Image-Assisted Dietary Assessment: A Systematic Review of the Evidence

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ABSTRACT

Images captured during eating episodes provide objective information to assist in the assessment of dietary intake. Images are captured using handheld devices or wearable cameras, and can support traditional self-report or provide the primary record of dietary intake. A diverse range of image-assisted methods have been developed and evaluated but have not been previously examined together. Therefore, a review was undertaken to examine all studies that have evaluated or validated image-assisted methods of dietary assessment for assessing dietary energy intake. Identified image-assisted methods that employ similar methodologies were grouped for comparison. English-language full-text research articles published between January 1998 and November 2013 were searched using five electronic databases. A search of reference lists and associated websites was also conducted. Thirteen studies that evaluated 10 unique image-assisted methods among adults aged 18 to 70 years were included. Ten studies used handheld devices and three studies used wearable cameras. Eight studies evaluated image-based food records, two studies explored the use of images to enhance written food records, and three studies evaluated image-assisted 24-hour dietary recalls. Results indicate images enhance self-report by revealing unreported foods and identify misreporting errors not captured by traditional methods alone. Moreover, when used as the primary record of dietary intake, images can provide valid estimates of energy intake. However, image-assisted methods that rely on image analysis can be prone to underestimation if users do not capture images of satisfactory quality before all foods are consumed. Further validation studies using criterion measures are warranted. The validity among children, adolescents, and elderly persons as well as the feasibility of using image-assisted methods in large samples needs to be examined. Additional research is also needed to better understand the potential applications and pitfalls of wearable cameras.
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THERE IS A CLEAR NEED FOR IMPROVED METHODS OF dietary assessment.[1,2] Despite advances in computer technologies to standardize methods and streamline analysis through software, traditional methods are still prone to substantial error and bias.[3-5] A main contributor to bias is reliance on self-report without the ability to verify the dietary information, which typically leads to underreporting of energy intake (EI), especially problematic in overweight and obese populations.[4,6-13] Despite the bias, self-report obtains valuable information about the foods people consume.

Due to the limitations of self-report and the perception that images may increase objectivity (a picture is worth a thousand words), various methods of image-assisted dietary assessment have been developed, pilot tested, or validated.[14-19] Image-assisted dietary assessment refers to any method that uses images/video of eating episodes to enhance self-report of traditional methods, or uses images/video as the primary record of dietary intake. The images of foods can be captured using any device, but two distinct approaches for capturing the image have been explored: active and passive.

Active methods typically require individuals to capture images of foods with handheld devices, such as digital cameras or smartphones. Generally images are captured before and after eating episodes (to record waste) and a reference marker is placed near the foods to assist image analysis techniques (manual or automated).[20-22] Often the images of foods are supported by supplementary text or voice recordings describing the foods, or require user input to confirm details extracted from the image (within a software application), such as food type or portion size.[20,23,24] The active approach helps ensure the images obtained are relatively consistent for image analysis, but relies on users to remember to use the camera at every eating episode.

The passive approach uses wearable cameras to automatically capture point-of-view images of daily events, including eating episodes, with virtually no user input. Thus, passive image capture does not rely on users to capture images of foods; however, the images captured are not directed specifically at foods, nor do they contain a reference marker to assist analysis. A novel aspect of passive image capture, in comparison to active methods, is the ability to aid memory recall during retrospective assessment without the need for the user to manually record dietary intake during the assessment period.[18,25]

Due to a variety of technologies suitable for use in image-assisted methods, and the differences between the active and passive approach, there is a diverse range of methods not previously examined or easily compared. Stumbo and colleagues[26] detailed the methods employed in selected image-assisted methods in development (yet to be validated), and Illner and colleagues[27] examined the strength and weaknesses of several innovative technologies in dietary assessment. However, to date no review has examined the current evidence regarding the use of image-assisted dietary assessment methods. The aim of this review was to examine all studies that have evaluated or validated an image-assisted method of dietary assessment compared with a reference method for assessing dietary EI. Due to the diversity of image-assisted methods identified, we grouped and categorized methods that employ similar methodologies for comparison.

METHODS

Eligibility Criteria

All studies that evaluated or validated an image-assisted method of dietary assessment compared to a reference method for assessing dietary EI were included. Technical reports associated with the studies and methods of image-assisted dietary assessment included were only used to support the description of the method and supporting systems used.

Exclusion Criteria

Studies that did not report EI or compare EI with a reference method were excluded. Methods of image-assisted dietary assessment under development that have not been evaluated among users described in technical reports were excluded. Studies that used precaptured images or image databanks to assist portion size estimation in traditional methods of dietary assessment were also excluded.

Information Sources and Search Strategy

Five electronic databases were searched: MEDLINE, PubMed, Web of Science, the Cumulative Index to Nursing and Allied Health Plus, and ProQuest. The searches were conducted during November 2013. A search strategy was developed using a combination of Medical Subject Headings and key words. The search string was modified where appropriate for use in the other databases. Search limiters included English language, human participants, and studies reported between 1998 and the search date to ensure all technologies evaluated in image-based methods were identified. (See Figure 1 for an example search strategy for MEDLINE database.) A manual search of included articles reference sections, and associated websites, supplemented the search of electronic databases. Corresponding authors of identified image-assisted methods in development (not evaluated or validated among users) were contacted to identify any additional studies. The search results from all databases and the manual search were imported into a reference software package EndNote (version 16, 2012, Thomson Reuters). After the removal of duplicates, the title and abstracts were screened by one reviewer (L. G.). The full-text studies that appeared relevant were then obtained and screened. Manuscripts potentially eligible for inclusion were discussed and their inclusion or exclusion were agreed upon by two authors (L. G. and C. N.).

