

Acceptance of Using an Ecosystem of Mobile Apps for Use in Diabetes Clinic for Self-Management of Gestational Diabetes Mellitus

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Abstract

Mobile applications (apps) for self-management of diseases such as diabetes and for general well-being, including keeping track of food, diet, and exercise, are widely available. However, consumers face a flood of new mobile apps in the app stores and have no guidance from clinicians about choosing the appropriate app. As much as clinicians would like to support a patient-centered approach and promote health and wellness mobile apps, they may be unable to provide advice due to the lack of comprehensive and reliable app reviews. This research reviewed a selection of health and wellness mobile apps suitable for the self-management of gestational diabetes mellitus (GDM). A prototype of an ecosystem that integrated the data generated by the apps was built and its usefulness and ease of use were evaluated. The results show that the ecosystem can provide support for GDM self-management by sharing health and wellness data across the diabetes clinic.

Keywords:

Ecosystem; Diabetes Mellitus; Mobile Applications

Introduction and Background

In recent years the Diabetes Clinic at Auckland Hospital has had an overwhelming number of female patients with gestational diabetes mellitus (GDM) [1]. The traditional method of manually recording blood glucose readings and maintaining a food diary is not efficient when compared to the telehealth technologies available today. For example, women are given glucometers and asked to check their blood glucose readings at least four times a day. The glucometer readings can be downloaded to a computer. Newer glucometers can download the glucometer readings to a smart phone using near field communication (NFC).

The currently available mobile applications (apps) for self-managing blood glucose and diet present another possibility. Although women mostly maintain their food diaries on paper, some women prefer to save them electronically in a spreadsheet and are familiar with mobile apps that monitor exercise and calorie intake. However, the clinicians at the clinic had not trialed the mobile apps that may be suitable for GDM self-management. They were not sure which health and wellness apps may be appropriate and felt they were slow in adopting the new technology. This study describes the development of an extensible "ecosystem" of mobile apps that supports GDM self-management by integrating patient data exported by the apps into the ecosystems' database. Clinicians can use the ecosystem to recommend a suitable app (or apps) to their patients and review the shared data in a clinical

context. More specifically, the research focuses on the app selection process and on the evaluation of the ecosystem's usefulness and ease of use.

Health and Wellness Mobile Apps

There are around 8000 health and wellness mobile apps for managing exercise, healthy living, weight loss, and chronic diseases, available on the two dominant smart phone platforms iPhone and Android [2]. In addition to blood glucose and weight tracking, the common set of functionalities include insulin and carbohydrate tracking, exercise tracking, maintaining a food diary supported by an internal food database, and the ability to share wellness data electronically [3, 4]. For example, My Meal Mate is a smart phone app that allows users to save favorite food combinations and recently logged food entries and to take photographs of food for memory recall [5]. Other useful functionalities include displaying a graph of calories consumed daily and showing the results of the analyses of important macronutrients. In a pilot randomized controlled trial for weight loss it was observed that My Meal Mate had a greater acceptance and satisfaction rating compared to traditional interventions such as using paper based food diaries or online weight loss programs [6].

Mobile App Selection Criteria

It may be difficult for consumers to identify the most suitable app. They can consider the set of features identified above or refer to a review such as Hickman and Elsworth's [7]. These authors identify the advantages and disadvantages of health related mobile apps based on a comparison across a range of criteria including cost, app rating by the public, exercise and food data functionality, the ability to share information on social networks, and compatibility with various mobile phone models. However, such reviews quickly become outdated as new and improved apps are added to the app stores.

The number of downloads and installations of an app gives a measure of its popularity. This indicator may be considered as a useful selection criterion, especially if coupled with checking the app reviews published on the app store web site. However, these reviews are not professional and may lack credibility.

