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Technology Interventions to Manage Food Intake: Where Are We Now?

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Abstract
Purpose of Review This review describes the state-of-the-art for dietary assessment using smartphone apps and digital technology and provides an update on the efficacy of technology-mediated interventions for dietary change.
Recent Findings Technology has progressed from apps requiring entry of foods consumed, to digital imaging to provide food intake data. However, these methods rely on patients being active in data collection. The automated estimation of the volume and composition of every meal consumed globally is years away. The use of text messaging, apps, social media, and combinations of these for interventions is growing and proving effective for type 2 diabetes mellitus (T2DM). Effectiveness of text messaging for obesity management is improving and multicomponent interventions show promise. A stand-alone app is less likely to produce positive outcomes and social media is relatively unexplored.
Summary A concentrated effort will be needed to progress digital dietary assessment. Researcher-designed technology programs are producing positive outcomes for T2DM but further research is needed in the area of weight management.

Keywords Dietary assessment · Digital food images · Diet apps · Text messages · Social media · mHealth

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Introduction

The influence of diet in the prevention and management of type 2 diabetes mellitus (T2DM) has been recognized for many decades. The Diabetes Prevention Program demonstrated that it is possible to reduce the incidence of type 2 diabetes in at-risk populations with ≥ 7% weight loss following a low fat/energy restricted diet and 150 min of physical activity [1]. For people living with T2DM, the American Diabetes Association acknowledges there is no one size fits all diet for management of glycemia, blood lipids, blood pressure, and weight goals [2]. It states what is required is an individualized approach for each person based on dietary preferences, access to foods, and personal goals. It is clear that nutrition is complex and best advice and support comes from a dietitian. However, the size of this workforce is clearly limited to address the so-called "diabesity" epidemic. Currently, there is significant activity to determine if modern communication technologies may provide a solution for widespread dissemination of nutrition counseling. In particular, the high ownership of smartphones that possess a range of functions and are accessible at all times might make them a useful tool.

Among the functions that smartphones possess is a camera (usually with video), text messaging, mobile software applications (apps), connection to social media, connectivity to websites as well as the phone that can all be utilized in the delivery of dietary intervention. The apps and camera can also be employed in measuring dietary intake for assessment by a dietitian but also for self-monitoring by the person with prediabetes or T2DM. The aim of this review is two-fold, firstly to provide an overview of the current state-of-the-art for measurement of food intake using modern technologies and secondly summarize the evidence base for the efficacy of dietary interventions with technology-mediated deliveries. The scope of dietary interventions includes text-message trials, smartphone apps as sole medium of intervention delivery and mobile health delivery using multiple communication technologies. The use of web-based assessment tools and treatment websites will not be discussed here and has been addressed in detail previously [3, 4].

Methods

The methodological approach that has been taken is a review of reviews including narrative, scoping, and systematic literature reviews published January 2013 until June 2017. Original studies published in 2015 through 2017 were searched for the dietary assessment methods. Intervention studies in 2016–17 were searched so as to include those published after the search dates included in the reviews. PubMed and Web of Science were searched for articles; those not published in English were excluded. For measurement of food intake the search terms were "nutrition assessment" "diet records" "diet surveys" "energy intake" "dietetics" "eating" "diet" "nutrition surveys" "dietary assessment" AND "smartphones" "cell phones" "app" "mobile applications" "mobile" "phone". For use of mobile technologies in dietary interventions, the following terms were searched "text message/messaging" "apps" "social media" "mHealth" AND "weight management/loss" "obesity" "diabetes" and "diabetes prevention". Outcomes of interest for dietary assessment were validity and reproducibility of measurements of nutrients and food groups. For the interventions, outcomes of interest included the effectiveness of interventions, changes in food and nutrient intakes, weight change and change in glycemia in people with type 2 diabetes mellitus (T2DM). We have not included interventions for type 1 diabetes mellitus or gestational diabetes.

Results

Using Smartphones to Measure Food Consumption

Six review articles that evaluated the evidence or provided an overview of smartphone-based methods to assess dietary intake were identified and used as the primary basis of this review [5, 6•, 7•, 8–10]. An additional three validation studies (four papers) not reported in the reviews were also identified and evaluated [11–14].

