to track the patient's blood glucose levels via a Bluetooth-enabled glucose meter. The food intake, exercise and weight gain during pregnancy were manually captured by the patient. The app reminded the patient to take medication, measure glucose levels and attend appointments. A GD educational component was available for the patient throughout the pregnancy. The platform included a web app which allowed healthcare professionals to remotely monitor and communicate with their patients so that they could analyse trends in the data and intervene when necessary.

The testing done on the prototype resulted in positive feedback with 60% of participants saying that they would use the GooDMoM mobile app to manage their GD and 70% of participants saying that they would use the GooDMoM web app to manage their patients with GD. This put the platform in a good position for beta development.

The solution has the potential to benefit patients both financially and timewise, by reducing the frequency of hospital visits required. It also has the potential to positively impact the healthcare professionals by reducing the tediousness of their workload and allowing for remote monitoring of patients. The platform can, thus, optimise the GD management process in South Africa and worldwide.

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List of Acronyms

API	Application Programming Interface
BaaS	Backend as a Service
BMI	Body Mass Index
CCT	Controlled Clinical Trial
CI	Confidence Interval
CSS	Cascading Style Sheets
GD	Gestational Diabetes
GDMM	Gestational Diabetes Mobile Management
HTML	HyperText Markup Language
HbA_{1c}	Haemoglobin A1c
IADPSG	International Association of Diabetes in Pregnancy Study Groups
IDE	Integrated Development Environment
LMIC	Low and Middle-Income Countries
mHealth	Mobile Health
NICE	National Institute for Health and Care Excellence
NICU	Neonatal Intensive Care Unit
OGTT	Oral Glucose Tolerance Test
PHR	Personal Health Record
PICO	Population, Intervention, Comparison, Outcome
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RCT	Randomised Controlled Trial
RSS	Really Simple Syndication / Rich Site Summary
SEMDSA	Society for Endocrinology, Metabolism and Diabetes of South Africa
SRSD	Software Requirements Specification Document
T1D	Type 1 Diabetes
T2D	Type 2 Diabetes
UI	User Interface
UX	User Experience
WHO	World Health Organisation

1. Introduction

This chapter introduces the topic of the thesis by highlighting the background of the problem and providing a detailed synopsis of the problem, rationale, aim, objectives and methodology. The chapter concludes with the presentation of the thesis' structure.

1.1. Background

Diabetes is a chronic, non-communicable condition which affects the body's ability to process glucose (American Diabetes Association, 2014). Glucose is a type of sugar, which is broken down from dietary intake and transported in the blood stream to the necessary cells in the human body (Diabetes UK, 2006). The pancreas releases insulin into the blood stream on demand to regulate the amount of glucose in the blood (Diabetes UK, 2006). The vast majority of diabetes cases fall under three categories: type 1 diabetes (T1D), type 2 diabetes (T2D) and gestational diabetes (GD) (Lanzola et al., 2016). GD arises during pregnancy and increases the risk of complications for both the mother and child before, during and after birth (Garnweidner-Holme et al., 2015). It has been shown to have a prevalence of up to 25% in parts of South Africa according to Adams & Rheeder (2017). However, this prevalence varies depending on screening methods, diagnostic criteria and the ethnic group involved in the study.

Once diagnosed, controlling blood glucose levels becomes a fundamental part of the management of GD (Kampmann et al., 2015). Eating healthily, exercising regularly, managing bodyweight and learning about one's disease are key to controlling blood glucose levels (Garnweidner-Holme et al., 2015). In some cases, insulin or oral medication may be necessary to aid the control of blood glucose levels (Kampmann et al., 2015). This means that women with GD need to track their glucose levels, food intake, exercise and weight throughout the gestational period and beyond (Buchanan, Xiang & Page, 2012).

Women diagnosed with GD are encouraged to record their blood glucose levels at least 3 to 4 times daily – once in the morning and after meals – either in a paper or digital logbook (Nhlapo, 2015). Delivering these measurements along with related alerts to healthcare professionals is important because this is the information that healthcare professionals use to manage and monitor their patients, which may include providing advice, modifying

medication or making diagnoses (Lanzola et al., 2016). Thus, regular medical check-ups are required for the healthcare professional to analyse the patient's blood glucose levels, and these occur every 1 to 4 weeks during the last 3 months of gestation (Mackillop et al., 2018).

According to a study done by the Society for Endocrinology, Metabolism and Diabetes of South Africa (SEMDSA) (2017), 9.5% of South Africans older than 15 are known to suffer from diabetes which is expected to increase by 140% by 2040. The most recently released mortality report from Statistics South Africa (2016a) shows that diabetes (5.5% mortality) has surpassed HIV/Aids (4.8% mortality) as the second highest cause of death in South Africa. On top of the list of natural diseases causing mortality is Tuberculosis (6.5% mortality). The high prevalence of diabetes combined with the increasing prevalence of obesity in women of a child-bearing age has resulted in a rapid rise in the prevalence of GD both worldwide and in South Africa (Kampmann et al., 2015). If this condition is poorly managed or is left untreated, women and their children will be at an increased risk of complications, before during and after birth (Kampmann et al., 2015).

Lau et al. (2016), Ming et al. (2016) and Rasekaba et al. (2015) have systematically reviewed various studies which indicate that mHealth may aid in the management of women with GD, which helps keep tighter glycaemic control and assists in preventing antenatal, perinatal and postpartum complications. Although these studies involved high-income countries, the principles of mHealth being used to aid the management of GD can be applied to low and middle-income countries (LMIC) like South Africa. According to Barron et al. (2018), South Africa has universal mobile phone penetration, 40% of which is smartphone use. As a result of this, mHealth can be used to aid the ongoing management required for GD in South Africa.

The major benefit offered by mHealth is the potential for remote diagnosis, monitoring and treatment (Bloomfield et al., 2014). This is especially important in LMIC like South Africa where it is not possible to access the entire population through physical healthcare institutions due to a lack of resources and the difficulty experienced by people in rural areas to access specialised healthcare services situated in urban areas as a result of high transport costs (Goldenberg et al., 2016). Thus, mHealth provides an inexpensive, more effective solution to the GD management problem (Lau et al., 2016).

1.2. Problem Statement

There is a high prevalence of GD in South Africa, which is continually increasing. South African women with GD are not effectively managed or educated about self-care, do not self-monitor frequently enough and, therefore, often succumb to various GD induced complications. The ineffective management of GD is largely due to financial and time constraints caused by the regularly required outpatient services. On the other hand, healthcare professionals do not monitor their patients frequently enough because of accessibility issues, which means they cannot intervene timeously to prevent diabetes complications.

1.3. Rationale

A diabetes self-management and remote monitoring mobile platform can be used for GD educational purposes, it can be used to track the various indicators (blood glucose levels, medication, exercise, food intake, weight gain and pregnancy specific indicators, among others) and it can be used by healthcare professionals to remotely monitor their patients. This will aid in the management of GD and may positively affect the patient's blood glucose levels and reduce the chance of GD induced complications. Pregnant women are easy to reach regarding health related information due to the regular contact they have with healthcare professionals and they are motivated for behavioural changes (Garnweidner-Holme et al., 2015). This means that they will likely be willing to utilise an mHealth platform as a tool to manage GD. The mHealth platform has secondary benefits in that it will reduce the frequency of outpatient services (Mackillop et al., 2018) and will, therefore, reduce the financial burden which results from transport costs.

The purpose of this project is to develop an easily accessible solution to the GD management problem facing pregnant South African women. There are three main components needed to fulfil the purpose; namely, to assess the current diabetes management practices in South Africa, to assess the existing mHealth solutions for GD and to design, develop and test the mHealth platform. The mHealth platform will consist of a mobile application (mobile app) for women with GD to manage their disease, a web application (web app) for healthcare professionals to remotely monitor their patients and the ability to wirelessly interface with Bluetooth-enabled glucose meters.

1.4. Aim and Objectives

This sub-section presents the aim of the thesis and the objectives required to meet that aim.

1.4.1. Aim

The aim is to develop an mHealth platform for GD self-management and for remote monitoring by health professionals to improve the cycle of care in South Africa.

1.4.2. Objectives

The objectives required to meet the aim are:

- to assess the current GD management practices in South Africa, focusing on:
    - GD epidemiology, complications and management practices, and
    - the effect that the public and private healthcare sectors have on the diabetes management practices.
- to assess the existing mHealth solutions for GD, focusing on:
    - the benefits and challenges of mHealth,
    - the effectiveness of mHealth applied to women with GD in comparison to standard GD management practices, and
    - the features and functions of existing GD mHealth platforms.
- to design, develop and test the mHealth platform for GD self-management and remote monitoring in South Africa, focusing on:
    - the development of software for women with GD to manage their disease,
    - the development of software for healthcare professionals to remotely monitor their patients,
    - the interface between the software and existing glucose meters, and
    - the testing of the developed platform.

1.5. Methodology

This section details the methodology that was followed in order to develop a GD self-management and remote monitoring mobile platform.

Figure 1.1 summarises the methodology in a flow diagram. This diagram integrates into the software development lifecycle (analyse, design, develop, test, deploy and maintain (Bassil, 2012)) by ending in the testing phase (with an alpha version of the platform).

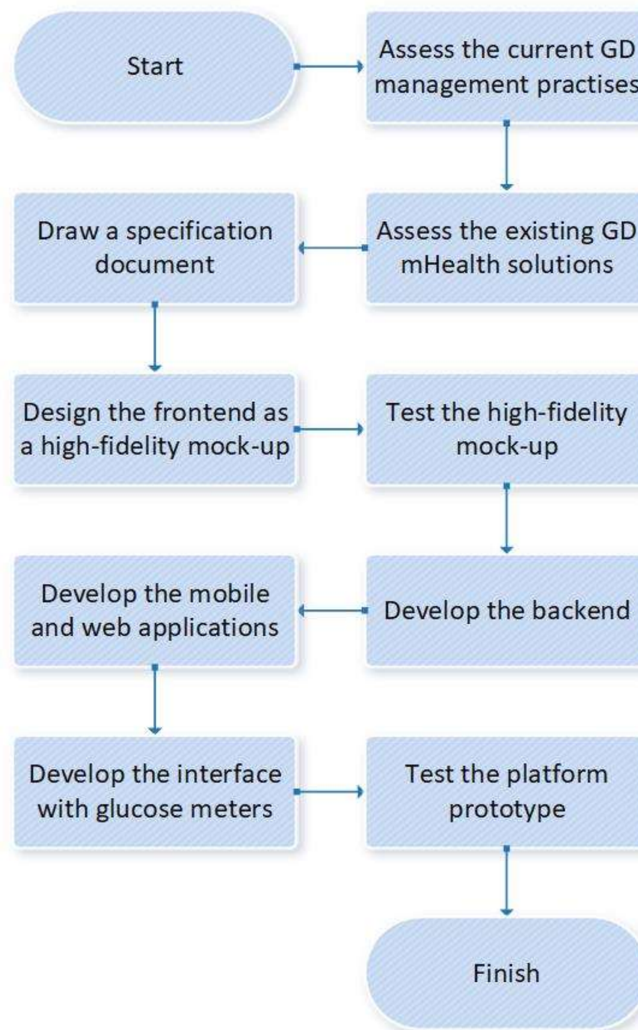


Figure 1.1: Methodology flow diagram

1.5.1. Assessment of Gestational Diabetes Management Practices in South Africa

The literature relating to the GD management practices in South Africa was reviewed using the Google Scholar database in the form of a narrative literature review. The review was performed in order to determine the problem and the need that should be addressed in order to develop a successful solution. Input from GD experts was included in the assessment of diabetes management practices in South Africa.

The literature was used to create a flow diagram illustrating the GD cycle of care in South Africa and its related shortcomings. The mHealth platform was developed to optimise the cycle of care and improve the management practices. The platform incorporated the standard GD management practices so that it met professional medical standards in South Africa.

1.5.2. Assessment of Existing mHealth Platforms for Gestational Diabetes

The existing mHealth platforms for GD were assessed by broadly using systematic review procedures. Meta-analysis was performed, using Review Manager (RevMan Version 5.3), to analyse data from the included studies in order to determine whether mHealth was more effective than standard care in the management of GD. The features and functions required for a GD mHealth platform were extracted from the included studies.

1.5.3. Design, Development and Testing of a Gestational Diabetes mHealth Platform

Figure 1.2 diagrammatically depicts the network architecture of the platform. It shows that the mobile app is for patients and the web app is for healthcare professionals. The architecture is split into two major sections: the frontend (mobile app and web app) and the backend. The design and development of each section are discussed separately.

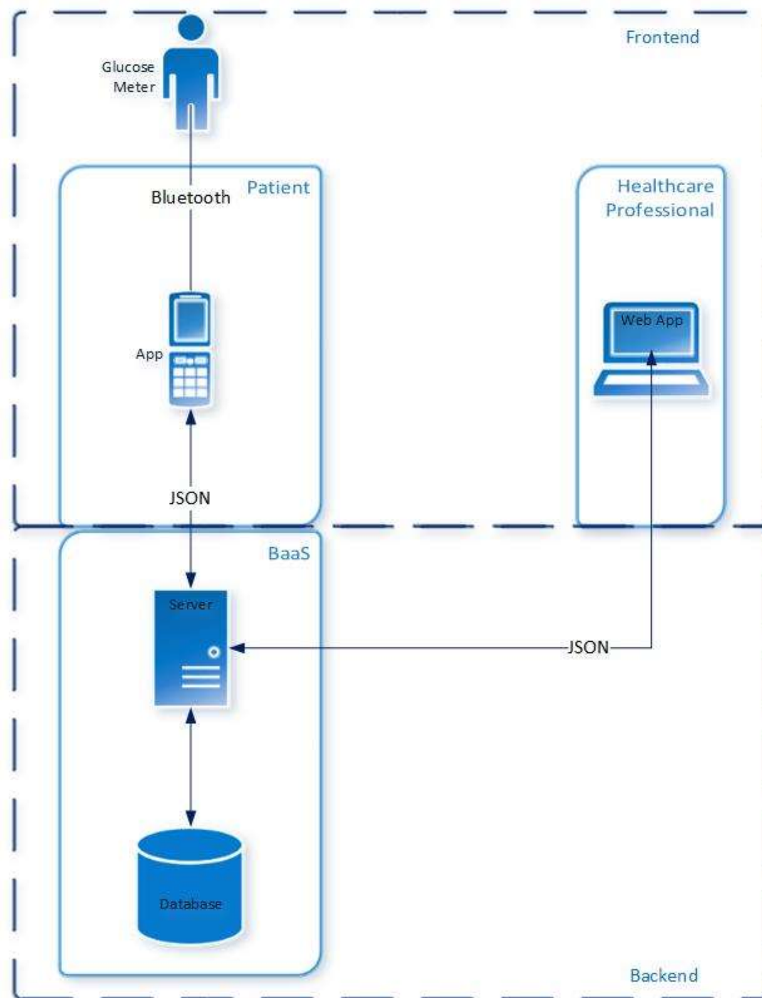


Figure 1.2: mHealth platform architecture

Prior to the commencement of the design phase, a software requirements specification document (SRSD) was collated. This document formalised the conceptual idea from the problem statement and rationale, providing a clear overview of the scope of the work. The SRSD was guided by the research completed in the first two objectives. The software requirements were used as the framework to guide the design and development process. Upon completion of the SRSD, the design phase could commence.

1.5.3.1. Design of the Frontend

Upon completion of the specification document, the user interface (UI) and user experience (UX) were designed. The UI was designed in conjunction with the UX, using Adobe XD to create low-fidelity mock-ups and wireframes, followed by interactive high-fidelity mock-ups.

Adobe XD was used as a wireframing tool, which provided a storyboard for the mobile app. The storyboard showed how the app flowed between screens, which represented the UX design. This concluded the design of the low-fidelity mock-up

Once the UI had been designed and a storyboard had been created, an interactive high-fidelity mock-up was developed in order to test the UX and evaluate the UI. The high-fidelity mock-up gave the mobile app and web app some functionality so that they could be tested by a group of potential users. This allowed technical malfunctions, like design errors and dead-end links, to be identified and the UI to be evaluated. The UI and UX were adapted during development of the prototype based on the effectiveness of the high-fidelity mock-up.

1.5.3.2. Development of the Backend

There are two main trends in mobile app development. The most common is the mobile-first approach where a single version of the app, aimed at a specific operating system is built, while other versions may be developed at a later stage (depending on the success of the first app) (Gropengießer & Sattler, 2014). The second trend is the application programming interface (API)-first approach (also known as backend as a service (BaaS)), where the backend is developed first so that apps can be built for various operating systems based on the same conditions (Gropengießer & Sattler, 2014).

A BaaS provider allows the backend to be easily extended from the Android operating system to iOS or a web app (Firebase, 2019a). It facilitates app updates seamlessly, it offers on-demand scalability options for improved performance and it secures data (Firebase, 2019a). Firebase is Google's BaaS which offers cloud services such as user authentication, real-time database, storage, hosting, and so on (Li et al., 2018). Firebase works seamlessly with Android mobile apps (because Firebase and Android are both owned by Google) and connects easily with Android Studio, the integrated development environment (IDE) (Firebase, 2019a). The Firebase cloud system also provides encrypted data transmission (Firebase, 2019b, Li et al., 2018).

A BaaS was used for the development of the backend because it offered more advantages than the mobile-first approach as described above. Firebase was used as the BaaS provider because of its desirable features. The BaaS was used to store data, including log-in credentials and blood glucose readings. The BaaS then distributed this data to the patient's app and the healthcare professional's app.

1.5.3.3. Development of the Mobile Application for Patients

The mobile app was developed as a native app on the Android operating system. A native mobile app was chosen instead of a web app due its unhindered access to device hardware which was required for the purpose of this project (Jobe, 2013). The Android operating system was chosen because it was the most popular operating system (Giachetti & Marchi, 2017).

Android Studio was used to develop the app because it was Android's official IDE and it used the Java programming language which was familiar to the developer. This meant that the mobile app would be developed as an Android native mobile app instead of a hybrid mobile app. Android Studio also had a dedicated emulator and featured easy integration with Firebase which suited the developer's needs.

1.5.3.4. Development of the Web Application for Healthcare Professionals

The web app was developed using a combination of HyperText Markup Language (HTML), Cascading Style Sheets (CSS) and JavaScript, which are the standard coding languages for web development (Jobe, 2013). A web app was chosen for healthcare professionals because healthcare professionals would not require access to the hardware of the device. The fact that web apps could run through a browser on any device (Jobe, 2013) made it a convenient choice.

Visual Studio Code, an IDE which supported HTML, CSS and JavaScript, included a comprehensive ecosystem of plugins which fully supported the needs of the software developer. It was thus used for the development of the web app.

1.5.3.5. Development of the interface with the Glucose Meters

The app was designed to interface with a Bluetooth-enabled glucose meter in order to avoid the accidental or purposeful error in entry that could occur during manual entry.

The interface can be facilitated with a wireless connection. Many glucose meters can wirelessly transfer data via Bluetooth or can transfer data through a wired connection using serial communication. Bluetooth is chosen to transfer the data because all smart glucose meters support Bluetooth connectability, whereas only some support wired transfer of data. It is also less convenient to transfer data over a wired connection in comparison to a wireless connection due to the limitations that come with wired connections of any sort.

The Android platform includes support for the Bluetooth network stack, which allows a mobile phone to wirelessly exchange data with other Bluetooth devices. The software developer has access to an Accu-Chek Instant glucose meter, which is readily available and affordable. Thus, this is the glucose meter which is used to transfer data to the app.

1.5.3.6. Testing of the Gestational Diabetes mHealth Platform

The platform was tested at various stages throughout the design and development process. Usability tests occurred once the frontend had been designed. The high-fidelity mock-up of the frontend was tested in the Division of Biomedical Engineering at the University of Cape Town, using a set of tasks (to ensure that all requirements had been met) and a usability questionnaire. The outcomes of the testing were used to guide the changes that the mock-up needed before it went into the development phase.

Once the platform had been developed, it underwent alpha tests consisting of black box testing. This was done by using students and staff, including engineers, dieticians, clinicians and other healthcare professionals, in the Biomedical Engineering Division at the University of Cape Town who carried out tasks that the typical user might perform. The goal was to identify issues which could be fixed once development on a beta version of the GD mHealth platform began.

1.6. Structure of Thesis

Chapter 2 fulfils the first objective, which is the assessment the current GD management practices in South Africa. Chapter 3 assesses the existing mHealth solutions for GD, which fulfils the second objective. The third objective is the design, development and testing of the GD mHealth platform, which will be discussed extensively in chapter 4. A general discussion to link the preceding chapters will take place in chapter 5. Finally, chapter 6 will conclude the thesis and will list the limitations and recommendations for future development.

2. Gestational Diabetes Management Practices in South Africa

This chapter reviews the existing gestational diabetes (GD) management practices in South Africa in the form of a narrative review in order to accurately identify the problem and the needs required to solve the problem. The GD epidemiology, complications and management practices are discussed, followed by a comparison of diabetes management practices in the private at public healthcare sectors of South Africa.

GD is defined by Buchanan, Xiang & Page (2012) as glucose intolerance with its onset or first recognition occurring during pregnancy. It is caused by a reduced pancreatic β-cell function, which does not produce sufficient insulin to meet the increased requirements of late pregnancy (Buchanan, Xiang & Page, 2012). This results in a high level of glucose in the blood, which is an identifying factor of diabetes (Diabetes UK, 2006). This, in turn, increases the risk of complications for both the mother and child before, during and after birth (Garnweidner-Holme et al., 2015). These complications can include emergency caesarean sections, gestational hypertension, neonatal hypoglycaemia, macrosomia, premature births, large for gestational age infants and Neonatal Intensive Care Unit (NICU) admissions (Carral et al., 2015, Given et al., 2015, Guo et al., 2018, Mackillop et al., 2018, Miremberg et al., 2018, Rasekaba et al., 2018).

GD is increasing in prevalence along with the increase in prevalence of obesity in women of child bearing age (Kampmann et al., 2015). The risks posed to both the mother and child due to the mismanagement of the disease is a major cause for concern (Adams & Rheeder, 2017). Therefore, it is important to pay attention to diagnostic, treatment and management procedures relating to pregnant women at risk of developing GD. This is especially important in a South African setting, because South Africa is now regarded as one of the world's most obese nations (Adams & Rheeder, 2017).

2.1. Epidemiology of Gestational Diabetes

Mathevula (2013) estimates that there are well over 1.5 million diabetics of all types in South Africa. According to the most recently released statistics from Statistics South Africa, diabetes (5.5% mortality) has surpassed HIV/Aids (4.8% mortality) to be the second highest cause of death in South Africa (Statistics South Africa, 2016a). Diabetes is a preventable non-communicable disease which can be treated, yet it is ranked closely behind the number one cause of death, Tuberculosis (6.5% mortality) (Statistics South Africa, 2016a). This is largely due to the inadequate management practices of those diagnosed with T1D, T2D or GD (Pillay, Lutge & Aldous, 2016, Rotchford & Rotchford, 2002).

Hyperglycaemia during pregnancy complicates 16% of live births worldwide according to a 2013 study (Kampmann et al., 2015). This percentage is likely to have increased since 2013 and will continue to increase into the future in line with the global trends in diabetes and obesity (Kampmann et al., 2015). In a South Africa where there are approximately 1 million births per year (Statistics South Africa, 2016b), the high prevalence of GD can result in a large number of complications due to mismanagement, which can add more pressure to a healthcare system which is already struggling to cope (Nhlapo, 2015).

Adams & Rheeder (2017) performed an observational study at a level 1 clinic in Johannesburg to determine the prevalence of GD in a South African population group. The results indicated that out of 554 patients studied, the prevalence of GD was 25.8% if the universal screening method and the International Association of Diabetes in Pregnancy Study Groups (IADPSG) criteria were used (Adams & Rheeder, 2017). The high prevalence of the disease in South Africa highlights the need for better GD management practises.

2.2. Gestational Diabetes Induced Complications

Complications that arise as a result of GD can be detrimental to both the mother and the child. These complications can arise during pregnancy, at delivery and after birth as explained in the following paragraphs.

Women with GD are more likely to have maternal complications like non-elective caesarean sections (19.5% of GD cases) than those without (13.5% of non-GD cases) (Buchanan, Xiang & Page, 2012, Kampmann et al., 2015). According to Kampmann et al. (2015), there is a high risk for women with GD to develop gestational hypertension disorders (11.3% of GD cases).

This finding is confirmed by Adams & Rheeder (2017) and Kim (2010), who found the prevalence of gestational hypertension in women with GD to be 34.3% and 10.7% - 15% respectively. GD results in a higher risk of shoulder dystocia (Kim, 2010) and a stronger chance of delivering a baby with macrosomia (Adams & Rheeder, 2017) than normal pregnancies. Some studies have found that the risk of stillbirth is increased fourfold during labour if the mother has GD (Buchanan, Xiang & Page, 2012, Kampmann et al., 2015, Kim, 2010).

Buchanan, Xiang & Page (2012) further investigated the perinatal complications in women with GD versus women without and found that for women with GD, premature births were 3% more frequent (confirmed by Kim (2010)), the need for intensive neonatal care was 1.3% more frequent, neonatal hypoglycaemia was 0.8% more frequent (confirmed by Kim (2010)) and large for gestational age new-borns were 7.9% more frequent.

After birth, women with a history of GD are at a greater risk of developing T2D (at least a sevenfold increase), while their children have a greater risk of being obese (twice more likely), developing the metabolic syndrome (four times more likely) and developing T2D early in their lives (six times more likely), according to Kampmann et al. (2015). GD also increases a woman's risk of the metabolic syndrome and cardiovascular disease postpartum threefold (Kampmann et al., 2015). The risks point to the need for better diagnosis, monitoring and treatment of women with GD so that these risks can be avoided.

2.3. Gestational Diabetes Cycle of Care

The GD cycle of care in South Africa is investigated in this section. Figure 2.1 depicts the GD cycle of care. The components of the cycle are discussed in the sections below.

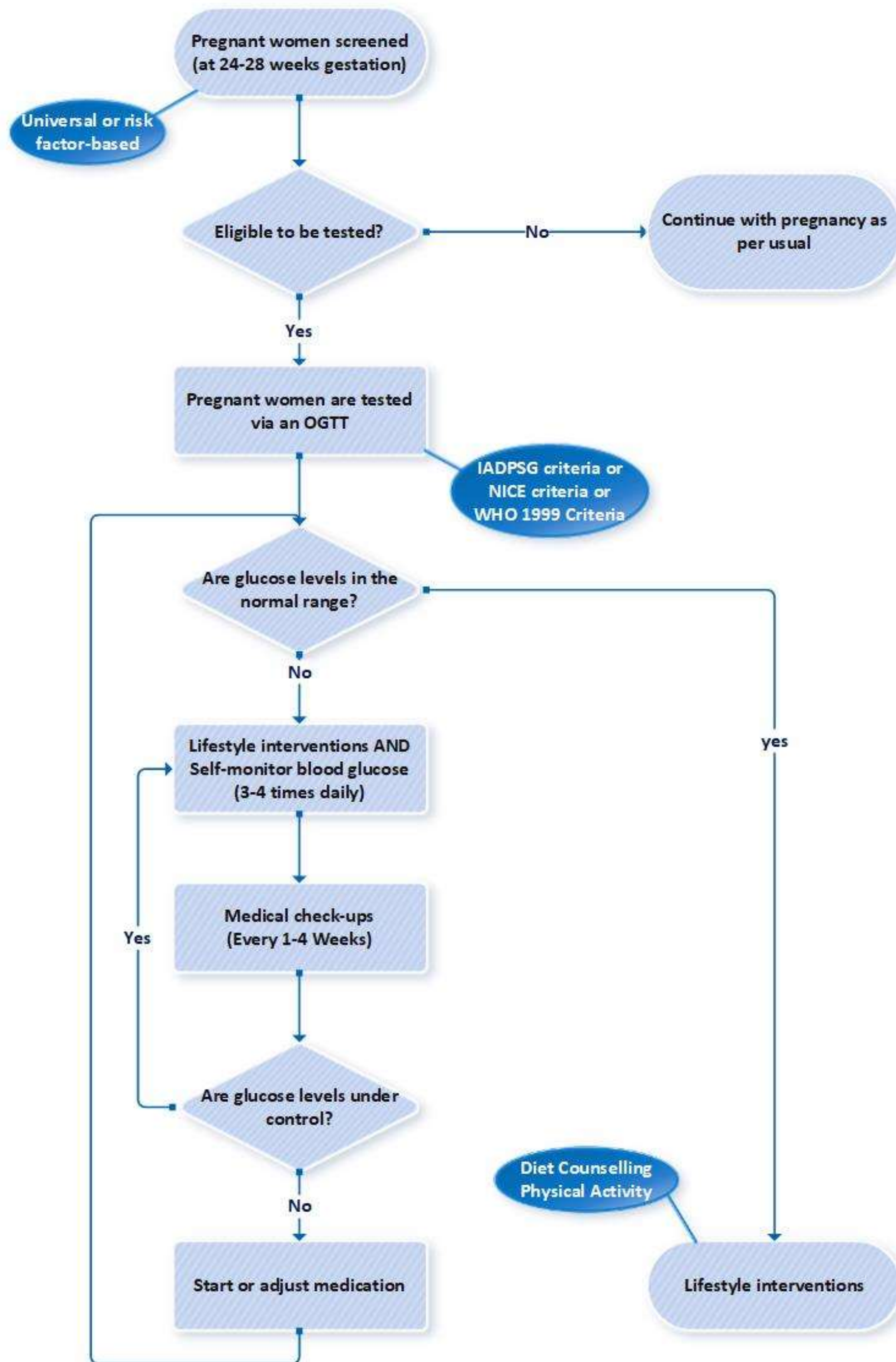


Figure 2.1: Gestational diabetes cycle of care

2.3.1. Risk Factors

The GD cycle of care begins when women, who are 24-28 weeks pregnant, are screened using various risk factors (Nhlapo, 2015). There are many risk factors relating to GD, including maternal obesity, advanced maternal age, a family history of diabetes, a previous history of GD and belonging to certain ethnic groups (Garnweidner-Holme et al., 2015). Those who are at risk undergo an oral glucose tolerance test (OGTT) for diagnosis purposes (Nhlapo, 2015).

2.3.2. Diagnosis

The diagnosis of GD involves an OGTT, because Haemoglobin A1c (HbA_{1c}) is inadequate as a diagnostic tool during pregnancy (Kampmann et al., 2015). However, screening procedures and diagnosis criteria in South Africa are disorderly (Adams & Rheeder, 2017). While current international opinion favours the universal screening of all pregnant women for GD using IADPSG criteria, SEMDSA recommends risk factor-based selective screening at 24 - 28 weeks' gestation using the World Health Organisation (WHO) 1999 criteria (Nhlapo, 2015). According to Adams & Rheeder (2017), risk factor-based selective screening is the predominant practice in South Africa; however, each provincial health department in South Africa can decide independently which diagnostic criteria to use (National Institute for Health and Care Excellence (NICE), IADPSG or WHO 1999 criteria). The variations in diagnostic criteria result in many women with GD not receiving uniform treatment.