For some consumer categories, interface usability may be a very important aspect of the app's functionality. For example, apps designed for the elderly should have a minimized set of functionalities [8, 9]. The interface should be self-explanatory and convenient to interact with, such as the large buttons used in the eCAALYX (Enhanced Complete Ambient Assisted Living Experiment) app for older people suffering from chronic diseases [8]. Unfortunately, not all app reviews

consider usability features [10]. Similarly, reviews rarely consider the possibility of integrating patient managed data with electronic health records. Ultimately, consumers have to rely on their own judgement in order to identify, trial, and adopt a suitable app.

Sharing Health and Wellness Data with Clinicians

Most commercially available health and wellness mobile apps have a provision to share generated data by email. A clinician can review the electronically shared data during a subsequent consultation with their patient. However, the data are not readily preserved and stored for future consultations, especially with other clinicians. In followup consultations, the physician, the nurse, or the dietician will have no access to the regular updates provided by the app. Hence, it is desirable to store patient managed health and wellness data in a central system accessible to all members of the clinical team. For example, the free to download iPhone app Easy Diet Diary allows for sharing data with a dietician provided that the dietician has purchased a license for Foodworks, a nutrient analysis software [11]. Easy Diet Diary uses food databases specific to Australia and New Zealand.

Exporting patient managed data to a proprietary database does not allow patients the flexibility to select the app of their choice. Furthermore, it may be convenient for patients to manage multiple health conditions through one health and wellness mobile app. Unfortunately, clinical trials and reviews of commercially available apps provide limited evidence about integrating health and wellness data with clinical systems.

This research set out to create a prototype of an ecosystem of mobile apps and devices that can be used to support GDM self-management. The system accepts, stores, and integrates shared health and wellness data from the ecosystem's components and makes them available to clinicians to search and review (Figure 1). The study addresses the following two research questions related to the design and implementation of the ecosystem:

RQ1. What are clinician criteria for including health and wellness apps in the ecosystem?

RQ2. What are the perceived usefulness and the perceived ease of use of the ecosystem?

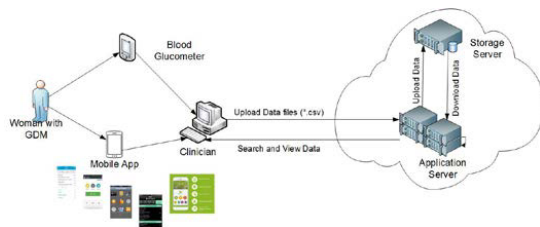


Figure 1 - An Ecosystem Integrating Health and Wellness Data

Method

A user-centered design approach towards the development of the ecosystem prototype was chosen as it needed to meet the requirements of its potential users, i.e., the clinicians treating women with GDM at the Diabetes Clinic and their patients. Information about the functional requirements and the data elements needed to build the ecosystem was obtained from physicians, obstetricians, dieticians, and midwives who

reviewed and evaluated mobile apps with food diary and exercise logging functionalities. Data were gathered through open-ended interviews [12]. The data were analyzed qualitatively in order to identify clinician criteria.

Participants

Two dieticians, a midwife, an obstetrician, and a physician participated in an initial mobile app evaluation round that aimed to extract design requirements. The ecosystem prototype was evaluated for its perceived usefulness and ease of use by the initial five participants, by five other clinicians from the same clinic, and by five patients (women with GDM). No real patient data were stored in the prototype.

Prototype Development

The ecosystem prototype was developed in stages with feedback sought from clinicians. The first round of interviews (with five clinicians) contributed to formulating the user requirements of the prototype. Clinicians were periodically emailed a stakeholder consultation document that provided details about the prototype as it was developed. This approach was chosen because clinician availability was limited, making focus group meetings difficult to organize and convene.

The stakeholder consultation document contained descriptions of the low fidelity prototype interfaces, the navigation features, and the prototype data elements necessary for GDM self-management. It also included a review of health and wellness apps that could potentially be added to the ecosystem. The clinicians trialed the apps specified in the document and provided feedback in a continuous dialogue conducted through email, text messages, and phone calls. As the research progressed, other mobile apps were suggested by the participants and more were also discovered by the researchers.