Two approaches to assess dietary intake using smartphones have most frequently been described, evaluated, and validated. These include [1] dietary record apps and [2] image-based dietary record apps [6•, 7•] that use images as the primary record of food consumption. Both approaches are prospective methods that require users to actively record all food and beverages consumed for a given period, usually 2 to 7 days.

Dietary Record Apps

Dietary record apps are simply digital versions of their pen and paper-based counterparts but have several key strengths for both users to record food consumption, and for dietitians/health practitioners to review and clarify recorded intake. Review articles have consistently reported that participants prefer using technologies to record dietary intake compared to pen and paper-based dietary records [3, 5, 6•, 7•]. Common app features that improve the recording process include integrated food composition databases, search functionality, and suggested food lists, saved favorite foods and recipes, and barcode scanners [5, 6•, 7•, 8]. Other features such as push notifications or text message reminders prompt users to record intake and improve data quality [7•, 15]. There are many commercially developed lifestyle apps freely available within app stores that include recording of dietary intake (e.g., MyfitnessPal®, MyFatSecret®), and more recently apps developed in collaboration with national dietitian associations such as eaTracker® (Dietitians of Canada) [16]. Many apps also track physical activity, provide feedback and goal setting, and integrate messaging and/or social media functionality. Russin et al. reviewed the functionalities of 45 free or free-trial apps found within Google' Play and Apple's App Store and found they were primarily targeted to people with diabetes mellitus and the general population [10]. These authors also evaluated apps developed for research and found 45% were targeted to people with diabetes mellitus [10].

With respect to validity, dietary records on smartphone apps developed for research purposes are comparable to traditional pen and paper-based dietary records, and to 24-h dietary recalls, but are still prone to similar misreporting issues found with self-report [11–14, 17]. Important evidence, however, was first provided from research validating dietary records initially developed for PDAs [18–21]. Carter et al. [17] validated the "My Meal Mate" dietary record app among 50 staff and students at Leeds University over a 7-day period using two randomized 24-h dietary recalls. These researchers still incorporated images but only to record food consumption when there was difficulty recording intake into the app [17]. No significant difference was found between methods for energy intake, but wide limits of agreement were evident at the individual level.

Three studies not included in the six reviews assessed the convergent validity of dietary record apps using two [13] or three [11, 12, 14] 24-h dietary recalls, among predominantly adult female samples ($N = 142$ total). Relatively small differences in estimated mean energy intake between methods (−422 to 607 kJ) and moderate to strong correlations ($r = 0.66$ to 0.77) were reported between the studies. Similar to the findings of Carter et al., wide limits of agreement were common among all three studies. Of note, however, using relative measures of validity such as the 24-h dietary recall with its sources of measurement error are likely to produce variable results [22]. Thus, validation studies using criterion methods such as doubly labeled water are needed but are currently lacking. Formal validation of most commercial apps available to the public are yet to be undertaken and such apps predominantly use US nutrition composition databases and, thus, would not be recommended for use in other countries [23].

Image-Assisted and Image-Based Methods

Since 2002, most studies using smartphones have primarily focused on image-based approaches, evident in the systematic review by Sharp et al., where 11/12 studies identified between 2002 and 2013 used image-assisted or image-based methods [5]. Image-based dietary record apps have been the predominant focus of research efforts over the past 5 years due to their promise to improve accuracy and reduce participant burden [6•, 7•, 8, 9]. Image-based approaches use manual image analysis (trained image analysts) or automated computer vision techniques to identify the food type and estimate portion size required to derive energy and nutrient intake from corresponding nutrition databases [6•, 7•, 8]. Automated systems require users to place fiducial markers next to the foods analyzed to assist analysis. Additional images captured post consumption account for uneaten items or food wastage [7•].