2.3.3. Disease Management

Once diagnosed, disease management becomes of key importance. It is recommended that women with GD manage their disease by controlling their blood glucose levels, and through lifestyle interventions, including nutritional therapy, meeting exercise goals and managing weight gain (depending on pre-pregnancy weight) (American Diabetes Association, 2018, Buchanan, Xiang & Page, 2012, Kim, 2010). In more extreme cases, GD can be managed by using pharmacotherapy (American Diabetes Association, 2018).

The American Diabetes Association (2018) recommends fasting and postprandial monitoring of blood glucose to achieve metabolic control in pregnant women with diabetes. Their guidelines are shown in Table 2.1. Glucose self-monitoring by patients is shown to minimise the risk of perinatal complications (Buchanan, Xiang & Page, 2012).

Table 2.1: Blood glucose level guidelines for gestational diabetes

Time	**Blood Glucose Level**
Pre-prandial	5.3 mmol/L
1 hour postprandial	7.8 mmol/L
2 hours postprandial	6.7 mmol/L

During gestation, the diet should provide an adequate calorie intake to promote neonatal and maternal health, help achieve glycaemic goals and promote appropriate gestational weight gain (American Diabetes Association, 2018, Kim, 2010). Relatively little information from controlled trials exist to guide nutritional recommendations for GD (Buchanan, Xiang & Page, 2012); however, it is known that reducing caloric intake for overweight women, limiting carbohydrate content to 35–40% of total calories and focusing on complex rather than simple carbohydrates can lower glucose levels more effectively than the standard diet for pregnant women (Buchanan, Xiang & Page, 2012). The second of these diet modifications has been shown to improve perinatal outcomes in comparison to higher carbohydrate diets (Buchanan, Xiang & Page, 2012). Low carbohydrate diets are associated with fewer macrosomic infants, fewer caesarean deliveries, and less pharmacotherapy; however, lower glycaemic rates are associated with high carbohydrate diets, but this may be because diets rich in complex carbohydrates and low glycaemic foods enable greater carbohydrate consumption (Kim, 2010).

Weight targets are particularly emphasised if glucose goals are not met (Kim, 2010). It has been shown that small reductions in weight can improve glycaemic control (Kim, 2010). Miao et al. (2017) assessed the association between gestational weight gain and pregnancy outcomes in women with GD and found that excessive gestational weight gain increased the incidence of caesarean section and macrosomia, while inadequate gestational weight gain reduced the incidence of large for gestational age babies when compared with adequate gestational weight gain. This shows the need for women with GD to manage their bodyweight to remain within target bodyweight ranges.

Physical activity may improve glucose tolerance by improving insulin sensitivity (Kim, 2010, Tobias et al., 2011). The general guideline for exercise duration is at least 30 minutes of exercise several days a week (Kim, 2010). Furthermore, Tobias et al. (2011) found that higher levels of physical activity before pregnancy or in early pregnancy are associated with a significantly lower risk of developing GD.

If pharmacologic treatment is required to achieve glycaemic targets, insulin is the preferred medication for treating hyperglycaemia in GD as it does not cross the placenta to a measurable extent, in comparison to Metformin and glyburide, which may by harmful to the foetus (American Diabetes Association, 2018, Kim, 2010). Oral agents lack long term safety data and are not recommended (American Diabetes Association, 2018).

Management of GD by healthcare professionals is currently performed through regular hospital attendance every 1 to 4 weeks, depending on the stage of gestation and the severity of hyperglycaemia (Mackillop et al., 2018). Women are encouraged to record their blood glucose levels at 3 to 4 times a day in a paper logbook to be discussed with a healthcare professional during an outpatient service (Garnweidner-Holme et al., 2015).

2.3.4. Record Keeping

In South Africa, medical records are generally paper-based, loosely written documents used to record relevant medical information and facts about a patient (Mostert-Phipps, Pottas & Korpela, 2012). Paper-based record keeping is associated with many problems, including the possible loss of data due to human error, records being damaged and logistical difficulties relating to the transfer of data between facilities (Neupane et al., 2014), which contribute to the ineffectiveness of GD management practices in South Africa. While some institutions in the private healthcare sector have made a transition to digital record keeping (Mostert-Phipps, Pottas & Korpela, 2012), the majority of women with GD from both sectors are still tracking their blood glucose levels in paper-based logbooks (Nhlapo, 2015). Apart from the problems mentioned above, paper-based logbooks are also susceptible to accidental and purposeful errors in data capture (Mackillop et al., 2014). The issues with paper-based logbooks point to the need to manage diabetes digitally instead.

2.3.5. The Effect of the Public and Private Sectors on the Management of Gestational Diabetes

The cycle of care for patients in South Africa differs between the private and public healthcare sectors. The large gap between the private and public healthcare sectors is largely due to the difference in funding for each (Young, 2016). The public sector is government funded and offered to all South Africans without charge, but incurs long waiting times, rushed appointments, the use of old facilities and equipment, poor disease control and poor prevention practices (Young, 2016). The private sector, on the other hand, has more funding available from consumers and medical aid companies, which results in a higher quality of care (Young, 2016). Adila Hassim (2007) found that R33.2 billion (39% of total national expenditure on health) was spent on the public sector in 2005 versus the R43 billion (61% of total national expenditure on health) spent on the private sector. In 2005, the public sector served 37.9 million people which equates to R875.98 per capita expenditure (Adila Hassim, 2007). In contrast, the private sector served only 6.9 million people which equates to R6231.88 per capita expenditure (Adila Hassim, 2007). This inequality affects the diabetes management practices in each sector.

The management of diabetes (T1D, T2D and GD) in South Africa presents certain problems, especially in low income areas. Over 70% of low income South Africans live in rural areas where healthcare accessibility is limited (Wouters et al., 2009). Poor diabetic control in the South African public sector is caused by the lack of regular blood glucose monitoring by healthcare professionals and the lack of action taken when blood glucose levels are not up to standard (Rotchford & Rotchford, 2002). Also contributing to poor diabetic control in South Africa is the fact that the adherence to treatment of chronic diseases is less than 66% (Mathevula, 2013, Wouters et al., 2009). Levitt (2008) says that the problem with diabetes management in South Africa is as a result of a lack of resources allocated to healthcare in low income economies, where the majority of the limited resources are allocated to acute care instead of chronic care. Levitt (2008) also cites the lack of functioning equipment for routine monitoring as a contributing factor to the poor management of diabetes as well as the lack of education programmes in place for patients and staff. These problems have resulted in 62% of diabetics in South Africa going undiagnosed (Pillay, Lutge & Aldous, 2016). These studies

show the need for a better method of managing diabetics in low income areas of South Africa which may benefit from the use of mHealth, according to Wouters et al. (2009).

Although the private healthcare sector in South Africa offers a greater quality of care than the public healthcare sector, diabetes management practices in the private sector are still suboptimal when assessed according to HbA_{1c} levels (Amod, Riback & Schoeman, 2012). According to data from the Council for Medical Schemes, about 3.3% of beneficiaries were treated for diabetes in South Africa in 2016 (Govuzela, Thsehla & de Villiers, 2018). Over 70% of these patients in the private sector had HbA_{1c} values greater than 7% (the target recommended by the SEMDSA guidelines at the time of the survey) versus 84.3% of patients in the public sector (Rotchford & Rotchford, 2002). The most common reason indicated by doctors for patients in the private sector not reaching their HbA_{1c} goals is due to a lack of compliance with lifestyle recommendations (29.5%) and a lack of efficacy for their intended antidiabetic treatment (23.5%) (Amod, Riback & Schoeman, 2012).

Chapter 3 builds on the research in this chapter by reviewing the existing mHealth solutions for GD. This is done to assess the effectiveness of mHealth for GD management and determine whether mHealth may benefit the current GD management practices in South Africa.

3. Existing mHealth Solutions for Gestational Diabetes

The objective of this chapter is to perform a comprehensive review of the literature relating to existing mHealth solutions for gestational diabetes (GD), including the benefits and challenges of mHealth, the effectiveness of mHealth used for GD and the important features and functions of existing GD mHealth solutions. The analysis broadly follows the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) framework (Moher et al., 2009).

3.1. Introduction

Mobile health (mHealth) is defined by Kahn, Yang & Kahn (2010) as the use of portable electronic devices for data communication via the internet to provide health information. The global penetration of smartphones is 48%, according to Kahn, Yang & Kahn (2010), which is one of the reasons that mobile devices are being used in the healthcare industry.

The nature of chronic diseases like diabetes requires a well-integrated and resource-rich healthcare system, which is why chronically ill patients are often poorly managed in low and middle income countries (LMIC) (Bloomfield et al., 2014). The need for those with chronic illnesses, like diabetes, to manage their own treatment means that public health systems must utilise mobile technologies in order to equip patients to do so (Kahn, Yang & Kahn, 2010). During the 2011 United Nations High Level Meeting on Non-Communicable Diseases, mHealth was highlighted as a key strategy to combat chronic diseases in LMIC (Bloomfield et al., 2014). Kahn, Yang & Kahn (2010) emphasised that the potential of mHealth in LMIC is as a result of the prominent use of smartphones in these countries. In South Africa (which has universal mobile phone penetration), 40% of all mobile phones are smartphones and this number is said to increase drastically in the near future (Barron et al., 2018). Bloomfield et al. (2014), who found that there are more mobile phone subscribers in south Saharan Africa than in the United States or European Union, agrees that there is a role for mHealth in Africa.

The benefits of using mHealth to manage diabetes and other chronic diseases is well documented. The main benefits of mHealth are the ability to graphically view trends (Årsand et al., 2010), the ability to collect data in real-time (Barron et al., 2018) and the potential for remote diagnosis, monitoring and treatment (Bloomfield et al., 2014, Kahn, Yang & Kahn, 2010, Veazie et al., 2018). The disease education abilities of mHealth (Bloomfield et al., 2014,

El-Gayar et al., 2013, Kahn, Yang & Kahn, 2010) and the improved self-management due to mHealth (Cafazzo et al., 2012, Kahn, Yang & Kahn, 2010) are associated with better health outcomes (Pais et al., 2017). The ability to connect to external devices for automatic data entry (Cafazzo et al., 2012, El-Gayar et al., 2013) and the ability to communicate directly with healthcare professionals (El-Gayar et al., 2013) regarding the recorded data are seen as major advantages of mHealth. There is a possibility of integrating mHealth platforms with a personal health record (PHR) (El-Gayar et al., 2013) or managing multiple health conditions through one health and wellness mobile app (Pais et al., 2017) which may be advantageous to the management of one's health. Social networking, which can be supported by mHealth, acts as a source of motivation and information and is thus seen as a major advantage of using mHealth (Cafazzo et al., 2012, Kahn, Yang & Kahn, 2010)

There are many challenges relating to mHealth, however. Bloomfield et al. (2014) state that while there are numerous examples of mHealth being used for chronic diseases, there is insufficient evidence to support the effectiveness of mHealth. Other disadvantages associated with mHealth include the transfer of incorrect information through error which may create alarm, the misinterpretation or misunderstanding of presented information due to inadequate literacy or hasty reading, the loss of human interaction for teaching and the possible loss of confidentiality (Kahn, Yang & Kahn, 2010). Wouters et al. (2009) state that healthcare professionals and patients in developing countries like South Africa may struggle to use new technologies or may see mHealth platforms as an extra burden in an already time-constrained, administration-intensive environment (Barron et al., 2018). Patients might regard mHealth as a replacement for a face-to-face visit with a health worker as opposed to being supplementary to face-to-face visits (Wouters et al., 2009). Network charges are also costly, especially for those in rural areas who arguably need the help of mHealth services most. This, combined with the fact that there may be parts of rural areas where network coverage is poor, may hinder the effectiveness of mHealth platforms (Wouters et al., 2009). Another concern raised in literature has to do with security and privacy related problems in mHealth which arise due to the unsecured transfer of private data or theft of a device which may contain private data (El-Gayar et al., 2013). Skar et al. (2018) pointed out that that the patients' trust in the subjective and intuitive knowledge of healthcare professionals will

decrease with the use of mHealth and that the responsibility for the patient to self-manage his or her own health may add further to the burden of the disease.

3.2. Methods

The methods detailed here describe the process followed in order to evaluate the effectiveness of mHealth when applied to GD as well as the important GD mHealth features and functions. The methods follow a systematic review process.

3.2.1. Research Question

This study focuses on the research question: "Will mHealth act as a more effective management solution for women with GD when compared with the existing GD management practices?"

Table 3.1 shows the PICO research question, which included the population (P) group of women with GD, the intervention (I), which was the use of mHealth, the comparison (C) group of women with GD who received the standard care and the outcome (O), which was the effectiveness of the management practices.

3.2.1.1. Population

The population included women with GD. However, pregnant women who had previously been diagnosed with T1D or T2D were also included, because they followed a similar cycle of care as women who were diagnosed with GD (over the last 12 to 16 weeks of gestation) according to Buchanan, Xiang & Page (2012).

3.2.1.2. Intervention and Comparison

The intervention of mHealth included all forms of electronic devices which transferred data via an internet connection to provide health information. The comparison was with the existing GD management practices (depicted in Figure 2.1).

3.2.1.3. Outcome

The primary outcome of this research was to gauge the effectiveness of the intervention by comparing intervention groups and comparison groups, measuring the:

- biological outcomes (blood glucose levels and Haemoglobin A1c (HbA_{1c}) levels),
- maternal outcomes (vaginal delivery rates, caesarean section rates, gestational ages at delivery and gestational hypertension rates),

- perinatal outcomes (birth weights, neonatal hypoglycaemia rates, macrosomia rates, Neonatal Intensive Care Unit (NICU) admission rates and premature birth rates),
- behavioural outcomes (patient compliance levels),
- economic outcomes (frequency of outpatient services and healthcare related costs), and
- cognitive outcomes (patient and healthcare professional satisfaction levels).

The secondary outcomes from this review determined what the existing mHealth solutions (and their features) for GD were and what the related benefits and challenges were. The outcomes were displayed on forest plots and analysed for statistical significance and level of heterogeneity.

Table 3.1: PICO research question

PICO	**Will mHealth act as a more effective management solution for women with GD when compared with the existing GD management practices?**
Population	Women with GD
Intervention	mHealth
Comparison	Existing GD management practices
Outcome	Effective management

3.2.2. Eligibility Criteria

Table 3.2 shows the inclusion and exclusion criteria applied during the search of each database. Journal articles were included due to the review process they underwent, ensuring good quality information. The January 2014 and December 2018 date restrictions excluded any mHealth interventions prior to this 5-year period, as these were deemed irrelevant as a result of fast progressing mHealth related technologies. Only English articles were included. All articles with population groups including animals or males were excluded because they did not form part of the research question.

Table 3.2: Inclusion and exclusion criteria

Article type	Peer-reviewed articles
Article publication date	2014 – 2018
Article language	English
Population species	Humans
Population gender	Female

3.2.3. Search Strategy

Table 3.3 shows the search strategy. It includes the keywords used to search the databases for relevant articles.

The search was performed from the 19th to the 23rd of November, 2018, with the help of a professional librarian, using the following databases: Academic Search Premier, CINAHL, Computers and Applied Sciences Complete, EBSCOHost, EI Compendex, Health Source: Nursing/Academic Edition, IEEE Electronic Library, Pubmed, PsycINFO, Scopus, Technology Research Database and Web of Science.

Table 3.3: Search strategy

Population: GD		
#1	MeSH terms	diabetes, gestational
#2	Free text	(gestational OR gestation OR pregnancy-induced OR (pregnancy induced)) AND (diabetes OR diabetic)
#3	(#1 OR #2) **(population)**	
Intervention: mHealth		
#4	MeSH terms	telemedicine OR computers, handheld OR medical informatics applications OR mobile applications
#5	Free text	Android OR blog OR cell phones OR cellular phones OR computer OR digital health OR digital health interventions OR e-counselling OR eHealth OR e-

		health OR Facebook OR handheld computers OR ICT OR information communications technology OR iPad OR iPhone OR internet-based OR messaging OR mHealth OR m-health OR mms OR mobile apps OR mobile applications OR mobile-based OR mobile devices OR mobile health OR mobile phones OR mobile technology OR online chat OR online social network OR phone OR podcasts OR portable electronic applications OR SMS OR smartphones OR smart phone OR social media OR telecommunication in medicine OR telecare OR telehealth OR telephone-based OR telemedicine OR text messaging OR text messages OR tweet OR twitter OR WhatsApp OR WeChat OR web-based OR web site OR website OR web app
#6	#4 OR #5 **(intervention)**	
#7	#3 AND #6 **(search without filters)**	
#8	Publication dates: 2014 - 2018	
#9	#7 AND #8 **(final search)**	

3.2.4. Study selection

The author screened all the articles based on their titles and abstracts to identify potentially significant articles from the original search. The full texts of the remaining articles were then evaluated by the author. Ineligible articles were excluded based on the eligibility criteria.

The title and abstract screening and full text screening criteria used were as follows:

- The population group in the article must have been about women who have GD.
- The intervention in the article must have been mHealth related.
- One of the primary outcomes investigated in the article must have been blood glucose levels.

3.2.5. Quality Assessment and Data Extraction

Each of the randomised control trials were scored for the risk of bias using the Cochrane Collaboration Risk of Bias Tool. Data relating to the primary and secondary outcomes was extracted by the author and stored using Review Manager (RevMan Version 5.3). The extracted data included blood glucose levels, HbA_{1c} levels, vaginal delivery rates, caesarean section rates, gestational ages, birthweights, hypoglycaemia rates, NICU admission rates, premature birth rates, hypertension rates, patient compliance rates and healthcare costs.

3.2.6. Statistical Analysis

Review Manager (RevMan Version 5.3) was used for the meta-analysis. For outcomes of the dichotomous data type, the Mantel-Haenszel statistical method was used with the risk ratio effect measure. For outcomes of the continuous data type, the inverse variance statistical method was used with the mean difference effect measure. Results were presented with a 95% confidence interval (CI).

A large amount of heterogeneity was expected because of the substantial variance in the included studies in terms of standards of care and research methodologies utilised. Therefore, the random effects analysis model was applied and the I^2 characteristic was reported. Heterogeneity was estimated using I^2, with an I^2 value greater than 50% representing substantial heterogeneity (Higgins et al., 2003). The results were seen as significant if P was less than 0.05 (Higgins et al., 2003). The pooled data was displayed in a forest plot, but only if there were more than three studies with relevant data.

3.3. Results

The search results from the systematic review and the statistical results from the meta-analysis are detailed in the sections below.

3.3.1. Study Selection

The search results are displayed in Table 3.4 and the search process used is depicted in Figure 3.1 as a PRISMA flow diagram (PRISMA, 2019).

Endnote was used as a reference management tool. Once the search was complete, all 1109 references were saved in Endnote, which was used to automatically remove duplicates, leaving 875 unique references. Once the title and abstract of the articles were screened as per the eligibility criteria, 49 references remained. The screening of the full text of each article

left 26 applicable articles. Articles were excluded for the following reasons: the article was a duplicate, the full text was inaccessible, the intervention was incorrect, the population was incorrect, or no results were given.

Table 3.4: Search results

Database	References	References after duplicates	References after title and abstract screening	References after full text screening
Academic Search Premier	180	135	8	3
CINAHL	96	32	6	2
Computers and Applied Sciences Complete	13	10	2	1
EI Compendex	54	38	1	1
Health Source: Nursing/Academic Edition	42	5	0	0
IEEE Electronic Library	0	0	0	0
PsycINFO	14	6	1	0
Pubmed	298	297	24	19
Scopus	72	33	2	0
Technology Research Database	41	27	0	0
Web of Science	299	292	6	0
Total	**1109**	**875**	**50**	**26**

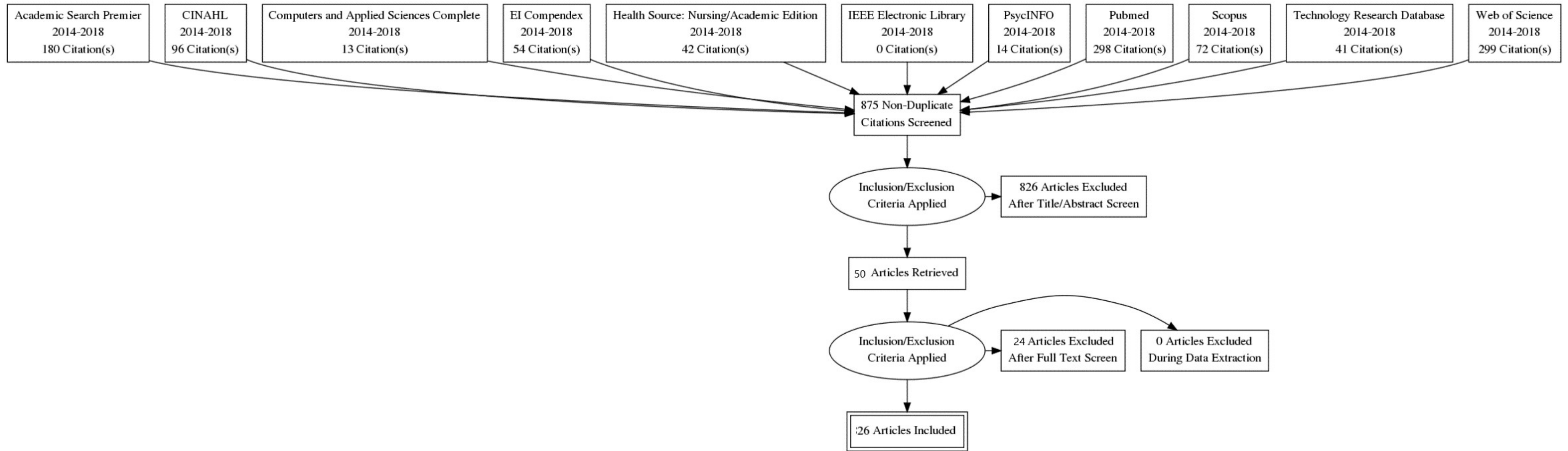


Figure 3.1: PRISMA flow diagram - generated using PRISMA Flow Diagram Generator (PRISMA, 2019)

3.3.2. Study Characteristics

The included studies can be split into different categories, including qualitative studies, quantitative studies, development and evaluation studies, systematic reviews and miscellaneous studies. Table 3.5 displays the studies arranged into their respective categories. Table 3.6 shows the characteristics of each qualitative study included in the meta-analysis.

The eight quantitative studies were focused on for the meta-analysis. The qualitative studies and development studies were primarily used to identify the main features and functions of existing mHealth solutions for GD. The systematic reviews were used as a source of related work to which results could be compared.

The eight quantitative studies included a total of 791 participants, 399 in the intervention group and 391 in the control group. The studies were conducted across nine countries, including the United States (Bartholomew et al. (2015)), Switzerland (Bromuri et al., 2016), Spain (Carral et al., 2015), Northern Ireland (Given et al., 2015), Republic of Ireland (Given et al., 2015), China (Guo et al., 2018), United Kingdom (Mackillop et al., 2018), Israel (Miremberg et al., 2018) and Australia (Rasekaba et al., 2018). All the individual studies were relatively small in size, ranging from 24 to 203 participants (a population size of around 1000 is required according to Ming et al. (2016)). All the studies were peer-reviewed articles and all of them were supported by grants. Seven of the studies used randomised controlled trial (RCT) designs and one used a controlled clinical trial (CCT) design (Carral et al., 2015).

Table 3.5: Study categories

Qualitative	Quantitative	Development and Evaluation	Systematic Review	Miscellaneous
• Garnweidner-Holme, L. et al. (2018) • Hirst et al. (2015) • Nicholson et al. (2016) • Pais et al. (2017) • Skar et al. (2018)	• Bartholomew et al. (2015) • Bromuri et al. (2016) • Carral et al. (2015) • Given et al. (2015) • Guo et al. (2018) • Mackillop, L. et al. (2018) • Miremberg et al. (2018) • Rasekaba et al. (2018)	• Jo & Park (2016) • Mackillop et al. (2014) • Garnweidner-Holme, Lisa Maria et al. (2015)	• Lau et al. (2016) • Ming et al. (2016) • Rasekaba et al. (2015)	• Anderson (2017) • Bashshur et al. (2015) • Chilelli, Dalfrà & Lapolla (2014) • Hirst et al. (2016) • Pustozerov et al. (2018) • Rigla et al. (2018) • Wickramasinghe, Teoh & Mercieca (2015)

Table 3.6: Study characteristics

Study	Population size (I:C)	Intervention Group	Blood glucose levels	HbA_{1c} Levels	Vaginal Deliveries	Caesarean Sections	Gestational Ages	Birthweights	Hypoglycaemia cases	Macrosomia cases	NICU Admissions	Premature Births	Hypertension cases	Outpatient Services	Compliances	Healthcare Costs
Bartholomew et al. (2015)	74 (40:34)	App logbook with automatic data entry Data reviewed via website by HP	✓												✓	
Bromuri et al. (2016)	24 (12:12)	App logbook with manual data entry Data reviewed via website by HP	✓													
Carral et al. (2015)	104 (40:64)	Website logbook with manual data entry Data reviewed via website by HP		✓		✓	✓	✓	✓			✓	✓			
Given et al. (2015)	47 (21:26)	Telemedicine hub with automatic data entry Data available on website logbook for patients Data reviewed via website by HP		✓		✓	✓	✓	✓	✓	✓	✓	✓			
Guo et al. (2018)	124 (64:60)	App logbook with automatic or manual data entry Data reviewed via app by HP		✓	✓	✓	✓		✓	✓				✓	✓	
Mackillop et al. (2018)	203 (101:102)	App logbook with automatic data entry Data reviewed via app by HP		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓
Miremberg et al. (2018)	120 (60:60)	App logbook with manual data entry Data reviewed via exported results by HP	✓		✓	✓	✓	✓			✓		✓		✓	
Rasekaba et al. (2018)	95 (61:34)	Website logbook with manual data entry Data reviewed via website by HP				✓	✓	✓		✓	✓			✓		✓
Total	791 (399:392)															

HP = healthcare professional, I = intervention group, C = control group

3.3.3. Study Quality

The study quality is assessed by evaluating the risk of bias. Figure 3.2 depicts the risk of bias of the eight quantitative studies and Figure 3.3 depicts the summary of the risk of bias.

Included studies displayed potential sources of methodological bias. A total of six studies out of the eight adequately randomised the sequence generation. There were two studies with adequate sequence concealment. Due to the nature of the intervention, blinding of participants and personnel was not possible in any of the studies. None of the studies addressed the blinding of outcome assessments and were all marked with an unclear risk. All the studies had an unclear risk of selective reporting.

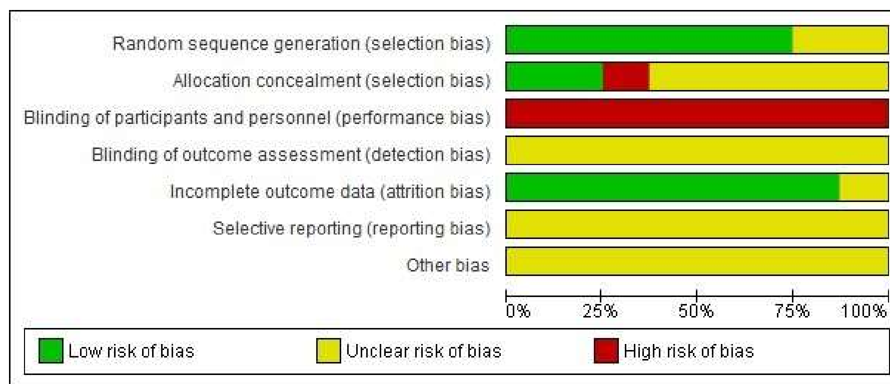


Figure 3.2: Risk of bias graph

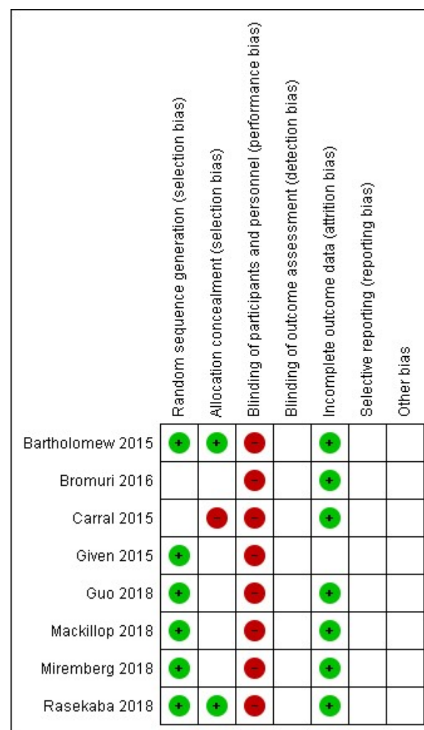
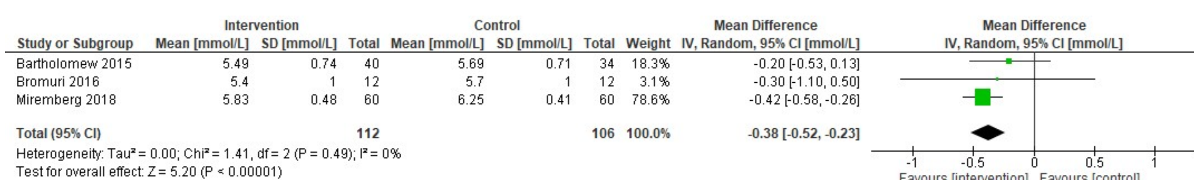


Figure 3.3: Risk of bias summary

3.3.4. Biological Outcomes

The biological results are displayed as forest plots. Figure 3.4 depicts the forest plot of the total blood glucose levels and Figure 3.5 depicts a forest plot of the HbA_{1c} levels.

There were three studies which assessed the blood glucose levels (Figure 3.4) as an outcome (Bartholomew et al., 2015, Bromuri et al., 2016, Miremberg et al., 2018). The meta-analysis revealed that the intervention reduced overall (pre-prandial and postprandial combined) blood glucose levels with a mean difference of -0.38 mmol/L (95% CI -0.52 mmol/L to -0.23 mmol/L). The results were homogeneous (I^2 = 0%) and were statistically significant (P < 0.00001).