Results

The stakeholder document initially included samples of the data exported from five health and wellness mobile apps selected by the researchers: My Meal Mate, Glucose Buddy, On Track, Doctor Diet, and Microsoft HealthVault. Sending the initial stakeholder document to clinicians started the process of iteratively and interactively capturing and refining the clinician criteria. Three selection criteria were used. First, all apps needed to support food diary and exercise functionality. Second, all apps needed to allow data sharing with third parties. Third, based on findings that cost was a significant factor influencing consumer's choice of a mobile app, [13] only free to download apps were considered.

Table 1 shows a summary of the properties of the first five health and wellness mobile apps reviewed by the research participants. All apps supported food diary functionality while four apps supported exercise tracking. However, the absence of a food database, as in the case of the apps OnTrack and Glucose Buddy, would make data entry rather difficult (and potentially inaccurate) as patients would have to fill in all food details.

Four of the apps provided options for exporting data that could be shared with clinicians. The app My Meal Mate did not have a data sharing option. However, the food and exercise data were stored in the user's mobile phone in a SQLite database. A reverse engineering process that used the app's internal food database allowed for extraction of data about food and exercise that could be integrated in the ecosystem and shared

with clinicians. The data also provided nutrient information about the food consumed. However, the app's food database and nutrient profiles were specific to branded food items found in UK supermarkets and not relevant to New Zealand app users.

Table 1 - Health and Wellness Mobile App Review

App	Food diary	Exercise	Export data to clinician	Data Format
My Meal Mate	Yes	Yes	No	SQLite
Glucose Buddy	Yes	Yes	Yes	CSV
OnTrack	Yes	Yes	Yes	XML
Doctor Diet	Yes	No	Yes	CSV, pdf report
Microsoft Health Vault	Yes	Yes	Yes	CSV

Microsoft HealthVault was available as an app for iPhone, but there was no equivalent suitable for Android phones. By default, the apps' capability to share data about food details with a clinician or a friend was limited. The settings can be changed to allow greater food data sharing. However, the process is not user friendly; it may be difficult for an ordinary user to perform the manipulation.

A drawback of the Doctor Diet app was that it focused on food and diet only. Users would have to install another app in order to record exercise.

The app Easy Diet Diary was added to the ecosystem in a subsequent stakeholder document. It features an easy to enter food dairy interface and supports extracting data for later integration within the ecosystem. However, as already mentioned, a clinician would need to purchase a license for the Foodworks app, in order to enable data sharing.

Clinician Criteria

Clinicians reviewed the apps' properties and functionalities. Their views and opinions were used to derive a set of criteria that mobile health and wellness apps needed to meet in order to be considered for inclusion in the ecosystem.

First, in order to be relevant to GDM self-management, the app needed to provide data about both physical activity and food intake, and also data about glucose level and treatment.

Clinician 4

Reflects physical activity and food diary together with treatment and dosage and sugar level.

Second, it was established that a mere calculation of the calories consumed by the patient was not sufficient as the intention of the app user, in this case, was not to lose weight but to manage their diet in order to control GDM. The type of food, its description, and portion size were important indications that needed to be captured, especially for dietitians and midwives. Such data would help clinicians support women with GDM to interpret glucose readings and manage insulin dosage.

Clinician 1

Yes, it is including pretty much everything that you want to know about: blood glucose, food diary, exercise. Calories will not tell you what you have eaten. Need to choose apps which

are usable. You need app(s) which get the calories, carbohydrate breakdown, protein and fat.

However, an app's capability to record carbohydrate content or carbohydrate counting was not critical as most women had GDM only during pregnancy. Furthermore, such patients may not have the carbohydrate counting skills commonly acquired by women with ongoing Type 1 diabetes. Therefore, the clinic had to develop a different approach when consulting women with GDM. In general, apps focusing on healthy lifestyle support would be suitable and more appropriate for women with GDM.

Clinician 3

Wellness data is representative. Easy to compare food diary, exercise, insulin dosage in comparison with blood glucose.