Two reviews have examined the evidence for image-assisted and image-based methods [6•, 7•] and concluded that image-assisted and image-based dietary records can improve accuracy over their conventional counterparts. Reduced recording burden, increased the objectivity of the image analysis (compared to traditional self-report) and the ability to re-review images if inconsistencies are found reduce the magnitude of under-reporting [6•, 7•]. Importantly, such benefits have been demonstrated among adults with obesity who are most likely to under-report [15]. However, image-based methods are still prone to under-reporting if users capture images of poor quality or forget to capture images of the food before consumption [6•]. Studies that have assessed the validity of image-based methods include both criterion validation using weighed meals and doubly labeled water, and convergent validation studies using 24-h dietary recall or traditional dietary records [6•, 7•].

However, further studies with larger sample sizes and different population groups are required to determine efficacy, and the degree of error versus time and high cost must be considered in assessing the efficiency of using image-based methods over normal dietary record apps. Additionally, despite notable ongoing improvements in computer vision techniques to improve food detection and portion size estimation [7•, 8, 9], automated image analysis is still within the realm of research. It is yet to be fully integrated into apps available for general use by the public or by health professionals [7•]. Automated image analysis is beginning to appear in some free commercially available apps, for example, the Calorie Counter app by FatSecret® now automatically identifies some foods within images to improve the recording process (but does not attempt to estimate portion size). Other image-based dietary record apps, such as MealLogger®, do not attempt to derive nutrient information from the image, rather they provide a visual record of dietary intake that can be reviewed by dietitians remotely in near real-time to provide feedback, thus providing a contemporary qualitative approach to dietary monitoring [24].

Using Technology to Deliver Nutritional Interventions

Thirty-one reviews and 36 original studies form the basis of this report. A range of different types of technology-mediated lifestyle and dietary interventions has been tested in randomized controlled trials. Reviews also include some non-randomized trials and cohort studies. These have included lifestyle-based programs for weight management and medical nutrition therapeutic programs to address nutrition in diabetes. These delivery channels include text messaging, apps, social media, and combinations of all of these, with or without phone coaching. Below, we summarize the findings by the major delivery mode.

Text Messaging

Text message-based interventions appeared about a decade ago especially for nutrition and weight loss [25]. For the management of diabetes, initially, text messaging was used more for relaying blood glucose concentrations to clinicians or giving reminders about clinic visits or treatments [26]. However, this later developed into more educational and motivational messages including nutrition.

There are a number of systematic reviews, some with meta-analyses, regarding nutrition interventions in overweight and obese people with or without T2DM. In a systematic review of 13 studies, most with a diet component, it was reported that six resulted in weight loss. A meta-regression of six studies in adults that included nutrition advice showed a weight loss of 2.17 kg (95% CI −3.41 to −0.93) $P < 0.001$, compared with control groups [27]. Most studies were of short duration being less than 6 months. However, since 2016 there were six published adult text message-based obesity interventions effective for weight loss [28–30] or maintenance [31–33]. Success was also demonstrated in the use of text messaging for 11 healthy eating interventions in developing countries with five of seven showing positive outcomes in nutrition [34].

Systematic reviews of studies in obese children and adolescents indicate very limited success [35]. Only three of seven randomized controlled trials (RCTs) resulted in weight loss in adolescents. Systematic reviews in children identified four text message interventions aimed at obese children and only one of three succeeded in weight loss maintenance [36, 37]. However, two more recent studies in adolescents, one to improve fruit and vegetable intake and the other to decrease processed meats, showed positive outcomes [38, 39].

Text messaging with dietary and physical activity advice for T2DM control also appears to be effective. A recent review of 15 controlled trials found that Hemoglobin A1c (HbA1c) was lower for intervention groups −0.53% (95% CI −0.59 to −0.47%) indicating better glycemic control [40•]. Others have also reported that text messaging results in lowered HbA1c [41–45] but a study in developing countries found no additional benefits [46]. In a review of six studies, Holcomb concluded the correct dose of texts was weekly messages for 3 months to yield the best HbA1c concentrations and bidirectional messaging between patient and health professional was needed [47].

Studies of lifestyle intervention for prediabetes or to improve chronic disease risk factors in patients with T2DM published since 2016 have all indicated positive results for at least one outcome measure. These include studies in Hispanic patients in the USA and a large study in India [48–50]. Fisher et al. showed that the addition of text messages to face-to-face classes in an intervention based on the Diabetes Prevention Program resulted in modest weight loss, lowering of HbA1c and systolic blood pressure [51]. The intervention in India for people with type 2 diabetes showed improved fruit, vegetable, and fat consumption [49].