Example Search Strategy
Source: MEDLINE[a]

1. exp[b] Technology/[c]
2. exp Cellular Phone/
3. smartphone$[d].mp.[e]
4. mobile phone$.mp.
5. mobile telephone$.mp.
6. personal digital assistant.mp.
7. PDA.mp.
8. exp Computers, Handheld/
9. tablet computer.mp.
10. device.mp.
11. life-logging.mp.
12. exp Video Recording/
13. video.mp.
14. image$.mp.
15. digital camera.mp.
16. wearable camera.mp.
17. sensecam.mp.
18. wearable sensor.mp.
19. camera.mp.
20. 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19
21. exp Nutrition Assessment/
22. exp Dietetics/mt [Methods]
23. dietary assessment.mp.
24. exp Diet/is, mt [Instrumentation, Methods]
25. exp Diet Surveys/
26. exp Nutrition Surveys/
27. 21 or 22 or 23 or 24 or 25 or 26
28. 20 and 27
29. limit 28 to (english language and humans and yr="1998 -Current")

[a]Appropriate search terms utilized for other databases.
[b]exp=exploded
[c]Medline Subject Heading for MEDLINE
[d]$=any character
[e]multi-purpose search [mp.] = Title, Original Title, Abstract, Subject Heading, Name of Substance, and Registry Word fields.

Figure 1. MEDLINE search strategy for the systematic review examining the evidence for image-assisted methods of dietary assessment. [a]Appropriate search terms used for other databases. [b]exp=exploded. [c]Medline Subject Heading for MEDLINE. [d]$=any character. [e]multipurpose search [mp.]=Title, Original Title, Abstract, Subject Heading, Name of Substance, and Registry Word fields.

Data Extraction

Data extraction was conducted by one reviewer (L. G.) using a custom data extraction form to extract general study details as follows: participant characteristics sex, age, and body mass index; inclusion/exclusion criteria; study setting; method of

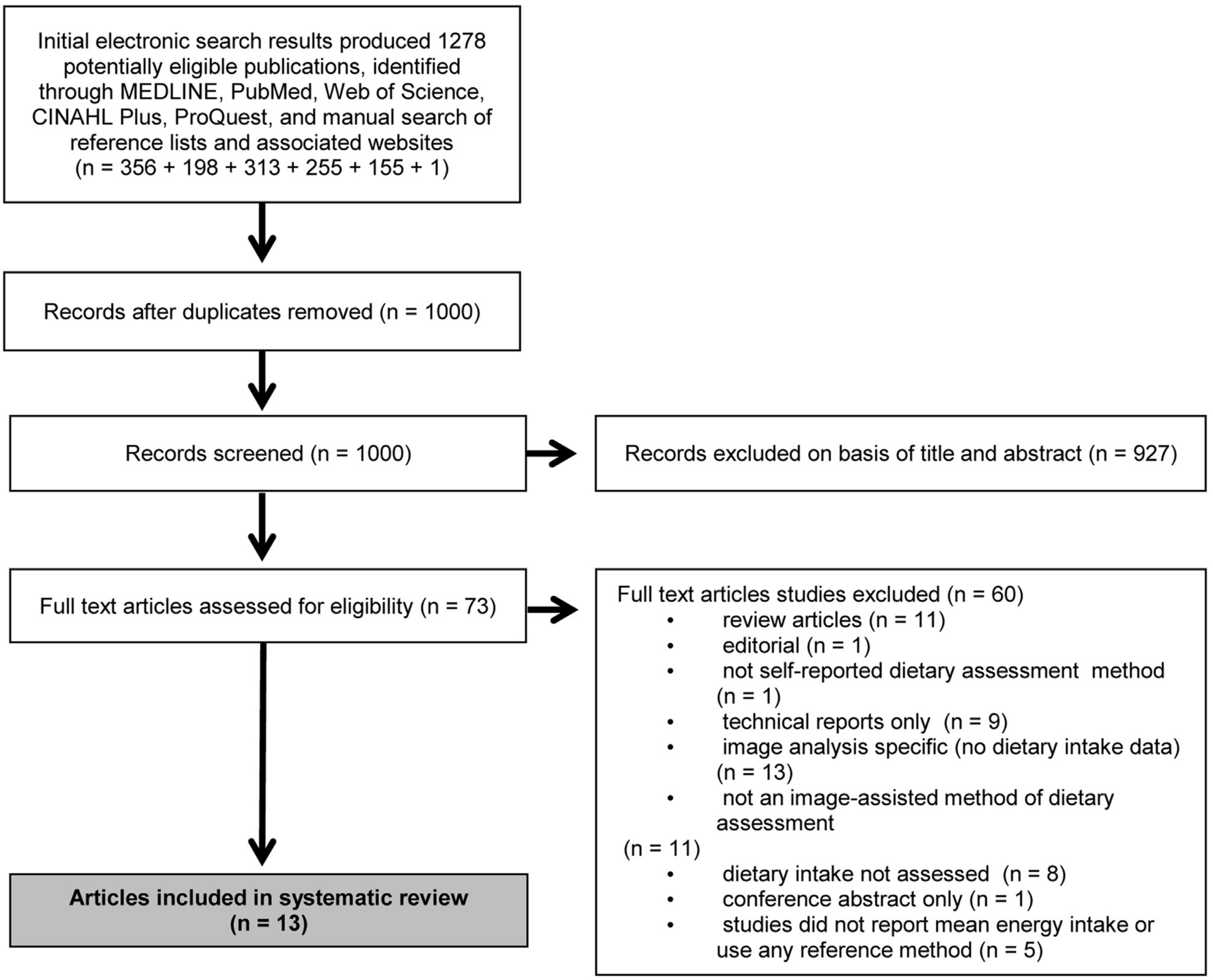

Figure 2. Flowchart and inclusion process for the systematic review examining the evidence for image-assisted methods of dietary assessment. CINAHL=Cumulative Index to Nursing and Allied Health Literature.

image-assisted dietary assessment; study design and duration; reference method used; mean EI or EE; statistical analysis; feedback regarding method/technology; and study limitations. When further information was sought, corresponding authors were contacted via E-mail. One follow-up E-mail was sent if no response was received to the first. Because of the substantial heterogeneity between image-assisted methods of dietary assessment used, study designs, durations, and populations only a narrative review was performed in this systematic review.