Only two apps, Glucose Buddy and On Track, satisfied all requirements. These apps allowed food description with portion size, which was required by dietitians and midwives. Thus, the ecosystem that was built following the initial requirement analysis included obtaining and integrating patient health and wellness data generated by Glucose Buddy and On Track. The blood glucose readings from the glucometer were also integrated into the prototype.

Ecosystem Usefulness and Ease of Use

The data extracted from the apps and available in the prototype's database were reviewed by participants in order to obtain further insights into the suitability of the apps. It was found that the perceived usefulness of the ecosystem was directly related to the perceived usefulness of the data provided by the mobile apps.

Clinicians reviewing the ecosystem found it useful as it succeeded in bringing together, in a single report, data from blood glucose readings, the food diary, and the exercise tracking.

Most of the women with GDM who participated in the research had experience using mobile apps, for example managing their diet, weight, and exercise (step counter). However, they were not knowledgeable about mobile apps that may be suitable for GDM self-management. After reviewing the mobile apps included in the ecosystem, women with GDM became interested in using them. They were enthusiastic about sharing their wellness data with clinicians as it would help them self-manage the condition, benefiting their own health and that of their babies.

Patient 1

(I would) absolutely use it and comfortable to share the data with clinician if suitable apps are available.

Both clinicians and women with GDM found the prototype easy to use as completing a task did not require going through many screen interfaces. For example, viewing a combined report about a food diary, blood glucose readings, exercise, and insulin dosage required, in most cases, one screen.

Most women preferred to log their food entries electronically rather than maintain a paper based record. However, training may be required for some, such as first time smart phone owners. Similarly, clinicians were confident they would learn to use the system as it resembled other hospital systems and would be used often (each time a patient visited the clinic). The study findings about the dimensions of perceived usefulness and ease of use of the ecosystem are presented in Table 2.

It took almost a year to gather the initial requirements, build the prototype, and review the ecosystem. At the end of the

process, most women visiting the clinic owned smart phones and were aware of or were already using health and wellness mobile apps. They often asked clinicians to recommend a suitable app. This highlighted yet again the usefulness of the ecosystem and the need to encourage and stimulate the adoption of the new technology by clinicians.

Table 2 - Ecosystem usefulness and ease of use

Variable	Study Findings
Perceived Usefulness	<ul style="list-style-type: none"> • Sharing patient data with the clinician team • Combining data from various sources • Empowering patients in self-management • Helping in food recall • Remotely managing patients • Reducing cost
Perceived Ease of Use	<ul style="list-style-type: none"> • Condensing data in one screen • Relevant information in one screen • Easy navigation • Existing experience with /awareness of mobile apps • Minimal training required

Extending the Ecosystem

Data interoperability was achieved by mapping the schema of the data coming from a mobile app to the target database in the ecosystem. The ecosystem design allowed the easy inclusion of new apps. Patient participants identified new apps that could be added to the ecosystem in order to increase its scope, e.g., MyFitnessPal and mySugr. Both apps were free to download and available for the most popular smart phones, iPhone and Android. Data generated by the apps could be shared by email.

mySugr had the option to export data in CSV format and could be easily incorporated in the ecosystem, thus extending its range of available apps. MyFitnessPal had the option to generate a report in pdf format. The “premium” (paid for) version of MyFitnessPal allowed sharing collected data with other partnering vendors such as FitBit and JawBone using a private application program interface (API). Although not useful for users with a non-premium account, MyFitnessPal is very popular. If its owners add the data sharing feature to the free version, adding the app to the ecosystem may be considered.

Another potential extension was the already assessed Easy Diet Diary app. It exports data to a proprietary nutrition database (Foodworks). However, its usefulness is rather limited as it is available for iPhone only.

Reviews about health and wellness mobile apps by members of the health care community provided a useful means for identifying more apps that could potentially be added to the ecosystem. For example, a group of dietitians from various hospitals and clinics review apps suitable for self-management of chronic diseases and general well-being. The reviews are published in a web portal accessible to the general public [14]. The reviews consider apps from different user perspectives (i.e., clinician or patient) and also from a technical perspective. The web site contains a list of mobile apps supporting healthy living and managing food, diet, and exercise. The list includes the already mentioned MyFitnessPal and mySugr, and also a paid app called Glooko.