While receiving a text message at the right time will serve as a prompt or cue to perform a particular dietary behavior, the content is important and should include informational and motivational messages for dietary behavior change. Bidirectional texting for patients to send weights and blood glucose readings back to the researcher/clinician also serves the purpose of self-monitoring and clinician monitoring and enables individual feedback important for effective change. This ongoing contact with a clinician might explain why the programs for diabetes are more successful than those for weight management as accountability to and feedback from the clinician motivates individual behavior. For weight management interventions delivered without direct accountability to a clinician, motivation may be lessened but it is also acknowledged that maintaining weight loss is more difficult than changing types of food consumed and managing blood glucose concentrations. The positive evidence published in the past 2 years would appear to indicate intervention program design is improving as we become more experienced in message design and learn about dose.

Apps

The past 10 years have seen an exponential rise in the availability of health and lifestyle-related smartphone apps [52, 53]. As indicated above many include a function for recording food intake. Few of these have been tested in experimental designs for their effectiveness in changing individual's diets and as most are based on the US databases of foods their relevance in other countries minimal. Published reviews of apps find them lacking in credibility with respect to the evidence base for best clinical practice and input of experts and use of behavior change techniques is minimal to moderate [23, 54, 55].

DiFilippo et al. located studies using apps to improve nutritional intake and aid weight loss [56]. One of the two resulted in weight loss [17] but the other showed no additional advantage of apps [57]. Two additional studies showing efficacy for weight loss reported in another review [58]. Ross and Wing report that using apps for self-monitoring diet combined with brief coaching calls was effective for weight loss [59]. As with the text message interventions, the duration of most of these studies is too short to ensure long-term maintenance of weight loss.

Since 2016, a different approach to the assessment of apps for lifestyle change and weight management has been the analysis of cohort data provided to researchers by the commercial app companies. Data from 35,921 participants using Noom Coach® two or more times in 6 months demonstrated significant reductions in BMI [60•]. Data from The Lose It® commercial app (Fitnow Inc., Boston MA) demonstrated a differential pattern of weight loss according to how frequently users logged data [61]. Those users recording for more than 40 days were more likely to lose 5% body weight versus infrequent users.

Apps appear to be beneficial for improving outcomes for T2DM [62–68]. As an example, Hou et al. reported on 14 studies of the use of apps for the management of diabetes care; nine of these were for T2DM and included advice on food intake. It was found that the app interventions resulted in a mean decrease in HbA1C (−0.49; 95%CI −0.68 to −0.30) [63]. As for text messages, the use of an app as a tool for self-monitoring combined with consulting with a health professional regularly might contribute to their success.

Social Media

Social media is being utilized to provide social support to those trying to change health behaviors and manage chronic disease but also as the delivery medium for education within an intervention. This includes the use of online blogs, Facebook, and Twitter. Maher et al. conducted a systematic review of online social networks seven of which involved diet and weight loss [69]. The effects were modest (either nil or small) and engagement and fidelity were low. Additional reviews confirm this finding [70–77]. The most recent studies have indicated more success with the "Loseit Reddit Community" online community reporting 92.9% lost weight

[78]. Other studies of online interventions indicate that more interaction with the community leads to better weight loss outcomes [79].

For chronic disease management such as T2DM, the evidence is scant. One systematic review of social media interventions included the use of blogs for diabetes management [80] but no positive outcomes on glycemic control were found.

Interventions Using Multiple mHealth Components

While there are discrete studies of text messaging, apps, and social media, some studies use multiple components in an intervention and the relative contributions of the different media are not always discernible nor do they need to be unless one mode is ineffective or expensive. It makes good sense to use multiple features of mobile health to enable wider engagement and address the individual needs of many. Some reviews report on the efficacy of mHealth with favorable findings but many of the reviews [81], rather than being studies of multiple components, are reviews that combine studies using different modalities of mHealth. A meta-analysis of mHealth effectiveness in pediatric obesity found a small effect on weight loss and on dietary changes which were mostly around fruit and vegetables and involved apps or text messages combined with class lessons. Hamine et al. reviewed mHealth interventions for chronic disease including 26 RCTs for diabetes mellitus with mixed modalities of mHealth intervention [82]. Eleven of the trials produced positive outcomes for HbA1c or blood glucose concentrations.