Quality Assessment

The majority of studies published in this field to date have been pilot or feasibility studies. Therefore, a formal assessment of study quality was not undertaken as the assessment would not provide meaningful outcomes. However, the study designs were examined to assess risk of bias regarding the review and analysis of captured images to obtain EI data. (There is potential for bias if the image analysis is conducted without independent image analysts/researchers blinded from the reference method.)

RESULTS

Search Results

Figure 2 shows a flow diagram depicting the search and inclusion of the studies. Of 1,278 potentially eligible articles initially identified, 13 met the inclusion criteria. Ten studies used active image capture[14-16,22-24,28-31] with handheld devices and three used passive image capture with wearable cameras.[17,18,32] Eight studies evaluated five different image-based food records captured using handheld digital cameras, personal digital assistants (PDAs) and smartphones.[14,16,22-24,28-30] Two studies evaluated the use of images to assist traditional written food records; one used a single-use/disposable camera,[15] and the other used a wearable camera.[32] Three studies evaluated the use of images to assist self-report during 24-hour dietary recalls. Two of the studies used wearable cameras[17,18] and one study used a handheld digital camera.[31] Three other image-assisted methods under development were identified by the search strategy but had not been evaluated among users assessing dietary energy intake.[19,33,34]

Characteristics of Included Studies

The 13 included studies are presented in the Table. The sample sizes of the studies were small. Six studies had fewer than 20 participants[15,17,18,24,29,30] six studies had between 20 and 50 participants,[14,22,23,28,31,32] and one study had 75 participants.[16] Seven studies recruited healthy adults,[16-18,22,29-31] two recruited university students,[23,28] two recruited adults with overweight and obesity,[14,15] one study recruited adults with type 2 diabetes,[24] and one study recruited a combination of athletes and physically active university students.[32] The mean age was available for 11 studies,[14,16-18,22,24,28-32] with the mean age ranging from 18 to 65 years. No study had participants younger than age 18 years or older than age 70 years. Sex was identified in all studies. Three studies recruited female participants only.[23,28,31] Five studies used criterion reference methods to evaluate EI data.[14,17,22,30,31] Two of the studies used doubly labeled water (DLW) to assess total energy expenditure (EE),[14,17] and three used weighed meals.[22,30,31] Eight studies used traditional methods of dietary assessment as reference methods.[15,16,18,23,24,28,29,32] Four studies used weighed food records,[16,23,28,29] three used estimated food records,[15,24,32] and one study used the 24-hour dietary recall.[18]

Image-Based Food Records

For the purpose of our review an image-based food record is any method where images of foods captured during eating episodes provide the primary record of dietary intake to determine energy and nutrient content. The first attempt to validate an image-based food record used camera-enabled PDAs in the Wellnavi method.[23,28] The Wellnavi method required users to capture images of foods, at a 45° angle, before and after eating episodes. Foods were placed on a table, and the PDAs stylus was placed beside foods as a visual reference for portion size estimation. After the images were captured, users were required to describe the foods and provide ingredients with written text on the screen (using the stylus), especially when the foods were considered difficult to judge using images alone. The images and description of the foods were transmitted wirelessly to a server for manual image analysis by registered dietitian nutritionists (RDNs). To aid analysis, a brief questionnaire was used to obtain additional information on dietary behaviors such as added sugar added to beverages, and typical condiment use.

Two pilot studies were conducted among female nutrition students (n=20 and n=28) who simultaneously recorded dietary intake using the Wellnavi method and weighed food record.[23,28] In the first study, diet was recorded for 1 day,[23] and in the latter participants recorded diet for 1 day in June and November.[28] Both studies found no significant differences in EI or macronutrients between the two methods.[23,28] A larger validation study was then conducted by Kikunaga and colleagues[16] among adults of the general Japanese population (n=75) who simultaneously recorded their diet for 7 days using the Wellnavi method and a weighed food record. Compared with the food record the Wellnavi method underestimated mean EI by 13.1% (1,977±405 kcal vs 1,718±361 kcal; $P<0.001$) and significantly underestimated all macronutrients. The authors noted that a high proportion of images did not contain any text describing the foods, which made accurate image analysis challenging for complex and traditional Japanese dishes.[16] Participant feedback in the pilot study indicated it was difficult to write text on the small screens (using the stylus),[23] which was likely a factor that contributed to the low compliance and subsequent underestimation of EI.[16] Moreover, limitations of the PDA technology including the bulk of the device, poor battery life, and image quality were apparent.

