GLOBAL HEALTH INNOVATION

OPEN UCT PUBLICATIONS

A review of mHealth interventions for diabetes in pregnancy

Jason Leslie Collier*, Jill Fortuin Abrahams

Division of Biomedical Engineering, Department of Human Biology, University of Cape Town, Cape Town, South Africa

Received 15 August 2019; Accepted 30 October 2019; Published online 27 November 2019

Abstract

Gestational diabetes mellitus (GDM) has high morbidity and risk for mortality when mismanaged. This is particularly relevant in low- and middle-income countries (LMIC), where GDM related complications occur at a higher rate, with worse outcomes, due to a lack of healthcare resources. Mobile health (mHealth) presents an opportunity to improve the management of GDM in LMIC. We conducted a meta-analysis, which found that using mHealth as an intervention for GDM caused a statistically significant decrease of 0.38 mmol/L (95% CI -0.52 mmol/L to -0.23 mmol/L) in overall blood glucose levels during pregnancy compared to the control group. There was a significantly higher probability of vaginal deliveries in the intervention group than the control group (risk ratio (RR) = 1.18, 95% CI 1.03 to 1.36). It was less likely for new-borns from the intervention group to be diagnosed with hypoglycaemia than new-borns from the control group (RR = 0.67, 95% CI 0.48 to 0.93). This review found evidence for mHealth offering improvements in biological, maternal, perinatal, cognitive and economic outcomes by aiding in the management of GDM. This could be particularly important to LMIC where the lack of resources and high healthcare-related costs contribute to the mismanagement of GDM.

Keywords: gestational diabetes; diabetes mellitus; pregnancy; digital health; meta-analysis

Introduction

Diabetes is a chronic, non-communicable condition which affects the body's ability to process glucose (American Diabetes Association, 2014). Gestational diabetes mellitus (GDM) 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).

Once GDM has been diagnosed, controlling blood glucose levels becomes a fundamental part of its management (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). Women with GDM are encouraged to record their blood glucose levels at least 3-4 times daily (Garnweidner-Holme et al., 2015). Delivering these measurements along with related information 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 (Mackillop et al., 2018). Thus, regular medical check-ups are required for the healthcare professional to analyse the patient's blood glucose levels, and these occur every 1-4 weeks during the last 3 months of gestation (Mackillop et al., 2018). If this condition is poorly managed or left untreated, women and their children will be at an increased risk of complications, before during and after birth (Kampmann et al., 2015).

Approximately 7% of all pregnancies (ranging from 1% to 14%, depending on the population studied and the diagnostic tests employed) are complicated by GDM (American Diabetes Association, 2014). In low and middle-income countries (LMIC), pregnancy is becoming more common in wealthier, older and more obese women, which means the prevalence of GDM in these countries is increasing rapidly (Kampmann et al., 2015). The intensive GDM management process is especially challenging in LMIC where access to resources and trained personnel is limited; this results in GDM-related complications occurring at a higher rate, with worse outcomes in LMIC (Goldenberg et al., 2016).

Lau et al. (2016), Ming et al. (2016) and Rasekaba et al. (2015) have systematically reviewed various studies which indicate that mobile health (mHealth) may aid in the management of women with GDM, to assist with tighter glycaemic control and in preventing antenatal, perinatal and post-partum complications. However, these studies involved high-income countries,

*Corresponding author: jasoncollier@live.com

http://Journals.uct.ac.za/index.php/GHI

leaving the question as to whether the principles of mHealth being used to aid the management of GDM can be applied to LMIC, as a result of the increased adoption of smartphones in LMIC (Bloomfield et al., 2014).

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 where it is not possible to access the entire population through physical healthcare institutions due to a lack of resources (Goldenberg et al., 2016). Thus, mHealth has the potential to provide a more cost efficient and effective solution to the GDM management problem (Lau et al., 2016). This combined with mHealth's other benefits, e.g. its ability to digitally record and display blood glucose data, underlies this review of the impact of mHealth on the management of GDM, and its potential in LMIC.

Methods

This study broadly follows the Preferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA) framework (Moher et al., 2009). The review addresses the research question: "Will mHealth be a more effective management solution for women with GDM when compared with existing GDM management practices?"

Inclusion criteria

Studies included in this review included women with GDM. However, pregnant women who had previously been diagnosed with type 1 diabetes (T1D) or type 2 diabetes (T2D) were also included, because they followed a similar cycle of care as women who were diagnosed with GDM (over the last 12 – 16 weeks of gestation), according to Mackillop et al. (2018).

The intervention of mHealth included all electronic devices which transferred data via an internet connection to provide health information. The intervention was compared to existing GDM management practises, which included the process of manually recording blood glucose levels in logbooks and presenting the data to healthcare professionals at medical check-ups. Screening, diagnosis and recommended lifestyle changes were the same for intervention and comparison groups.

The primary outcome of this research was to gauge the effectiveness of the intervention by comparing intervention groups and comparison groups regarding biological outcomes (blood glucose levels and HbA_{1c} levels). Secondary outcomes include:

- 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 in terms of blood glucose recordings),
- economic outcomes (frequency of outpatient services and healthcare related costs during pregnancy), and
- cognitive outcomes (patient and healthcare professional satisfaction levels).

Journal articles published between January 2014 and December 2018 were included; the fast progression of mHealth-related technologies meant that mHealth interventions prior to this 5-year period were deemed less relevant and thus were excluded. All articles with population groups including animals or males were excluded. Only quantitative studies in the form of randomised control trials (RCTs) and clinical control trials (CCTs) were included.