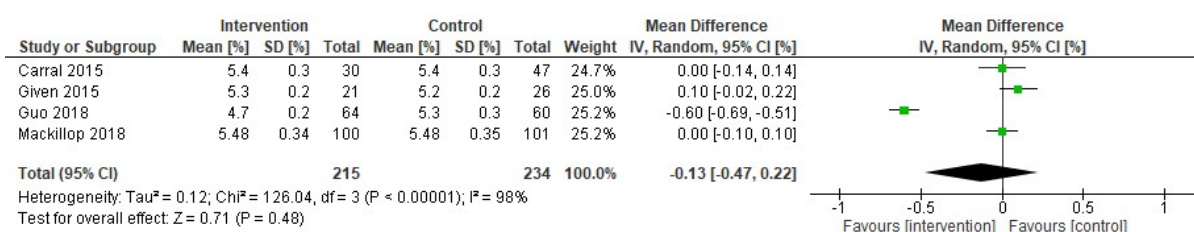


Study or Subgroup	Intervention Mean [mmol/L]	Intervention SD [mmol/L]	Intervention Total	Control Mean [mmol/L]	Control SD [mmol/L]	Control Total	Weight	Mean Difference IV, Random, 95% CI [mmol/L]
Bartholomew 2015	5.49	0.74	40	5.69	0.71	34	18.3%	-0.20 [-0.53, 0.13]
Bromuri 2016	5.4	1	12	5.7	1	12	3.1%	-0.30 [-1.10, 0.50]
Miremberg 2018	5.83	0.48	60	6.25	0.41	60	78.6%	-0.42 [-0.58, -0.26]
Total (95% CI)			**112**			**106**	**100.0%**	**-0.38 [-0.52, -0.23]**

Heterogeneity: Tau² = 0.00; Chi² = 1.41, df = 2 (P = 0.49); I² = 0%
Test for overall effect: Z = 5.20 (P < 0.00001)

Figure 3.4: Forest plot of blood glucose levels (total)

The HbA_{1c} levels (Figure 3.5) were also reduced by the intervention, as assessed by four studies (Carral et al., 2015, Given et al., 2015, Guo et al., 2018, Mackillop et al., 2014), with a mean difference of -0.13% (95% CI -0.47% to 0.22%). The results were substantially heterogeneous (I^2 = 98%) and not statistically significant (P = 0.48).



Study or Subgroup	Intervention Mean [%]	Intervention SD [%]	Intervention Total	Control Mean [%]	Control SD [%]	Control Total	Weight	Mean Difference IV, Random, 95% CI [%]
Carral 2015	5.4	0.3	30	5.4	0.3	47	24.7%	0.00 [-0.14, 0.14]
Given 2015	5.3	0.2	21	5.2	0.2	26	25.0%	0.10 [-0.02, 0.22]
Guo 2018	4.7	0.2	64	5.3	0.3	60	25.2%	-0.60 [-0.69, -0.51]
Mackillop 2018	5.48	0.34	100	5.48	0.35	101	25.2%	0.00 [-0.10, 0.10]
Total (95% CI)			**215**			**234**	**100.0%**	**-0.13 [-0.47, 0.22]**

Heterogeneity: Tau² = 0.12; Chi² = 126.04, df = 3 (P < 0.00001); I² = 98%
Test for overall effect: Z = 0.71 (P = 0.48)

Figure 3.5: Forest plot of HbA_{1c} levels

Bartholomew et al. (2015) and Bromuri et al. (2016) assessed the effects of the intervention on pre-prandial and postprandial blood glucose levels. Both found that the mean pre-prandial and postprandial blood glucose levels were less for the women using mHealth interventions than for women receiving regular care. The rate of off target measurements was found to be lower in the intervention group than in the control group for both pre-prandial and postprandial measurements (Guo et al., 2018, Miremberg et al., 2018). These findings were supported by Mackillop et al. (2018) who reported that blood glucose declined faster in the

intervention group compared to the control group by a statistically significant margin. Mackillop et al. (2018) also found that, although HbA_{1c} levels increased for both groups from recruitment to delivery, the intervention group's HbA_{1c} levels increased at a lesser rate than the control group's HbA_{1c}; however, this was not statistically significant.

3.3.5. Maternal Outcomes

The following forest plots are illustrated as per the maternal outcomes: Figure 3.6: Forest plot of normal vaginal deliveries, Figure 3.7: Forest plot of caesarean sections, Figure 3.8: Forest plot of emergency caesarean sections, Figure 3.9: Forest plot of gestational ages at delivery and Figure 3.10: Forest plot of gestational hypertension or pre-eclampsia.

Mackillop et al. (2018), Miremberg et al. (2018) and Guo et al. (2018) found that there was a higher probability of vaginal deliveries (Figure 3.6) in the intervention group than in the control group (shown by a risk ratio of 1.18). The results were homogeneous (I^2 = 0%) and statistically significant (P = 0.02).

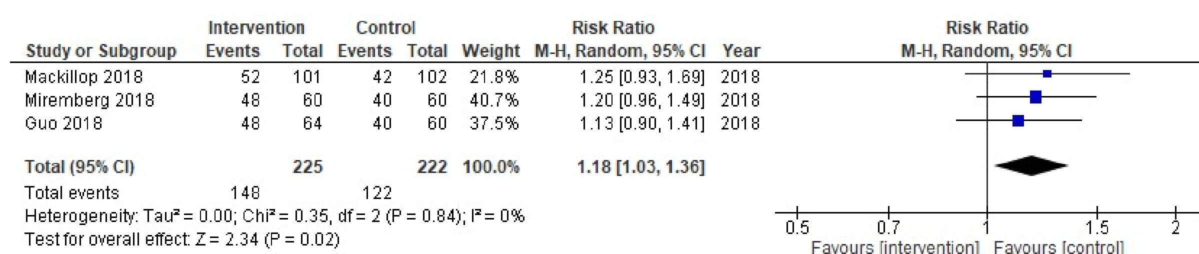


Figure 3.6: Forest plot of normal vaginal deliveries

There were six studies (Carral et al., 2015, Given et al., 2015, Guo et al., 2018, Mackillop et al., 2018, Miremberg et al., 2018, Rasekaba et al., 2018) which reported on the number of caesarean sections (Figure 3.7). The results showed that women in the intervention groups were less likely to have a caesarean section (shown by a risk ratio of 0.81). The results were of an acceptable level of heterogeneity (I^2 = 46%) but were not statistically significant (P = 0.17).

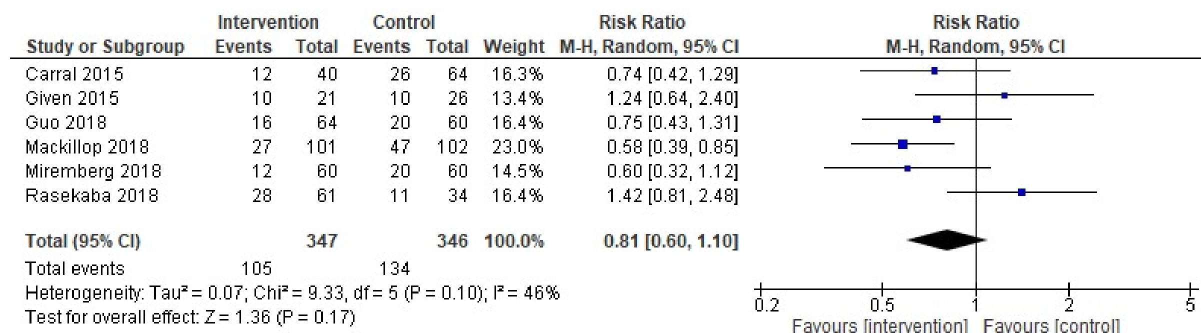


Figure 3.7: Forest plot of caesarean sections

Of the above six studies, three (Mackillop et al., 2018, Miremberg et al., 2018, Rasekaba et al., 2018) reported on the number of emergency caesarean sections (Figure 3.8). Although the results were substantially heterogeneous (I^2 = 66%) and not statistically significant, they found that women in the intervention group were less likely to have an emergency caesarean section than women in the control group (shown by a risk ratio of 0.23).

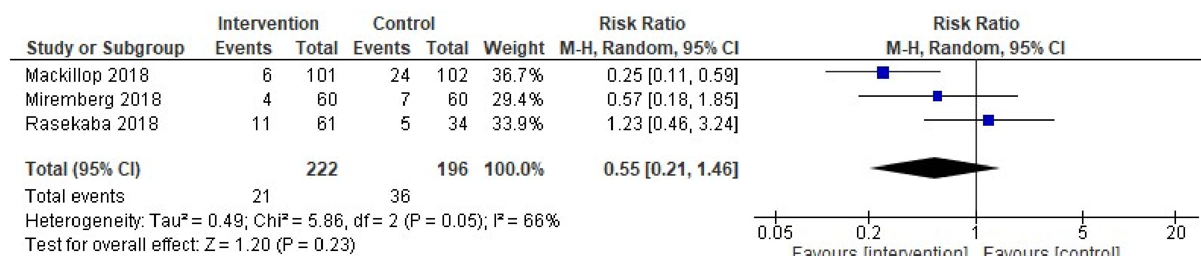


Figure 3.8: Forest plot of emergency caesarean sections

The gestational ages at delivery were reported on by six studies (Carral et al., 2015, Given et al., 2015, Guo et al., 2018, Mackillop et al., 2018, Miremberg et al., 2018, Rasekaba et al., 2018). Figure 3.9 shows that there was practically no difference in gestational ages at delivery between the groups (shown by a risk ratio of 0.01). The data was substantially heterogeneous (I^2 = 78%) and was not statistically significant (P = 0.05).

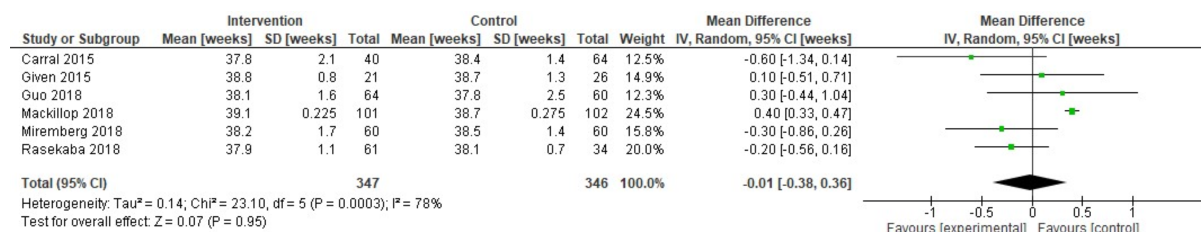


Figure 3.9: Forest plot of gestational ages at delivery

There were four studies (Carral et al., 2015, Given et al., 2015, Mackillop et al., 2018, Miremberg et al., 2018) which assessed the number of gestational hypertension cases (Figure 3.10). The studies found that women in the intervention group were less likely be diagnosed with gestational hypertension than women in the control group (shown by a risk ratio of 0.67). The results were homogeneous (I^2 = 0%) but were not statistically significant (P = 0.42).

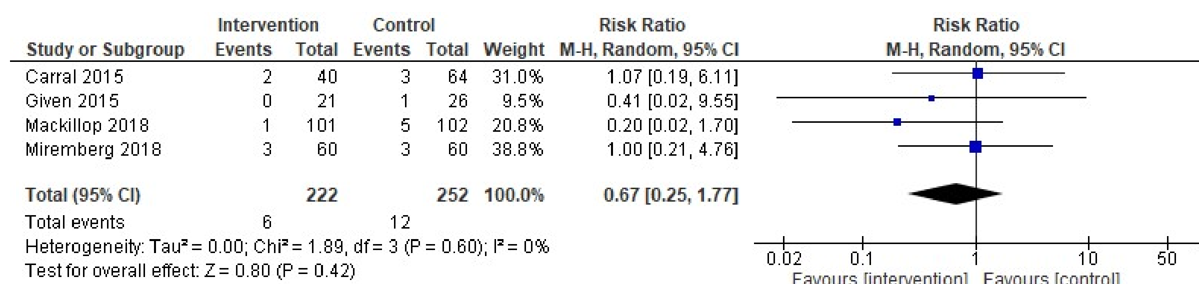


Figure 3.10: Forest plot of gestational hypertension or pre-eclampsia

Miremberg et al. (2018) and Carral et al. (2015) also investigated the number of women who had to undergo insulin treatment during pregnancy and found that women in the intervention group were significantly less likely to be on insulin during pregnancy than women in the control group.

3.3.6. Perinatal outcomes

The following forest plots are illustrated as per the maternal outcomes: Figure 3.11: Forest plot of birthweights, Figure 3.12: Forest plot of neonatal hypoglycaemia cases, Figure 3.13: Forest plot of macrosomia cases, Figure 3.14: Forest plot of NICU admissions and Figure 3.15: Forest plot of premature births.

Birthweights (Figure 3.11) in the control and intervention groups were assessed by five studies (Carral et al., 2015, Given et al., 2015, Mackillop et al., 2018, Miremberg et al., 2018, Rasekaba et al., 2018). The results showed that the mean birthweight of new-borns from the intervention group was 16.94 g (95% CI -105.74 g to 139.62 g) higher than that of new-borns from the control group. The results were substantially heterogeneous (I^2 = 52%) and not statistically significant (P = 0.79).

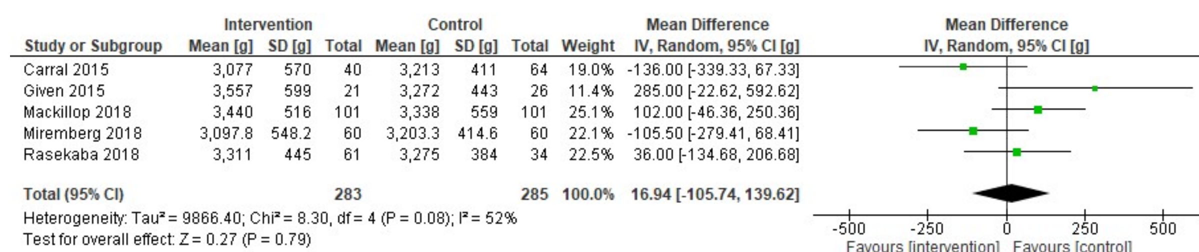


Figure 3.11: Forest plot of birthweights

The meta-analysis of the neonatal hypoglycaemia cases (Figure 3.12) showed that it was less likely for new-borns from the intervention group to be diagnosed with hypoglycaemia than new-borns from the control group (shown by a risk ratio of 0.67), as shown by four studies (Carral et al., 2015, Given et al., 2015, Guo et al., 2018, Mackillop et al., 2018). The results were homogeneous (I^2 = 0%) and were statistically significant (P = 0.02).

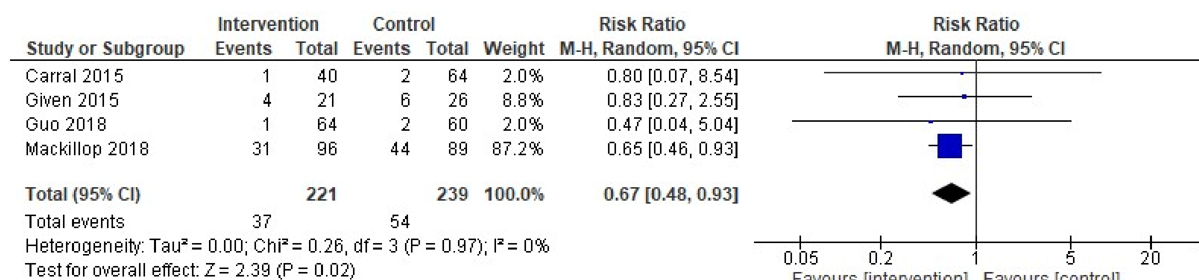


Figure 3.12: Forest plot of neonatal hypoglycaemia cases

There were three studies (Given et al., 2015, Guo et al., 2018, Rasekaba et al., 2018) which assessed the number of macrosomia cases (Figure 3.13). The studies found that new-borns from the intervention group were more likely have macrosomia than new-borns from the control group (shown by a risk ratio of 1.44). The results were of an acceptable heterogeneity (I^2 = 40%) but were not statistically significant (P = 0.54).

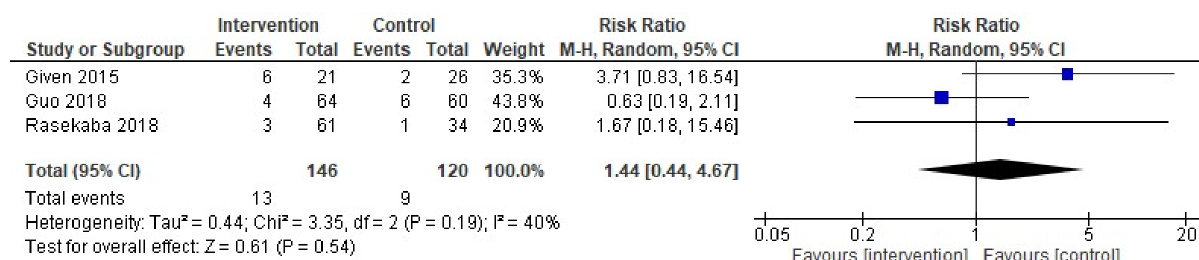
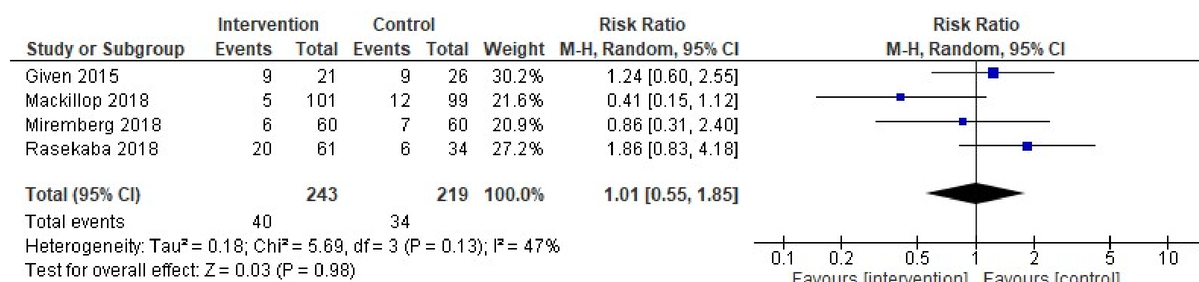


Figure 3.13: Forest plot of macrosomia cases

NICU admissions (Figure 3.14) in the control and intervention groups were assessed by four studies (Given et al., 2015, Mackillop et al., 2018, Miremberg et al., 2018, Rasekaba et al.,

2018). The results showed that there were practically no differences in the likelihood of new-borns being admitted to the NICU between the intervention and control groups (shown by a risk ratio of 1.01). The results were of an acceptable heterogeneity (I^2 = 47%) but were not statistically significant (P = 0.98).

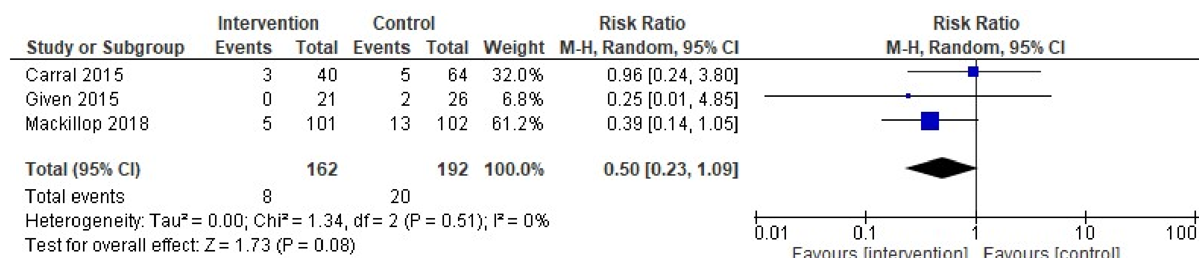


Study or Subgroup	Intervention Events	Intervention Total	Control Events	Control Total	Weight	Risk Ratio M-H, Random, 95% CI
Given 2015	9	21	9	26	30.2%	1.24 [0.60, 2.55]
Mackillop 2018	5	101	12	99	21.6%	0.41 [0.15, 1.12]
Miremberg 2018	6	60	7	60	20.9%	0.86 [0.31, 2.40]
Rasekaba 2018	20	61	6	34	27.2%	1.86 [0.83, 4.18]
Total (95% CI)		**243**		**219**	**100.0%**	**1.01 [0.55, 1.85]**
Total events	40		34			

Heterogeneity: Tau² = 0.18; Chi² = 5.69, df = 3 (P = 0.13); I² = 47%
Test for overall effect: Z = 0.03 (P = 0.98)

Figure 3.14: Forest plot of NICU admissions

The meta-analysis of the premature births (Figure 3.15) showed that it was less likely for new-borns from the intervention group to be born prematurely than new-borns from the control group (shown by a risk ratio of 0.50), as shown by three studies (Carral et al., 2015, Given et al., 2015, Mackillop et al., 2018). The results were homogeneous (I^2 = 0%) but were not statistically significant (P = 0.08).



Study or Subgroup	Intervention Events	Intervention Total	Control Events	Control Total	Weight	Risk Ratio M-H, Random, 95% CI
Carral 2015	3	40	5	64	32.0%	0.96 [0.24, 3.80]
Given 2015	0	21	2	26	6.8%	0.25 [0.01, 4.85]
Mackillop 2018	5	101	13	102	61.2%	0.39 [0.14, 1.05]
Total (95% CI)		**162**		**192**	**100.0%**	**0.50 [0.23, 1.09]**
Total events	8		20			

Heterogeneity: Tau² = 0.00; Chi² = 1.34, df = 2 (P = 0.51); I² = 0%
Test for overall effect: Z = 1.73 (P = 0.08)

Figure 3.15: Forest plot of premature births

Both Carral et al. (2015) and Mackillop et al. (2018) found that women in the intervention group were more likely to produce large for gestational weight new-borns than women in the control group; however, these findings were not statistically significant.

3.3.7. Cognitive Outcomes

There were three studies which assessed patient compliance (actual blood glucose measurements divided by instructed measurements) as an outcome (Bartholomew et al., 2015, Guo et al., 2018, Miremberg et al., 2018). The meta-analysis revealed that women in the intervention group were 10.9% (95% CI -0.27% to 22.06%) more compliant than women in the control group. The results were substantially heterogeneous (I^2 = 99%) and were not

statistically significant (P = 0.06). Mackillop et al. (2018) and Bromuri et al. (2016) supported these findings; however, their measures of compliance were different to the three studies included in the meta-analysis.

Figure 3.16 shows a forest plot of the patient compliance percentages.

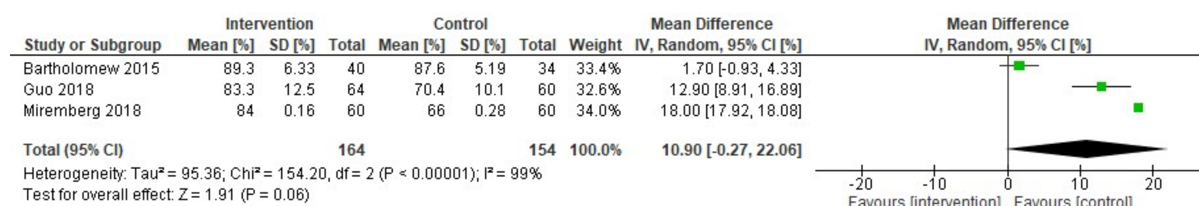


Figure 3.16: Forest plot of patient compliance

3.3.8. Economic Outcomes

Mackillop et al. (2018) assessed the healthcare costs for women with GD. It was found that women in the intervention group paid a mean cost difference of –£1044 (95% CI –£2186 to £99) less than women in the control group. However, the results were not statistically significant. Rasekaba et al. (2018) found that the intervention had no impact on service provider costs.

The frequency of outpatient services was reduced by the intervention, as assessed by three studies (Guo et al., 2018, Mackillop et al., 2018, Rasekaba et al., 2018), with a mean difference of -1.35 (95% CI -3.36 to 0.65). The results were substantially heterogeneous (I^2 = 96%) and were not statistically significant (P = 0.19). Carral et al. (2015) supported these findings but reported the results in a different manner to the studies included in the meta-analysis.

Figure 3.17 shows a forest plot of the frequency of outpatient services.

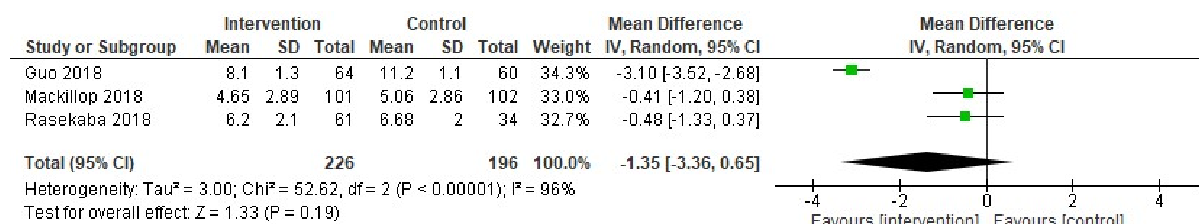


Figure 3.17: Forest plot of the frequency of outpatient services

3.3.9. Behavioural Outcomes

Garnweidner-Holme et al. (2018) investigated how health care professionals perceived the provision of mHealth to women with GD and found that they saw it as an appropriate tool for

the management of GD. Hirst et al. (2015) assessed the user satisfaction of a GD mHealth platform using a structured questionnaire assessing (1) general satisfaction, (2) equipment issues, and (3) relationship with the diabetes care team and found that GD mHealth was acceptable and convenient for a large proportion of women.

The benefits reported by the various studies included:

- the convenience of recording blood glucose levels digitally as opposed to using paper logbooks (Garnweidner-Holme et al., 2018, Pais et al., 2017, Skar et al., 2018) and the convenience of viewing the results graphically (Skar et al., 2018),
- the smaller chance of error in digital data entry (Mackillop et al., 2018),
- the alerts and reminders provided by the mHealth platform (Anderson, 2017),
- the two-way communication with healthcare professionals who can provide feedback (Anderson, 2017),
- the ease of access to GD related information for patients (Garnweidner-Holme et al., 2018, Skar et al., 2018),
- the transport and outpatient service time saved for patients (Hirst et al., 2015),
- the real-time analysis of blood glucose data by healthcare professionals (Mackillop et al., 2018),
- the ease of access to patient data for healthcare professionals (Pais et al., 2017), and
- time and cost effectiveness of remote monitoring for healthcare professionals (Pais et al., 2017).

The challenges reported by the various studies included:

- the technical difficulties, especially relating to the automatic transfer of blood glucose levels, which created a barrier for use for patients (Garnweidner-Holme et al., 2018, Skar et al., 2018),
- the lack of interoperability between mHealth apps and glucose meter devices (Skar et al., 2018),
- ensuring that mHealth provided GD information matched with healthcare provided information (Garnweidner-Holme et al., 2018, Skar et al., 2018),
- the general nature of the GD information (Skar et al., 2018),

- providing culturally inclusive nutritional advice to patients (Garnweidner-Holme et al., 2018),
- the possible loss of privacy of patient data (Given et al., 2015), and
- convincing healthcare professionals to adopt the new technology (Skar et al., 2018).

3.3.10. Features and Functions of a GD mHealth Platform

The reviewed literature found the following GD mHealth platform features and functions to be prominent. The GD mHealth platform should:

- record initial assessment data (Bromuri et al., 2016, Jo & Park, 2016),
- automatically upload blood glucose data (Garnweidner-Holme et al., 2018, Guo et al., 2018),
- record the patient's food intake (Garnweidner-Holme et al., 2015, Guo et al., 2018, Jo & Park, 2016, Miremberg et al., 2018, Rasekaba et al., 2018), physical activity duration (Garnweidner-Holme et al., 2015, Guo et al., 2018, Jo & Park, 2016, Miremberg et al., 2018), body weight (Bromuri et al., 2016, Given et al., 2015, Jo & Park, 2016, Miremberg et al., 2018), blood pressure (Bromuri et al., 2016, Given et al., 2015, Miremberg et al., 2018) and symptoms (Bromuri et al., 2016, Rasekaba et al., 2018) in addition to blood glucose,
- allow the patient to label blood glucose readings with pre-prandial or postprandial tags (Bromuri et al., 2016, Carral et al., 2015, Guo et al., 2018, Mackillop et al., 2014) and allow comments to be added if necessary (Mackillop et al., 2014)
- record the medication that is taken (Bromuri et al., 2016, Carral et al., 2015, Jo & Park, 2016, Mackillop et al., 2014, Miremberg et al., 2018, Rasekaba et al., 2018)
- display all recorded data both graphically (Bromuri et al., 2016, Jo & Park, 2016, Mackillop et al., 2014, Miremberg et al., 2018) and numerically (Bromuri et al., 2016, Mackillop et al., 2014), with colour-coded thresholds (Mackillop et al., 2014), for a selectable period,
- provide reminders and alerts to patients (Guo et al., 2018, Jo & Park, 2016),
- allow healthcare professionals to provide feedback and educational information (Bartholomew et al., 2015, Garnweidner-Holme et al., 2015, Guo et al., 2018, Jo & Park, 2016, Mackillop et al., 2018),

- allow two-way communication between patients and healthcare professionals to occur (Carral et al., 2015, Guo et al., 2018, Mackillop et al., 2014), and
- transmit data to healthcare professionals for remote monitoring (Bartholomew et al., 2015, Bromuri et al., 2016, Carral et al., 2015, Given et al., 2015, Guo et al., 2018, Mackillop et al., 2014).

The healthcare professional's web app should allow healthcare professionals to:

- view all linked patients with a summary (Bromuri et al., 2016, Mackillop et al., 2014),
- display and modify personal information and clinical information (Bromuri et al., 2016, Mackillop et al., 2014),
- display remotely recorded data graphically and in tabular form for a selectable period (Mackillop et al., 2014),
- add a note next to noteworthy data (Bromuri et al., 2016, Mackillop et al., 2014),
- be alerted to patients who are not meeting clinical goals (Bromuri et al., 2016, Mackillop et al., 2014, Mackillop et al., 2018),
- view and schedule consultations (Bromuri et al., 2016),
- read and write messages to and from patients (Carral et al., 2015, Mackillop et al., 2014), and
- determine when the patient will require more strips with a strip counter (Mackillop et al., 2014).

Initial assessment data should record:

- pre-pregnancy bodyweight (Bromuri et al., 2016, Jo & Park, 2016),
- height (Jo & Park, 2016),
- due date (Bromuri et al., 2016, Jo & Park, 2016),
- history of diabetes (Bromuri et al., 2016, Jo & Park, 2016),
- residential address (Bromuri et al., 2016), and
- contact details (Bromuri et al., 2016).

3.4. Discussion

The eight studies included in the meta-analysis were small in population size (Ming et al., 2016), assessed different forms of mHealth technologies and were deemed to contain a moderate source of potential bias, so it was not possible to draw concrete conclusions from

all of the results. It was shown that mHealth offered several advantages in terms of biological, maternal, perinatal, cognitive and economic outcomes. Many of the outcomes which favoured mHealth were based on substantially heterogeneous results ($I^2 > 50\%$) and non-statistically significant margins ($P > 0.05$). It was reassuring that the evidence clearly showed that mHealth was not associated with harmful effects.