To describe multicomponent interventions in more detail, we report on the individual trials published in 2016 and 2017. A multicomponent intervention to prevent weight gain in younger adults included brief coaching calls, text messaging, emails, apps, and downloadable resources. In an RCT design, the intervention resulted in a significant decrease in weight in the treatment arm versus control arm at 12 weeks and even greater differences at 9 months [83]. Another multicomponent intervention for young adults used social and mobile media in a 24 month long RCT showing significant weight loss in the treatment arm at 6 months but not at 24 months [84•]. The MINISTOP randomized controlled trial was based on a smartphone app that was educational but also used social support and behavior change techniques to enable parents to help their preschoolers develop healthy eating habits [85•]. Regular push notifications to prompt engagement, data entry of behavior, and weekly feedback were included and access to a dietitian or psychologist always available. The primary outcome was body fat and secondary outcomes were the intake of fruit, vegetables, candies, and sugar-sweetened beverages as well as physical activity and sedentary time. After 6 months, no difference in body fat was found, but the improvement in a composite score that included body fat plus the six secondary outcomes was significantly higher in the intervention than controls (0.36 units ±1.47 $P < 0.02$) [85•].

A ubiquitous heath care system that included blood glucose monitoring, an activity monitor, patient entry of food and beverage intake and baseline anthropometric data and medical data entered by the health professional was trialed in an RCT. The system gave automatic advice via messages to participants' phones and a server for their diet and was studied in patients with [86•] diabetes aged over 60 years. The intervention resulted in significantly lower HbA1c ($P < 0.01$) compared with those who self-monitored blood glucose concentrations [86•]. After 6 months, the u-healthcare group changed from HbA1c 8.0 ± 0.7 to 7.3 ± 0.9% whereas the self-monitoring controls had 8.1 ± 0.8 to 7.9 ± 1.2%.

As our ability to harness multiple delivery channels that modern communication technology affords us, it should be possible to build more sophisticated interventions that monitor the input from sensors and apps and allow timely, relevant advice as shown in the last example. It will take considerable research effort but the field is progressing [87•]. Cost-effectiveness of these interventions must be considered. Further challenge may surround the regulation of diabetes apps [88] and the problem of security of consumers' data cannot be underestimated [89].

Limitations and Strengths of the Review

There are several limitations to our review that should be addressed. This review did not follow the strict protocol of a systematic review of reviews nor rate the quality of each review or include studies other than those in English. However, the strength is that we have followed a systematic approach to finding and interpreting the relevant literature concentrating on reviews but then including searches of the primary studies, produced after the dates of the literature reviews. Only two databases were searched and it is possible that we failed to locate some studies. However, sufficient evidence was found to report on the current state-of-the-art of technology for dietary assessment and intervention.

Conclusions

In conclusion, advances are being made in the use of technology for managing food intake but we are not quite there yet. Recent studies indicate we have mastered text messaging in adults and in those with T2DM. Social media is a relatively untapped field needing further research. Apps have produced results in those withT2DM for glycemic control but not yet with weight loss and food intake. Multicomponent interventions that include some input from a health professional as is the case with most interventions for chronic disease may produce the best outcomes.

Current research efforts and trends in commercial apps indicate that images, either as the primary dietary record or as a complimentary log for qualitative dietary assessment, will become the norm in clinical practice. Progress in the advancement of computer vision for this field will dictate the manner in which images are used. As weight-management apps improve and gain favor with health professional bodies, their integration into patient care will increase but software for review of incoming data will need to evolve to best utilize this data. Machine learning may allow more individualized care plans according to patient data received.

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Compliance with Ethical Standards

Conflict of Interest Margaret Allman-Farinelli reports personal fees from NMHRC, and non-financial support from Qantas. Luke Gemming declares that he has no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors. The articles included in this review that were conducted by the authors ensured all procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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