Search strategy

Table 1 shows the search strategy (adapted where necessary to specific databases). It includes the keywords used to search the databases for relevant articles. The search was performed in the following databases, with the help of a professional librarian: 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. Endnote was used as a reference management tool.

Study selection

The first author and co-author screened all articles based on title and abstract in an effort to identify potentially significant articles from the original search. The full texts of the remaining articles were then evaluated; ineligible articles were excluded based on the inclusion criteria.

The title and abstract screening and full text screening criteria used were as follows: the population group in the article was women with GDM or pregnant women who had previously been diagnosed with type T1D or T2D; the intervention was mHealth-related; and one of the primary outcomes was blood glucose levels.

Table 1. Search strategy (adapted where necessary to specific databases).

#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)	
#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	
#7	#3 AND #6	
#8	Publication dates: 2014 - 2018	
#9	#7 AND #8	

Quality Assessment and Data Extraction

Each of the included studies was scored for risk of bias using the Cochrane Collaboration Risk of Bias Tool (Higgins et al., 2003). Data relating to the primary and secondary outcomes were extracted by the author and stored in a Review Manager (RevMan Version 5.3) comparison table. 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.

Statistical Analysis

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

Given the variance across studies regarding technologies employed, standards of care, and research methods, a large amount of heterogeneity was anticipated. Therefore, the random effects analysis model was applied and the I^2 characteristic 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 considered significant if the p value was less than 0.05. The pooled data were displayed in a forest plot, but only if there were more than three studies with relevant data.

Results

The search process is depicted in Figure 1 as a PRISMA flow diagram (PRISMA, 2019). Once the search was complete, all 1109 references were saved in Endnote, which was used to automatically remove duplicates, leaving 875 unique articles. Once the title and abstract of the articles were screened as per the eligibility criteria, 50 articles remained. The screening of the full text of each article left 8 relevant articles. Articles were excluded for the following reasons: the article was a duplicate, i.e. the results had been published elsewhere (n = 8), the full text was inaccessible (n = 7), the intervention or the population did not meet inclusion criteria (n = 6), the results were not aligned with the required outcomes (n = 16), or the article was not quantitative (specifically a RCT or CCT) in nature (n = 5).

Study Characteristics

Quantitative studies were used in the meta-analysis and to identify the main features and functions of existing mHealth solutions for GDM. Systematic reviews were used as a source of related work to which results could be compared. Table 2 shows the characteristics of the eight quantitative studies extracted.

The eight quantitative studies included 791 participants, 399 in the intervention group and 392 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 was required according to Ming et al. (2016)). All the included articles were peer-reviewed, and all were supported by grants. Seven studies used RCT designs and one used a CCT design (Carral et al., 2015).

Study Quality

The study quality was assessed by evaluating the risk of bias. Figure 2 depicts the risk of bias of the eight quantitative studies. All the trials displayed potential sources of methodological bias. Six studies out of the eight adequately randomised the sequence generation. Two studies had 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 all were marked with an unclear risk. All the studies had an unclear risk of selective reporting.