The main strength of this study was the robust and rigorous search strategy used to identify relevant articles. The included articles were scanned for additional articles which the search might have missed, but none were found, testifying to the thoroughness of the search strategy. Several limitations were identified. First, the exclusion criteria limited the search to English articles over a five-year period from 2014 to 2018 (this period was chosen to exclude articles based on technology older than five years). The included articles were all based in developed countries which meant that the results might not apply to developing countries like South Africa. Second, the small overall population size was a limitation because the meta-analysis was likely to be underpowered and lacking the ability to detect less common perinatal outcomes like shoulder dystocia and stillbirth. Third, the variation in the mHealth technologies being tested, the screening protocols that were implemented and the local medical practices might have contributed to the substantial heterogeneity ($I^2 > 50\%$) in many of the outcomes. Fourth, there were seven articles omitted because the full text was not accessible. None of the omitted articles were RCTs or CCTs, so they were not expected to affect the results. Lastly, only one reviewer was involved in the review process so there was a strong likelihood of bias in the article selections.

The biological outcomes showed that the mHealth intervention caused a statistically significant ($P < 0.00001$) decrease in overall blood glucose levels (pre-prandial and postprandial combined). This was different from previous systematic reviews assessing studies conducted prior to 2014, which found non-statistically significant evidence ($P = 0.91$) that the mHealth intervention reduced blood glucose levels in women with GD (Ming et al., 2016, Rasekaba et al., 2015). The improved blood glucose levels might be as a result of newer mHealth technologies, which had become more effective due to the continuous research on this subject, or it might be a skewed result due to the limitations of the study. The reduction in blood glucose levels were likely due to women, who were using the intervention, receiving direct feedback from healthcare professionals, the ease of access to GD information through

the intervention, the monitoring of diet, weight gain and medication adherence, and the automated alerts and reminders that went with the mHealth interventions.

The results showed that mHealth interventions helped women to reduce their HbA_{1c} levels, which was consistent with previous systematic reviews (Lau et al., 2016, Ming et al., 2016, Rasekaba et al., 2015). However, the reduction in HbA_{1c} levels found was not statistically significant (P = 0.48) and was based on substantially heterogenous data (I^2 = 98%). The reduction in HbA_{1c} levels was likely due to tighter control of blood glucose levels due to the use of mHealth.

The maternal outcomes showed that the intervention successfully increased the probability of a normal vaginal delivery by a statistically significant amount (P = 0.02), based on homogeneous data (I^2 = 0%). The intervention was found to cause non-statistically significant reductions in the probability of caesarean sections (P = 0.17), emergency caesarean sections (P = 0.23) and gestational hypertension (P = 0.42). All the outcomes were based on data of an acceptable heterogeneity, except the emergency caesarean section outcome (I^2 = 66%). The meta-analysis found no difference in gestational ages at delivery. These findings were not in keeping with the previous systematic reviews which assessed maternal outcomes. Previous systematic reviews found mHealth to cause a non-statistically significant increase in caesarean sections (P = 0.41) (Lau et al., 2016, Ming et al., 2016) and gestational hypertension cases (P = 0.31) (Ming et al., 2016). However, Rasekaba et al. (2015) agreed with the findings of the current study, also finding a non-statistically significant decrease in caesarean sections (P = 0.37) due to mHealth. None of the previous systematic reviews that were investigated reported on the normal vaginal delivery rates as is done in the current study. A larger sample size might yield statistically significant results.

The meta-analysis of the perinatal outcomes found that there were no statistically significant results for the analysis on birthweights, macrosomia rates, NICU admissions or premature births, as found by previous systematic reviews (Lau et al., 2016, Ming et al., 2016). There was, however, a statistically significant reduction in the probability of neonatal hypoglycaemia (P = 0.02), based on homogeneous data (I^2 = 0%), which was not found in previous systematic reviews. Although not statistically significant, the meta-analysis also found a notable (P = 0.08) reduction in the probability of a premature birth due to the use of mHealth. A larger sample size might yield statistically significant results.

The cognitive outcomes were found not to be statistically significant; however, patient compliance was notably improved by the intervention (P = 0.06). The data was substantially heterogeneous (I^2 = 99%) due to the possible differences in methods used to measure patient compliance. Patient compliance was not measured by previous systematic reviews; however, these systematic reviews found that mHealth motivated patients in the self-management of their disease (Lau et al., 2016, Ming et al., 2016, Rasekaba et al., 2015), which was a possible cause for the improved compliance.

Economic outcomes were assessed by previous systematic reviews which found that mHealth reduced the need for face-to-face consultations and unplanned face-to-face consultations while achieving similar maternal and perinatal outcomes (Ming et al., 2016, Rasekaba et al., 2015). Rasekaba et al. (2015) found two studies which reported a net cost saving for GD patients using mHealth. The reduction of the frequency of outpatient services was a probable cause for the healthcare costs for patients to be reduced. The findings from Ming et al. (2016) and Rasekaba et al. (2015) were supported by the current study which reported a notable, but not statistically significant (p = 0.19) reduction in outpatient services due to mHealth (although this result was based on substantially heterogeneous data (I^2 = 96%)). The current study analysed two RCTs which reported on healthcare costs and found that one reported notable, but not statistically significant (no P value was reported) cost savings (Mackillop et al., 2018) and the other reported no difference in cost savings (Rasekaba et al., 2018) due to mHealth.

It was found that the five qualitative studies (Garnweidner-Holme et al., 2018, Hirst et al., 2015, Nicholson et al., 2016, Pais et al., 2017, Skar et al., 2018) that were assessed all reported that mHealth was associated with high levels of patient satisfaction which was in keeping with previous studies (Ming et al., 2016). The major benefits of using mHealth to manage GD included the convenience of digital record keeping and the time and cost effectiveness associated with being remotely monitored by healthcare professionals. Some of the challenges reported included technical difficulties associated with the use of technology and various data privacy concerns.

The features and functions of the various mHealth solutions for GD were assessed and are presented in the results section. It must be noted that none of the mHealth solutions assessed functioned as a pregnancy management tool at the same time as a GD management tool. An

opportunity was identified which was to develop an mHealth platform for GD which incorporated the crucial features required for GD management (according to research), but which also functioned as a pregnancy management tool.

In conclusion, mHealth has the potential to improve biological, maternal, perinatal, cognitive and economic outcomes, but further research is required to conclusively assess its effect on these outcomes. There is no evidence on the postpartum and long-term effects of mHealth on women who had GD, which needs to be investigated. Although many of the outcomes require further research in order to obtain statistically significant results, there are at least no negative effects caused by mHealth. Its major advantage may lie in its ability to support remote monitoring and reduce outpatient services, thereby reducing healthcare costs for patients. Its ability to motivate and educate patients may be what causes tighter glycaemic control, and this may lead to positive maternal and perinatal outcomes.

The outcomes of this chapter inform the design process which is discussed in Chapter 4. The design uses the best features of all the existing mHealth solutions for GD and combines them with pregnancy-related features for a comprehensive GD mHealth platform

4. Design, Development and Testing of a Gestational Diabetes mHealth Platform

This chapter focuses on the final objective, which uses the findings from the previous objectives (to assess the current gestational diabetes (GD) management practices and the existing mHealth solutions for GD) to direct the design, development and testing of the GD mHealth platform.

4.1. Design Requirements

The platform consists of three integrated systems: the mobile app for patients, the web app for healthcare professionals and the backend for administrators. Each system has its own set of design requirements.

4.1.1. Mobile Application

The mobile app was required to:

- record personal and clinical data, including the user's full name, identity number, contact details (cell phone number and email address), residential address, healthcare professional's name and unique identifier, height, pre-pregnancy bodyweight, diabetes type and due date,
- wirelessly interface with Bluetooth-enabled glucose meters to automatically receive blood glucose data,
- track the patient's blood glucose levels (with pre-prandial and postprandial labels), carbohydrate intake, activity duration, bodyweight, medication and symptoms,
- include pregnancy specific tools and trackers, for example a blood pressure tracker and a due date calculator,
- display data both graphically and numerically with colour-coded thresholds,
- remind the patient to test blood glucose levels, take medication and attend scheduled appointments,
- educate the patient on self-care and other diabetes related information,
- allow two-way communication between patients and healthcare professionals, and
- transmit data to a backend for remote access by healthcare professionals.

4.1.2. Web Application

The web app was required to:

- view and modify the patient's personal and clinical information,
- display remotely recorded data graphically and numerically for a selectable period,
- allow notes to be recorded,
- alert healthcare professionals of patients who are not meeting clinical goals,
- read and write messages to and from patients,
- view and schedule consultations, and
- only allow authorised access to private data.

4.1.3. Backend

The backend was required to:

- be scalable,
- store all data securely and privately,
- allow administrators to manage all users,
- allow administrators to make live updates to the mobile app and web app, and
- allow the administrator to send out push notifications.

4.2. Frontend Design

The description of the design is divided into two sections: the first section discusses the design of the mobile app and the second section discusses the design of the web app. The various design requirements are discussed using "art boards" of the design for illustrative purposes.

4.2.1. Mobile Application Design

The mobile app was designed primarily as a GD self-management tool for patients to reduce the frequency of outpatient services required and improve glycaemic control, among other things. It served a secondary purpose as a pregnancy tracker. Pregnancy related features were added to the prototype of the mobile app during the development phase.

Figure 4.1 shows the chosen colour palette, generated using Material Palette (Material Palette, 2019). The shades of purple were chosen based on the femininity associated with it. Green was chosen as an accent colour because of the positivity associated with it. The colour palette was manually implemented during the design phase. Because Android Studio could associate a theme with user defined colours, which it automatically applied, the colour palette was only fully implemented during the development phase.

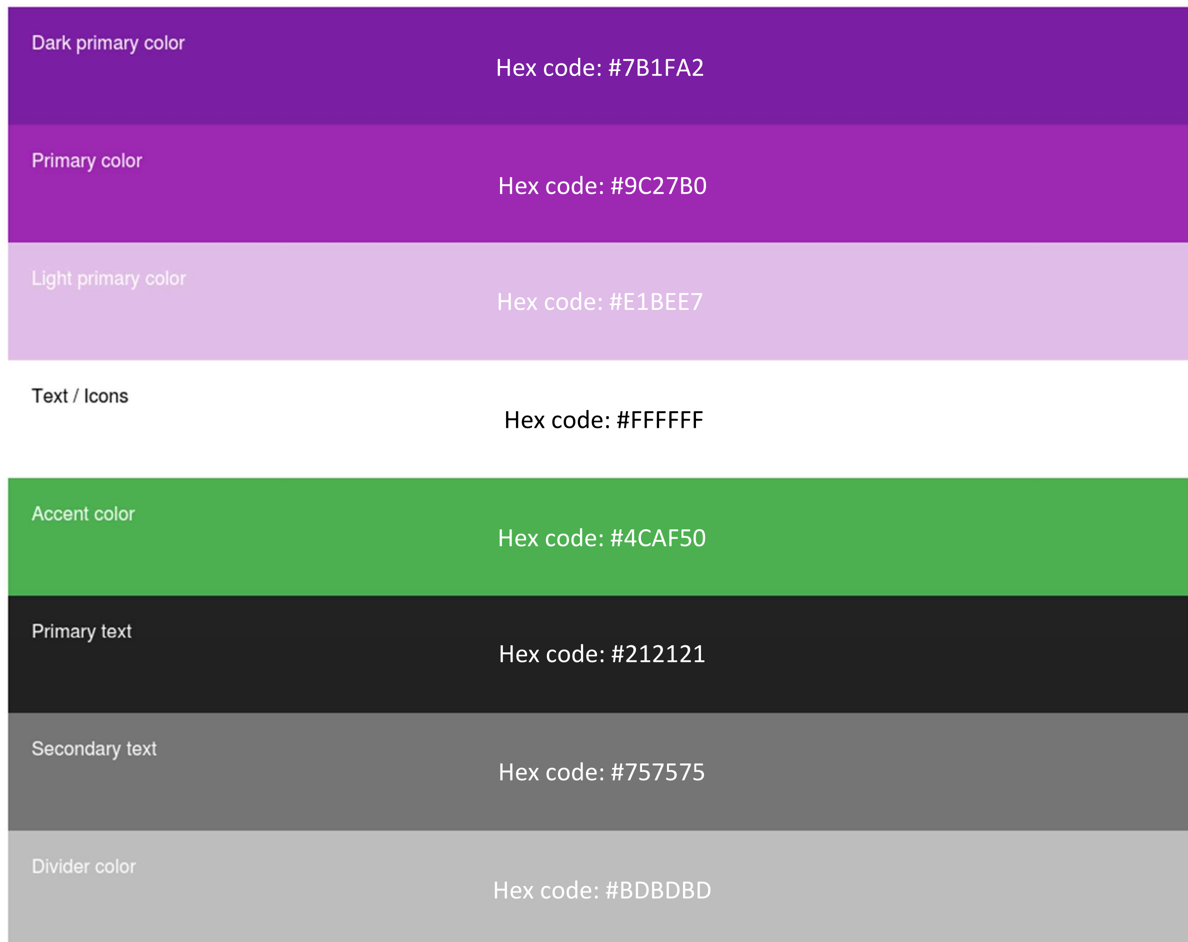


Figure 4.1: Colour palette

Figure 4.2 shows the design of the mobile landing board. The platform was named "GooDMoM", derived from the acronym GDMM (Gestational Diabetes Mobile Management), because of its purpose as a GD management tool. The name was chosen to represent soon-to-be mothers, who were motivated to manage their disease to prevent adverse outcomes for themselves and their children, thus being "good moms".

Figure 4.2: Mobile landing board

4.2.1.1. Mobile Sign-up Design

The sign-up process was designed to record the account details, personal details and clinical details, as specified in the design requirements. The design allowed accounts to be created using the patient's full name and was intended to link to the patient's email address. This decision was made because email-based accounts were safer than cell phone number-based accounts since a stolen cell phone could be used to hijack a patient's cell phone number-based account. An email-based account should allow the account owner to change account details via email by using a separate device (if the primary device was stolen), thus providing better security. Figure 4.3 shows the design of the first mobile sign-up board, which records the patient's account details.

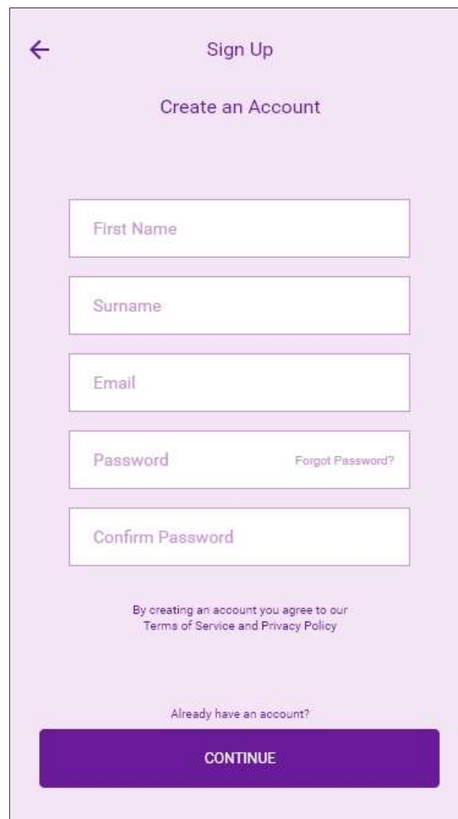


Figure 4.3: Mobile sign-up board 1

The second stage of the sign-up process was designed to record the personal details of the patient, including the patient's full name and identity number, which would be used to validate the patient and ensure that each patient was associated with only one account. If the patient had data stored on another database, the data could be merged with the GooDMoM database based on the patient's identity number. The personal details board was also designed to record the patient's cell phone number so that the patient could be contacted via a phone call and the patient's home address details so that medical assistance could be sent to the patient if necessary. Figure 4.4 shows the design of the second mobile sign-up board, which records the patient's personal details.

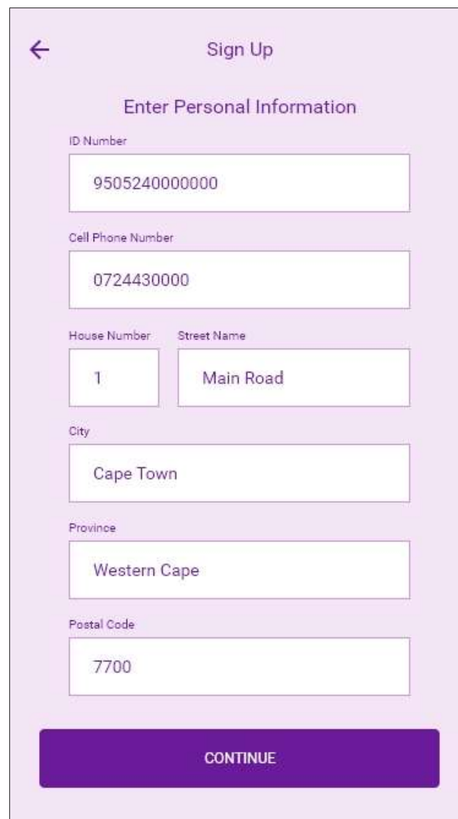


Figure 4.4: Mobile sign-up board 2

The third stage of the sign-up process was designed to record the clinical details, which included the healthcare professional's name and user identification code. The healthcare professional's user identification code would provide the programmatic link between the patient and her healthcare professional, while the surname should allow administrators to identify the patient's healthcare professional if the patient mistyped the user identification code. The clinical details board was also designed to record the patient's height and pre-pregnancy bodyweight which would be required to calculate the patient's body mass index (BMI). The diabetes type would give the linked healthcare professional an indication of how to treat the patient and an indication of the extent of the patient's pre-existing knowledge about the management of diabetes. The due date would be recorded so that patient's healthcare professional could evaluate the patient's biological measures based on her stage of gestation and the patient could use it as a motivating goal to aim for. The prototype of the mobile app would include a due date calculator to allow women to accurately estimate their due date. Figure 4.5 shows the design of the third mobile sign-up board, which records the patient's clinical details.

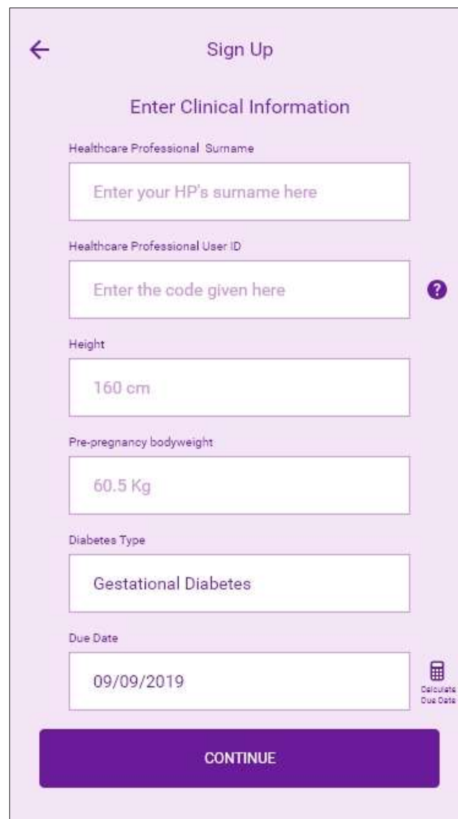


Figure 4.5: Mobile sign-up board 3

4.2.1.2. Mobile Dashboard Design

Figure 4.6 shows the design of the mobile "feed" board. The "feed" (renamed to "dashboard" during development) was designed to display all recorded data. As specified in the design requirements, the data was depicted graphically (in the form of a line graph) and numerically (in the form of averages for the selected period). A line graph was chosen because it allowed trends to be visualised. Displaying the numerical values as averages, as opposed to listing the value of each entry, simplified the amount of data on the screen, which would be particularly useful on smartphone screens which were relatively small compared to computer screens. The data of each individual entry would be viewable through a pop-up screen by clicking on a data point on the line graph; however, this would only be implemented during the development of the prototype. The line graph was designed to display the healthcare professional-specified target range so that the patient could clearly see when she was not meeting her targets. In the development phase, out of target values would be displayed in a different colour to draw attention to them.

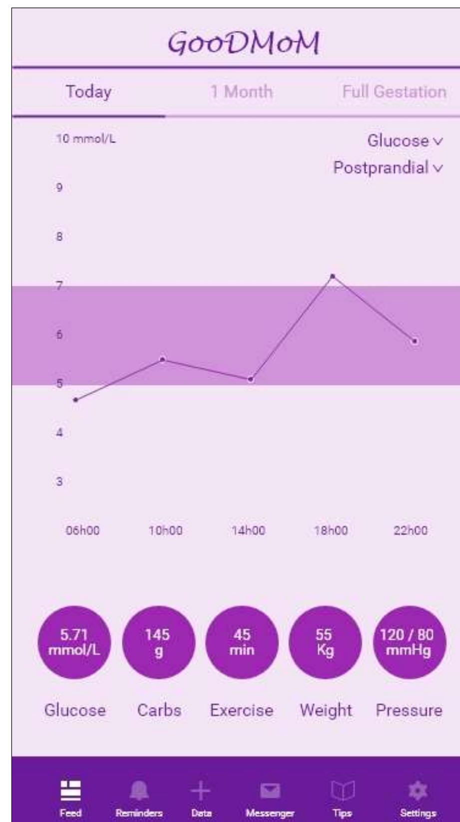


Figure 4.6: Mobile feed board

Figure 4.7 shows the design of the data entry board. As specified in the design requirements, the mobile app should record blood glucose levels, carbohydrates, activity duration, bodyweight, blood pressure, medication and symptoms. It was decided that there should be one data entry screen for all measurements, as opposed to having separate screens for each measurement type. The decision was made in order to maintain the simplicity in navigating the mobile app.

Blood glucose levels were intended to be recorded digitally by the mobile app, which patients found easier than recording on paper, as revealed in the Chapter 3 review of existing mHealth solutions for GD. In the prototype of the mobile app, the blood glucose levels would be transferred from the glucose meter to the mobile app via Bluetooth by tapping the synchronise icon. Blood glucose levels could be entered manually if there was a problem with the Bluetooth transfer, but would be programmatically marked as manual so that the patient's healthcare professional would know that the data might not be trustworthy. The point of automatically entering the results was to avoid accidental or purposeful errors in recording, as mentioned in Chapter 3. All blood glucose recordings would be associate with a time, a date, whether they were pre-prandial or postprandial, and a location. Users would be

asked to specify when their reading was taken in relation to a meal, for example "after lunch" or "before supper". In the prototype, the readings would be programmatically categorised as pre-prandial or postprandial based on when they were taken. Reviewing blood glucose data in terms of pre-prandial and postprandial readings could allow healthcare professionals and patients to identify the effects of meals on blood glucose data. Separating pre-prandial and postprandial blood glucose readings would also prevent unnecessary alarm when comparing the different types of readings (for example, postprandial blood glucose readings should be expected to be notably higher than pre-prandial blood glucose readings, but an ignorant patient might be alarmed when seeing the difference). The location was designed to be recorded via a drop-down menu which would give certain options, including "home" and "work" as examples. This should be recorded so that certain trends that might be associated with the patient's location at the time of recording could be identified.

The data entry board was designed to record the details of the patient's diet in the form of an estimate of the amount of carbohydrates consumed as well as a description of the meal. By clicking on the drop-down arrow, the patient would also be able to choose the food type and the number of portions consumed, as opposed to manually entering the meal, for ease of use. Carbohydrates should be tracked specifically because they could have a large effect on blood glucose levels, as mentioned in the Chapter 2 review of existing GD management practices. The app was designed to facilitate the manual tracking of the patient's activity duration and allowed the patient to provide a description of the activity. As described in Chapter 2, activity data should be tracked because of its importance in reducing blood sugar levels and enabling the body to use insulin. Bodyweight should be tracked because maintaining a healthcare professional-recommended bodyweight was important to the management of GD and pregnancy. Blood pressure should be monitored for healthcare professionals to detect the onset of gestational hypertension and provide the necessary treatment. Pills, renamed as medication during the development phase, should be tracked so that the healthcare professional could monitor the patient's compliance in taking prescribed medication. Lastly various symptoms experienced by the patient would be tracked via a drop-down menu, which could be used by healthcare professionals in making diagnoses and prescribing medication.

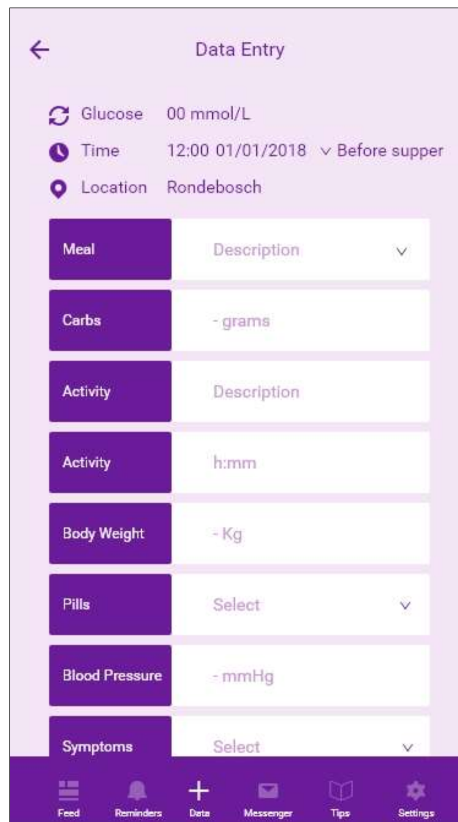


Figure 4.7: Mobile data entry board

4.2.1.3. Mobile Reminders Design

The reminders were designed to remind the patient to test blood glucose levels, take medication and attend appointments. Alerts and reminders were one of the benefits of using an mHealth platform to manage GD, as seen in Chapter 3. Chapter 3 also showed that mHealth increased the level of patient compliance regarding measuring blood glucose levels. This was largely due to the reminders and alerts used in the various mHealth platforms, hence the reason why the feature was included in this design.

Figure 4.8 shows how the reminders board displays the events. The board was designed to list the events in chronological order and display just the event title, time and date for simplicity purposes. The additional information could be viewed or edited by tapping on the relevant event in the prototype.

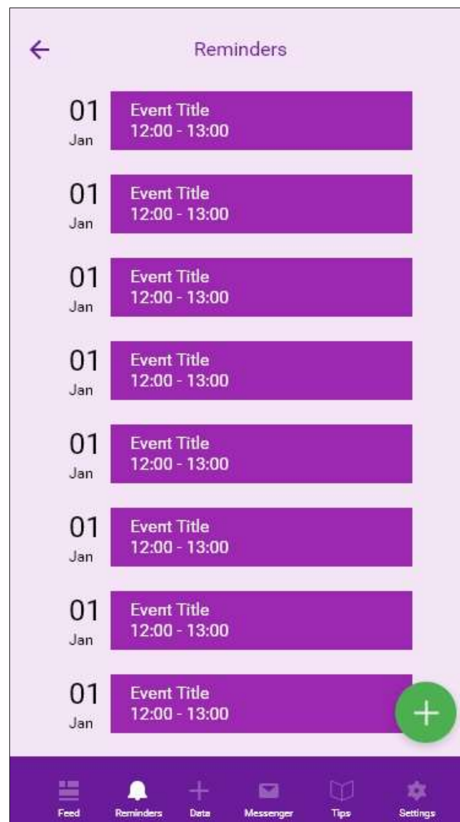


Figure 4.8: Mobile reminders board

Figure 4.9 shows the design for the reminder entry board. It was found that patients needed to be reminded to measure their blood glucose levels, take their medication and attend scheduled appointments, as specified in the design requirements. Patients would be required to title their reminder for identification purposes and choose the reminder type. The patient should select the time of the event and choose a repeat. The repeats were especially useful for medication and glucose measurement reminders which would need to repeat daily, but also apply to appointment reminders which might need to repeat every 1 to 4 weeks. The patient could also enter a location if the reminder was for an appointment and additional notes could also be added.

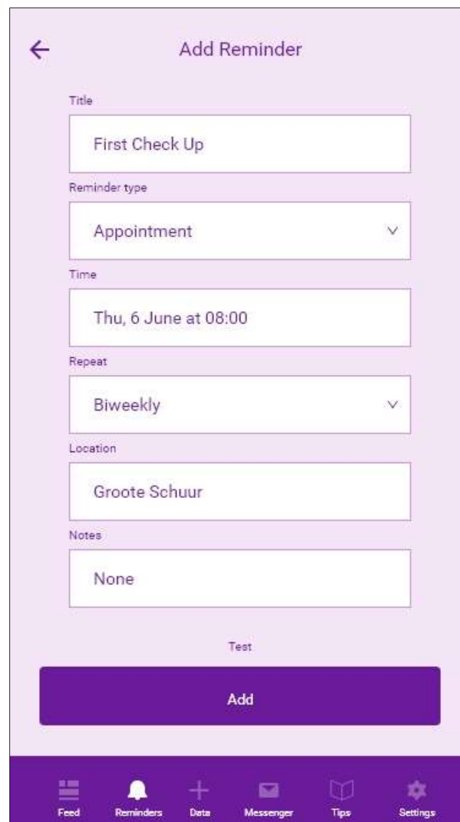


Figure 4.9: Mobile reminder entry board

4.2.1.4. Mobile Messenger Design

Having a two-way communication channel was found in the literature review of chapter 3 to be a major benefit of using mHealth in the management of GD, because it allowed patients to receive feedback from healthcare professionals regarding their progress and further allowed patients to ask healthcare professionals questions. Figure 4.10 shows the design of the mobile messenger board.

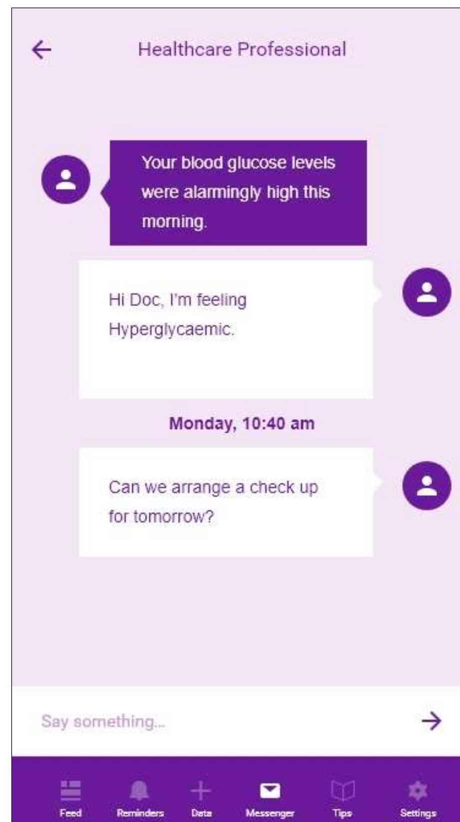


Figure 4.10: Mobile messenger board

4.2.1.5. Mobile Tips Design

The fact that mHealth platforms allowed easy access to GD related information was cited as a major benefit in chapter 3. It allowed the patient to review the information wherever and whenever she wanted and prevented the patient from misinterpreting or forgetting information issued by healthcare professionals at an appointment. However, there were concerns that the information supplied by mHealth platforms did not always match the information supplied by healthcare professionals. The information was often too general and the information was not culturally inclusive. The benefits were deemed to outweigh the challenges, so it was decided that the tips section should be included.