Lassen et al[29] conducted a study using a standalone handheld digital camera to evaluate the potential of the digital method image-based food record. While seated, users were required to capture images of foods on a table, at a 45° angle, before and after eating episodes. Users were required to separate different meal components on the plate to assist analysis and a ruler was placed beside foods as a reference for portion size estimation. A notebook was provided to record the recipes and ingredients in grams or common household measures.[29] Manual image analysis was conducted by two image analysts trained using a reference database of commonly consumed foods developed from a feasibility study.[29]

A sample of healthy adults (n=19) simultaneously recorded their dinners for five nights (excluding beverages) using the digital method and weighed food records. Compared with the food record the digital method underestimated mean EI by 11.3% (dinner only; 526±178 kcal vs 471±167 kcal; $P<0.001$).[29] Participant feedback revealed difficultly remembering to record intake, particularly when eating out, or for rapidly consumed items not eaten from a plate. Moreover, some participants noted it was awkward to separate foods on the plate before capturing an image.[29]

Rollo and colleagues[24] conducted a pilot study to test Nutricam, an image-based food record application on a mobile telephone. Similar to other methods before and after images were captured of foods on tables, at a 45° angle, before and after eating episodes. Additional images were captured if necessary to ensure the images were clear for analysis. A reference card was placed next to foods for portion size estimation, and provided prompts for a brief voice recording (≤30 seconds) to describe the food name, type, brand/product name, and preparation/cooking method of each food item. The images and associated voice recordings were assessed independently by an RDN.[24]

Adults with type 2 diabetes (n=10) simultaneously recorded their dietary intake using Nutricam and an estimated food record for 3 days. Compared with the food record Nutricam underestimated mean EI by 9.3% (1,660±439 kcal vs 1,505±469 kcal; $P<0.05$). Only 71% of Nutricam entries included an image of adequate quality for analysis, and only 66% of entries included a voice recording, which explained the underestimation. The authors also noted it was the difficult to analyze complex dishes. Participant feedback revealed memory failure as the most common reason why they did not capture an image of the foods consumed.[24]

The Remote Food Photography Method (RFPM), and the mobile telephone food record (mpFR) are more sophisticated methods that incorporate automated image analysis

Table. Studies that have evaluated or validated an image-assisted method of dietary assessment compared to a reference method assessing dietary energy intake

Author	Method	Method of image capture	Participants/(N), mean age (y±SD[a]), body mass index±SD	Reference method(s)	Difference compared with reference[b] (%)	*P* value[c]	Feedback of method/ technology	Study limitations
Image-based FRs[d]								
Lassen and colleagues, 2010[29]	Digital Photography Method	Active Nikon Coolpix SS210 digital camera	Healthy adults/N=23[e] Age: 37±16 BMI: 24±3	5-day weighed FR (dinner only)	−11.3	<0.001	• Easy to complete • High compliance (94%) • Difficulties when away from home or food prepared by others • Participants reported awkward to separate items • Did not appear to influence eating habits to any great extent • Sometimes larger servings were chosen or sauces not consumed to avoid taking extra images	No criterion measure, sample size, no beverages in analysis, food items separated on plate, only dinner
Kikunaga and colleagues, 2007[16]	Wellnavi method	Active PDA[f] with camera + telephone card	Healthy adults/N=75 Age: 49±10 BMI: 24±4	7-day weighed FR	−13.1	<0.001	• Most participants did not capture images at 45° angle, which made image analysis difficult • Low compliance using stylus made image analysis difficult without supporting text • Traditional Japanese foods hard to visually identify	No criterion measure, normal body size
Martin and colleagues, 2009[22]	Remote Food Photography Method	Active Motorola i860 mobile telephone	Healthy adults/N=50 Age: 32±2[g] BMI: 27±1[g]	3-d weighed meals Dine-in group (n=25) (lunch and dinner in laboratory) Takeout group (n=25) (lunch in laboratory) Takeout group (dinner in simulated free-living conditions)	 −4.7 −5.5 −6.6	 0.046 0.076 0.017	• Most participants satisfied with the Remote Food Photography Method and ease of use • Almost all participants rated that they prefer the Remote Food Photography Method over a written FR • Some participants forgot to take images of food • Some EMA[h] messages were sent at the wrong time • Suggestion to maintain a written FR in case of technology failure	Food items separated on multiple plates, limited number of foods provided, only dinner consumed in free-living conditions, only 3-d assessment

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Table. Studies that have evaluated or validated an image-assisted method of dietary assessment compared to a reference method assessing dietary energy intake (*continued*)

Author	Method	Method of image capture	Participants/(N), mean age (y±SD[a]), body mass index±SD	Reference method(s)	Difference compared with reference[b] (%)	*P* value[c]	Feedback of method/ technology	Study limitations
Martin and colleagues, 2012[14]	Remote Food Photography	Active	Study 1 Overweight and obese adults/N=40 Age: 43±14 BMI: 24±48 Study 2 Overweight and obese adults/N=50 Age: 41±13 BMI:31±5	Study 1 1-wk Remote Food Photography Method vs 2-wk DLW[i] Standard EMA group (n=22)[j] Customized EMA group (n=13)[j] Study 2 2 weighed buffet meals in laboratory (N=49)[j] 1-wk Remote Food Photography Method vs 2-wk DLW (N=42)[j]	 −36.3 −12.4 −0.7 −6.4	 <0.0001 0.22 0.67 0.16	• 82% of participants rated their satisfaction with the method as 5 or higher on a 6-point Likert scale • 93% and 89% rated the ease of use as 5 or higher • 93% and 96% rated the usefulness of the run-in period and training as 5 or higher on a 6-point Likert scale	Study 1 No participants older than age 65 y, small sample size in customized group, mainly women Study 2 No participants older than age 65 y, mainly women, only 1-wk of assessment compared with DLW
Wang and colleagues, 2002[23]	Wellnavi method	Active PDA with camera+ telephone card	Female nutrition students/N=20 Age: NR[k] BMI: NR	1-d weighed FR	6	>0.05	• Certain foods hard to visualize separately for analysis • Difficulty using the PDA stylus on small screen • Battery charging was time consuming • PDA was considered heavy • Few (10%) indicated the method was satisfactory, 40% somewhat satisfactory, 25% somewhat unsatisfactory, and 25% participants unsure	No criterion measure, sample size, female nutrition students, 1-d assessment