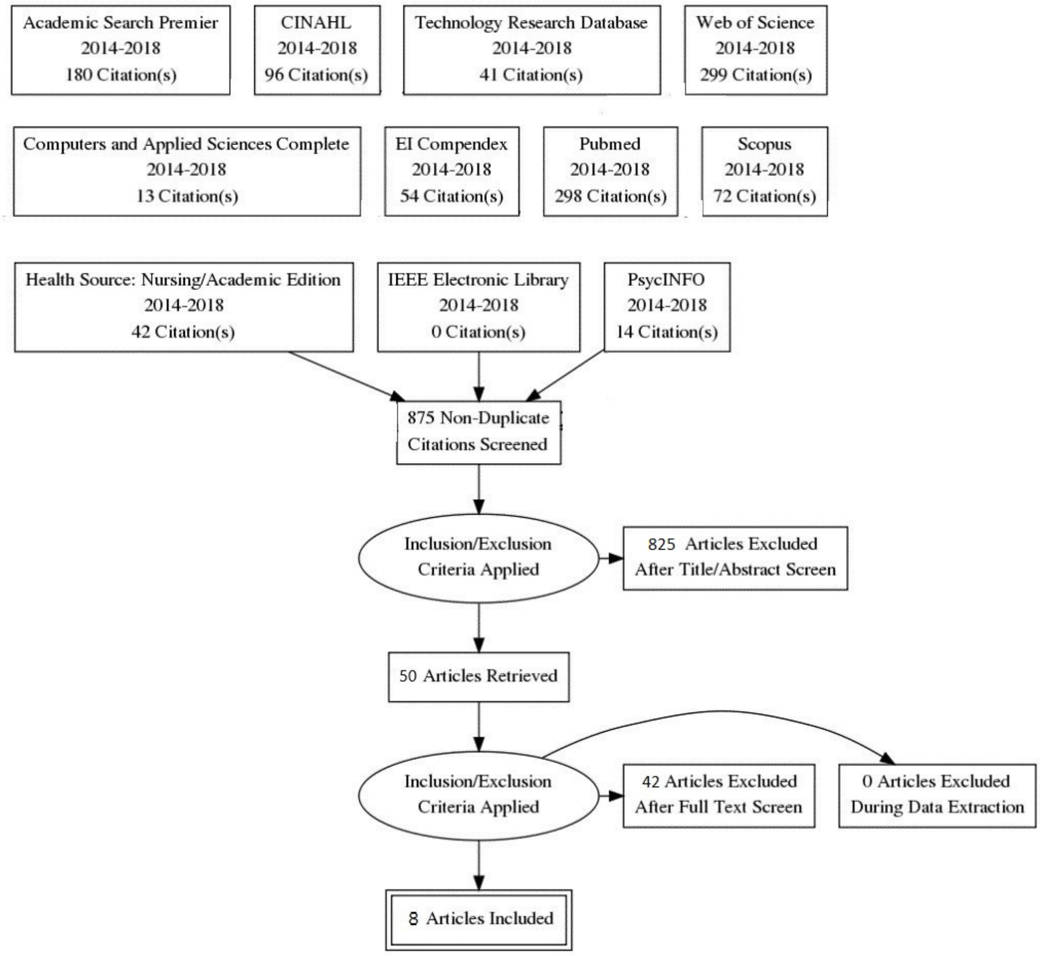

Figure 1. PRISMA flow diagram

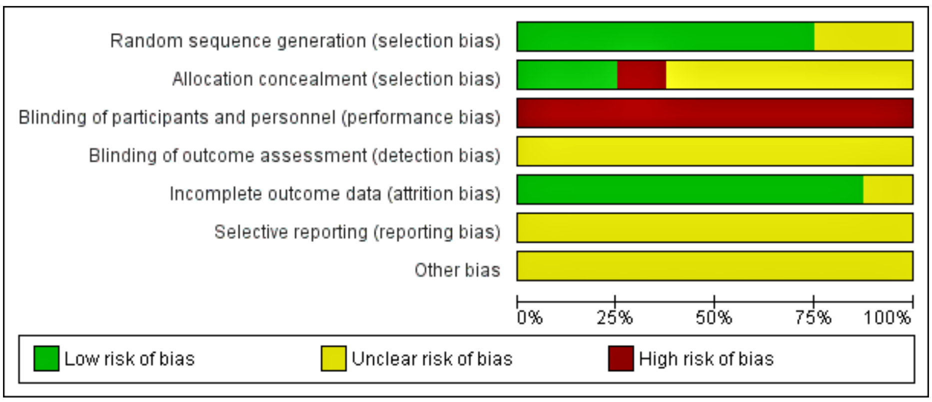

Figure 2. Risk of bias.

Table 2. Characteristics of included studies.

Study	**Population Size (Intervention:Control)**	**Population Type**	**Intervention Type**	**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)	GDM & T2D	App logbook with automatic data entry Data reviewed via website by HP	✓												✓	
Bromuri et al. (2016)	24 (12:12)	GDM	App logbook with manual data entry Data reviewed via website by HP	✓													
Carral et al. (2015)	104 (40:64)	GDM, T1D & T2D	Website logbook with manual data entry Data reviewed via website by HP		✓		✓	✓	✓	✓			✓	✓			
Given et al. (2015)	47 (21:26)	GDM	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)	GDM	App logbook with automatic or manual data entry Data reviewed via app by HP		✓	✓	✓	✓		✓	✓				✓	✓	
Mackillop et al. (2018)	203 (101:102)	GDM	App logbook with automatic data entry Data reviewed via app by HP		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓
Miremberg et al. (2018)	120 (60:60)	GDM	App logbook with manual data entry Data reviewed via exported results by HP	✓		✓	✓	✓	✓			✓		✓		✓	
Rasekaba et al. (2018)	95 (61:34)	GDM	Website logbook with manual data entry Data reviewed via website by HP				✓	✓	✓		✓	✓			✓		✓
Total	791 (399:392)																

HP=Healthcare Professional

Biological Outcomes

Three studies assessed blood glucose levels (Figure 3) 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 (3 studies, n = 218 participants, 95% CI -0.52 mmol/L to -0.23 mmol/L, $I^2 = 0\%$).

The HbA_{1c} levels (Figure 4) were 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% (4 studies, n = 449 participants, 95% CI -0.47% to 0.22%, $I^2 = 98\%$).

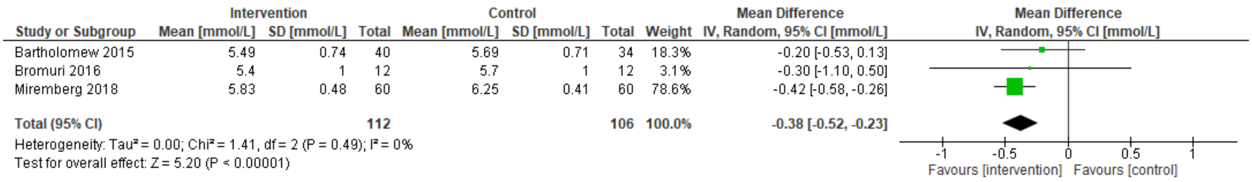

Figure 3. Forest plot of blood glucose levels (total).