Figure 4.11 shows the design of the mobile tips board, named “Tips and Tricks”, but renamed to “Tips” during development for simplicity purposes. The tips board was designed to display each tip as an image with a title and a timestamp, similar to news apps. The patient would be able to open the article by tapping on the relevant tip. This feature of the mobile app was designed to work with a custom-built GD database of information, which would target South African women with GD related information based on their stage of gestation.

Figure 4.11: Mobile tips board

4.2.1.6. Mobile UX Design

Figure 4.12 depicts the mobile UX design. It shows the artboards as “frames” with “wires”, which indicate the flow between one and another as a result of user interaction.

The design of the UX was focused on simplicity and usability, in line with current practices for mHealth apps (Stoyanov et al., 2015). Stoyanov et al. (2015) developed a tool for assessing the quality of mHealth apps and determined that functionality (which directly affects UX) was one of the categories of importance. The functionality was influenced by the performance, ease of use, navigation and gestural design of the app (Stoyanov et al., 2015). As such, these were all key areas in the design process.

Regarding the functionality of the GooDMoM mobile app, a bottom navigation bar was used to navigate through the features of the mobile app. This was chosen, because it clearly displayed the main features of the mobile app, maintaining the simplicity and promoting intuitive use. Bottom navigation bars were ideal for those with smaller hands, because it was suited to one-handed navigation, which was necessary on large screen smartphones. This suited the population to which this mobile app was aimed.

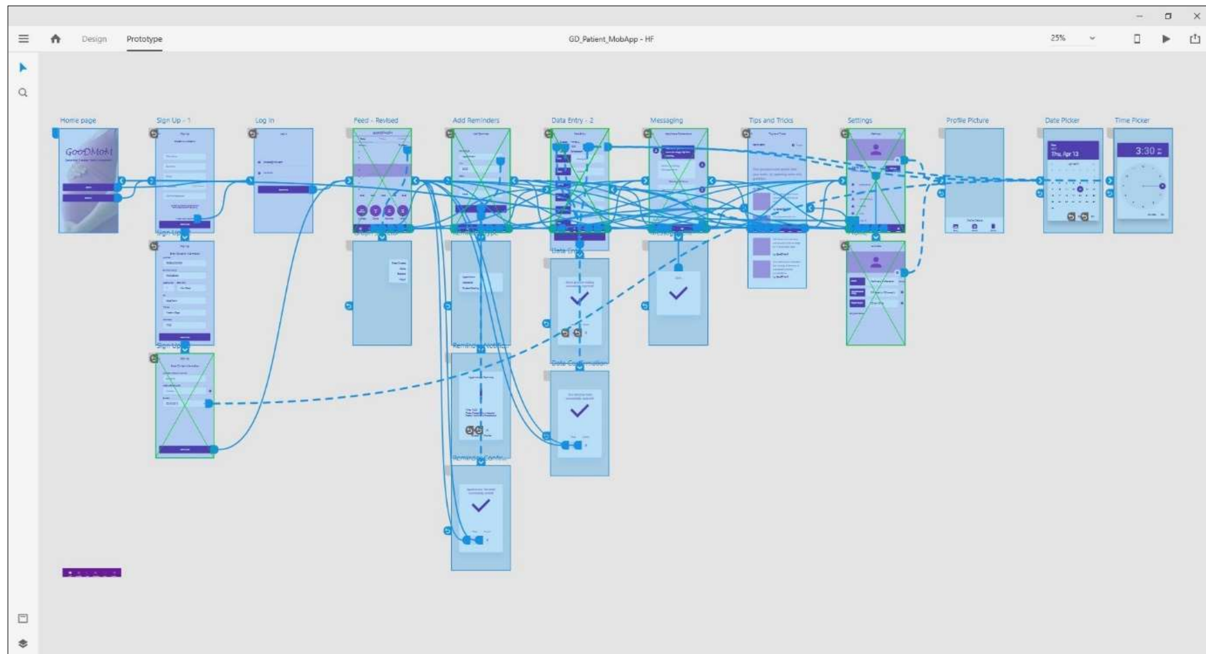


Figure 4.12: Mobile UX

4.2.2. Web Application Design

The web app was designed for healthcare professionals to remotely monitor their patients I real-time, improving the ease of access to patient data, as specified in the design requirements.

Figure 4.13 shows the design for the home board. The colours shown in Figure 4.1 and the name of the platform were maintained for uniformity purposes. To access the home page, healthcare professionals would be required to sign-in (this would only be implemented during development of the prototype). This satisfied the design requirement to only allow authorised personnel to access private data.

The design of the linked patient database board is shown in Figure 4.14. This board is designed to display all of the patients who are linked to the signed in healthcare professional. Each patient's full name and display picture would be displayed. The healthcare professional could click on a patient's name or display picture to access her data.

Figure 4.15 shows the personal details board. It was called "personal details" but was renamed to "patient details" during development to avoid confusion. It was designed to display and modify the personal and clinical information entered by the patient during the sign-up process, including the patient's full name, identity number, email address, cell phone number, residential address, date of birth (derived from the first six numbers of the identity

number), due date, diabetes type pre-pregnancy bodyweight, height and BMI. The reason why these specific personal and clinical details were focused on was discussed in section 4.2.1. The linked healthcare professional should able to set the patient's blood glucose level goals, bodyweight goals and activity duration goals (this would only be implemented during development of the prototype). These goals would be displayed to the patient on her mobile app. It was necessary that the healthcare professional set the goals digitally so that the patient could determine when she was out of range when viewing her results (there would be an automatic colour change for an out of range data point as mentioned in section 4.2.1.). Setting the goals digitally also meant that there could be no misinterpretation due to a misunderstanding or any other similar problem. Lastly, the healthcare professionals would also be able to add comments for their own benefit.

Figure 4.16 shows the design of the digital patient history board. The design of the form was based on the standard form used for patients. Data from existing electronic health records should be able to be copied to the GooDMoM database. If patients filled out a paper form, a healthcare professional or an assistant would copy the information to the digital form. An electronic health record was important, because it would allow patients to transfer between medical facilities and between healthcare professionals without the hassle of transferring or refilling forms. It also meant that there would be a history of changes made to the form. Lastly, electronic health records could not be lost like paper-based forms can.

The design of the web feed board (renamed to dashboard during development) is shown in Figure 4.17. The ability to analyse patient data in real-time was found in Chapter 3 to be a major benefit for healthcare professionals using a GD mHealth platform. The healthcare professional's feed was designed to mimic the patient's mobile app-based feed, allowing healthcare professionals to view blood glucose levels, carbohydrates, activity duration, bodyweight, blood pressure and medication adherence. The data could be viewed by day, by month or by the full gestational period. Blood glucose data could be separated into pre-prandial and post prandial. During development, functionality to display the data in numerical form, add notes where necessary, view symptoms associated with various readings and alert the healthcare professional of patients who were not meeting goals (which was identified as a benefit of GD mHealth platforms in Chapter 3) would be added to satisfy the design requirements.

Figure 4.18 shows the design of the messenger board. This board was designed to allow healthcare professionals to communicate directly with their patients by sending and receiving messages, as specified in the design requirements. The messenger should allow healthcare professionals to provide feedback on the patient's data and answer the patient's GD-based questions, which patients identified as a major benefit of using a GD mHealth platform in Chapter 3.

Figure 4.19 shows the design of a calendar board. The design requirements specified that the healthcare professional should be able to view and schedule consultations with their linked patients. Appointments scheduled by linked patients would be displayed and healthcare professionals should be able to schedule and view appointments. Keeping a digital record of appointments would be beneficial, because the digital platform would be able to remind the various parties of the appointment. It would also prevent miscommunication and it would keep records of all past appointments. During development, functionality would be added to allow healthcare professionals to add appointment notes and to mark whether the patient attended or not.

Figure 4.20 shows the designed web UX. The web UX followed the simplicity which was at the core of the design of the mobile app and web app. The simplicity was necessary because one of the challenges associated with GD mHealth platforms, as found in Chapter 3, was to convince healthcare professionals to use the new technology. A simple UX would go a long way toward achieving this.

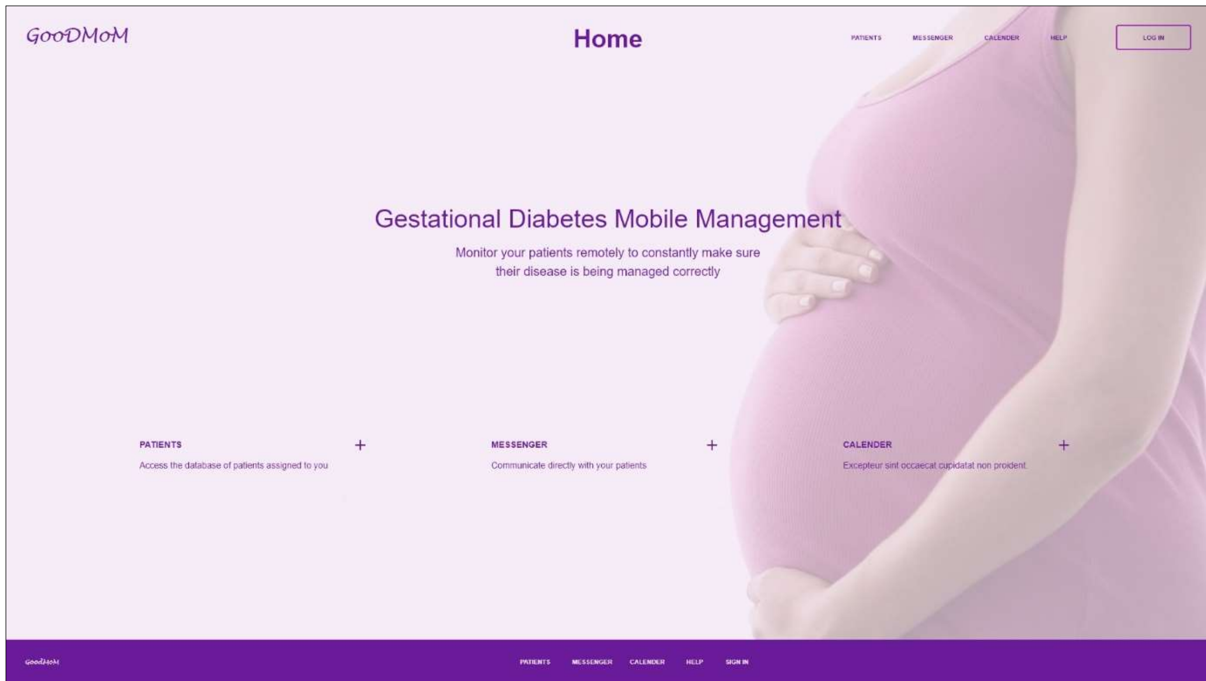


Figure 4.13: Web home board

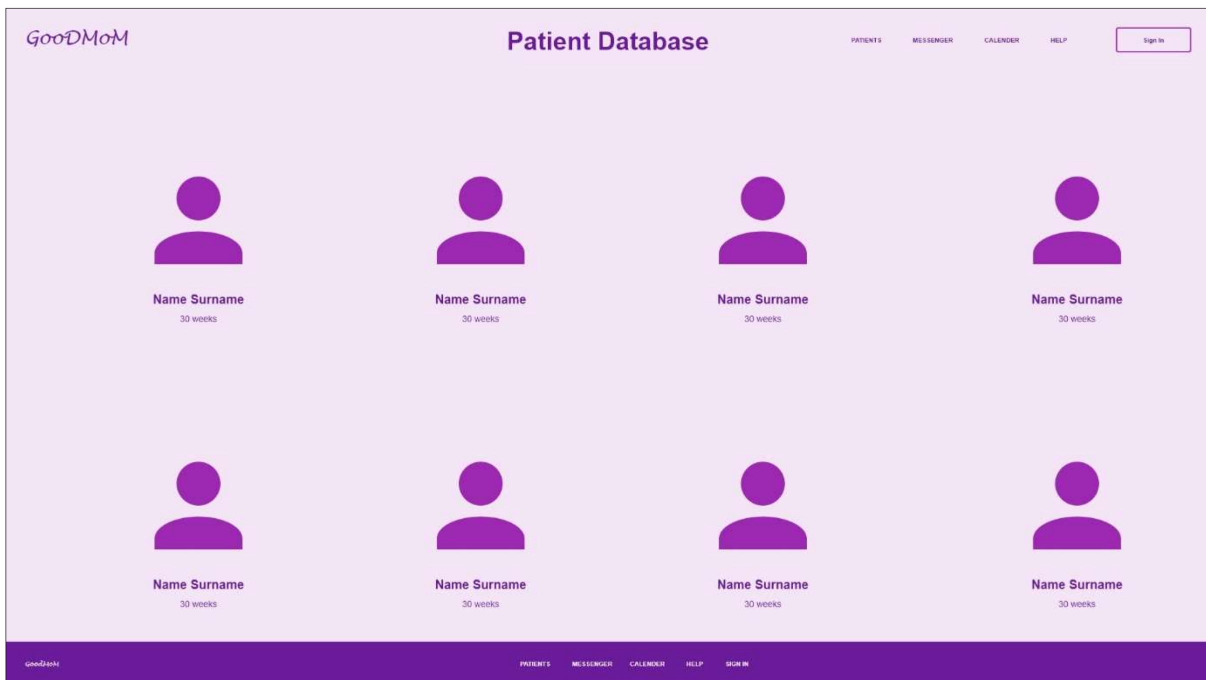


Figure 4.14: Web patient database board

Figure 4.15: Web patient personal details board

Figure 4.16: Web patient history board

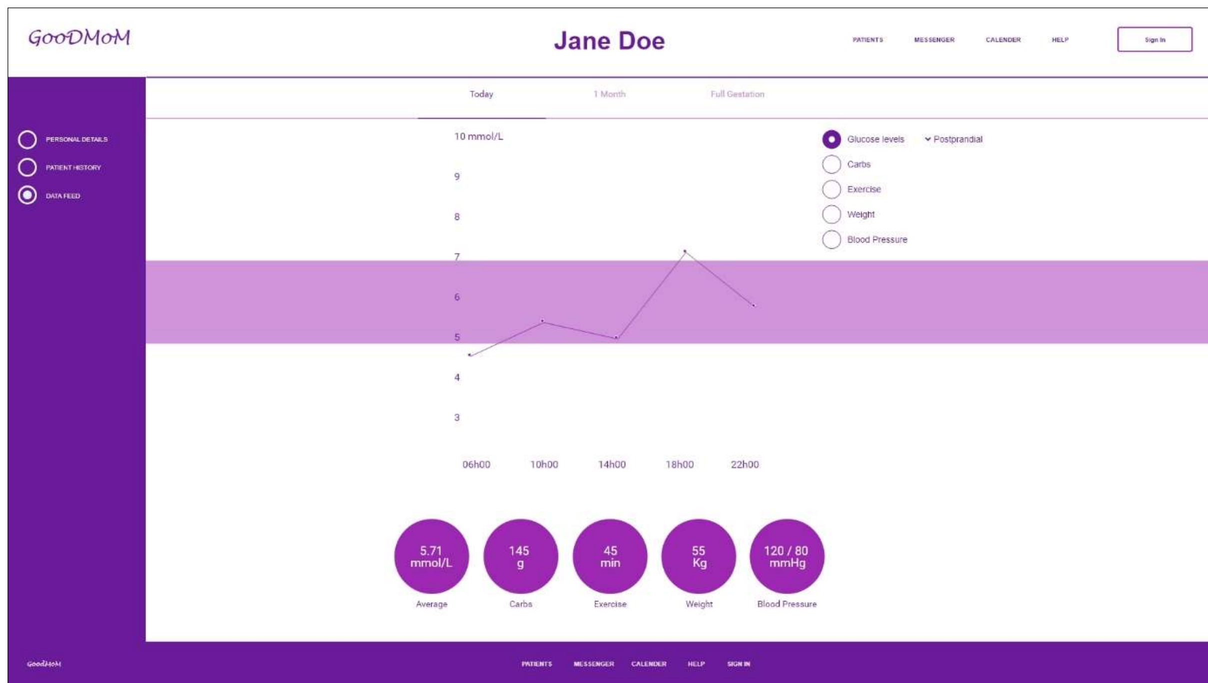


Figure 4.17: Web feed board

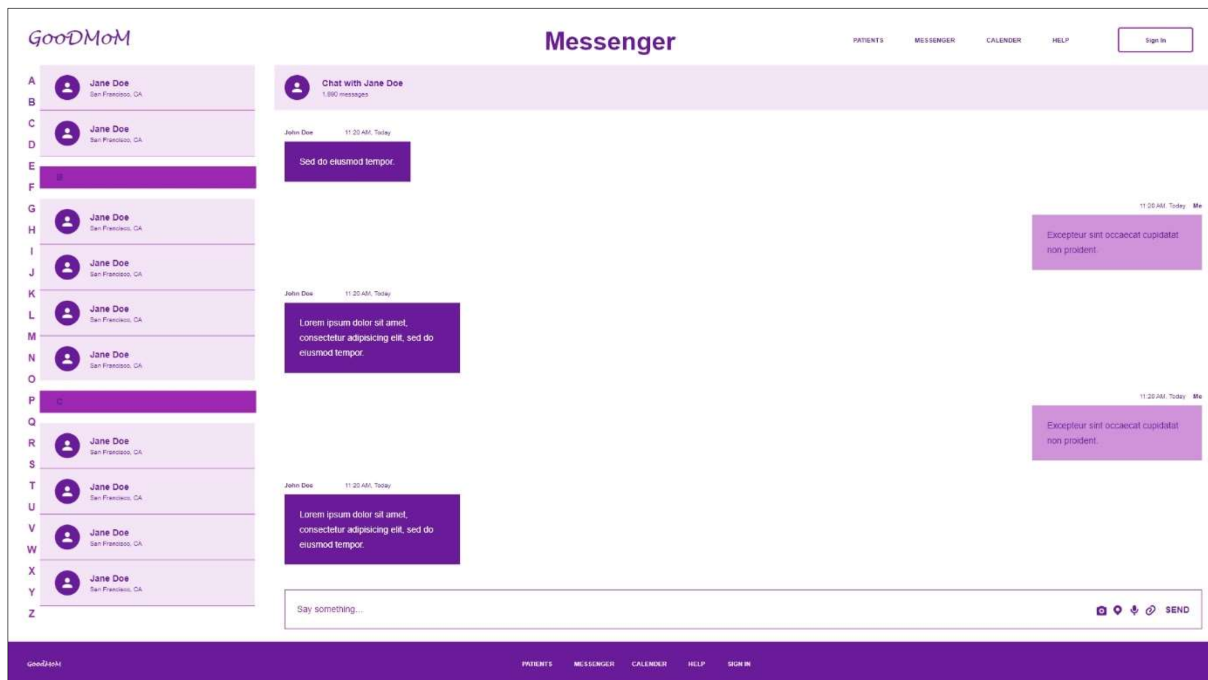


Figure 4.18: Web messenger board

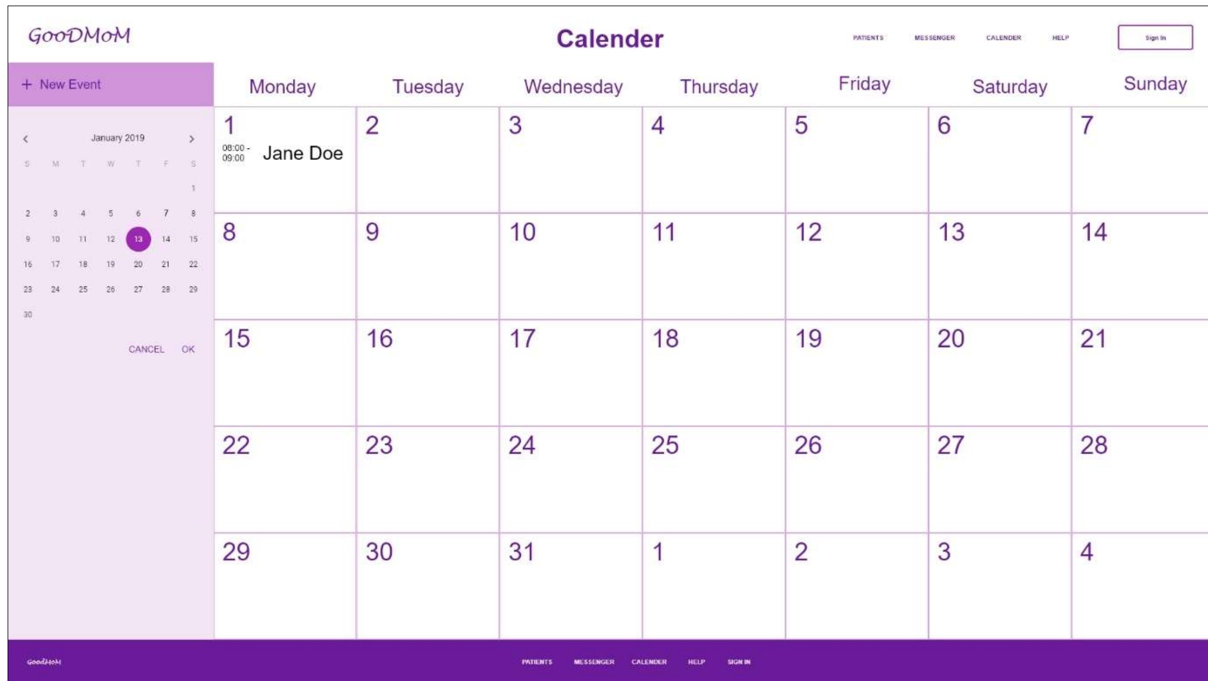


Figure 4.19: Web calendar board

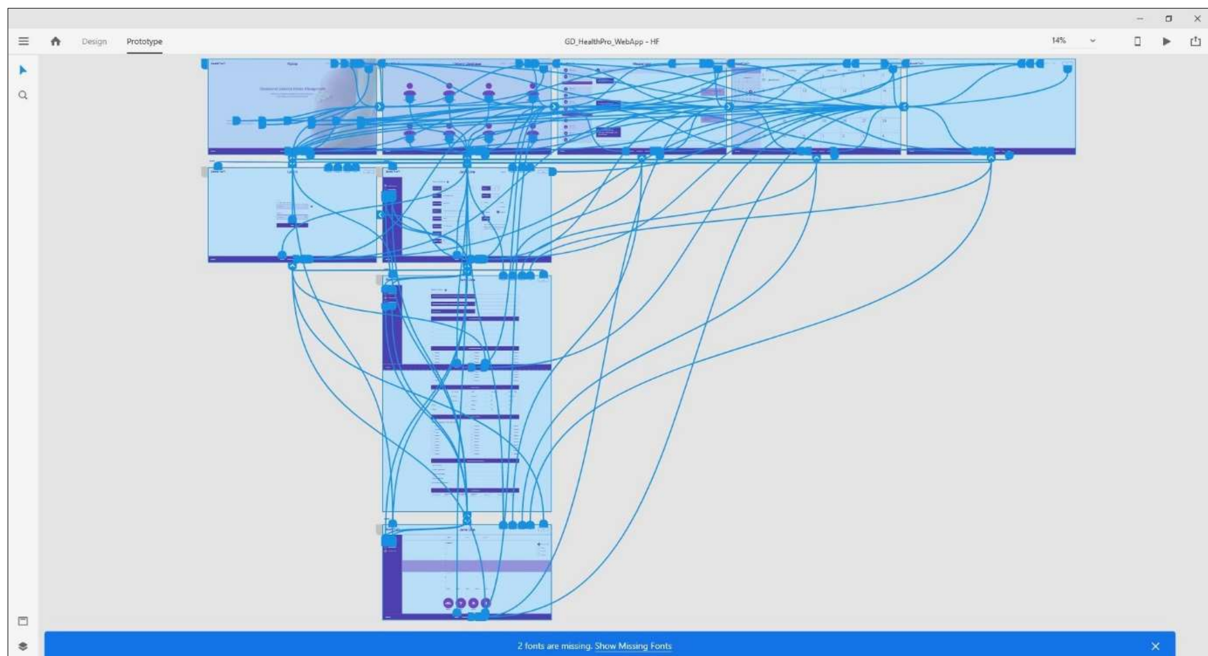


Figure 4.20: Web UX

4.3. Testing of the High-Fidelity Mock-up

The high-fidelity mock-up was tested in the form of a usability study. The main goal of the usability study performed on the high-fidelity mock-up was to get feedback on the UI design. The secondary goal was to test the UX of the high-fidelity mock-up. The outcomes of the usability study were applied to the development of the prototype.

The questionnaire used to gauge the usability of the high-fidelity mock-up can be seen in Appendix A. The results of the study are given below in two sections, one for the mobile app and one for the web app.

4.3.1. Demographics of participants

For this usability study, 14 applicable participants were identified and willing to participate, all part of the Biomedical Engineering Division at the University of Cape Town. Of the 14 participants to whom the study was sent, 10 replied. The 10 participants had an average age of 29.7 years and were 70% male and 30% female. The small population size was deemed adequate, because the study was based on an early stage of development which required brief feedback in order to continue with development.

Table 4.1 displays the results of the pre-task questions in tabular form. The pre-task questions were designed to gauge the level of knowledge of the participants in terms of technology-based knowledge and diabetes-based knowledge.

Table 4.1: Pre-task questions (high-fidelity mock-up)

Question
1. On a scale of 1 to 5 (1 = not at all confident, 5 = very confident), how would you rate your level of confidence in using your mobile phone. **1:** 0% **2:** 0% **3:** 0% **4:** 30% **5:** 70%
2. On a scale of 1 to 5 (1 = not at all knowledgeable, 5 = very knowledgeable), how would you rate your level of knowledge about diabetes? **1:** 0% **2:** 30% **3:** 50% **4:** 10% **5:** 10%
3. How many times per day do you test your blood glucose levels?

1 = Never, 2 = Rarely (once per week), 3 =Occasionally (2-3 times per week), 4 = Frequently (1-2 time per day), 5 = Very Frequently (3+ times per day) **1:** 80% **2:** 20% **3:** 0% **4:** 0% **5:** 0%
4. Have you used an app to track your blood glucose levels (if you have diabetes)? **Yes:** 0% **No:** 100%

Based on the pre-task questions seen in Table 4.1, it could be noted that the group of participants were all confident in the use of their mobile phones, with the majority rating themselves as very confident (70% of participants). The level of knowledge about diabetes was spread, with the majority (50% of participants) having an average knowledge. Only 20% of the participants had tested their blood glucose levels, albeit rarely. Of those participants, none of them had ever used an app to track their blood glucose levels. The participants were thus technologically proficient, with an average to low knowledge of diabetes. This should be considered when analysing the data, because the target market might not have the same characteristics.

4.3.2. Mobile Application Usability

The 10 participants were given a list of tasks and were asked to fill out a usability questionnaire after they finished the list of tasks.

Table 4.2 displays the results of the tasks to be completed in tabular form and Table 4.3 displays the results of the post-task questions in tabular form. The results are discussed below.

Table 4.2: Tasks to be completed (mobile high-fidelity mock-up)

Task	Percentage of Users Who Completed the Task
1. Sign-up	100%
2. View the feed	100%
3. Sign out	100%

4. Sign-in	100%
5. Add a reminder (appointment, medication or glucose reading)	100%
6. Enter data (glucose reading, meal, activity, bodyweight, medication, blood pressure, symptoms)	100%
7. Synchronise data with glucose meter on data entry screen	100%
8. Send a message to healthcare professional	100%
9. View “Tips and tricks” articles	100%
10. Go to settings 10.1. View profile 10.2. Change profile picture	100% 100% 100%

Table 4.3: Post-task questions (mobile high-fidelity mock-up)

1. On a scale of 1 to 5 (1 = negative, 5 = positive), how would you rate the ease of your experience with the GooDMoM app? **1:** 0% **2:** 0% **3:** 0% **4:** 40% **5:** 60%
2. On a scale of 1 to 5 (1 = unsuitable, 5 = suitable), how suitable did you think the GooDMoM name was for the platform? **1:** 0% **2:** 10% **3:** 20% **4:** 40% **5:** 30%
3. On a scale of 1 to 5 (1 = unattractive and inappropriate, 5 = attractive and appropriate), how would you rate the colour scheme of the app? **1:** 0% **2:** 10% **3:** 10% **4:** 20% **5:** 60%
4. On a scale of 1 to 5 (1 = cluttered and confusing, 5 = well-spaced and easily understandable), how would you rate the layout of the app? **1:** 0% **2:** 0% **3:** 10% **4:** 10% **5:** 80%

5. Did you have any navigational issues? **Yes:** 20% **No:** 80%
6. Which feature did you think was most important? 1 = The feed, 2 = The reminders, 3 = The data capture, 4 = The messenger, 5 = The tips and tricks **1:** 50% **2:** 20% **3:** 30% **4:** 0% **5:** 0%
7. Were there any features you did not understand? **Yes:** 10% **No:** 90%

Detailed instructions were given to each participant on how to complete each task (as seen in the usability study questionnaire in Appendix A). According to Table 4.2, 100% of participants were able to successfully complete each task

According to Table 4.3, the general experience of the mobile app was positive with 60% of participants rating their experience as highly as possible. Participants also praised the UI design, especially the colour scheme with 60% of participants giving the app the highest rating for attractiveness and appropriateness. Regarding the layout, 80% of participants awarded the highest level for spacing and understandability. However, there was mixed feedback about the suggested name, "GooDMoM", which stands for Gestational Diabetes Mobile Management. It was suggested that the name might imply that women who do not use the app were bad mothers, which was not necessarily the case. A name change could be considered at a later stage.

A few participants were specifically impressed with the bottom navigation, which makes one-handed navigation possible, no matter the size of the screen. However, 20% of the participants had navigational issues as seen in Table 4.3. These issues were a result of only the icons in the bottom navigation bar being clickable, not the text as well. This should be rectified in the prototype.