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Table. Studies that have evaluated or validated an image-assisted method of dietary assessment compared to a reference method assessing dietary energy intake (*continued*)

Author	Method	Method of image capture	Participants/(N), mean age (y±SD[a]), body mass index±SD	Reference method(s)	Difference compared with reference[b] (%)	*P* value[c]	Feedback of method/ technology	Study limitations
Wang and colleagues, 2006[28]	Wellnavi method	Active PDA with camera+ telephone card	Female nutrition students/N=28 Age: 20±5 BMI: 21±3	2x1-d weighed FR June and November	−3.8 (June) 2.3 (November)	>0.05 >0.05	• The majority considered the Wellnavi less burdensome compared with FR • About half indicated they could continue using Wellnavi for 1 mo • Nearly one-third indicated being self-conscious about their meals seen by strangers	No criterion measure, sample size, female nutrition students, 2x1-d assessment only
Rollo and colleagues, 2011[24]	Nutricam	Active Sony Ericsson K800i mobile telephone	Adults with type 2 diabetes/N=10 Age: 65±34 BMI: 34±7	Estimated 3-d FR	−9.3	0.03	• Software was easy to use and study participants preferred Nutricam over the FR • All subjects were confident they could use Nutricam to record their dietary intake for 1 mo • Some poor-quality images restricted image analysis • Participants commonly reported failure to use Nutricam at eating episodes • 20-sec voice recording limit was too short	No criterion measure sample size, no criterion measure, short duration, adults with type 2 diabetes only, only 3-d assessment
Schap and colleagues, 2012[30]	Mobile telephone FR	Active IPhone 3GS (Apple Inc)	Adults from campus community/N=12 Age: 23[l] (median) BMI: 24±4	3 nonconsecutive days of weighed meals (portions of known quantities provided)	−6.4	0.243	• Some foods were not photographed by participants	Sample size, short duration, no criterion measure for total energy intake, foods items known by analysts, only 3-d assessment
Image-assisted FRs								
Gregory and colleagues, 2006[15]	Food diary with photographs	Active Single-use camera	Adults with obesity/N=9 Age: NR BMI: >30	Estimated 3-d FR (nonconsecutive) Dietitian 1 Dietitian 2	 8 5.2	 0.71 0.87	• Images revealed misreporting errors	No criterion measure, sample size, little detail on the changes to energy intake due to the addition of photographs

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Table. Studies that have evaluated or validated an image-assisted method of dietary assessment compared to a reference method assessing dietary energy intake (*continued*)

Author	Method	Method of image capture	Participants/(N), mean age (y±SD[a]), body mass index±SD	Reference method(s)	Difference compared with reference[b] (%)	*P* value[c]	Feedback of method/ technology	Study limitations
O'Loughlin and colleagues, 2013[32]	SenseCam-assisted FR	Passive SenseCam (Microsoft Corporation) wearable camera	Healthy young adults/N=47 Trainee jockeys/n=17 Age: 18±2 BMI: NR Gaelic footballers/n=15 Age: 22±1 BMI: NR Active university students/n=15 Age: 23±1 BMI: NR	Estimated 1-d FR alone Trainee jockeys (n=11)[j] Gaelic footballers (n=10)[j] Active university students (n=13)[j]	12 22.7 11.2	≤0.001 ≤0.001 ≤0.01	• User and camera error resulted in 28% (n=13) of participant data excluded from analysis • Camera not worn properly by all participants • Poor image quality in low-light conditions	No criterion measure, mainly physically active participants, no details on changes made due to images
Image-assisted 24-h dietary recalls								
Arab and colleagues, 2011[17]	Image-DietDay 24-hour dietary recall	Semi-passive Nokia N80 mobile telephone	Healthy adults/N=14 Age: 35±12 BMI: 27±7	3x Image-DietDay 24-h dietary recall vs 2-wk DLW	7.6	NR	• No technical failures occurred • Battery not always sufficient • Device cumbersome to wear for the majority of participants • 57% found the images helpful, and 79% were comfortable using the ImageViewer • Sometimes eating behavior was affected (eating out less often and eating more rapidly)	Sample size, predominantly women, motivated adults already participating in nutrition research

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Table. Studies that have evaluated or validated an image-assisted method of dietary assessment compared to a reference method assessing dietary energy intake (*continued*)

Author	Method	Method of image capture	Participants/(N), mean age (y±SD[a]), body mass index±SD	Reference method(s)	Difference compared with reference[b] (%)	*P* value[c]	Feedback of method/ technology	Study limitations
Gemming and colleagues, 2013[18]	SenseCam-assisted 24-h dietary recall	Passive SenseCam wearable camera	Healthy adults/N=10 Age:33±11 BMI:26±11	1 24-h dietary recall alone	12.5	0.02	• Wearing SenseCam was a low burden • Images helped participants remember unreported foods • Posture and body shape affect lens direction • Poor image quality in low-light environments • Imaging frequency too low to capture all foods consumed • Device fault resulted in loss of images for 2 participants	No criterion measure, sample size, mainly males, only 1 24-h dietary recall
Lazarte and colleagues, 2012[31]	Food Photography 24-h recall	Active Samsung Digimax S760 digital camera	Adult women/N=43 Age: 35±9 BMI: 25±4	1-d weighed meals (kept by research assistant)	−3.9	<0.05	• Some foods obscured in images • Memory lapses could not always identify unknown food	Only 1-d assessment, women only