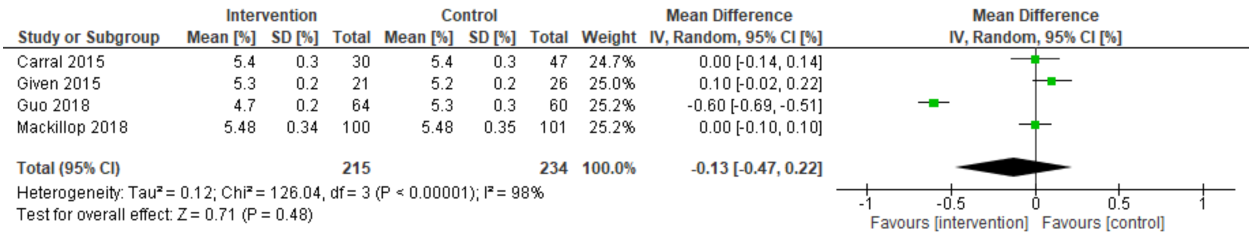

Figure 4. Forest plot of HbA_{1c} levels.

Maternal Outcomes

Mackillop et al. (2018), Miremberg et al. (2018) and Guo et al. (2018) found a higher probability of vaginal deliveries (Figure 5) in the intervention group than in the control group (RR = 1.18; 3 studies, n = 447 participants, 95% CI 1.03 to 1.36, $I^2 = 0\%$).

Six studies reported on the number of caesarean sections (Carral et al., 2015, Given et al., 2015, Guo et al., 2018, Mackillop et al., 2018, Miremberg et al., 2018, Rasekaba et al., 2018) as seen in Figure 6. The results showed that women in the intervention groups were less likely to have a caesarean section (RR = 0.81; 6 studies, n = 693 participants, 95% CI 0.60 to 1.10, $I^2 = 46\%$).

Of the above six studies, three reported on the number of emergency caesarean sections (Mackillop et al., 2018, Miremberg et al., 2018, Rasekaba et al., 2018). They found that women in the intervention group were less likely to have an emergency caesarean section than women in the control group (RR = 0.23; 3 studies, n = 418 participants, 95% CI 0.21 to 1.46, $I^2 = 66\%$).

Four studies assessed the number of gestational hypertension cases (Carral et al., 2015, Given et al., 2015, Mackillop et al., 2018, Miremberg et al., 2018). These studies found that women in the intervention group were less likely be diagnosed with gestational hypertension than women in the control group (RR = 0.67; 4 studies, n = 474 participants, 95% CI 0.25 to 1.77, $I^2 = 0\%$). There was no difference found in gestational ages at delivery between the intervention and control groups.

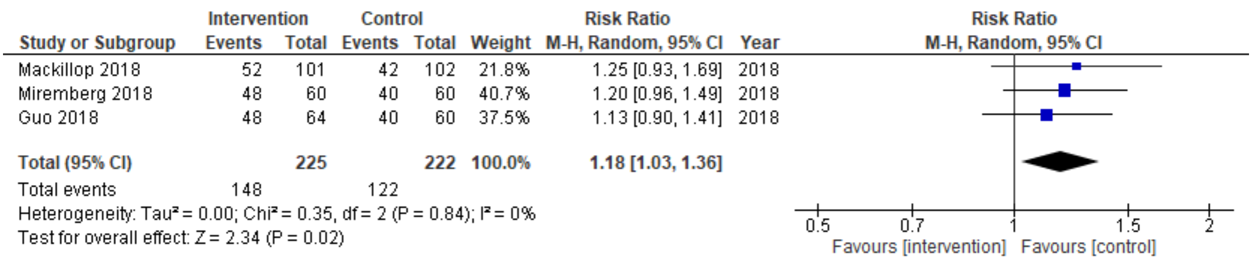

Figure 5. Forest plot of normal vaginal deliveries.

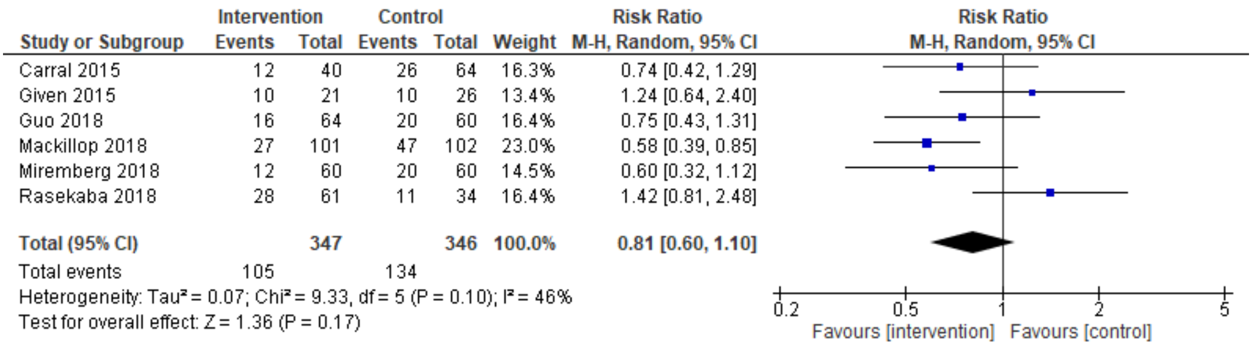

Figure 6. Forest plot of caesarean sections.

Perinatal Outcomes

The neonatal hypoglycaemia cases (Figure 7) were assessed by four studies (Carral et al., 2015, Given et al., 2015, Guo et al., 2018, Mackillop et al., 2018). The results 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 (RR = 0.67; 4 studies, n = 460 participants, 95% CI 0.48 to 0.93, $I^2 = 0\%$).