In order to be able to integrate shared data from Glooko in to a central database, the clinic would also need to purchase a license. However, clinics with limited funding may not be able to invest in adding paid apps to the ecosystem unless the benefits in terms of self-management interventions and health outcomes are shown to be of much higher value compared to free apps with similar functional capabilities.

Overall, the prototype showed that an extensible ecosystem of mobile apps suitable for the self-management of GDM can be successfully set up. To support privacy protection, the ecosystem facilitated patient access to their health and wellness data while clinicians had to be authorized by patients in order to access their data. Such practices are recommended by researchers [15, 16].

Discussion

The ecosystem described above helped demonstrate the potential of using mobile apps in the self-management of GDM. New and improved apps may evolve. With appropriate clinician approval and evaluation, these may be ready for integration into the ecosystem. Evaluation criteria can be developed using the required app features (Table 1) and the usefulness and ease of use dimensions identified in the research (Table 2).

The selected Android and iPhone apps had the capability of exporting data in various formats, either shared through an email or saved in a cloud database. In the first version of the prototype, clinicians suggested that they should upload patient data to the ecosystem’s database themselves. They did not trust the accuracy of the data created by patients and wanted to review them first. Clinicians preferred receiving data through email. In most cases, data in formats such as CSV and XML would open easily without installing additional software. However, the next step (integrating the data in the prototype’s database manually) appeared to be an additional workload for clinicians, especially for midwives who met women with GDM on a regular basis.

Manually managing each patient’s file is not an efficient method of exchanging health data. There is evidence of better health outcomes when patients are involved in the self-management of their own diseases [17, 18]. Patients should be trusted to upload their own wellness data into the prototype accurately, even if patient generated health data are somewhat dissimilar to data captured by clinicians and stored in conventional health information systems. Sharing patient generated data across the clinic is beneficial as it helps clinicians keep track of their patients’ progress remotely and in a cost efficient manner.

Data entry and exporting data from mobile apps to another system is not yet automated and seamless. However, existing APIs have the potential to share patient generated health and wellness data from participating mobile apps and sensor devices, thus enabling the creation of an app ecosystem. Data interoperability is achieved as APIs “know” the source and target data schema. However, it can be expected that future mobile apps will have an API capability of transparently sharing data with other systems. For example, several major commercially available wearable tracking devices for step counting, sleep, and heart beat monitoring already support sharing data with other apps.

Although data interoperability was achieved by mapping data from mobile apps to the target prototype’s database, semantic interoperability is still an issue. Clinical standards such as

SNOMED CT, HL7 and the recently introduced draft version of FHIR do not have the provision to include patient generated health and wellness data.

Conclusion

An ecosystem of mobile apps for GDM self-management was set up for patients seen in Diabetes Clinic at Auckland Hospital. Clinicians reviewed the requirements of the ecosystem through a continuous dialogue and discussion by email, phone conversations, and interviews. The review process helped formulate app selection criteria and identify the usefulness and ease of use dimensions of the ecosystem. The women with GDM who participated in the research were confident that the use of these new technologies would help them.

Promoting health information exchange and system interoperability is a prime objective of the “meaningful use” data sharing framework [19]. Despite potential changes in this, it is likely that in the future, services allowing secure, accurate, and timely health data exchange between consumer-focused systems will be available through APIs. This study contributes to the body of knowledge in the area of electronic sharing of health and wellness data from consumer wellness systems in order to improve the quality of health care and involve citizens as active participants in the health care process.