With regard to the sign-up process (seen in Figure 4.3, Figure 4.4 and Figure 4.5), the feedback from the participants suggested that only the email address, the identity number, the cell phone number and the healthcare professional's unique identifier should be mandatory. The

user should be able to complete the other fields at a later stage so that users who did not know all their details during the sign-up would not be unnecessarily lost. These fields were suggested to be mandatory because the email address was needed for account creation, the identity number was necessary to ensure that each patient could only have one account, the cell phone number was needed for contact purposes and the healthcare professional's unique identifier was needed to link the patient to a specific healthcare professional. It was suggested that when the patient typed in a certain healthcare professional's unique identifier, that healthcare professional should first accept the request on the web app before the link was formed for security and privacy purposes.

Based on the feedback received from participants, the feed (seen in Figure 4.6), which graphically displayed the patient's data was deemed the most important feature of the app (as agreed upon by 50% of the participants), according to Table 4.3. However, participants did mention that the numbers on the axes should be made bigger and grid lines should be included on the graph. It was recommended by a few participants that data points should change colour based on whether they fall within the healthcare professional's specified range or not. The word "feed" should also change to "dashboard", which would be a better fit for a screen that displays data.

With regard to the reminders boards (seen in Figure 4.8 and Figure 4.9), participants pointed out that there should be functionality to view and edit events which have already been created. The design for the display of events was only updated after this usability study was conducted. It was mentioned that the app should be able to export reminders to a dedicated calendar app on the user's phone. There should also be consistency in the use of the word "medication", as opposed to "pills" which is less generic, throughout the platform.

The main concern with the data entry board (seen in Figure 4.7) was that the name in the navigation bar ("data") suggested that data could be viewed there, but the icon suggested that data could be added there. The contradiction between the icon and the text should be rectified in the prototype. It was suggested that there should be a dedicated dashboard, which would allow patients to view their data graphically and provide access to the data entry screen, as opposed to providing direct access to the data entry screen in the navigation bar. According to Table 4.3, 10% of the participants did not understand the data entry process, pointing out that the method of adding data was confusing. The reason was that it was unclear

whether the user should fill in all the data fields every time or if the user could fill in only specific data fields at a time. These concerns should be addressed in the development of the prototype.

The feedback regarding the messenger (seen in Figure 4.10) advised that the associated icon be changed to a text bubble instead of a letter, as letters were seen as more formal than text bubbles. This could influence patients against contacting their linked healthcare professionals.

4.3.3. Web Application Usability

The web app usability study was sent to the 10 participants who replied to the mobile app usability study. There were 6 replies from the 10 who were sent the study.

Table 4.4 shows the percentage of users who were able to complete the task given to them while using the high-fidelity mock-up. Table 4.5 displays the post-task feedback from participants. The results are discussed below.

Table 4.4: Tasks to be completed (web high-fidelity mock-up)

Task	Percentage of Users Who Completed the Task
1. Log in	100%
2. View the patient database	100%
3. View a specific patient	100%
4. View the patient's personal details, patient history and dashboard	100%
5. View the messenger	100%
6. View the calendar	100%
7. View the Home screen	100%

Table 4.5: Post-task questions (web high-fidelity mock-up)

1. On a scale of 1 to 5 (1 = negative, 5 = positive), how would you rate the ease of your experience with the GooDMoM web app?
1: 0% **2:** 0% **3:** 17% **4:** 0% **5:** 83%

2. On a scale of 1 to 5 (1 = cluttered and confusing, 5 = well-spaced and easily understandable), how would you rate the layout of the web app? **1:** 0% **2:** 0% **3:** 0% **4:** 33% **5:** 67%
3. Did you have any navigation issues? **Yes:** 17% **No:** 83%
4. Was there any functionality you believe needs to be added? **Yes:** 0% **No:** 100%

Detailed instructions were given to each participant on how to complete the task (as seen in the usability study questionnaire in Appendix A). Table 4.4 shows that 100% of participants were able to successfully complete each task.

According to Table 4.5, 83% of participants rated their experience with the web app as positively as possible. Regarding the layout of the web app, 67% of users highly rated the app as well-spaced and understandable.

There were a few minor navigational issues in the web app, experienced by 17% of the participants, according to Table 4.5. The first issue with the navigation was that there was no clear home button – the platform name was not an intuitive home button. It was noted from the feedback that all scrollable pages needed a vertical scrollbar. When scrolling, the header should be fixed to the top of the screen. The last issue with the navigation was that the text in the header was too small. These issues should be addressed in the prototype.

The participants agreed unanimously that there was no functionality which needed to be added to the web app, according to Table 4.5. This meant that, according to the participants, the web app had the core features which it required to satisfy its objective.

On the calendar board (seen in Figure 4.19), the days which did not fall into the month in view should be faded out in order to avoid confusion in the prototype. The healthcare professional should have the option to add appointments to his or her email-linked digital calendar according to participants' feedback.

The feedback regarding the messenger (seen in Figure 4.18) advised that the healthcare professional be alerted to new messages in some way. This should be included in the prototype in the form of email alerts or via web pop-ups.

There was some general feedback, based on the platform as a whole. Participants pointed out that the font in a few areas was too small and should be rectified in the prototype. It was mentioned that more contrasting colour should be added. Human images should be added to make the app easier to identify with for pregnant women. Lastly, more pregnancy related features should be added during development of the prototype, like a due date progress bar.

4.4. Backend Development

The backend used Firebase as a service to authorise users and store data securely. It was found that Firebase provides scalability, allows administrators to manage all users, allows administrators to make live updates to the mobile app and web app, and allows the administrator to send out important push notifications as specified in the design requirements (Firebase, 2019a). Firebase offered the necessary security and privacy for the data stored on its servers, as shown in their security practices:

- Firebase restricted and logged access to systems that contained personal data (Firebase, 2019b).
- Firebase only permitted access to personal data by those who signed in with Google Sign-In and 2-factor authentication (Firebase, 2019b).
- Firebase encrypted data during transfer (Li et al., 2018).

Figure 4.21 shows the list of authorised users on the backend (populated for demonstration purposes). Figure 4.22 shows the database containing all the stored data, which is in JSON format.

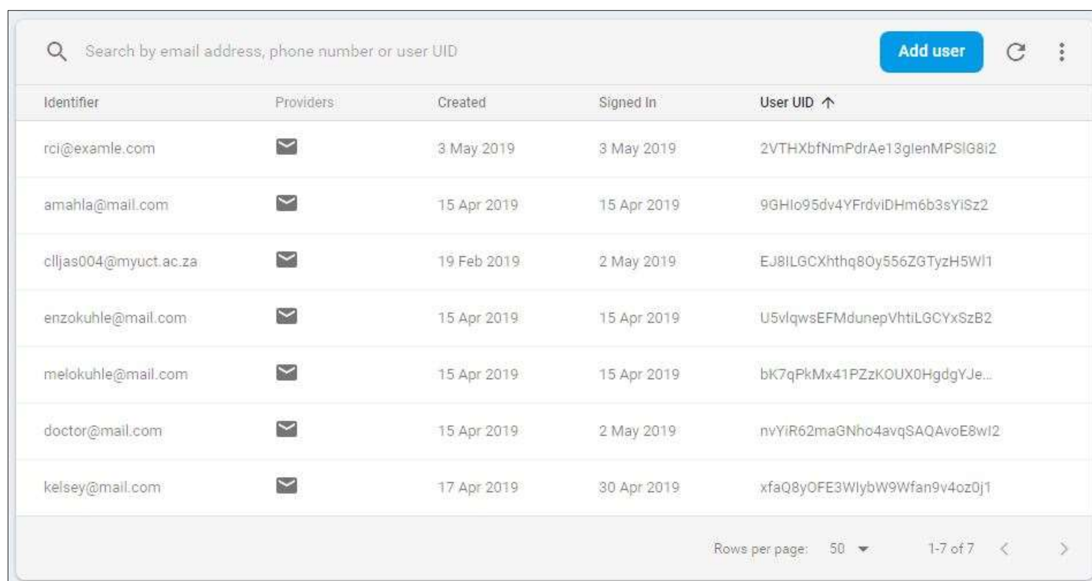


Figure 4.21: Backend user list

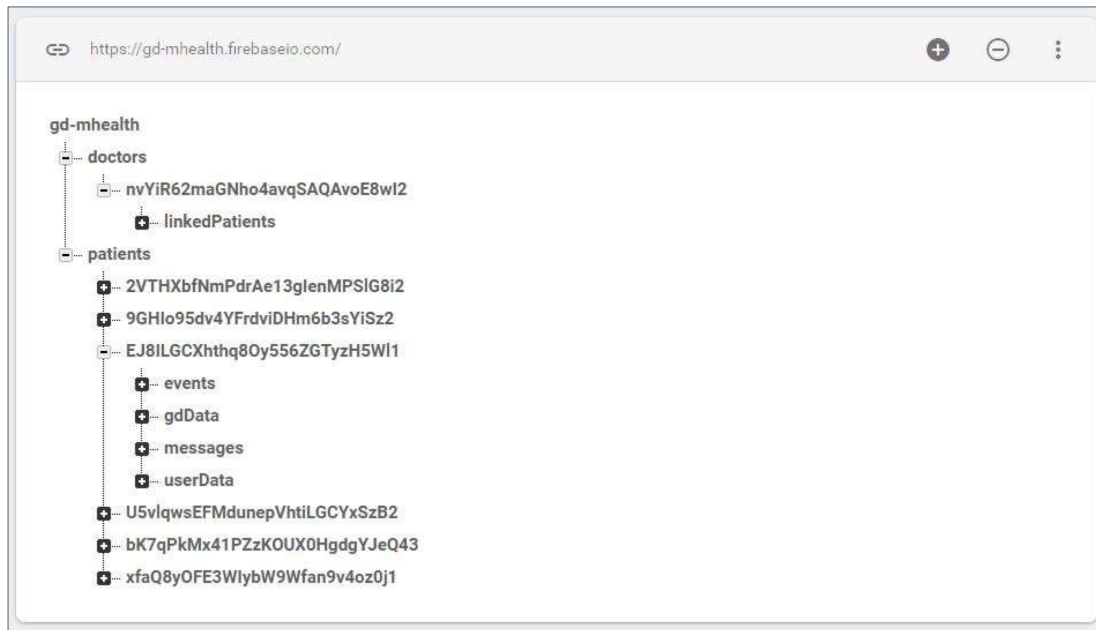


Figure 4.22: Backend database

4.5. Frontend Development

The frontend was developed using the Android Studio IDE. The frontend development was influenced by the high-fidelity mock-up's UI and UX design as well as feedback from the usability study done on the high-fidelity mock-up.

The description of the development is divided into two sections: one section for the mobile app and the other for the web app.

4.5.1. Mobile Application

Each phase of the development of the mobile app is detailed separately, with screenshots and a description relating to that phase.

4.5.1.1. Sign-Up and Sign-In

Figure 4.22 shows the mobile landing screen. Figure 4.23, Figure 4.24 and Figure 4.25 show the 3-step mobile sign-up process.

Patients were required to sign-up with an email address as seen in Figure 4.23. If the email entered already had an account associated with it, the patient would be asked to enter a password to sign-in. The personal details entry screen required patients to record their identity number (in order to be validated) and cell phone number (so that the patient could be contacted) as seen in Figure 4.24. It was optional, but recommended, that the patient recorded her home address so that medical assistance could be sent if necessary. The last screen in the sign-up process, seen in Figure 4.25, recorded clinical details, like the patient's healthcare professional's details, including the unique identification code (in order to link the patient to their healthcare professional programmatically). This screen also recorded the patient's height, pre-pregnancy bodyweight, diabetes type and due date (the due date calculator is shown in Figure 4.34), which were all required fields for the patient to be profiled. The information gained in the sign-up process was displayed to the healthcare professional as seen in Figure 4.38.

Figure 4.23: Mobile landing screen

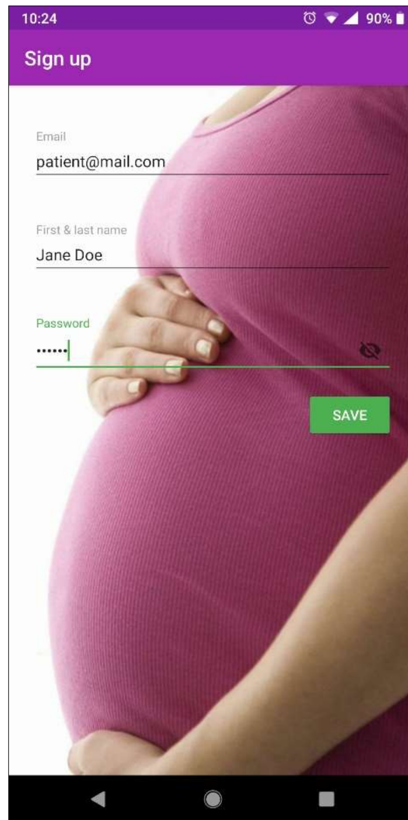


Figure 4.24: Mobile sign-up screen 1

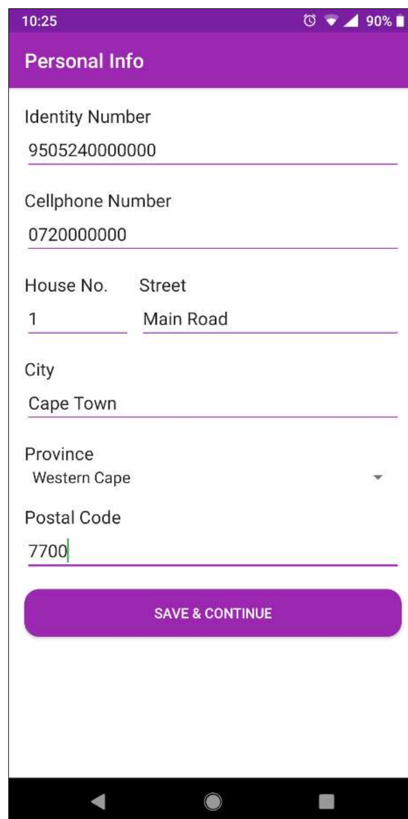


Figure 4.25: Mobile sign-up screen 2

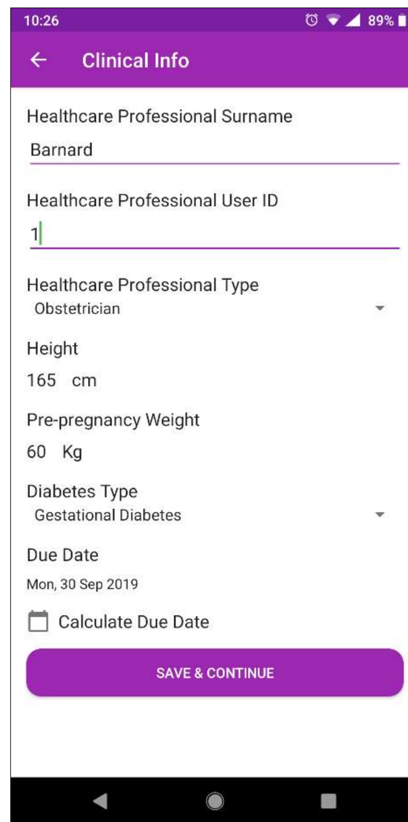


Figure 4.26: Mobile sign-up screen 3

4.5.1.2. Dashboard

The dashboard (as seen in Figure 4.26) displayed the recorded data, including blood glucose levels, carbohydrates, activity time, bodyweight, blood pressure and pregnancy progress. The data to be displayed could be chosen via a drop-down menu and the period (day, month or gestational period) of the data to display could be selected. The data was displayed in green if it was within the range specified by the patient's healthcare professional, red if it was above range and blue if it was below range. A dialog was displayed if a data point was selected, which showed additional information associated with that data point, like the symptoms that the user associated with that reading (seen on the right of Figure 4.27). This data was synchronised with the linked healthcare professional's web app via the Firebase backend so that the patient could be monitored remotely and in real-time (see Figure 4.39).

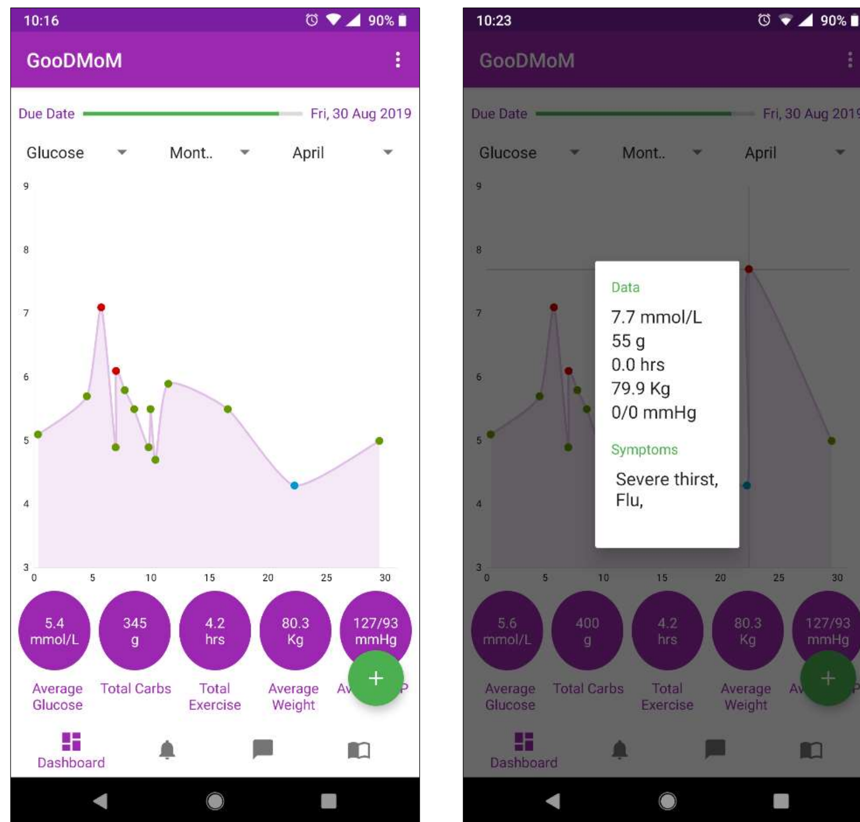


Figure 4.27: Mobile dashboard screen

Data could be added via the mobile data entry screen seen in Figure 4.27. Blood glucose data could be recorded by clicking on the synchronise icon or the “0.0 mmol/L” text at the top of the screen. All blood glucose data should be labelled in relation to the nearest meal, for example “before meal” or “2 Hr after meal”, which would be saved programmatically as pre-prandial and postprandial so that healthcare professionals could view the pre-prandial and postprandial data separately. Meal data, activity data, bodyweight data, and blood pressure data could be manually entered. The patient could also record that they had taken the medication from a list of pre-entered (by the healthcare professional) prescribed medications. Symptoms experienced by the patient at the time of data entry could be selected from a list of common symptoms shown in a dialog box which displayed when the user tapped the symptoms text box. Each data entry allowed the patient to record the time and location of the entry too.

The ability to automatically transfer data from a glucose meter via Bluetooth was not successfully implemented. The app was able to scan for and connect to a Bluetooth-enabled glucose meter but was not able to make sense of the data. To do this, permission and assistance would be required from the glucose meter’s developer but had not been acquired.

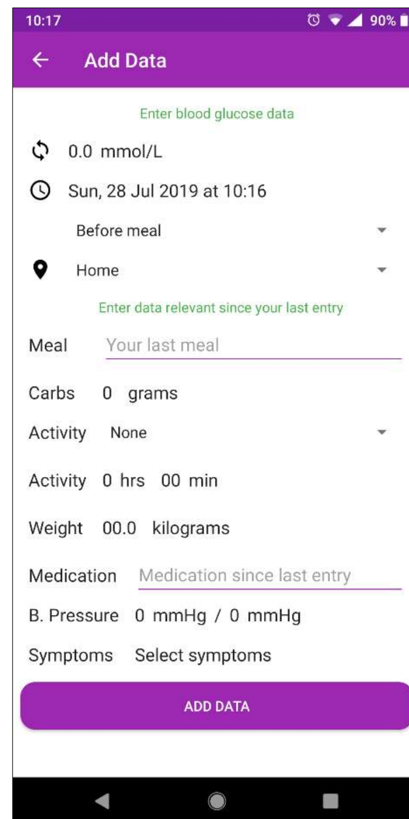


Figure 4.28: Mobile data entry screen

4.5.1.3. Reminders

The mobile reminders screen presented a list of manually entered reminders as seen in Figure 4.28. Appointment reminders, glucose test reminders and medication reminders were all supported. The displayed reminders were green if the patient fulfilled them and red if the patient did not. The reminders alerted the patient on the patient's device (in the form of a notification, of which the settings can be modified in the settings screen) at a user-chosen time before the event was to occur. The appointment reminders synchronised with the linked healthcare professional's web app via the Firebase backend (as seen in Figure 4.40). All reminders could be selected to see more details or to edit if necessary.

The mobile reminder entry screen shows how reminders were added (as seen in Figure 4.29). The patient could enter a title, select the reminder type, choose the start and end dates and times, add a repeat, enter a location, enter a description, choose the notification time and export the event to another calendar app on the phone. In a future iteration, the app should also automatically generate a series of necessary antenatal care and GD-related appointments to take place throughout the gestational period.

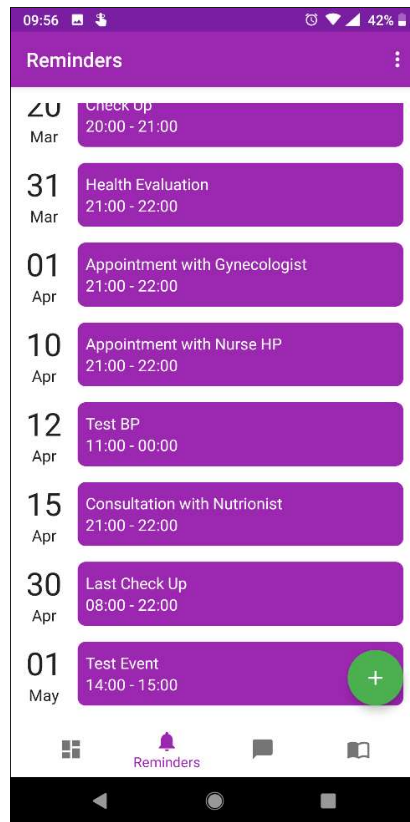


Figure 4.29: Mobile reminders screen

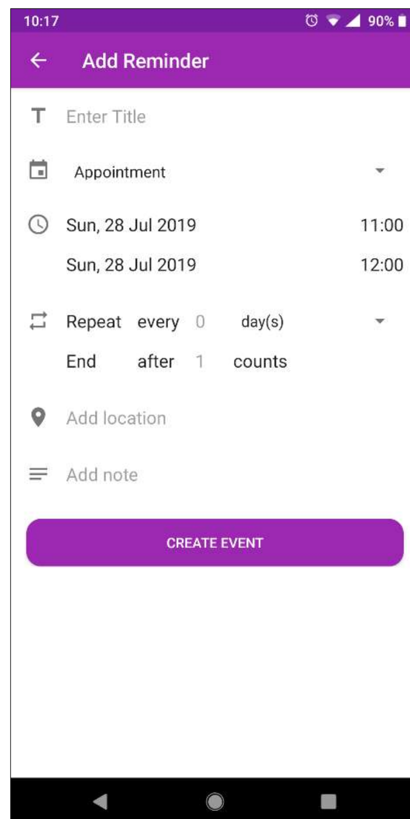


Figure 4.30: Mobile reminder entry screen

4.5.1.4. Messenger

The messenger screen, seen in Figure 4.30, provided a direct line of communication between the healthcare professional (as seen in Figure 4.37) and the patient. The patient could use this as a channel to ask for advice directly and the healthcare professional could offer feedback or use this to intervene remotely if the healthcare professional noticed any warning signs while monitoring the patient's data. The patient would be alerted to new messages in the form of a notification (the settings of which could be modified in the settings screen).

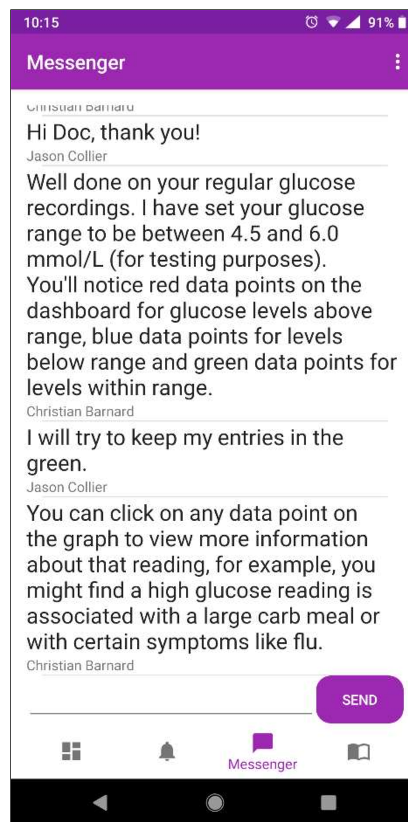


Figure 4.31: Mobile messenger screen

4.5.1.5. Tips

The tips screen (seen in Figure 4.31) was intended to serve as a GD and pregnancy educational database which could be displayed to the patient in the form of written posts. Each post should be displayed at the necessary point during the patient's gestational timeline. The posts should inform the patient on what to expect at various points during her pregnancy and how to handle her diabetes (among other topics).

This educational database had not yet been created, so the screen was showing blog posts from various diabetes and pregnancy feeds which had a rich site summary (RSS) feed. The posts could be opened in the mobile app through a web view (seen on the right of Figure 4.32).

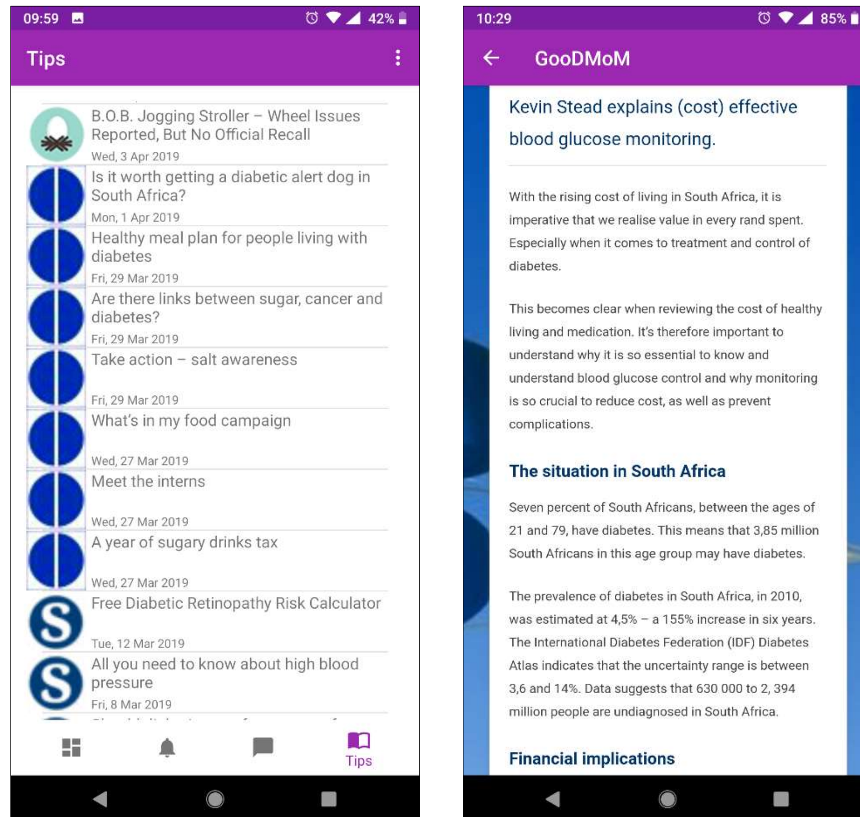


Figure 4.32: Mobile tips screen

4.5.1.6. Settings

The settings screen (seen on the left of Figure 4.33) allowed the patient to edit the display name and notifications. The help and feedback screen (seen on the right of Figure 4.33) allowed the patient to view the app version, copyright details and send an email to the administrator.

The edit profile screen (seen in Figure 4.34) allowed the patient to add or change the linked healthcare professional. It also allowed the patient to add or update her personal and clinical details, as well as view healthcare professional selected goals for blood glucose levels, activity time, carbohydrates and bodyweight. The screen gave access to the due date calculator (seen on the right of Figure 4.34) and showed the healthcare professional prescribed medication. The pre-pregnancy weight and height were used to calculate and display the patient's BMI.

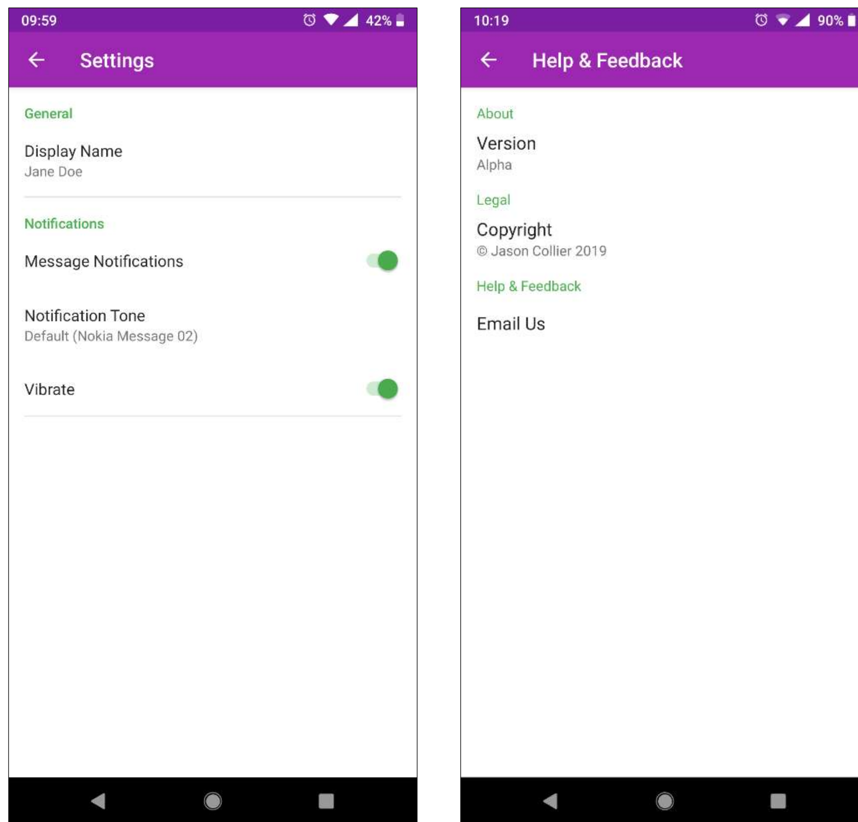


Figure 4.33: Mobile settings and help & feedback screens

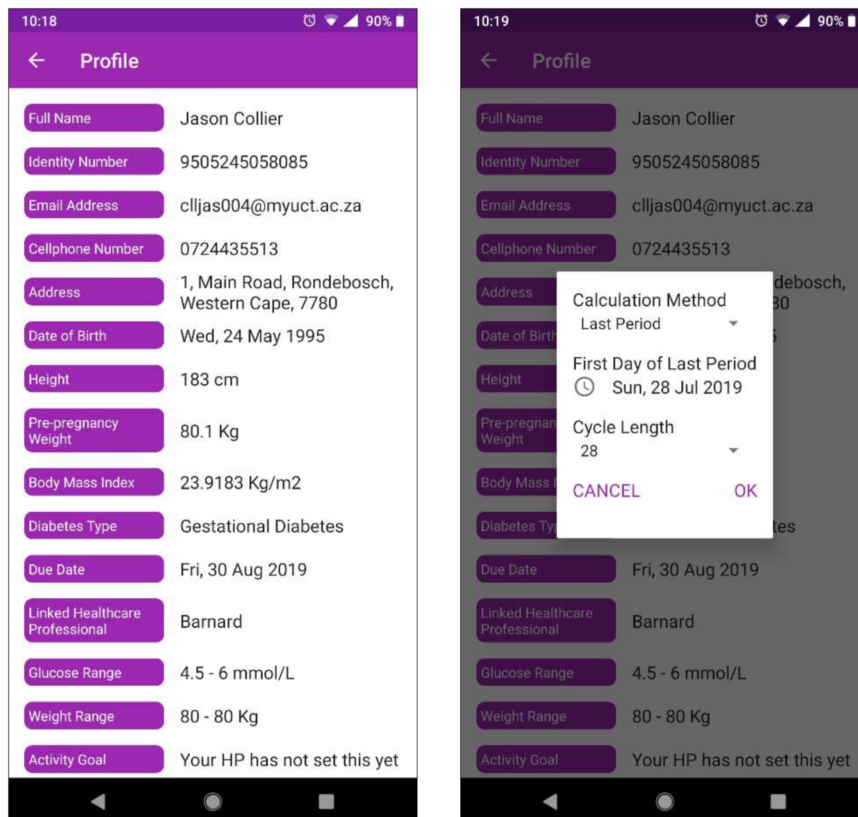


Figure 4.34: Mobile profile screen

4.5.2. Web Application

Each phase of the development of the web app will be detailed separately, with screenshots and a description relating to that phase.