The meta-analysis of the premature births (Figure 8) showed that it was less likely for new-borns from the intervention group to be born prematurely than new-borns from the control group (RR = 0.50; 4 studies, n = 354 participants, 95% CI 0.23 to 1.09, $I^2 = 0\%$), as shown by four studies (Carral et al., 2015, Given et al., 2015, Mackillop et al., 2018).

Three studies (Given et al., 2015, Guo et al., 2018, Rasekaba et al., 2018) assessed the number of macrosomia cases. The studies found that new-borns from the intervention group were more likely to have macrosomia than new-borns from the control group (RR = 1.44; 3 studies, n = 266 participants, 95% CI 0.44 to 4.67, $I^2 = 40\%$). There were no differences found in birthweights and NICU admissions between the intervention and control groups.

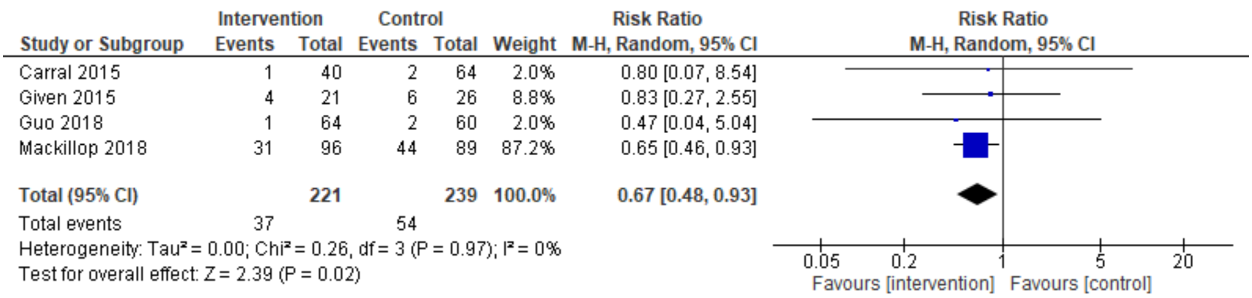

Figure 7. Forest plot of neonatal hypoglycaemia cases.

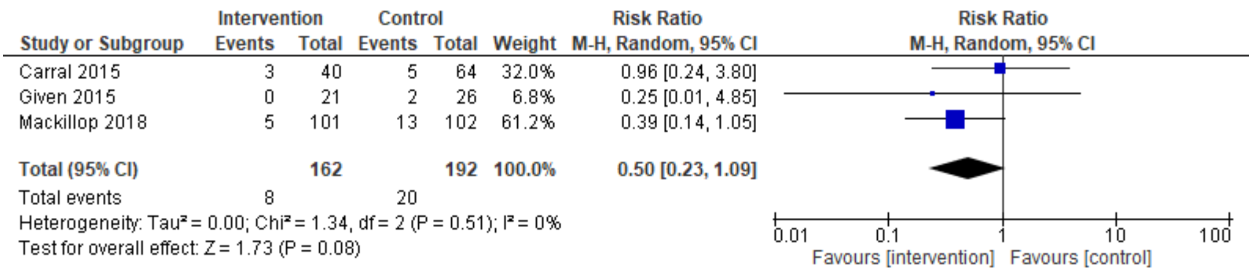

Figure 8. Forest plot of premature births.

Cognitive Outcomes

Three studies 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% (3 studies, n = 318 participants, 95% CI -0.27% to 22.06%, $I^2 = 99\%$) more compliant than women in the control group. Mackillop et al. (2018) and Bromuri et al. (2016) supported these findings; however, their measures of compliance were different to those of the three studies included in the meta-analysis. Figure 9 shows a forest plot of the patient compliance percentages.

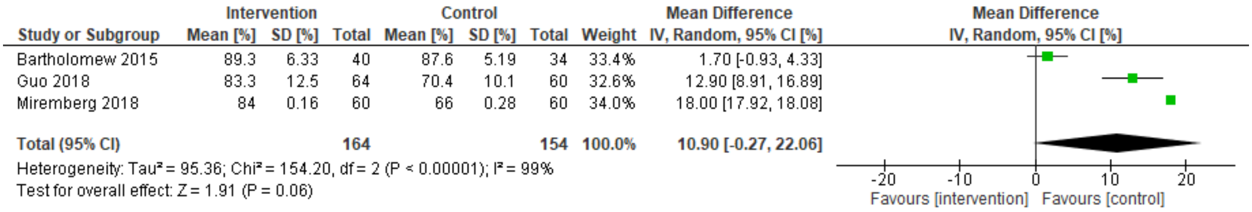

Figure 9. Forest plot of patient compliance

Economic Outcomes

Mackillop et al. (2018) assessed the healthcare costs for women with GDM. It was found that women in the intervention group paid a mean of £1044 (1 study, n = 203 participants, 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 (3 studies, n = 422 participants, 95% CI -3.36 to 0.65, I^2 = 96%). Carral et al. (2015) supported these findings but reported the results in a different manner to the studies included in the meta-analysis. Figure 10 shows a forest plot of the frequency of outpatient services.

