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Review Article

The Promise and Peril of Mobile Health Applications for Diabetes and Endocrinology

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We are in the midst of what some have called a ''mobile health revolution''. Medical applications (''apps'') for mobile phones are proliferating in the marketplace and clinicians are likely encountering patients with questions about the medical value of these apps. We conducted a review of medical apps focused on endocrine disease.
We found a higher percentage of relevant apps in our searches of the iPhone app store compared with the Android marketplace. For our diabetes search in the iPhone store, the majority of apps (33%) focused on health tracking (blood sugars, insulin doses, carbohydrates), requiring manual entry of health data. Only two apps directly inputted blood sugars from glucometers attached to the mobile phone. The remainder of diabetes apps were teaching/training apps (22%), food reference databases (8%), social blogs/forums (5%), and physician directed apps (8%). We found a number of insulin dose calculator apps which technically meet criteria for being a medically regulated mobile application, but did not find evidence for FDA-approval despite their availability to consumers. Far fewer apps were focused on other endocrine disease and included medical reference for the field of endocrinology, access to endocrine journals, height predictors, medication trackers, and fertility apps.
Although mobile health apps have great potential for improving chronic disease care, they face a number of challenges including lack of evidence of clinical effectiveness, lack of integration with the health care delivery system, the need for formal evaluation and review and organized searching for health apps, and potential threats to safety and privacy.

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Mobile phone usage among US adults and adolescents is becoming nearly ubiquitous. According to the 2012 Pew Research Center's Internet and American Life Project, 85% of adults and 77% of adolescents own a mobile phone. Furthermore, half of adults and adolescents with mobile phones now carry smartphones, phones with a mobile computing platform (1–3). Because of its widespread dissemination, mobile technology holds great promise for transforming the health care delivery system.

Mobile health, referred to as mHealth, is defined as 'mobile computing, medical sensor, and communications technologies' that can enhance chronic disease care beyond the traditional outpatient physician–patient encounter. This includes applications (which we will refer to as 'apps' hereafter) that run on mobile phones, sensors that track vital signs and health activities, and cloud-based computing systems (4, 5). There has been an explosion of medical apps over the last 5 yr, with more than 13 000 apps on health care topics alone available to Apple iPhone users (6) and over 6000 medical apps available to Android users (7). Close to one in five individuals with a smartphone have downloaded a health app (1) resulting in 44 million health app downloads in 2012 and it is predicted that there will be 142 million downloads by 2016 (8). Apps focused on endocrine disease, particularly those focused on diabetes, are proliferating in the marketplace.

Clinicians are likely encountering patients with questions about health apps and their clinical effectiveness. We therefore conducted a review of the

available medical apps focused on endocrine disease from the iPhone and Android platforms. Our objective was to provide information about general functions of currently available apps, as well as outline current challenges for the integration of health-related apps with the health care delivery system.

Methods

To our knowledge, there is no accepted search method for identifying mobile health applications. Therefore, we entered the Apple iTunes store (for the iPhone) and the Android marketplace (for the Android) on 27 January 2013 and used the general search bar for identifying health-related mobile apps. We used the following search terms to identify apps that were related to endocrine disease: diabetes, type 1 diabetes, endocrinology, endocrine, endo, thyroid, adrenal, and hormone. There is no ability to limit search terms; therefore, we hand-searched each term separately.

In our initial searches, we excluded non-English applications and apps that did not relate to endocrine disease or diabetes. We found that for the Android marketplace, there were a large number of apps identified by our search (i.e., 'At least 1000 results') but the search algorithm would only allow us to view the first 400+ apps. Furthermore, searches in the Android marketplace yielded a low percentage of relevant results (see results). Finally, in contrast to the iPhone, there is no Application Programming Interface for Android to allow for import of app information into a database. We therefore focused on applications from the iPhone platform as a paradigm for understanding the variety and scope of applications.

Each app in the iTunes store usually provides a text summary, which gives a basic description of the uses and functions of the apps. We used this summary to assess the relevance and classify apps into categories, as we could not download all apps due to both memory and cost considerations.

For each iTunes search term, we assessed the percentage of apps that were relevant to diabetes or endocrine disease and then grouped the relevant apps into a variety of categories. We were able to retrieve all results for the endocrine searches, but only a subset of the apps from the diabetes search, as the API only allows one to get a subset of apps (n = 500). Of these 500, we randomly picked 100 apps and enumerated the estimated frequencies of app categories for the diabetes search. In Table 1, we provide examples of apps and their features in the areas of diabetes and endocrinology, according to specific categories. This list is neither exhaustive, nor an endorsement of app quality.