[a]SD=standard deviation.
[b]Difference in mean energy intake compared to reference method (%).
[c]Exact *P* value if reported.
[d]FR=food record.
[e]Energy intake data for 19 participants.
[f]PDA=personal digital assistant.
[g]Standard error of the mean.
[h]EMA=ecological momentary assessment.
[i]DLW=doubly labeled water.
[j]Fewer participants due to dropouts and/or excluded data.
[k]NR=not reported.
[l]Standard deviation not reported.

techniques into comprehensive dietary assessment systems.[14,20,35] The RFPM was adapted from a validated method to assess EI using images in cafeteria settings (not self-captured).[36,37] Like other methods, users are required to capture images of foods on a table at 45°, before and after eating episodes.[22] A reference card with a printed pattern is placed next to foods to correct for color and assist in the estimation of the food's area.[38] The captured images are transmitted wirelessly to a server in near real time for analysis using a custom program. Features from the images are extracted for each food identified for food classification,[38] and the program compares the foods with a searchable image archive of foods and portion sizes matched to the Food and Nutrient Database for Dietary Studies (USDA Food and Nutrient Database for Dietary Studies, version 3.0, 2008).[22] The food area is converted to grams based on the association between food area and weight for each respective food.[38] RDNs reviewed the data and made changes as required and could contact users immediately if the images/data are of poor quality.[38] Users are instructed to record dietary intake using pen and paper or leave a voice message describing the foods if they forget to capture images. To remind participants to record dietary intake, the RFPM incorporates the use of ecologic momentary assessment (EMA); that is, automated prompts at meal times that require a user response.[14,22]

The validity and reliability of the RFPM was initially assessed using weighed meals and a manual procedure of image analysis.[22] A sample of healthy adults (N=50) recorded their diet for 3 days using the RFPM. The dine-in group (n=25) recorded their lunch and dinners in the laboratory, whereas the takeout group (n=25) recorded their lunch in the laboratory and dinner in simulated free-living conditions (preweighed foods provided in a cooler).[22] Compared with the weighed meals the RFPM underestimated the mean EI by 4.7% (dine-in group), and 5.5% (takeout group) in laboratory conditions, and by 6.6% in simulated free-living conditions (takeout group).[22] An assessment of reliability between three RDNs analyzing the images demonstrated good agreement for EI (interclass correlation coefficient 0.88, 95% CI 0.81 to 0.91) and food type selection (interclass correlation coefficient 0.99, 95% CI 0.99 to 0.99).[22]

The RFPM was refined before a further development study among overweight and obese participants (N=40) evaluated different EMA approaches: a standard EMA (n=24) and customized EMA (n=16).[14] Participants recorded their diet for 1 week during a 2-week DLW protocol to assess total EE, and were provided standard EMA (set meal times) or customized EMA (individualized meal times). Using standard EMA the mean EI:EE was underestimated by 36.3% compared with only 12.4% in the customized EMA group.[14] After further refinement the RFPM was validated in a sample of overweight and obese participants in both laboratory (n=49, two weighed buffet meals) and free-living conditions (n=42, RFPM recorded diet for 1 week of a 2-week DLW protocol).[14] Compared with weighed meals, mean EI estimated by the RFPM was very similar (587±209 kcal vs 583±190 kcal; P=0.67), and compared with DLW in free-living conditions the mean EI:EE was underestimated by 6.4% (2,360±626 kcal vs 2,208±665 kcal; P=0.16). Participant feedback indicated the majority were satisfied with the method and indicated the method was easy to use compared with written records.

The mpFR uses a similar procedure to the RFPM with users required to capture images of foods on a table, at a 45° angle, before and after eating episodes. The captured images are transmitted wirelessly to a server for analysis using a custom program. A checked fiducial marker (reference marker) is placed next to foods to assist the automated system to estimate food volume.[20] The foods are segmented into individual food items using a series of techniques[37,39-41] before classification and volume estimation using calculations based on the food's shape.[37]

Using a different approach to the RFPM, images of foods are labeled and the results are sent back to the user to confirm or modify the foods and portion size determined by the automated system (rather than by researchers). After user adjustments and confirmation the foods are indexed with the Food and Nutrient Database for Dietary Studies before results are sent to researchers/RDNs. A backup electronic food record is built into the smartphone application when users forget to capture images.

At the time of writing, only a pilot study (within a doctoral thesis) designed to inform a larger validation of the mpFR has been reported which assessed energy intake among users.[30] The pilot used manual image analysis with trained image analysts (not the automated system described above).[30] A sample of adults from the campus community (N=12) were provided with a range of foods (portions known and excess to their energy requirements) on 3 nonconsecutive days to eat in both laboratory and free-living conditions, and instructed to record all eating episodes with the mpFR. Compared with the presumed EI (determined from returned uneaten foods) the mean EI was underestimated by 6.4%. (Image analysts had knowledge of the foods and portions provided.) Participant feedback was not reported, but other research evaluating usability of the mpFR indicated users find the method easy to use and preferred it over a traditional food record.[42,43]

Image-Assisted Food Records

For the purpose of our review an image-assisted food record is any method where images captured during eating episodes are used to enhance or supplement a traditional text-based food record (written or electronic). Gregory and colleagues[15] conducted a feasibility study among adults with obesity (N=9) to explore the use of a handheld disposable/single-use film camera to enhance an estimated food record over 3 nonconsecutive days. Participants were required to capture a picture at arm's length from the table, and placed a 15-cm ruler as a reference for plate size. Foods were then recorded into a booklet provided. After the testing period the food record and photographs were reviewed independently by two RDNs. Compared with the food record alone, reviewing the photographs increased the mean EI by 8% for RDN 1 and by 5.2% for RDN 2, but this was not statistically significant (P=0.87). No data pertaining to how the image review specifically changed EI was provided, but identification of misreporting errors was noted by the authors.