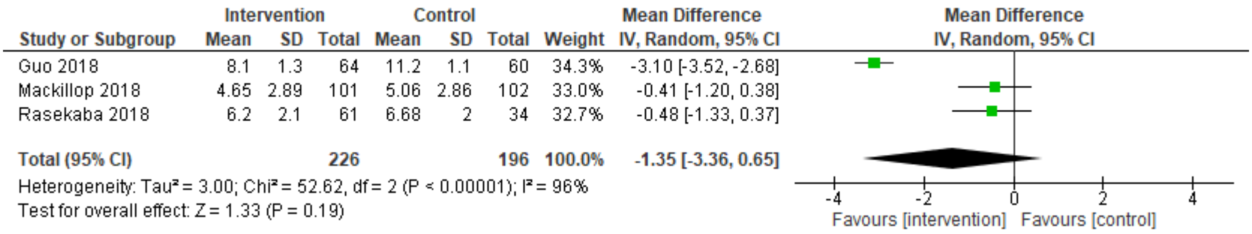

Figure 10. Forest plot of the frequency of outpatient services

Behavioural Outcomes

The benefits reported by the various studies included:

- the convenience of recording blood glucose levels digitally as opposed to 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 GDM 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:

- 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 GDM information matched with healthcare provided information (Garnweidner-Holme et al., 2018, 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).

Discussion

The eight studies included in the meta-analysis were small in population size and assessed different mHealth technologies, so it was not possible to draw conclusions from all of the results. It was shown, however, that mHealth offered several advantages in terms of biological outcomes, maternal outcomes, perinatal outcomes, cognitive outcomes and economic outcomes. Many of the outcomes that favoured mHealth were based on substantially heterogeneous results ($I^2 > 50\%$) and statistically non-significant margins ($P > 0.05$). The evidence showed no association of mHealth with harmful effects.

Several limitations were identified. The search was limited to English articles over a 5-year period from 2014 to 2018 to exclude articles based on mHealth technology older than 5 years (due to the fast progression of mHealth related technologies); this may have excluded relevant articles. The included studies all took place in developed countries which meant that the mHealth solutions reviewed would have to be adapted to suit LMIC contexts. 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. The variation in the mHealth technologies being tested, in the screening protocols that were implemented and in local medical practices, may have contributed to the substantial heterogeneity across many of the outcomes. Finally, seven studies were omitted because the full text was not accessible; however, none of the omitted studies were RCTs or CCTs, so they were not expected to affect the results.

The eight studies included in the meta-analysis were deemed to contain moderate sources of potential bias. This was largely due to the fact that the blinding of participants and personnel was not possible in any of the studies and none of the studies addressed the blinding of outcome assessments or the risk of selective reporting.

The biological outcomes showed that mHealth resulted in a statistically significant decrease in overall blood glucose levels (pre-prandial and postprandial combined). This was different from studies reviewing trials conducted prior to 2014, which did not find statistically significant evidence that the mHealth intervention reduced blood glucose levels in women with GDM (Ming et al., 2016, Rasekaba et al., 2015). The improved blood glucose levels may be as a result of newer mHealth technologies, which had become more effective due to the continuous research on this subject, or this may be a skewed result due to the limitations of the study, such as the small population size. The reduction in blood glucose levels was likely due to women, who were using the intervention, receiving direct feedback from healthcare professionals, the ease of access to GDM 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 impact of mHealth on blood glucose levels could be larger in LMIC, because of the higher mismanagement occurring in these countries due to a lack of resources (Goldenberg et al., 2016).

The results showed that mHealth interventions helped women to reduce their HbA_{1c} levels, which is consistent with previous meta-analyses (Lau et al., 2016, Ming et al., 2016, Rasekaba et al., 2015). The reduction in HbA_{1c} levels found were not statistically significant and were based on substantially heterogenous data, however. 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 mHealth successfully increased the probability of a normal vaginal delivery by a statistically significant amount, based on homogeneous data. Reductions in the probability of caesarean sections, emergency caesarean sections and gestational hypertension, as a result of the intervention, were not statistically significant. All these outcomes were based on data of acceptable heterogeneity, except for the emergency caesarean section outcome. The meta-analysis found no difference in gestational ages at delivery. These finding were not in keeping with previous meta-analyses that assessed maternal outcomes. Previous studies found mHealth to result in increases in caesarean sections (Lau et al., 2016, Ming et al., 2016) and gestational hypertension cases (Ming et al., 2016); these studies reported results that were not statistically significant. However, the findings of the current study agree with those of Rasekaba et al. (2015), who also found a statistically non-significant decrease in caesarean sections due to mHealth. None of the previous systematic reviews reported on normal vaginal delivery rates as is done in the current study.

The meta-analysis of the perinatal outcomes found no statistically significant results for the analysis on birthweights, macrosomia rates, NICU admissions or premature births, as found by previous reviews (Lau et al., 2016, Ming et al., 2016). There was, however, a statistically significant reduction in the probability of neonatal hypoglycaemia, based on homogeneous data, which was not found in previous studies. Although not statistically significant, the meta-analysis also found a notable reduction in the probability of a premature birth due to the use of mHealth.

The cognitive outcomes were not statistically significant; however, patient compliance was improved by the intervention. The data were substantially heterogeneous due to the possible differences in methods used to measure patient compliance. Patient compliance was not measured in previous studies, but previous studies found that mHealth motivated patients in the self-management of their disease (Lau et al., 2016, Ming et al., 2016, Rasekaba et al., 2015); this may explain the improved compliance found in the present analysis. It is expected that mHealth could have a larger impact on patient compliance in LMIC, where the interventions could be used to manage blood glucose levels remotely, addressing access constraints.