We did not comprehensively assess the various lifestyle apps focusing on healthy eating and physical activity, due to the sheer quantity of these apps, which would require an entire separate review. We do, however, highlight some innovative strategies of some of these apps to provide information about future trends in app development.

Results

Android marketplace search results

As we reported above, searches in the Android marketplace yielded fewer relevant results compared with the iPhone app store. A search for the term 'diabetes' yielded 480 hits, of which only 50% were relevant (n = 240). A search for the term 'endocrinology' yielded 152 apps of which we estimate only 10% were relevant (n = 16 general endocrinology and n = 4 diabetes).

iPhone app store search results

From here on, we focus on our findings from the iPhone app store. A search for the term 'diabetes' yielded approximately 600 apps, of which the majority were related to diabetes. We eliminated approximately 14% of apps that were not related to diabetes and 4% that were not in English. We now describe the general categories of apps encountered.

Apps for medical management of diabetes

We are aware of just one app for medical management of diabetes which has received clearance from the Food and Drug Administration (FDA), but is only approved for adults with type 2 diabetes (9). Welldoc Diabetes Manager allows individuals to track, record, and chart their blood glucose levels and has a proprietary analytic system to identify trends in the blood sugar patterns and provide real-time, clinically based feedback and coaching to patients. Furthermore, the app can share diabetes data directly with the patient's health care team.

Apps for tracking and displaying health information

The largest proportion of diabetes apps (33%) focus on health tracking. For example, many apps allow the user to track blood sugars, insulin doses, carbohydrates, weight, and activity. A number of apps present users with their blood glucose levels in both numeric and graphical format. Not all apps have a data export option, but some allow patients to send logs in pdf and csv files to their healthcare provider through email or fax, or through uploads to Dropbox, a cloud based storage system. In addition to blood sugar, some apps also allow for tracking of laboratory studies (HbA1c, LDL, etc.). The majority of apps require the user to manually enter their health data into the app. Just a

Table 1. Examples of commercially available applications and their features in the areas of diabetes and endocrinology, according to specific categories. This list is neither exhaustive, nor an endorsement of app quality.

	Cost*	iPhone/ Android	Description
Medical Management			
Welldoc Diabetes Manager	Free	both	Logs, records, charts blood glucose. Provides personalized real-time feedback and coaching to patients through proprietary analytic system, offered through a health management company or employer. Transmits securely to a cloud and has ability to integrate with an electronic medical record.
Tracking and Visualization of Health Information			
Data Entered by Patient			
Glucose Buddy	$6.99 Free version available	both	Logs blood glucose, carbohydrate, insulin doses, activity. Reminders to test blood sugar can be set. Integrated with a food database and a community forum.
WaveSense Diabetes Manager	Free	iPhone	Logs blood glucose, carbohydrate, insulin doses, activity. Graphs the data and provides ability to email reports.
LogFrog	$2.99 Free version available	iPhone	Logs blood sugar, carbs, insulin, exercise, A1c. Child Friendly Interface. Reminders to test blood sugar can be set. Data can be exported as a google spreadsheet.
GoMeals	Free	both	Logs blood glucose, calories, carbs, activity and comes with an integrated food database.
Data Uploaded from Blood Glucose Monitor			
Glooko Log Book	Free	iPhone	Logs blood glucose, carbohydrate and insulin doses. Includes integrated food database.
iBGstar Diabetes Manager	Free	iPhone	Logs blood glucose, carbohydrates, and insulin doses.
Social Forums/Blogs			
Diabetic Connect	Free	both	Links with a network of diabetes patients and provides a forum for discussion with other diabetes patients.
Glu	Free	both	Associated with T1D Exchange, a national registry of patients with type 1, and is specifically geared towards individuals with type 1. Combines online networking and forums, and health information.
Teaching/Training			
Glucagon	Free	iPhone	Show users how to properly administer Glucagon. Can schedule reminders when to review the process.
Dexcom	Free	both	Training videos, sensor insertion instructions and other educational materials regarding the use of Dexcom continuous glucose monitor
Counting carbs with Lenny	Free	both	Teaches carb counting to children through animations and games.
Managing Type 1 Diabetes	Free	iPhone	Interactive app designed for the education of children and their families through animated graphics.
RapidCalc Diabetes Manager	$7.99	iPhone	User inputs target blood glucose levels, correction factors, carbohydrate ratios, and carbohydrates and recommends an insulin dose. Also adjusts doses for exercise intensity, recent hypoglycemia, and alcohol intake.
Nutritional References			
Calorie King Food Search	Free	both	Nutrition database for over 70,000 foods including 260 fast food chains and restaurants.
Calorie Counter by CalorieCount.com	Free	both	Allows users to scan barcodes on food packaging to search for nutrition information.
Delicious Diabetic Recipes	$0.99 (iPhone) Free (Android)	both	Provides low carbohydrate recipes.
Exercise Apps			
Data Entered by Patient			
Nexercise	Free	both	Users can earn real rewards (e.g. gift cards) for meeting exercise goals. Also, allows users to compete with friends for points.