4.5.2.1. Sign-Up and Sign-In

The healthcare professional sign-up process was initiated by the healthcare professional and verified by the administrators of the platform. Once signed up, the healthcare professional could sign-in via email as seen in Figure 4.35. This took the healthcare professional to the home page as seen in Figure 4.36, from which the other pages could be navigated to.

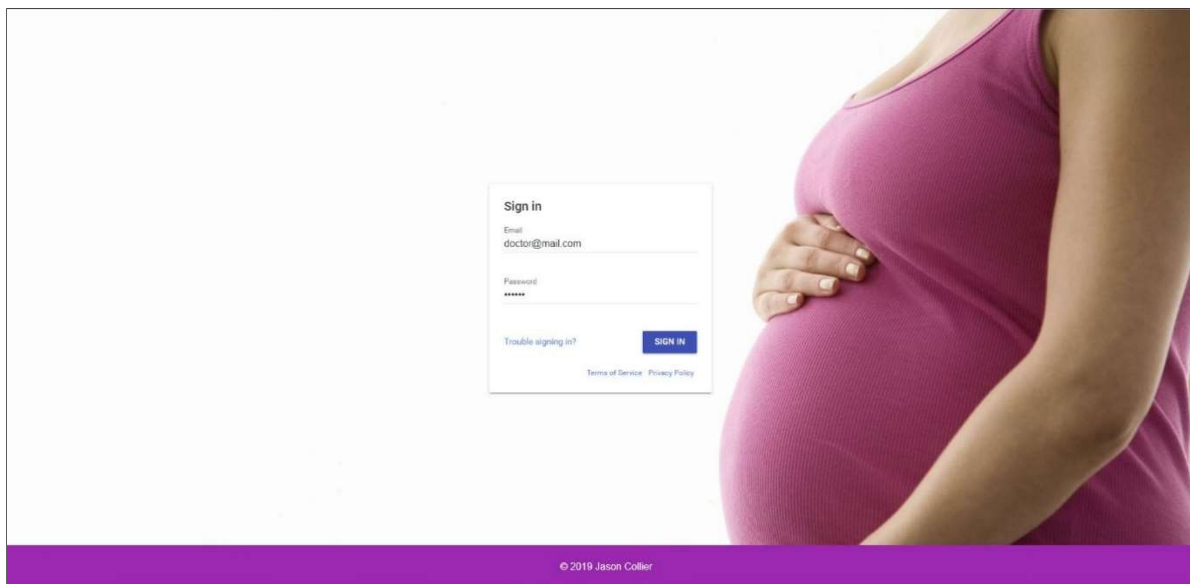


Figure 4.35: Web sign-in page

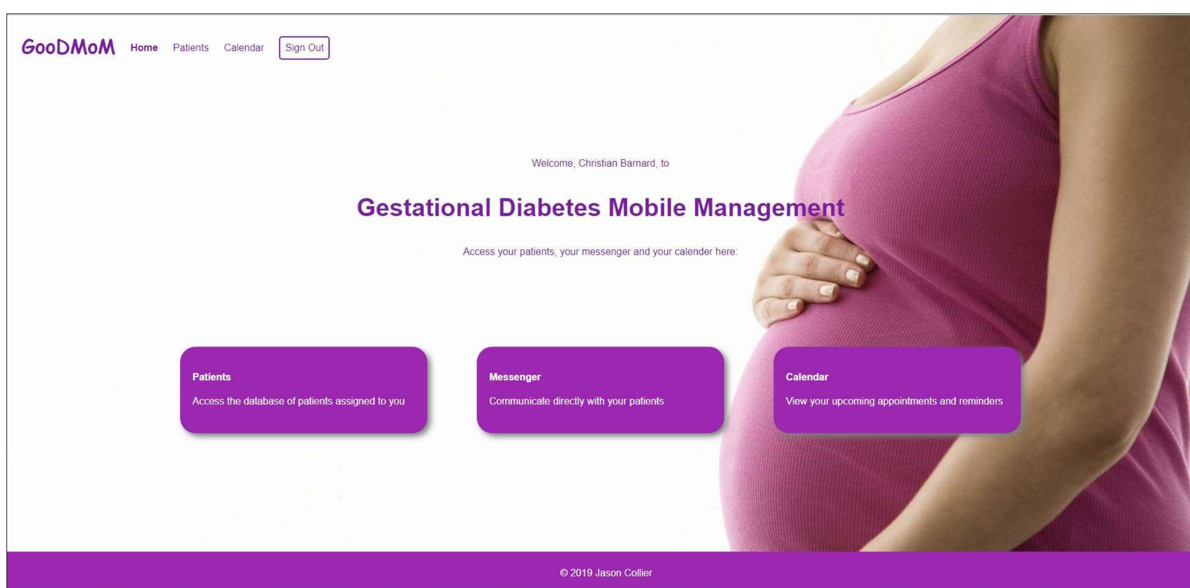


Figure 4.36: Web home page

4.5.2.2. Patients

The patients' page, seen in Figure 4.37, displayed all the patients linked to the signed in healthcare professional. When a patient entered a healthcare professional's user ID during the patient's sign-up process, the healthcare professional would receive a notification which he or she could accept for the link to be made or decline for the link not to be made. The healthcare professional could select a patient which would load that patient's data.

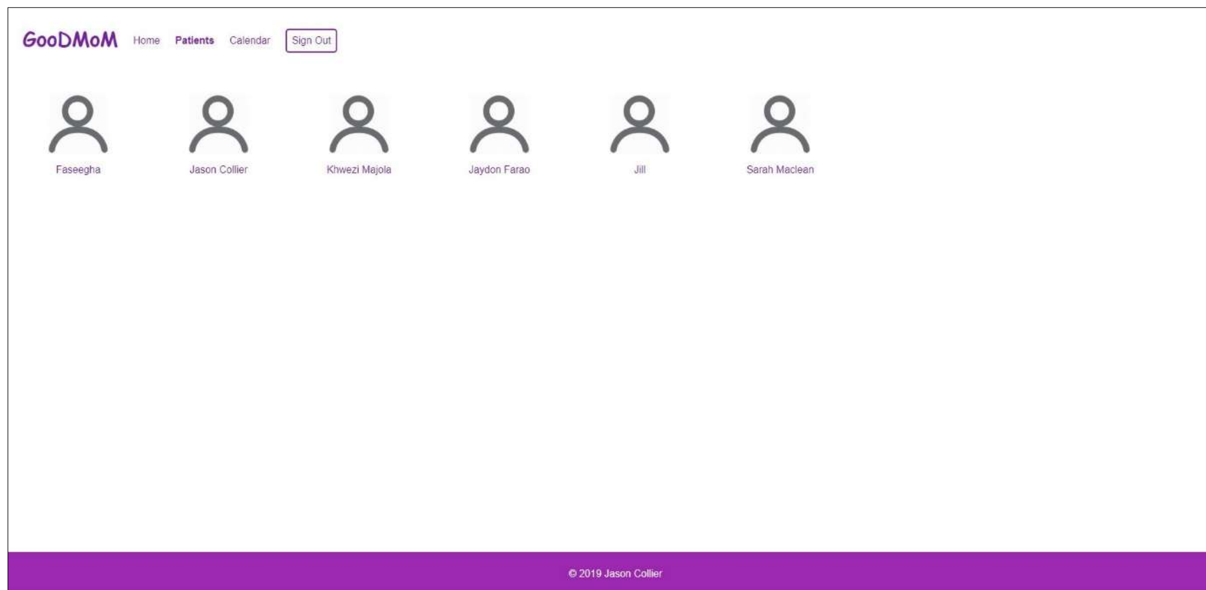


Figure 4.37: Web patient list page

4.5.2.3. Messenger, Patient Details, Patient History and Dashboard

The messenger (Figure 4.38), patient details (Figure 4.39), patient history and dashboard (Figure 4.40) pages could be accessed by loading a specific patient's data. These pages displayed confidential information that only the patient and linked healthcare professional should access. The selected patient's name was displayed on the side navigation bar as seen in these figures.

The messenger page, as seen in Figure 4.37, provided a direct line of communication between the healthcare professional and the selected patient. The patient could use this to ask for health-related advice and the healthcare professional could use this to intervene remotely if there were warning signs in the patient's data. Healthcare professionals could also use the messenger to provide feedback on the patient's progress.

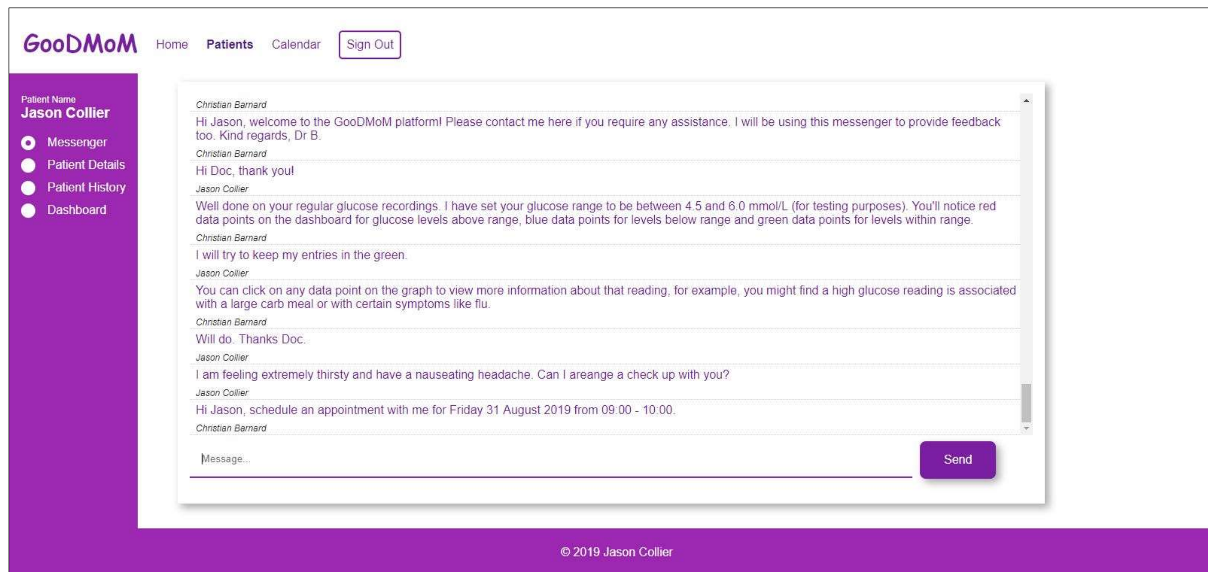


Figure 4.38: Web messenger page

The patient details page (seen in Figure 4.38) displayed the selected patient's personal and clinical details, as entered during the patient's sign-up (seen in Figure 4.23, Figure 4.24 and Figure 4.25). The patient's pre-pregnancy weight and height were used to calculate and display the patient's BMI. The healthcare professional could set target ranges for the selected patient's blood glucose levels, bodyweight, carbohydrates and activity duration. It also allowed the healthcare professional to remotely choose the medication that the selected patient should use.

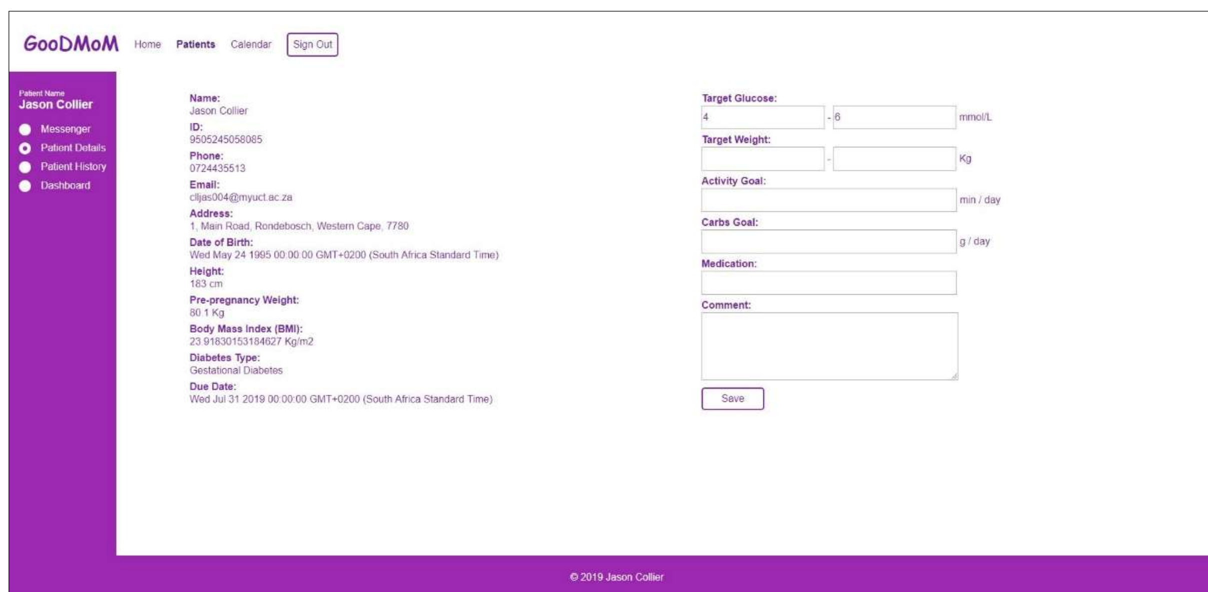


Figure 4.39: Web patient details page

The patient history page was an online form based on the patients' medical history. This was like an electronic health record. The healthcare professional or an assistant would copy information from a paper-based form into the electronic health record. Functionality should be added to receive data from another database which had a specific patient's health record. However, this page was not developed, because it was deemed unnecessary since electronic health records already exist.

The dashboard page (seen in Figure 4.40) allowed the healthcare professional to remotely monitor the recorded data in real-time (as seen in Figure 4.28), including blood glucose levels, carbohydrates, activity time, bodyweight, blood pressure and medication adherence. The period (day, month or gestational period) of the data to display could be selected. The data was displayed in green if it was within the HP specified range, red if it was above range and blue if it was below range. The colour changes were done in order to alert the healthcare professional. Each data point could be selected to show more details, including patient symptoms associated with that data point. All data was displayed both graphically and numerically, as seen in Figure 4.40. Healthcare professionals could make notes next to any data entry by selecting that entry.

Figure 4.40: Web dashboard page

4.5.2.4. *Web Calendar Page*

The calendar page, as seen in Figure 4.41, displayed the healthcare professional's appointments. The healthcare professional could manually add appointments, but the appointments that the healthcare professional's linked patients created were automatically displayed (if the healthcare professional accepted the appointment request). These appointments could be added to the healthcare professional's email calendar too. The healthcare professional could select a past event and mark whether the patient attended that event or not, which would change the colour of the event (where red means the patient missed the appointment and green means the patient attended the appointment). Each appointment could be clicked to view extra information and add appointment notes.

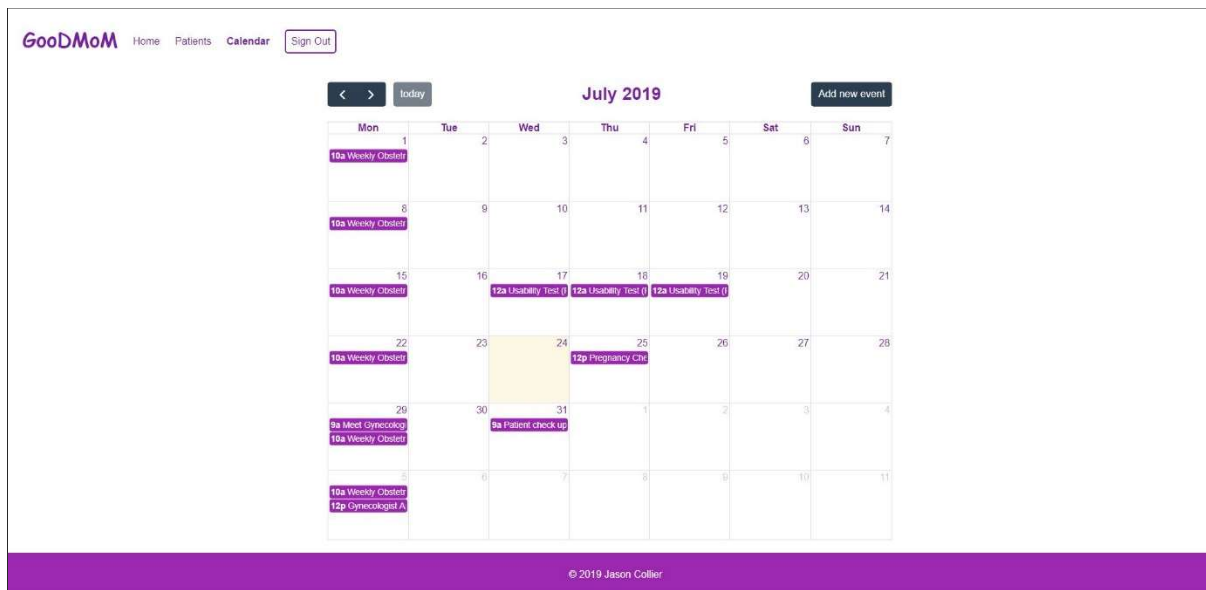


Figure 4.41: Web calendar page

4.6. Testing of the Prototype

The prototype was tested in the form of a usability study. The main goals of the usability study performed on the prototype were to test the usability of the prototype quantitatively, find major technical malfunctions in the code and receive qualitative feedback. The outcomes of the usability study could be implemented in future development. This test took the form of in-lab testing, meaning that the participants were all from the University of Cape Town - no actual patients or external persons were tested during this iteration of testing. The platform was tested using the black box testing method – a method in which the internal code of the

software being tested was not known to the tester. This method suited software behavioural testing instead of logic or algorithm testing.

The participants involved in the study tested the mobile app by completing a set of specific tasks. At the completion of the set of tasks, each participant needed to complete a demographic questionnaire and a post-task usability questionnaire. The web app was tested in the same way.

Each participant was given an explanation on the background of the project and the problem that the project solved. None of the participants were shown how to use the mobile app or web app; therefore the impartiality was maintained. Each participant spent two or three full days with the mobile app and glucose meter (depending on availability of the participant, the two smartphones with the software and the glucose meter), taking four readings per day (in the morning, before lunch, after lunch, and in the late afternoon). These times were chosen to fit into the working day so that the participants were not inconvenienced by asking them to record in their free time at home. The author acted as the healthcare professional monitoring each participant through the web app, providing feedback and answering questions via the messenger. After the participant completed testing the mobile app, the participant tested the web app by following a separate set of tasks. The web app usability test lasted about 30 minutes.

The two mobile smartphones used for testing were the Hisense U962 and the Vodacom Smart Mini 7. Both phones came with Android 6.0, had Bluetooth capabilities and cost less than R1000 at the time of purchase. These phones were chosen because they were the cheapest smartphones which met the minimum requirements for the mobile app to function properly. The glucose meter used was the AccuChek Instant meter with AccuChek Instant test strips and SoftClix lancets. This glucose testing set was chosen because it was popular and affordable in South Africa.

The questionnaire used to gauge the usability of the prototype and receive qualitative feedback can be seen in Appendix B. The results of the study are given below in two sections, one for the mobile app and one for the web app.

4.6.1. Demographics

There were 10 participants that were included in the study. The group was 50% male and 50% female, and the average age was 31.3 years. The group consisted of staff and students from the Division of Biomedical Engineering, University of Cape Town. The participants were all university graduates, including engineers, clinicians, dieticians, pharmacists and other healthcare professions. The small population size was deemed adequate to gauge the usability of the prototype and gain feedback for future development (full-scale clinical trials should only be implemented at a later stage of development). The group was "extremely" confident in the use of smartphones and computers, with 70% and 80% rating their confidence at the highest possible level respectively. The majority of the participants used health apps occasionally (80%) and health websites rarely (50%). The level of knowledge about diabetes was spread, with the majority (60% of participants) having an average knowledge. Only 40% of the participants had tested their blood glucose levels. Of all the participants, only 10% had ever used an app to track their blood glucose levels. The participants were thus technologically proficient, with an average knowledge of diabetes. This should be considered when analysing the data, because the target market may not have the same characteristics.

Table 4.6: Demographics of participants (prototype usability study)

1. How confident are you in using a smartphone (1 = extremely unconfident, 5 = extremely confident)? **1:** 0% **2:** 0% **3:** 30% **4:** 0% **5:** 70%
2. How confident are you in using a computer (1 = extremely unconfident, 5 = extremely confident)? **1:** 0% **2:** 0% **3:** 20% **4:** 0% **5:** 80%
3. How often do you use a health app (fitness apps, sleep apps, diet apps etc.)? 1 = Never, 2 = Rarely (once per week), 3 =Occasionally (2-3 times per week), 4 = Frequently (1-2 time per day), 5 = Very Frequently (3+ times per day) **1:** 0% **2:** 10% **3:** 80% **4:** 0% **5:** 10%
4. How often do you use a health website to track data (fitness sites, dieting sites etc.)?

1 = Never, 2 = Rarely (once per week), 3 =Occasionally (2-3 times per week), 4 = Frequently (1-2 time per day), 5 = Very Frequently (3+ times per day) **1:** 10% **2:** 50% **3:** 30% **4:** 10% **5:** 0%
5. How knowledgeable are you about diabetes (1 = extremely ignorant, 5 = extremely knowledgeable)? **1:** 0% **2:** 20% **3:** 60% **4:** 0% **5:** 20%
6. How often do you test your blood glucose levels? 1 = Never, 2 = Rarely (once per week), 3 =Occasionally (2-3 times per week), 4 = Frequently (1-2 time per day), 5 = Very Frequently (3+ times per day) **1:** 60% **2:** 20% **3:** 0% **4:** 20% **5:** 0%
7. Have you used an app to track your blood glucose levels? 1 = Never, 2 = Rarely (once per week), 3 =Occasionally (2-3 times per week), 4 = Frequently (1-2 time per day), 5 = Very Frequently (3+ times per day) **1:** 90% **2:** 10% **3:** 0% **4:** 0% **5:** 0%

4.6.2. Mobile Application

The task completion rate is recorded in Table 4.7 and the results of the usability questionnaire are in Table 4.8. The results seen in the tables are discussed in the paragraphs below.

Table 4.7: Tasks to be completed (mobile prototype)

Task	**Percentage of Users Who Completed the Task**
1. Sign-up	100%
2. Add glucose reading reminders via the “Reminders” screen	100%
3. Record glucose data at the time specified above via the “Dashboard” screen	100%

4. Send a message to the healthcare professional via the “Messenger” screen	90%
5. View the diabetes and pregnancy related articles via the “Tips” screen	100%
6. View your profile summary via the “Profile” screen	100%
7. Change the notification tone via the “settings” screen	70%
8. Send a feedback email via the “Help & Feedback” screen	70%
9. Sign out	100%

Table 4.8: Post-task questions (mobile prototype)

1. Was the GooDMoM app easy to use (1 = extremely difficult, 5 = extremely easy)? **1:** 0% **2:** 0% **3:** 50% **4:** 30% **5:** 20%
2. Did you find the dashboard to be informative (1 = extremely uninformative, 5 = extremely informative)? **1:** 0% **2:** 0% **3:** 20% **4:** 50% **5:** 30%
3. Did you find the reminders to be helpful (1 = extremely unhelpful, 5 = extremely helpful)? **1:** 0% **2:** 40% **3:** 30% **4:** 20% **5:** 10%
4. Did you find the direct line of communication to the healthcare professional to be advantageous (1 = extremely disadvantageous, 5 = extremely advantageous)? **1:** 0% **2:** 0% **3:** 20% **4:** 30% **5:** 50%
5. Did you find the articles in the “tips” screen to be informative (1 = extremely uninformative, 5 = extremely informative)? **1:** 0% **2:** 10% **3:** 20% **4:** 50% **5:** 20%
6. Which feature did you think was most important to the management of GD? 1 = The dashboard, 2 = The reminders, 3 = The messenger, 4 = The tips, 5 = none

1: 50% **2:** 42.9% **3:** 7.1% **4:** 0% **5:** 0%
7. Did you think the GooDMoM platform would help you manage your GD? 1 = Definitely not, 2 = Probably not, 3 = Maybe, 4 = Probably, 5 = Definitely **1:** 0% **2:** 0% **3:** 10% **4:** 30% **5:** 60%
8. Would you use the GooDMoM platform to manage your GD? 1 = Definitely not, 2 = Probably not, 3 = Maybe, 4 = Probably, 5 = Definitely **1:** 0% **2:** 0% **3:** 20% **4:** 20% **5:** 60%

The participants were instructed to perform the tasks shown in Table 4.7, which represented general tasks that would be performed by patients using the mobile app, without any coaching. Most of the tasks were completed by 100% of the participants, except for tasks 4, 7 and 8 which had completion percentages of 90%, 70% and 70% respectively. Task 4 required patients to send a message to the healthcare professional – the messenger icon in the navigation bar was not seen by the one participant who did not complete this task. Task 7 required participants to change the notification tone via the “Settings” screen and task 8 required participants to send an email via the “Help & Feedback” screen. The notifications for both reminders and messages did not always work as expected, which was probably the reason that 30% of participants marked this task as uncompleted. The probable reason that the feedback email did not work was because the receiving email address (the GooDMoM administrator’s email address) was the same as the sending email address (the phone’s default email address) causing the error. This incident would not have occurred if participants had used their own phones with their own email addresses and, thus, required no further investigation.

Most of the participants found the mobile app “adequately easy” to use (50%). There were a few minor navigational issues and technical malfunctions though. A few participants pointed out that using the back button on the Android phone produced unexpected behaviour. The back button would need to be configured correctly during development of the beta version. There were two participants who found the blood glucose entry to be “hidden”. One participant recommended that the mobile app should programmatically check whether the

glucose data has been entered or not before allowing the user to save the data and the other recommended that the glucose reading entry should be more prominently displayed on the screen. Another participant pointed out that because the new message notifications did not work, he did not view the messages regularly. There was also a suggestion to add the ability enter the different types of data (glucose, carbohydrates, weight, exercise and blood pressure) on separate screens.

Of the main features of the mobile app, 50% of the participants found the dashboard “very informative”, 50% of the participants found the messenger “extremely advantageous” and 50% found the tips to be “very informative”. The participants provided varied feedback about the reminders, rating them as either “unhelpful” (40%), “helpful” (30%), “very helpful” (20%) or “extremely helpful” (10%). The dashboard and the reminders were both rated as the most important features of the mobile app by 50% and 42.9% of participants, respectively.

The participants enjoyed the direct line of communication with the healthcare professional, who answered questions, provided feedback and alerted participants to various features of the mobile app. However, the messages did not have a timestamp, which must be rectified so that users could see when messages were sent.

The participants did not have a good experience with the reminder and message notifications, which did not always work. Crash reports showed that the background service in charge of delivering notifications was crashing. This was a technical malfunction that should be investigated and fixed during development of the beta version so that users can get the full value of appointment, medication and glucose reminders, as well as new message reminders. Missed reminders should also continuously notify the user until the user responds, as pointed out by one participant. It was suggested that the reminders screen should be made to replicate a calendar app, where month, week, 3-day, day and schedule views were available. The reminders were only shown in a schedule view at the time of writing.

Regarding the dashboard, it was suggested that it should include a continuous weekly display (with horizontal scrolling). The Haemoglobin A1c (HbA_{1c}) value should be calculated and displayed on the dashboard too. During data entry, the symptom selector should update the user’s selection on the screen so that the user could see what he or she had selected. Two participants thought that the nutritional data should be given more importance. One of them suggested that incorporating automated nutritional tips based on the glucose level readings

would be beneficial. The other participant recommended that functionality be added which would allow users to quantify what they had eaten by selecting a food type and the number of portions of that food type. This would be necessary because not all food showed nutritional information on the packaging (for example, fruits and vegetables).

There were a few general comments, including from one participant who pointed out that during the sign-up process, the first name and surname should be entered separately, as opposed to together. There were a few comments made about the time picker on the data entry and reminder entry screens, which confused some participants. It was suggested that the time picker be discarded and replaced with a dialog which would allow the user to type in the time instead of selecting it. Lastly, the fact that the mobile app could only work when connected to the internet was an issue. An offline mode should be incorporated during development of the beta version.

The results showed that 60% of the participants believed that the GooDMoM platform would "definitely help" them manage their GD and 60% of the participants said that they would "definitely use" the GooDMoM platform to manage their GD if they had the disease. Overall, the outcome from the usability studies was positive and placed the mobile app in a good position for beta development to begin.

4.6.3. Web Application

The task completion rate is in Table 4.9 and the results of the usability questionnaire are in Table 4.10. The results seen in the tables are discussed in the paragraphs below.