Economic outcomes were assessed in previous studies, which found that mHealth reduced the need for 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 GDM patients using mHealth. The reduction in the frequency of outpatient services was a probable reason for the healthcare costs for patients to be reduced. The Ming et al. (2016) and Rasekaba et al. (2015) findings were supported by the current study which reported a notable, but statistically non-significant reduction in outpatient services due to mHealth (although this result was based on substantially heterogeneous data). The reduction in the frequency of outpatient services would be of specific importance in LMIC, given the lack of access to healthcare facilities. This may result in a reduction in cost for patients with GDM in LMIC.

Five studies (Garnweidner-Holme et al., 2018, Hirst et al., 2015, Nicholson et al., 2016, Pais et al., 2017, Skar et al., 2018) reported that mHealth was associated with high levels of patient satisfaction; this was in agreement with a previous meta-analysis (Ming et al., 2016). The major benefits of using mHealth to manage GDM 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 in the study included technical difficulties associated with the use of technology and various data privacy concerns.

Conclusion

Using mHealth as an intervention resulted in a statistically significant decrease 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. It was less likely for new-borns from the intervention group to be diagnosed with hypoglycaemia than new-borns from the control group. The results suggest that mHealth has the potential to aid the management and monitoring of women with GDM in LMIC, but further research would be required to address LMIC contexts specifically. The major advantage of mHealth in LMIC could lie in its ability to support remote monitoring and reduce outpatient services, thereby reducing healthcare costs for patients. This would be particularly beneficial in resource-scarce settings where conventional methods of GDM management, such as seeing a healthcare professional at a healthcare facility, are not always possible due to the lack of availability, lack of access and high healthcare-related costs.

Acknowledgements

This research was supported by the National Research Foundation of South Africa.

References

American Diabetes Association. 2014. Diagnosis and Classification of Diabetes Mellitus. *Diabetes Care.* 37(Supplement 1):S81-90. DOI:10.2337/dc14-S081.

Anderson, M. 2017. Patient Web Portal Use among Women with Gestational Diabetes. *Theses and Dissertations.* 1438. Available: https://dc.uwm.edu/etd/1438.

Bartholomew, M.L., Soules, K., Church, K., Shaha, S., Burlingame, J., Graham, G., Sauvage, L. & Zalud, I. 2015. Managing Diabetes in Pregnancy Using Cell Phone/Internet Technology. *Clinical Diabetes.* 33(4):169-74. DOI:10.2337/diaclin.33.4.169.

Bloomfield, G.S., Vedanthan, R., Vasudevan, L., Kithei, A., Were, M. & Velazquez, E.J. 2014. Mobile health for Non-Communicable Diseases in Sub-Saharan Africa: a Systematic Review of the Literature and Strategic Framework for Research. *Globalization and Health.* 10(1):49. DOI:10.1186/1744-8603-10-49.

Bromuri, S., Puricel, S., Schumann, R., Krampf, J., Ruiz, J. & Schumacher, M. 2016. An Expert Personal Health System to Monitor Patients affected by Gestational Diabetes Mellitus: A Feasibility Study. *Journal of Ambient Intelligence & Smart Environments.* 8(2):219-37. DOI:10.3233/AIS-160365.

Carral, F., Ayala, M.d.C., Fernández, J.J., González, C., Piñero, A., García, G., Cañavate, C., Jiménez, A.I. et al. 2015. Web-Based Telemedicine System Is Useful for Monitoring Glucose Control in Pregnant Women with Diabetes. *Diabetes Technology Therapeautics.* 17(5):349-54. DOI:10.1089/dia.2014.0223.

Garnweidner-Holme, L., Borgen, I., Garitano, I., Noll, J. & Lukasse, M. 2015. Designing and Developing a Mobile Smartphone Application for Women with Gestational Diabetes Mellitus Followed-Up at Diabetes Outpatient Clinics in Norway. *Healthcare.* 3(2):310-23. DOI:10.3390/healthcare3020310.

Garnweidner-Holme, L., Hoel Andersen, T., Sando, M.W., Noll, J. & Lukasse, M. 2018. Health Care Professionals' Attitudes Toward, and Experiences of Using, a Culture-Sensitive Smartphone App for Women with Gestational Diabetes Mellitus: Qualitative Study. *Journal of Medical Internet Research Mhealth Uhealth.* 6(5):e123. DOI:10.2196/mhealth.9686.

Given, J.E., Bunting, B.P., O'Kane, M.J., Dunne, F. & Coates, V.E. 2015. Tele-Mum: A Feasibility Study for a Randomized Controlled Trial Exploring the Potential for Telemedicine in the Diabetes Care of Those with Gestational Diabetes. *Diabetes Technology Therapeutics.* 17(12):880-8. DOI:10.1089/dia.2015.0147.

Goldenberg, R.L., McClure, E.M., Harrison, M.S. & Miodovnik, M. 2016. Diabetes During Pregnancy in Low-and Middle-Income Countries. *American Journal of Perinatology.* 33(13):1227-35. DOI:10.1055/s-0036-1584152.

Guo, H., Zhang, Y., Li, P., Zhou, P., Chen, L.M. & Li, S.Y. 2018. Evaluating the Effects of Mobile Health Intervention on Weight Management, Glycemic Control and Pregnancy Outcomes in Patients with Gestational Diabetes Mellitus. *Journal of Endocrinology Investigation.* 10.1007/s40618-018-0975-0. DOI:10.1007/s40618-018-0975-0.