Table 1. *Continued*

	Cost*	iPhone/ Android	Description
Data collected by Accelerometer/global positioning system (GPS) on the phone			
Runkeeper	Free	both	Tracks runs, walks, and bikes with GPS. Audio coaching provided during workout.
Fitbit	Free	both	Tracks food, activity, weight, and sleep. Notifications can be set to encourage user to reach goals. Users have ability to see friends step count as well.
Nike Fuel Band	Free (Requires purchase of Nike FuelBand Sensor)	both	Requires an external wearable sensor that keeps track of user's steps and everyday activities.
Zombies, Run!	$3.99	both	Immersive running game and audio adventure that combines music and voice-overs to motivate the user to run faster
Physician Directed Apps			
MedCalc 3000-endocrine	$4.99	both	Includes formulas, clinical criteria sets and decision trees used by Endocrinologists.
Endocrinology & Endo Emergency	$5.99 (iPhone) $2.99 (Android)	both	Provides information on how to manage urgent endocrine cases.
The Endocrine Society	Free	both	Contains articles from the Journal of Clinical Endocrinology & Metabolism.
Journal of the American Diabetes Association	Free	both	Subscribers have access to abstracts and full-text articles from Diabetes, Diabetes Care, Diabetes Spectrum or Clinical Diabetes. Non-subscribers have access to abstracts over 6 months old.
DG Apps	Free	iPhone	Searchable catalog of physician directed apps
Endocrine Non-Diabetes Consumer Apps			
How Tall?	$4.99	iPhone	Calculates a predicted height based on current height and bone age.
Thyroid Tracker	$3.99 (iPhone) $4.99 (Android)	both	Tracks laboratory values, medication, doses, and symptoms. Reports can be emailed to physician.
Addison Guide	$2.99 (iPhone) $3.51 (Android)	both	Provides information about situations in which those with Addison's disease might consider different medication dosing. Stores personal and medical information in case of emergency.
My Mobile Fertility	Free	both	Provides consumer education on treatments for infertility. Includes directory of fertility centers.
Hormone	$2.99 Free version available	iPhone	Tracks and charts female body temperatures, sexual activity and menses.

DG, Doc Guide.
*As of 1 March 2013.

few apps can directly upload glucose levels to a mobile phone, which includes Glooko, which has a cable that can connect with a number of meters, and the iBGStar, which plugs directly into the iPhone. Apart from the Welldoc system, we did not encounter apps with the ability to integrate directly into physician workflows or Electronic Medical Record systems.

Apps for teaching/training

Approximately 22% of diabetes apps are focused on teaching/training for the patient. Some teach the principles of carbohydrate counting through interactive graphics and games, to aid in the learning process. We found a number of apps that serve as insulin dose calculators; the consumer inputs the target blood sugar, correction factor, carbohydrate ratio, as well as the blood sugar and estimated carbohydrate before a given meal, and the app will provide a suggested dose of insulin to give. Some of these calculators will also adjust recommended insulin doses according to physical activity and alcohol intake. Finally, there are apps that provide training for users in medication administration (e.g., glucagon) or device use (Dexcom Continuous Glucose Monitoring Systems).

Food reference databases

Approximately 8% of the diabetes apps were food reference databases, i.e., references for carbohydrate counting. Another 5% had recipes for users with diabetes. Some apps combined carbohydrate counting guides with tracking tools.

Social forums/blogs

Approximately 5% of the apps were social networks, social forums, or blogs meant to connect patients with diabetes to each other so that they may share information and experiences.

Physician-directed apps

Although most apps were patient facing, approximately 8% were intended for use by the health care provider, providing medical reference information. Others apps were for diabetes journals which provide electronic access to their articles through an app if the individual has a subscription.