Table 4.9: Tasks to be completed (web prototype)

Task	Percentage of Users Who Completed the Task
1. Sign-in	100%
2. View the patients assigned to Dr Barnard via the "Patients" page	100%
3. View the patient details of [your name]	100%
4. View [your name]'s dashboard	100%

5. View the "Calendar" page	100%
6. Send a message	100%

Table 4.10: Post-task questions (web prototype)

1. Was the GooDMoM web app easy to use (1 = extremely difficult, 5 = extremely easy)? **1:** 0% **2:** 0% **3:** 20% **4:** 30% **5:** 50%
2. Did you find the patient profile easy to understand and navigate (1 = extremely difficult, 5 = extremely easy)? **1:** 0% **2:** 0% **3:** 0% **4:** 60% **5:** 40%
3. Did you find the direct line of communication to the patient to be advantageous (1 = extremely disadvantageous, 5 = extremely advantageous)? **1:** 0% **2:** 0% **3:** 10% **4:** 20% **5:** 70%
4. Did you find patient details with goals and ranges to be advantageous (1 = extremely disadvantageous, 5 = extremely advantageous)? **1:** 0% **2:** 10% **3:** 10% **4:** 20% **5:** 60%
5. Did you find the dashboard to be informative (1 = extremely uninformative, 5 = extremely informative)? **1:** 0% **2:** 0% **3:** 10% **4:** 30% **5:** 60%
6. Did you find the calendar easy to understand and use (1 = extremely difficult, 5 = extremely easy)? **1:** 0% **2:** 0% **3:** 20% **4:** 30% **5:** 50%
7. Did you think the GooDMoM platform would help you to manage patients with GD (if you were a GD healthcare professional)? 1 = Definitely not, 2 = Probably not, 3 = Maybe, 4 = Probably, 5 = Definitely **1:** 0% **2:** 0% **3:** 10% **4:** 20% **5:** 70%

8. Would you use the GooDMoM platform to manage your patients with GD (if you were a GD healthcare professional)?

1 = Definitely not, 2 = Probably not, 3 = Maybe, 4 = Probably, 5 = Definitely

1: 0% **2:** 10% **3:** 0% **4:** 20% **5:** 70%

All the tasks shown in Table 4.9 were completed by 100% of the participants. These tasks represented the main tasks that would be performed by a healthcare professional, so it was a promising sign that all participants were able to complete the tasks without coaching.

Most of the participants found the web app "extremely easy" to use (50%). One of the reasons given which decreased the ease of use was that there was no loading icon shown while data was being loaded onto the page. This gave users the impression that the web app was not working for a few moments until the data was loaded. Regarding the patient's page, it was suggested to display the linked patients in an alphabetical list, rather than with icons and names. Another reason given by participants was that it was possible to deselect an icon in the side navigation bar which could lead to unexpected navigational errors (when viewing the patient's messenger, details or dashboard). One participant suggested that it would be more beneficial to open a patient's profile on the dashboard page rather than on the messenger page. There was a general suggestion to add the ability to change patient details from the web app. The ability to add a comment on the patient details page confused some participants, because it only allowed one comment to be added. Lastly, the data pop-up was not stable when participants attempted to view additional data associated with a data point by hovering the pointer over that data point, which should be rectified in the beta version. Besides the navigational issues, most participants found the patient profile to be "very easy" to understand and navigate (60%).

Participants found the messenger to be "extremely advantageous" (70%), while they found the patient details page and the dashboard to be "extremely advantageous" (60%) and "extremely informative" (60%), respectively. However, there was a concern raised regarding the extent of the commitment of the healthcare professional to respond to the patient's messages, especially during emergencies that occur during off-hours.

Most participants found the calendar to be “extremely easy” to understand and use (50%). There were some issues with the calendar, which included the inability to edit events. Two participants recommended that the user should be able to add an event on a specific day by clicking on that day’s box. Another participant suggested that while adding an event, a drop-down box with reasons for the event should be added.

Most participants agreed that the GooDMoM web app would “definitely help” healthcare professionals to manage their patients (70%) and that, if they were healthcare professionals, they would “definitely use” the GooDMoM web app to manage their patients (70%). This was a positive outcome for the alpha version which was deemed ready for beta development.

The usability study performed on the prototype of the GD mHealth platform concludes the development of the alpha version of the platform. The results and feedback gained in this usability study will inform the development of the beta version, which will be used for controlled trials and field testing. The thesis continues with Chapter 5, which summarises and discusses the thesis as a whole.

5. Discussion

This thesis has examined the identified problem, investigated the gestational diabetes (GD) cycle of care in South Africa, analysed the effectiveness and the features of existing GD mHealth platforms and documented the design, development and testing of a new GD mHealth platform. The following paragraphs synthesise and discuss the information presented so far.

It has been found that South African women with GD are not managed or educated about self-care effectively, do not self-monitor frequently enough, if at all, and, therefore, often succumb to various GD induced complications. The GooDMoM platform is designed to manage patients with GD by allowing them to monitor blood glucose readings and by offering an educational tool to its users, thus reducing the likelihood of GD induced complications.

The ineffective management of GD is largely due to financial and time constraints caused by the regularly required outpatient services. Women with GD have to commit to outpatient services every 1 to 4 weeks depending on the severity of their condition and the stage of gestation (Mackillop et al., 2018). Even with the regularly required outpatient services, healthcare professionals are still not able to monitor their patients frequently enough, which means they cannot intervene timeously to prevent diabetes complications or provide feedback as often as they might like. The GooDMoM platform offers healthcare professionals the ability to remotely monitor their patients in real-time. This may reduce the required frequency of outpatient services, which may lighten the financial and time burden placed on patients. The platform is also designed to aid healthcare professionals in making better diagnoses and timeous interventions when necessary.

The fact that that record keeping in South Africa's public healthcare sector is mostly paper-based contributes to the ineffectiveness of GD management practices in South Africa. Paper-based record keeping is associated with many problems, including the possible loss of data due to human error, records being damaged and logistical difficulties relating to the transfer of data. While the private healthcare sector has made a transition to digital record keeping, most women with GD from both sectors are still tracking their blood glucose levels in paper-based logbooks. Apart from the problems mentioned above, paper-based logbooks are also susceptible to accidental and purposeful errors in data capture. The GooDMoM platform

eradicates the risks associated with paper-based record keeping by seamlessly recording and uploading the data to the backend where it is safely stored and can be analysed by healthcare professionals.

The GD cycle of care in South Africa is not as straight forward as depicted in Figure 2.1. One reason is that the screening methods and diagnostic criteria vary throughout South Africa, because each provincial health department can decide independently which diagnostic criteria to use. This makes determining the exact prevalence of GD in the country nearly impossible. In a country where there is a vast gap in healthcare quality between the public and private sectors, implementing the required cycle of care is easier said than done. The lack of resources in the public sector also means that the quality of care for patients in the public healthcare system may be poor. The GooDMoM platform is designed to make the management and treatment of GD more accessible and uniform, thus ensuring a higher quality of care for all patients.

Implementing various management practices reduces the risk of complications occurring as a result of GD, thus forms part of the GD cycle of care. Maintaining control of blood glucose levels is of utmost importance when it comes to the management of GD, because good glycaemic control has been directly linked to reducing the risk of GD induced complications. Lifestyle interventions such as nutritional therapy, meeting exercise goals and managing weight gain also play an integral part in the management of GD. This is because diets low in simple carbohydrates reduce blood glucose levels, exercise improves glucose tolerance by improving insulin sensitivity and managing bodyweight to remain within target bodyweight ranges helps to maintain glycaemic control. In more extreme cases pharmacotherapy can be used to help maintain glycaemic control; however, it must be noted that insulin is the preferred medication as it does not cross the placenta to a measurable extent, as opposed to alternatives. The GooDMoM platform aids patients in making various lifestyle interventions by allowing them to track their meals, exercise, weight, blood pressure and medication.

Many researchers had found mHealth to be a potential solution to the GD management problem. A systematic review and meta-analysis were performed to investigate various mHealth solutions for their effectiveness in aiding the management of GD. The initial search identified 1109 potential articles, but this was eventually narrowed down to 26 applicable articles of which eight were quantitative studies that were used for meta-analysis. These

studies were all relatively small in population size, assessed different forms of mHealth platforms and were deemed to contain moderate to high potential sources of methodological bias, so it was not possible to draw concrete conclusions from the results. Having said that, mHealth did offer advantages in terms of biological outcomes, maternal outcomes, perinatal outcomes, cognitive outcomes and economic outcomes, as described in the paragraph below. Many, but not all, of the outcomes which favoured mHealth were based on substantially heterogenous results and non-statistically significant margins.

A notable result from the meta-analysis found that using mHealth as an intervention caused a statically significant decrease in overall blood glucose levels (pre-prandial and postprandial combined) of 0.38 mmol/L (95% CI 0.52 mmol/L to 0.23 mmol/L) when compared to a control group. One of the maternal outcomes showed that the intervention successfully increased the probability of a normal vaginal delivery by a statistically significant amount. There was also a statistically significant reduction in the probability of neonatal hypoglycaemia occuring. Non-statistically significant results found that mHealth reduced HbA_{1c} levels, improved maternal outcomes by reducing the risk of emergency caesarean sections and gestational hypertension, improved perinatal outcomes by reducing the risk of premature births, improved patient compliance and reduced the frequency of outpatient services (which may reduce the cost of care)

Larger randomised controls are required to confirm the findings of the systematic review. Based on these benefits and the fact that the evidence clearly shows that mHealth is not associated with harmful effects of any nature, it is acceptable to hypothesise that an mHealth platform can improve the management of women with GD in South Africa.

Some of the notable benefits identified by patients using mHealth to manage their GD included the convenience in recording blood glucose levels digitally as opposed to paper logbooks, the ease of access to GD related information, the transport time saved, the outpatient service time saved and the ability for healthcare professionals to remotely monitor patients in real-time. The challenges reported by patients included the technical difficulties with parts of the mHealth systems and the possible loss of data privacy and security.

The important features and functions included in existing mHealth platforms were identified in order to inform the design of the GooDMoM platform. To summarise the features, a GD mHealth platform must have the ability to automatically receive blood glucose data and

manually track the patient's carbohydrates, activity duration, bodyweight, medication and symptoms. It must display data both graphically and numerically with colour-coded thresholds, send alerts and reminders to patients, educate patients on self-care and other diabetes related information, allow two-way communication between patients and healthcare professionals and transmit data to a backend for remote access by healthcare professionals. The platform must link the patient's and healthcare professional's calendar for consultations and store clinical and personal data on a database for real-time remote monitoring by healthcare professionals. These features were implemented during the design and development of the GooDMoM platform.

The platform was tested in the form of a usability study. Staff and student from the Division of Biomedical Engineering, University of Cape Town, acted as patients and healthcare professionals to test the mobile app and web app, respectively. The participants included in the usability study were all technologically proficient, with an average to low knowledge of diabetes, and were qualified as engineers, clinicians, dieticians, pharmacists and other health related professions. The results showed that 50% of participants were males and 50% were females. The average age of participants was 31.3 years of age. These participants might not be representative of the target group, which was considered when analysing the data.

Participants praised the UI design, especially the colour scheme and the layout of both the mobile app and web app. However, there was mixed feedback regarding the platform name, GooDMoM. Some of the notable findings from the usability study included that 50% of participants rated the mobile app as "easy", 30% as "very easy" and 20% as "extremely easy" to use. The results showed that 50% of participants rated the dashboard as the most important feature, while 60% of participants said that they would "definitely use" the mobile app to manage their disease. Regarding the web app, 50% of participants rated the web app as "extremely easy" to use and 70% of participants said they would "definitely use" the GooDMoM platform to manage their patients with GD (if they were a GD healthcare professional). These results meant that the platform exceeded its requirements and placed the platform in a good position for further development.

The feedback gained in the usability study will be used to guide the development of a beta version of the platform. This version will be ready for field testing and controlled trials.

6. Conclusion

This chapter will conclude the thesis by presenting the main points of the thesis. It also lists the limitations and recommendations for further development and future research.

The aim of this project was to develop an mHealth platform for GD self-management and for remote monitoring by health professionals to improve the GD cycle of care in South Africa. It was decided that the solution to the GD management problem would involve the use of mHealth. The developed mHealth platform, called GooDMoM, used a mobile app for patients and a web app for healthcare professionals. Research showed that such a platform could benefit patients both financially and timewise, by reducing the frequency of outpatient services required. It could also positively impact glycaemic control, maternal outcomes, perinatal outcomes and patient compliance. It could impact positively on the healthcare professionals by reducing the tediousness of their workload and allowing for remote monitoring of patients. If the platform were to be implemented in South Africa, it would have the potential to optimise the GD management process in both the public and private healthcare sectors in the country.

6.1. Limitations

A limitation identified relating to the assessment of GD management practices in South Africa was the fact that no GD healthcare professionals were interviewed, and no physical observations were made regarding the matter. The management practices and the cycle of care were assessed through a narrative literature review using the limited amount of research articles available. This limitation meant that assumptions made based on the literature review might not be reliable.

The main limitations of the systematic review conducted to assess the effectiveness of existing GD mHealth platforms included the fact that all the studies identified were relatively small in population size and all of them were conducted in developed countries. These limitations meant that all the results obtained might not be representative of the South African population.

The prototype used Firebase as a backend, which meant the prototype relied on Firebase's privacy and security. This could bring the privacy and security of patients' data into question. Another limitation of the prototype was that the mobile app is Android based, which excluded

iPhone users. Lastly, the app did not have functionality built in to support community healthcare workers who would benefit from a version of the mobile app which would allow them to monitor multiple patients. This function could benefit rural communities where patients might not have access to smartphones but could be monitored by a community-based healthcare worker.

6.2. Recommendations

The GD management practices used in South Africa, including their flaws, need to be researched further. This can be done through a more user-centred approach, interviewing healthcare professionals directly involved in the management of GD, like obstetricians and midwives, and patients with GD.

A large RCT is required to be done at a healthcare institution in South Africa to assess the effectiveness of mHealth in the management of diabetes. It is recommended that this trial consist of at least 1000 women with GD. Once the GooDMoM platform is ready for clinical testing, an RCT will be the next step.

The GooDMoM platform requires its own backend to be developed with security, privacy and scalability in mind. This will allow administrators to be in control of the data without relying on a third party such as Firebase. This will also keep costs down as user numbers increase. An iOS version of the app is required as well as the ability to allow community-based healthcare workers to use the mobile app to be inclusive of all South African women with GD.

Future developments include:

- the creation of a South African GD information database for the tips screen,
- the ability to automatically generate tips based on data trends and gestational stage,
- the ability to offer decision support based on user data,
- the ability to use an image reader to add medication based on the barcode,
- the automated generation of antenatal appointments,
- the use of blockchain to transfer data securely,
- the integration with existing digital health platforms like MomConnect, and
- the addition of pregnancy specific features like a contraction timer, baby kick counter and baby size visualiser in order to make GooDMoM comprehensive.

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Appendix A: High-Fidelity Mock-Up Testing

Demographics

Name: Click or tap here to enter text.

Date: Click or tap to enter a date.

On a scale of 1 to 5 (1 = not at all confident, 5 = very confident), how would you rate your level of confidence in using your mobile phone or computer?

1☐ 2☐ 3☐ 4☐ 5☐

On a scale of 1 to 5 (1 = not at all knowledgeable, 5 = very knowledgeable), how would you rate your level of knowledge about diabetes?

1☐ 2☐ 3☐ 4☐ 5☐

How many times per day do you test your blood glucose levels?

a. Never
b. Rarely (once per week)
c. Occasionally (2-3 times per week)
d. Frequently (1-2 time per day)
e. Very Frequently (3+ times per day)

1☐ 2☐ 3☐ 4☐ 5☐

Have you used an app to track your blood glucose levels (if you have diabetes)?

Yes ☐ No ☐

Mobile Application High-fidelity Mock-up

Tasks to be performed

Please complete the tasks below and mark the tasks that you complete:

1. **Sign-up** ☐

Once the mock-up has opened on the home screen, click the "SIGN-UP" button to open the "Create Account" screen. Click the "CONTINUE" button to open the "Enter Personal Information" Screen. Click the "CONTINUE" button to complete the sign-up process.

2. **View the feed** ☐

Click on the "Feed" icon in the toolbar to open the feed screen.

3. **Log out** ☐

Once signed in, click on the "Settings" icon in the toolbar to open the "Settings" screen. Click on the "Log Out" icon or text to log out.

4. **Log in** ☐

On the home screen, click the "LOG IN" button to open the "Log In" screen. Click the "CONTINUE" button to complete the log in process.

5. **Add a reminder** (appointment, medication or glucose reading) ☐

Once logged in, click on the "Reminders" icon in the toolbar to open the "Add Reminder" screen. Click on the "ADD" button to add the reminder. Click on the "Okay" text or on the tick button when the confirmation pop-up displays.

6. **Enter data** (glucose reading, meal, carbs, activity, bodyweight, medication) ☐

Once logged in, click on the "Data" icon in the toolbar to open the "Data Entry" screen.

7. **Synchronise data** with glucose meter on data entry screen ☐

Click on the synchronise icon or the "Glucose" text near the top of the data entry screen to synchronise with the Bluetooth enabled glucose meter. Click on the "Okay" text or on the tick button when the confirmation pop-up displays. Scroll down and click the "ADD" button to add the data. Click on the "Okay" text or on the tick button when the confirmation pop-up displays.

8. **Send a message** to healthcare professional ☐

Once logged in, click on the "Messenger" icon in the toolbar to open the messenger screen in order to message a healthcare professional. Click on the send arrow near the bottom right of the screen to send a message. Click anywhere on the screen to dismiss the "sent" pop-up.

9. **View "Tips and tricks" articles** ☐

Once logged in, click on the "Tips" icon in the toolbar to open the "Tips and tricks" screen. Scroll down to view more articles.

10. **Go to settings** ☐

Once logged in, click on the "Settings" icon in the toolbar to open the "Settings" screen.

a. View profile ☐

On the "Settings" screen, click the "PROFILE" button to view profile.

b. **Change profile picture** ☐

On the "settings" screen or the profile screen, click on the camera icon to view change or remove a profile picture.

Post-task questions

1. On a scale of 1 to 5 (1 = negative, 5 = positive), how would you rate the ease of your experience with the GoodMoM app?

   1☐ 2☐ 3☐ 4☐ 5☐

2. On a scale of 1 to 5 (1 = unsuitable, 5 = suitable), how suitable did you think the GooDMoM name was for the platform?

   1☐ 2☐ 3☐ 4☐ 5☐

3. On a scale of 1 to 5 (1 = unattractive and inappropriate, 5 = attractive and appropriate), how would you rate the colour scheme of the app?

   1☐ 2☐ 3☐ 4☐ 5☐

4. On a scale of 1 to 5 (1 = cluttered and confusing, 5 = well-spaced and easily understandable), how would you rate the layout of the app?

   1☐ 2☐ 3☐ 4☐ 5☐

5. Did you have any navigation issues? Yes ☐ No ☐

   If so, please briefly describe your issue:

   Click or tap here to enter text.

6. Which feature did you think is most important?

1. The feed (graphically and statistically displays results)
2. The reminders (remind the user about appointments medication and glucose testing)
3. The data capture (automatically capture blood glucose data and manually capture the rest)
4. The messenger (directly communicate with a healthcare professional)
5. The tips and tricks

   1☐ 2☐ 3☐ 4☐ 5☐

7. Were there any features you did not understand? Yes ☐ No ☐

   If so, please briefly describe which one and why:

   Click or tap here to enter text.

Web Application High-fidelity Mock-up

Tasks to be performed

Please complete the tasks below and mark the tasks that you complete:

1. **Log in** ☐

Once the mock-up has opened on the home screen, click the "LOG IN" button to open the "Log In" screen. Click the "LOG IN" button to complete the log in process.

2. **View the patient database** ☐

Click on "PATIENTS" anywhere on the screen to open up the "Patient Database" where the doctor can access his patients.

3. **View a specific patient** ☐

Click on a specific patient to open their profile.

4. **View the patient's personal details, patient history and dashboard** ☐

On the patient's profile, use the navigation bar on the left to view the patient's "PERSONAL DETAILS", "PATIENT HISTORY" (can scroll down to view more) and "BLOOD GLUCOSE LEVELS".

5. **View the messenger** ☐

Click on "MESSENGR" anywhere on the screen to open up the "Messenger" where the doctor can communicate with linked patients.

6. **View the calendar** ☐

Click on "Calendar" anywhere on the screen to open up the "Calendar" where the doctor's appointments will be displayed (linked to patient's mobile app).

7. **View the Home screen** ☐

On any screen, click on the GooDMoM symbol in the top left to return to "Home"

Post-task questions

1. On a scale of 1 to 5 (1 = negative, 5 = positive), how would you rate the ease of your experience with the GoodMoM web app?

   1☐ 2☐ 3☐ 4☐ 5☐

2. On a scale of 1 to 5 (1 = cluttered and confusing, 5 = well-spaced and easily understandable), how would you rate the layout of the web app?

   1☐ 2☐ 3☐ 4☐ 5☐

3. Did you have any navigation issues? Yes ☐ No ☐

   If so, please briefly describe your issue:

   Click or tap here to enter text.

4. Was there any functionality you believed needed to be added? Yes ☐ No ☐

   If so, please briefly describe what:

   Click or tap here to enter text.

5. If you have any other comments, please describe them below:

   Click or tap here to enter text.

Appendix B: Prototype Testing

Demographics

Name: Click or tap here to enter text.

Date: Click or tap to enter a date.

Age: Click or tap here to enter text.

Gender: Choose an item.

1. How confident are you in using a smartphone?
   a. ☐ Extremely confident
   b. ☐ Very confident
   c. ☐ Adequately confident
   d. ☐ Unconfident
   e. ☐ Extremely unconfident
2. How confident are you in using a computer?
   a. ☐ Extremely confident
   b. ☐ Very confident
   c. ☐ Adequately confident
   d. ☐ Unconfident
   e. ☐ Extremely unconfident
3. How often do you use a health app (fitness apps, sleep apps, diet apps etc.)?
   a. ☐ Very Frequently (3+ times per day)
   b. ☐ Frequently (1-2 time per day)
   c. ☐ Occasionally (2-3 times per week)
   d. ☐ Rarely (1 time per week or less)
   e. ☐ Never
4. How often do you use a health website to track data (fitness sites, dieting sites etc.)?
   a. ☐ Very Frequently (3+ times per day)
   b. ☐ Frequently (1-2 time per day)
   c. ☐ Occasionally (2-3 times per week)

d. ☐ Rarely (1 time per week or less)

e. ☐ Never

5. How knowledgeable are you about diabetes?

a. ☐ Extremely knowledgeable

b. ☐ Very knowledgeable

c. ☐ Adequately knowledgeable

d. ☐ Ignorant

e. ☐ Extremely ignorant

6. How often do you test your blood glucose levels?

a. ☐ Very Frequently (3+ times per day)

b. ☐ Frequently (1-2 time per day)

c. ☐ Occasionally (2-3 times per week)

d. ☐ Rarely (1 time per week or less)

e. ☐ Never

7. Have you used an app to track your blood glucose levels?

a. ☐ Very Frequently (3+ times per day)

b. ☐ Frequently (1-2 time per day)

c. ☐ Occasionally (2-3 times per week)

d. ☐ Rarely (1 time per week or less)

e. ☐ Never

Mobile Application Prototype

Tasks to be performed

Please complete the tasks below and mark the tasks that you complete:

1. **Sign-up** ☐

When asked to enter your healthcare professional's surname, user ID and type, enter "Barnard", "1" and obstetrician respectively. For your diabetes type, select "Gestational Diabetes". Calculate your due date via the "Last Period" method, with the first day of last period being 1 March 2019 and the cycle length being 28 days.

2. **Add glucose reading reminders via the "Reminders" screen** ☐

(1) Add a morning glucose reading reminder which repeats every 1 day for 3 counts at 09:30 starting on day 1 of testing. (2) Add a pre-lunch glucose reading reminder which repeats every 1 day for 3 counts at 12:30 starting on day 1 of testing. (3) Add a post-lunch glucose reading reminder which repeats every 1 day for 3 counts at 13:30 starting on day 1 of testing. (4) Add an afternoon glucose reading reminder which repeats every 1 day for 3 counts at 16:30 starting on day 1 of testing.

3. **Record glucose data at the time specified above via the "Dashboard" screen** ☐

Use the glucose meter to measure your blood glucose levels. For each data entry, record your meal data, activity data, weight data, medication data, blood pressure data and symptoms ONLY if relevant since the last entry.

4. **Send a message to the healthcare professional via the "Messenger" screen** ☐

Reply to the healthcare professional's message.

5. **View the diabetes and pregnancy related articles via the "Tips" screen** ☐

Open one of the articles which interest you.

6. **View your profile summary via the "Profile" screen** ☐

Can you see your calculated BMI as well as your glucose goals entered by your healthcare professional?

7. **Change the notification tone via the "settings" screen** ☐
8. **Send a feedback email via the "Help & Feedback" screen** ☐

Once all tasks have been completed, please email the admin saying, "all tasks have been completed".

9. **Sign out** ☐

Please enter any additional comments here:

Click or tap here to enter text.

Post-task questions

1. Was the GooDMoM app easy to use?
   a. ☐ Extremely easy
   b. ☐ Very easy
   c. ☐ Adequately easy
   d. ☐ Difficult
   e. ☐ Extremely difficult

   Please describe any issues with the ease of use (navigation, layout, bugs etc.):

   Click or tap here to enter text.

2. Did you find the dashboard to be informative?
   a. ☐ Extremely informative
   b. ☐ Very informative
   c. ☐ Adequately informative
   d. ☐ Uninformative
   e. ☐ Extremely uninformative
3. Did you find the reminders to be helpful?
   a. ☐ Extremely helpful
   b. ☐ Very helpful
   c. ☐ Adequately helpful
   d. ☐ Unhelpful
   e. ☐ Extremely unhelpful
4. Did you find the direct line of communication to the healthcare professional to be advantageous?
   a. ☐ Extremely advantageous
   b. ☐ Very advantageous
   c. ☐ Adequately advantageous
   d. ☐ Disadvantageous
   e. ☐ Extremely disadvantageous
5. Did you find the articles in the “tips” screen to be informative?

a. ☐ Extremely informative
b. ☐ Very informative
c. ☐ Adequately informative
d. ☐ Uninformative
e. ☐ Extremely uninformative

6. Which feature did you think is most important to the management of gestational diabetes?
   a. ☐ The dashboard
   b. ☐ The reminders
   c. ☐ The messenger
   d. ☐ The tips
   e. ☐ None

   If you did not like any of the features, please explain why:

   Click or tap here to enter text.

7. Did you think the GooDMoM platform would help you manage your gestational diabetes?
   a. ☐ Definitely
   b. ☐ Probably
   c. ☐ Maybe
   d. ☐ Probably not
   e. ☐ Definitely not

8. Would you use the GooDMoM platform to manage your gestational diabetes?
   a. ☐ Definitely
   b. ☐ Probably
   c. ☐ Maybe
   d. ☐ Probably not
   e. ☐ Definitely not

Do you have any other comments? If so, please add them here:

Click or tap here to enter text.

Web Application Prototype

Tasks to be performed

Please complete the tasks below and mark the tasks that you complete:

1. **Sign-in** ☐

Go to https://gd-mhealth.firebaseapp.com in your web browser. You will be using Dr Christian Barnard's profile (this is a fake profile for testing purposes) to complete these tasks. The email is doctor@mail.com and the password is "abc123" to sign-in to this profile.

2. **View the patients assigned to Dr Barnard via the "Patients" page** ☐

Open the "Patients" page to view the list of patients assigned to you. Click on [your name] to enter [your name]'s profile.

3. **View the patient details of [your name]** ☐

View [your name]'s patient details by clicking on "Patient Details" on the side navigation. Edit [your name]'s target weight and add a comment saying, "I have viewed the details" and save it.

4. **View [your name]'s dashboard** ☐

View [your name]'s dashboard by clicking on "Dashboard" on the side navigation. Change the time display to "Day" and choose a date on which [your name] recorded glucose data. Hover your mouse over the highest glucose recording and view the carbs and symptoms that may be associated with that recording. Go to the "Full Gestation" time period and refresh the glucose chart to display "Fasting" and "Postprandial" glucose readings.

5. **View the "Calendar" page** ☐

Open the "Calendar" page and click on one of the events in May to display more details. Add an event for [your name] on today's date titled "Usability Test". Verify that it appears on the calendar.

6. **Send a message** ☐

Send a message to Jason Collier once you have completed the tasks saying, "Tasks completed". Do this by opening Jason Collier's profile and clicking on "Messenger" on the side navigation

Post-task questions

1. Was the GooDMoM web app easy to use?

    f. ☐ Extremely easy

    g. ☐ Very easy

    h. ☐ Adequately easy

    i. ☐ Difficult

    j. ☐ Extremely difficult

    Please describe any issues with the ease of use (navigation, layout, bugs etc.):

    Click or tap here to enter text.

2. Did you find the patient profile easy to understand and navigate?

    f. ☐ Extremely easy

    g. ☐ Very easy

    h. ☐ Adequately easy

    i. ☐ Difficult

    j. ☐ Extremely difficult

3. Did you find the direct line of communication to the patient to be advantageous?

    f. ☐ Extremely advantageous

    g. ☐ Very advantageous

    h. ☐ Adequately advantageous

    i. ☐ Disadvantageous

    j. ☐ Extremely disadvantageous

4. Did you find patient details with goals and ranges to be advantageous?

    a. ☐ Extremely advantageous

    b. ☐ Very advantageous

    c. ☐ Adequately advantageous

    d. ☐ Disadvantageous

    e. ☐ Extremely disadvantageous

5. Did you find the dashboard to be informative?

    a. ☐ Extremely informative

b. ☐ Very informative

c. ☐ Adequately informative

d. ☐ Uninformative

e. ☐ Extremely uninformative

6. Did you find the calendar easy to understand and use?

a. ☐ Extremely easy

b. ☐ Very easy

c. ☐ Adequately easy

d. ☐ Difficult

e. ☐ Extremely difficult

If you did not like any of the features, please explain why:

Click or tap here to enter text.

7. Did you think the GooDMoM platform would help you to manage patients with gestational diabetes (if you were a gestational diabetes healthcare professional)?

f. ☐ Definitely

g. ☐ Probably

h. ☐ Maybe

i. ☐ Probably not

j. ☐ Definitely not

8. Would you use the GooDMoM platform to manage your patients with gestational diabetes (if you were a gestational diabetes healthcare professional)?

f. ☐ Definitely

g. ☐ Probably

h. ☐ Maybe

i. ☐ Probably not

j. ☐ Definitely not

Do you have any other comments? If so, please add them here:

Click or tap here to enter text.