O'Loughlin and colleagues[32] conducted a study to assess whether images can enhance the food record using the wearable camera (SenseCam, Microsoft Corporation). SenseCam is a wearable camera worn around the neck on a lanyard with a wide-angled lens,[44,45] and images are captured passively at approximately 20-second intervals (~2,000 to

3,000 images per day). Internal flash memory is sufficient for 1 week and battery capacity is adequate for a typical 12- to 16-hour day. Once turned on, the SenseCam operates continuously until the camera is switched off (a privacy button can be activated to cease image capture temporally).

For 1 day, trainee jockeys (n=17), Gaelic footballers (n=15), and physically active university students (n=15) wore the SenseCam and recorded their diets using an estimated food record. After the testing period the food record was reviewed by the participant and RDN for ambiguous information before viewing the SenseCam images. Compared with the food record alone, viewing the SenseCam images significantly increased mean EI by 12%, 23%, and 11% for the trainee jockeys, Gaelic footballers, and physically active university students, respectively ($P \leq 0.001$, $P \leq 0.001$, and $P \leq 0.01$).[32] In all three groups only one participant's food record remained unchanged after image review. No data pertaining to exactly how the image review altered the EI was provided, but unreported foods and misreporting errors were noted by the authors. The study design had a risk for interviewer bias because changes to dietary intake were made by the same RDN. Technical problems with SenseCam devices and user error resulted in incomplete data for 13 participants (28%) and were not included in the analysis. The authors[32] also noted poor image quality in low light environments and devices were frequently not worn correctly affecting image quality.

Image-Assisted 24-Hour Recalls

For the purpose of our review an image-assisted 24-hour dietary recall is any method where images captured during eating episodes are used to self-report during the 24-hour dietary recall method. Arab and colleagues[17] first tested the feasibility of a web-based, self-administered, image-assisted 24-hour dietary recall (Image-DietDay) in a sample of healthy adults (N=14). For 6 to 10 days of a 15-day DLW protocol participants wore a customized mobile telephone around the neck (using a lanyard) that captured images every 10 seconds during eating episodes. The images were transmitted wirelessly to a server for processing (blurry and dark images removed), and a selection of images (<100) were presented in an image viewer to assist participants during three Image-DietDay 24-hour recalls. Compared with DLW, Image-DietDay overestimated the mean EI:EE by 7% (2,711±1,225 kcal vs 2,519±609 kcal, respectively). The study design did not permit any analysis regarding how the images assisted the recall but participant feedback indicated that most found the images helpful. However, in some cases wearing the telephones may have altered usual eating behaviors. The authors[17] also noted the battery life was not always sufficient to last an entire day and the telephone's narrow field of view was not ideal for dietary assessment.[17] Other testing of the system reported an imaging frequency of 10 seconds captured few images of rapidly consumed foods (eg, fruit), and no images of socially undesirable foods, such as candy, or chips.[46]

Gemming and colleagues[18] tested the feasibility of a SenseCam-assisted interviewer-administered 24-hour dietary recall in a sample of healthy adults (N=10). Participants wore the SenseCam for 2 days while conducting their usual daily activities. Day 1 familiarized participants with the SenseCam and the images from Day 2 were used to assist participants' self-report after the final pass of the 24-hour dietary recall. To reduce the potential for interviewer bias the researcher did not suggest changes or scrutinize self-reported intakes, but queried unreported food items present in the images. Compared with 24-hour dietary recall alone the images increased mean EI by 12.5% (2,738±502 kcal vs 3,080±712 kcal; P=0.02).[18] The increase was primarily due to 41 unreported food items across the sample. The unreported foods were from a range of food groups, and included both snack foods and more substantial food items. Eight changes to portion size and 12 misreporting errors were also identified by participants, but together these changes had little influence on EI.[18] Participant feedback indicated the images were helpful and enabled participants to provide more accurate information, but some indicated they were uncomfortable in public situations, such as riding a bus or purchasing foods. Limitations regarding SenseCam were also apparent. The imaging frequency was too slow to capture rapidly consumed foods, images were poor quality in low-light environments, and posture and body shape affected lens angle resulting in some nonuseful images.[18]

Lazarte and colleagues[31] examined the use of handheld digital cameras to enhance self-report in the food photography interviewer-administered 24-hour multiple pass recall method (FP 24-hR). The FP 24-hR was validated among a group of healthy Bolivian women (N=43) for a single 24-hour period. Participants were provided a photo kit that contained a camera and mat with a 1.5-cm grid and captured two images at 50 cm distance from the table (at 90° and 45° angles) before and after eating episodes.[31] Researchers visited each participant's home during the testing period and weighed all meals. The following day a different trained interviewer assessed the participant's diet, and on the final pass of the 24-hour dietary recall the interviewer used the FP 24-hR images to confirm or modify the portion sizes and enquire about any foods that were partially obscured.[31] Compared with weighed meals the FP 24-hR underestimated mean EI by only 4% (1,456±63 kcal vs 1,399±62 kcal; $P<0.05$), and Bland-Altman plots revealed good agreement between methods with no systematic bias.[31] No specific analysis pertaining to how the images changed the initial recall was reported.[31]