Endocrine apps

We were able to retrieve all apps from the endocrine search, which was a much smaller number compared with our diabetes search. Furthermore, the percentage relevant to the topic was also much lower. The percent relevance and n for our searches was as follows: ''endocrinology'' 52% (n = 17), ''endocrine'' 28% (n = 16), ''endo'' 11% (n = 16), ''hormone'' 39% (n = 22), ''thyroid'' 32% (n = 6), and ''adrenal'' 0.6% (n = 1). The general nature of the endocrine apps included: medical reference for the field of endocrinology, access to endocrine journals, final height predictors, medication trackers, and fertility apps.

Whereas the majority of the diabetes apps were designed for patients rather than physicians, the majority of the endocrine apps were designed for physicians rather than patients. In addition, there was not a lot of overlap in apps found by the endocrine and diabetes searches. For example, there were only five diabetes apps that appeared in the endocrine search.

Exercise apps

Although we did not perform an exhaustive review of exercise apps, we highlight some features of novel apps that would encourage patients, particularly pediatric patients with obesity or diabetes to lead healthier lifestyles.

Exercise tracking is a popular feature. Some exercise apps require the user to wear a separate sensor, (i.e., the Nike Fuel Band, Jawbone Up, or the Fitbit), which links with the mobile phone to transmit the data. Other apps such as Runkeeper use the accelerometer and Global Positioning System (GPS) native to the cellphone to track activity levels including running, walking, biking, or hiking.

Gamification, which is defined as the use of game techniques to solve real-world problems, represents an important motivational component to try and encourage users to engage in more activity (10). For example, some apps like Nexercise give people rewards for exercising, such as discounts or gift cards. Other apps like Zombies, Run! provide an immersive running game and audio adventure that combines music and voice-overs to motivate the user to run faster as the zombies get too close. Finally, a number of apps make exercise 'social', through support from and/or competition between friends by linking to social media like Facebook and Twitter.

Discussion

As we have shown, the number and variety of apps for diabetes and endocrine disease are large, and growing rapidly. However, the majority of these apps have not been tested or evaluated for improvements in health outcomes. Most of the apps were consumer facing, and although patients could send health information to their provider, for example by email, these apps (except for the Welldoc app) did not actively engage providers and did not have capabilities for integration of data into provider workflows or an Electronic Medical Record (EMR). Although diabetes and endocrine-related mobile health apps hold great promise for the future, their seamless integration into regular clinical care has yet to materialize. Furthermore, there are a number of additional challenges to be overcome.

Uncertainty about the effectiveness of mobile applications for improving health outcomes

For an app to be recommended by a health care provider, there ideally should be evidence of effectiveness for improving health outcomes. Despite the large quantity of apps that exist on the consumer market, few have been formally evaluated for effectiveness. Free et al. recently conducted a systematic review of the effectiveness of mobile technology interventions delivered to health care consumers. They found 75 studies that fit their criteria, of which most were described as low quality. They concluded that there was evidence for the effectiveness of text messaging interventions for increasing adherence in antiretroviral therapy and smoking cessation studies, but that results were not consistent for other areas (11). Of the studies from their search, they identified 13 that focused on patients with diabetes (12–24). Five were focused on type 1 diabetes (12–16), and of these three were focused on children (12–14). However, these were all text messaging interventions published before 2010, which did not evaluate the features that are now commonly available on current diabetes smartphone apps. Given the increasing amount of economic investment in mHealth, it is clear that further

formal studies are needed to identify the potential health benefits of mobile technology.

Potential safety concerns with the use of mobile applications

Another critical issue is the safety of consumer apps. The US FDA regulates all medical devices marketed in USA, and in July of 2011, the FDA issued draft guidelines for determining when medical apps should be classified as a medical device. The FDA draft guidelines define mobile medical apps as (1) apps that are used as an accessory to an already regulated medical device; (2) apps that are attached to sensors or other devices to transform it into a medical device; or (3) apps that allow the user to input patient-specific information and using a formula output a patient-specific result, diagnosis, or treatment recommendation that is used for making clinical decisions.

The FDA states, 'When the *intended use* of a mobile app is for the diagnosis of disease or other conditions, or the cure, mitigation, treatment, or prevention of disease, or is intended to affect the structure or any function of the body of man, the mobile app is a device' (25). Intention is designated by 'labeling, claims, advertising materials, or oral or written statements by manufacturers or their representatives'.

The FDA does not consider the following to be medical mobile apps: (1) reference/electronic 'copies' of medical textbooks, or (2) mobile apps that are solely used to log, record, track, evaluate, make decisions or suggestions related to developing, or maintaining general health and wellness (25). However, we note that these draft guidelines have not yet been finalized.