Higgins, J.P.T., Thompson, S.G., Deeks, J.J. & Altman, D.G. 2003. Measuring Inconsistency in Meta-Analyses. *BMJ.* 327(7414):557. DOI:10.1136/bmj.327.7414.557.

Hirst, J.E., Mackillop, L., Loerup, L., Kevat, D.A., Bartlett, K., Gibson, O., Kenworthy, Y., Levy, J.C. et al. 2015. Acceptability and User Satisfaction of a Smartphone-Based, Interactive Blood Glucose Management System in Women with Gestational Diabetes Mellitus. *Journal Diabetes Science & Technology.* 9(1):111-5. DOI:10.1177/1932296814556506.

Kampmann, U., Madsen, L.R., Skajaa, G.O., Iversen, D.S., Moeller, N. & Ovesen, P. 2015. Gestational Diabetes: A Clinical Update. *World Journal of Diabetes.* 6(8):1065-72. DOI:10.4239/wjd.v6.i8.1065.

Lau, Y., Htun, T.P., Wong, S.N., Tam, W.S. & Klainin-Yobas, P. 2016. Efficacy of Internet-Based Self-Monitoring Interventions on Maternal and Neonatal Outcomes in Perinatal Diabetic Women: A Systematic Review and Meta-Analysis. *Journal of Medical Internet Research.* 18(8):e220. DOI:10.2196/jmir.6153.

Mackillop, L., Loerup, L., Bartlett, K., Farmer, A., Gibson, O.J., Hirst, J.E., Kenworthy, Y., Kevat, D.A. et al. 2014. Development of a Real-Time Smartphone Solution for the Management of Women with or at High Risk of Gestational Diabetes. *Journal of Diabetes Science & Technology.* 8(6):1105-14. DOI:10.1177/1932296814542271.

Mackillop, L., Hirst, J.E., Bartlett, K.J., Birks, J.S., Clifton, L., Farmer, A.J., Gibson, O., Kenworthy, Y. et al. 2018. Comparing the Efficacy of a Mobile Phone-Based Blood Glucose Management System With Standard Clinic Care in Women With Gestational Diabetes: Randomized Controlled Trial. *Journal of Medical Internet Research.* 6(3):e71. DOI:10.2196/mhealth.9512.

Ming, W.K., Mackillop, L.H., Farmer, A.J., Loerup, L., Bartlett, K., Levy, J.C., Tarassenko, L., Velardo, C. et al. 2016. Telemedicine Technologies for Diabetes in Pregnancy: A Systematic Review and Meta-Analysis. *Journal of Medical Internet Research.* 18(11):e290. DOI:10.2196/jmir.6556.

Miremberg, H., Ben-Ari, T., Betzer, T., Raphaeli, H., Gasnier, R., Barda, G., Bar, J. & Weiner, E. 2018. The Impact of a Daily Smartphone-Based Feedback System Among Women with Gestational Diabetes on Compliance, Glycemic Control, Satisfaction, and Pregnancy Outcome: a Randomized Controlled Trial. *American Journal of Obstetrics & Gynecology.* 218(4):453.e451-7. DOI:10.1016/j.ajog.2018.01.044.

Moher, D., Liberati, A., Tetzlaff, J. & Altman, D.G. 2009. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: the PRISMA Statement. *Annals of Internal Medicine.* 151(4):264-9. DOI:10.1016/j.ijsu.2010.02.007.

Nicholson, W.K., Beckham, A.J., Hatley, K., Diamond, M., Johnson, L.S., Green, S.L. & Tate, D. 2016. The Gestational Diabetes Management System (GooDMomS): Development, Feasibility and Lessons Learned from a Patient-Informed, Web-Based Pregnancy and Postpartum Lifestyle Intervention. *BMC Pregnancy Childbirth.* 16(1):277. DOI:10.1186/s12884-016-1064-z.

Pais, S., Parry, D., Petrova, K. & Rowan, J. 2017. Acceptance of Using an Ecosystem of Mobile Apps for Use in Diabetes Clinic for Self-Management of Gestational Diabetes Mellitus. *Student Health Technology Informatics.* 245:188-92.

PRISMA. 2019. *PRISMA Flow Diagram Generator*. Available: http://prisma.thetacollaborative.ca/

Rasekaba, T.M., Furler, J., Blackberry, I., Tacey, M., Gray, K. & Lim, K. 2015. Telemedicine Interventions for Gestational Diabetes Mellitus: A Systematic Review and Meta-Analysis. *Diabetes Research & Clinical Practice.* 110(1):1-9. DOI:10.1016/j.diabres.2015.07.007.

Rasekaba, T.M., Furler, J., Young, D., Liew, D., Gray, K., Blackberry, I. & Lim, W.K. 2018. Using Technology to Support Care in Gestational Diabetes Mellitus: Quantitative Outcomes of an Exploratory Randomised Control Trial of Adjunct Telemedicine for Gestational Diabetes Mellitus (TeleGDM). *Diabetes Research & Clinical Practice.* 142:276-85. DOI:10.1016/j.diabres.2018.05.049.

Skar, J.B., Garnweidner-Holme, L.M., Lukasse, M. & Terragni, L. 2018. Women's Experiences with Using a Smartphone App (the Pregnant+ App) to Manage Gestational Diabetes Mellitus in a Randomised Controlled Trial. *Midwifery.* 58:102-8. DOI:10.1016/j.midw.2017.12.021.