DISCUSSION

We conducted the first systematic review to examine studies that have evaluated or validated methods of image-assisted dietary assessment. Research to date has primarily explored the potential of image-assisted methods in pilot and feasibility studies, and few methods have been formally validated using criterion measures and adequately sized samples.[14,22,31] However, several studies have demonstrated how images can enhance self-reported dietary intake by revealing unreported foods and misreporting errors.[15,18,32] The additional dietary information obtained from the images appears to increase reported EI[15,18,32] and likely reduces random errors.[47] Furthermore, when used as the primary record of dietary intake, images can be analyzed to obtain valid and reliable estimates of EI with reduced measurement error (for EI) compared with traditional methods.[4,6-14,22] Due to the complexity and diversity of foods, EI is likely to be underestimated if the methods procedure is not followed correctly by the user, the images are of poor quality, or if the user forgets to capture images before the eating episode.[14,16,24,29]

Trade-offs during image analysis are also made because certain dietary components, including hidden ingredients and cooking method that affect energy and nutrient composition, cannot be determined with image analysis alone. Consequently, it appears essential that images of foods must be supported by additional dietary information to achieve optimal accuracy.[16,22,24] However, the coding errors associated with image analysis are likely to be random[47] and less problematic compared with the systematic bias observed when food type and portion size are self-reported.[48-52] Thus, there are both strengths and limitations of using images to assess dietary intake, but these cannot be entirely understood until further high quality studies have been conducted. Moreover, as image-assisted methods and systems continue to develop, the strengths and limitations will also evolve.

The search strategy identified three other image-assisted methods in development (yet to be evaluated among users)[19,26,33,34] that have innovative features that may enhance image-assisted methods further. Two of these methods, The food intake visual recognizer,[33] and the diet data recorder system[34] are image-based food records (on smartphones) that also incorporate the use of automated image analysis systems.[33,34,53] However, the food intake visual recognizer aims to incorporate voice recognition software to clarify details of dietary intake, and the diet data recorder system[34] removes the need for a reference marker by using a laser within a smartphone case to project a visual reference to assist analysis.[34]

Techniques to analyze images without a reference marker have also been described for the bespoke wearable camera eButton (Laboratory for Computational Neuroscience, Bioengineering, University of Pittsburgh, Pittsburgh, PA) (worn on the chest) specifically designed for the passive assessment of dietary intake and physical activity.[19,21,54] The eButton and other future wearable devices may address some technical limitations, such as insufficient battery life, poor quality images, and insufficient imaging frequencies[17,18,32] but will need to capture useable images in all environments and during non-daylight hours to effectively record dietary intake.[17,18,32] Considering the diversity and complexity of dietary intake in free-living environments, accurate assessment of dietary intake using passive methods alone will be very challenging.

Privacy concerns also need to be addressed. Though wearable cameras capture images of third parties in a similar manner to smartphones or security cameras, their acceptance and etiquette for use in society is yet to be established. The limited release of smart-wearable eyewear like Google Glass (Google) has received substantial media attention regarding the device's innovative applications, but also concerns regarding privacy at a government level.[55] It appears wearable devices need to be paused or switched off in certain buildings or locations, and images could be captured accidentally when the user or others expect privacy, which is especially problematic if the research involves children and the images are transmitted automatically in real time. To address privacy concerns related to the use of wearable cameras in health research, Kelly and colleagues[56] developed an ethical framework that provides guidelines for best practice. Other potential safeguards could also alleviate privacy concerns, such as automated face-blurring, and sensors (accelerometers) to trigger image capture or store images (in memory) only when eating is detected.[57,58] However, it is clear that further research is required to better understand these ethical issues and potential solutions.

Other questions regarding image-assisted dietary assessment remain. No study has validated an image-assisted method among elderly persons (aged >70 years), children, and adolescents, and the feasibility of image-assisted methods in large studies (N>100) has not been demonstrated. Older adults may fail to remember the method more often and are potentially less accustomed to using smartphones and other technologies, whereas usability studies among children and adolescents indicate they prefer methods using technologies over traditional methods.[42,59,60] With respect to large samples, participants will need to own or be provided with a suitable device (to reduce the potential for respondent bias),[47] which increases study costs.

Limitations of our review need to be considered. The majority of studies reviewed were pilot and feasibility studies; thus, future research may not reflect the results of these preliminary studies. Due to the heterogeneity of the technologies used, methods employed to assess dietary intake, and different study designs, only a narrative review could be conducted. Furthermore, limiting the search strategy to scientific journal articles may have excluded the most recent technologies or unpublished information because some commercial methods may not undergo scientific testing.

Study heterogeneity also made evaluating study quality challenging. The European Micronutrient Recommendations Aligned Network of Excellence scoring system is a useful tool to objectively assess the quality of dietary intake validation studies,[61] but is not particulalry suited to rating the quality of studies evaluating image-based methods. The European Micronutrient Recommendations Aligned Network of Excellence system allocates points for the data gathered by a face-to-face interview, but image-based methods can be assessed remotely by independent analysts/researchers.[61] Development of a scoring system that differentiates between traditional self-report data and data obtained independently from image analysis (manual or automated) would be useful.

CONCLUSIONS

Current evidence regarding the validity of image-assisted methods of dietary assessment is limited, but studies to date have demonstrated images can enhance self-report data and provide the primary record of dietary intake to obtain valid estimates of EI (when incorporated into a comprehensive system). Additional validation studies using criterion measures are needed. The validity among children, adolescents, and elderly persons, as well as the feasibility of using image-assisted methods in large samples, warrants examination. Wearable cameras are a recent development in dietary assessment but further research is required to better understand the potential applications and pitfalls of using wearable technologies.

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