Developers of apps that are classified as medical devices must submit to an FDA regulatory process. Under Section 510(K) of the Food, Drug, and Cosmetic Act, device manufacturers are required to perform safety and effectiveness testing of their device with another marketed model, and submit this data to the FDA. Only after their device receives 510(k) clearance are they permitted to market the device in the USA.

Welldoc, Glooko, and IBGStar are the most well-known apps that have received 510(k) clearance from the FDA. It has been estimated that only 75 apps total across the medical landscape (i.e., across all diseases) have received 510(k) clearance (26). Interestingly, in our search we did discover a number of apps that serve as insulin dose calculators (n = 8), which give patient-specific treatment recommendations, and would technically fall into the category of needing FDA approval. When we looked these 'medical advice' apps up in the 510(k) Premarket Notification database (27) we did not find any documentation to suggest that these apps have received FDA approval, revealing the gap between FDA oversight and the app market that consumers are currently accessing.

In both the iPhone and Android stores, many of the endocrine and diabetes apps were categorized as 'medical' in their descriptions, but this designation is presumably provided by the app maker, and not by any particular review body. Although the FDA guidelines discuss the differences between a medical mobile app and an app for health and wellness, consumers may be unaware of this distinction and may incorrectly assume that the 'medical' label implies an endorsement for medical effectiveness. This could have adverse health consequences, as outlined by a recent study of dermatologic apps for detecting suspicious skin lesions (28). The authors evaluated apps that used photography to characterize the risk of a skin lesion; they found a high percentage of these apps incorrectly classified cancerous lesions such as melanoma as 'unconcerning'. If patients substitute use of an app for a visit to a medical professional, this could have adverse health consequences.

Similarly, the insulin dose calculators that we found not only recommended insulin doses based on carbohydrate ratios and correction factors, but also recommended dose adjustments according to physical activity, alcohol intake, and recent hypoglycemia. Given that these factors may have different effects on individual patients with diabetes, it is certainly possible that use of these apps could lead to adverse events.

Threats to privacy and security of information transmitted through mobile apps

With an increasing number of users of mobile technology, there is growing concern about threats to consumer privacy, and health privacy in the case of health-related apps, given that wireless carriers, mobile operating system developers, handset manufacturers, app companies, and advertisers can access a wealth of personal information from the phone. The Federal Trade Commission has issued a staff report recommending that the critical players in the mobile industry give consumers disclosures about what data is being collected and how that data is being used (29); however, in our review we did not see many apps with these disclosures, given that there is no current enforcement of these regulations. This is of particular concern if the apps are being used by children (30).

Difficulties with finding relevant apps

In our search, we found that a number of apps are available exclusively through just one platform, either Android or iPhone, which limits consumers'

choices. Second, the search capabilities for both app stores are relatively rudimentary, without the ability to perform more advanced searches. Both stores carry user reviews, but the reliability of these reviews remains to be determined, with the majority of apps having a very small numbers of reviews (ranging from none to an average of 20–30). Finally, the app search algorithms are not transparent (i.e., it has been speculated that the iPhone app store is continually changing the search algorithms) which could affect patient access and choice of apps depending on when they access the store (31).

A few independent organizations have embarked on a formal app review process. Happtique, a digital platform that curates apps, has drafted app certification standards that they plan to use to certify apps that are reliable and safe, and includes requirements for operability, privacy, security, and content (32). DocGuide (DG) apps from Doctor's Guide Publishing Ltd., is a catalog of iPhone and iPad medical apps that is focused on reviewing apps developed for practicing physicians and other health care professionals (33). Finally, iMedicalApps is an online publication whose physician editors along with a team of physician, medical trainees, mHealth analysts, and other health professionals provide independent reviews of mobile medical technology; iMedicalApps has been cited by the Cochrane Collaboration as a trusted website (34,35).

We acknowledge limitations of our study. We focused on applications from the iPhone store; given the differences in overall search relevance that we found for iPhone and Android, results for the Android store could yield very different results. Furthermore, our findings are based on a search at one point in time, but by the time this review has been published, the number and variety of apps available in the consumer marketplace will have no doubt increased in number and variety.

Conclusion

In summary, mHealth has great potential for assisting patients with chronic disease management and for motivating healthy behaviors. However, further work is needed to: (1) prove the effectiveness of these apps; (2) integrate the use of apps with health care providers into the health care delivery system; and (3) provide consumers with systematic and reliable information about the safety and medical utility of mobile health applications.

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Conflict of interest

J. M. L. has served as a medical advisor to the T1D Exchange and myglu.org

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