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References

- [1] National Women’s Annual Clinical Report. <http://nationalwomenshealth.adhb.govt.nz/Portals/0/Annual%20Reports/ACR%20master%20MOH%20July%202015.pdf>
- [2] Aitken M. Patient Apps for Improved Healthcare: From Novelty to Mainstream. IMS Institute for Healthcare Informatics. http://www.imshealth.com/deployedfiles/imshealth/Global/Content/Corporate/IMS%20Health%20Institute/Reports/Patient_Apps/IIHI_Patient_Apps_Report.pdf 2013.
- [3] Tran J, Tran R and White JR. Smartphone-based glucose monitors and applications in the management of diabetes: an overview of 10 salient “apps” and a novel smartphone-connected blood glucose monitor. *Clinical Diabetes*. 2012; 30(4): 173-178.
- [4] Eng DS and Lee JM. The promise and peril of mobile health applications for diabetes and endocrinology. *Pediatric diabetes*. 2013; 14(4): 231-238.
- [5] Carter MC, Burley VJ, Nykjaer C and Cade JE. ‘My Meal Mate’ (MMM): validation of the diet measures captured on a smartphone application to facilitate weight loss. *British Journal of Nutrition*. 2013; 109(03): 539-546.
- [6] Carter MC, Burley VJ, Nykjaer C and Cade JE. Adherence to a smartphone application for weight loss compared to website and paper diary: pilot randomized controlled trial. *Journal of medical Internet research*. 2013; 15(4).
- [7] Hickman I and Elsworth B. Review of apps for monitoring food intake and exercise. <http://www.dietitianconnection.com/component/content/article/52-products/resources-materials/924-review-of-apps-for-monitoring-food-intake-and-exercise-2012>.
- [8] Boulos MN, Wheeler S, Tavares C and Jones R. How smartphones are changing the face of mobile and participatory healthcare: an overview, with example from eCAALYX”. *Biomedical engineering online*. 2011; 10(24): 1-14.
- [9] Prescher S, Bourke AK, Koehler F, Martins A, Sereno F H, Boldt ST and Nelson J. Ubiquitous ambient assisted living solution to promote safer independent living in older adults suffering from co-morbidity, In

Conference proceedings of Annual International Conference of the IEEE Engineering in Medicine and Biology Society. 2011: 5118-5121.

- [10] El-Gayar O, Timsina P, Nawar N and Eid W. Mobile applications for diabetes self-management: status and potential. *Journal of diabetes science and technology*. 2013; 7(1): 247-262.
- [11] Easy Diet Dairy. <https://easydietdiary.zendesk.com/hc/en-us/articles/206615603-How-do-I-send-my-diary-to-my-nutrition-professional-to-view-in-FoodWorks->
- [12] Martin JL, Clark DJ, Morgan SP, Crowe JA and Murphy E. A user-centred approach to requirements elicitation in medical device development: A case study from an industry perspective, *Applied Ergonomics*, 2012; 43(1): 184-190.
- [13] Krebs P and Duncan DT. Health app use among US mobile phone owners: a national survey. *JMIR mHealth and uHealth*. 2015; 3(4).
- [14] Health Navigator. <https://www.healthnavigator.org.nz/app-library/d/diabetes-apps/>
- [15] JASON, Mitre Corporation. A robust health data infrastructure. US Agency for Healthcare Research and Quality publication no. 14-0041-EF. http://healthit.gov/sites/default/files/ptp13-700hhs_white.pdf. 2014.
- [16] Hull S. Patient-Generated Health Data Foundation for Personalized Collaborative Care. *Computers Informatics Nursing*. 2015; 33(5): 177-180.
- [17] Holtz B and Lauckner C. Diabetes management via mobile phones: a systematic review”. *Telemedicine and e-Health*, 2012; 18(3): 175-184.
- [18] Free C, Phillips G, Galli L, Watson L, Felix L, Edwards P and Haines A. The effectiveness of mobile-health technology-based health behaviour change or disease management interventions for health care consumers: a systematic review”. *PLoS Med*, 2013; 10(1): e1001362.
- [19] Medicare and Medicaid Programs. Electronic Health Record Incentive Program-Stage 3 and Modifications to Meaningful Use in 2015 Through 2017. <https://www.federalregister.gov/documents/2015/10/16/2015-25595/medicare-and-medicaid-programs-electronic-health-record-incentive-program-stage-3-and-modifications>

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