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TITLE PAGE

Title

Issues in Measuring and Interpreting Diet and Its Contribution to Obesity

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Human and Animal Rights and Informed Consent

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Conflict of Interest

All authors declare no conflict in interest.

Abstract

Purpose: This review summarises the issues related to the measurement and interpretation of dietary intake in individuals with overweight and obesity, as well as identifying future research priorities.

Recent findings: Some aspects of the assessment of dietary intake have improved through the application of technology-based methods and the use of dietary biomarkers. In populations with overweight and obesity, mis-reporting bias related to social desirability is a prominent issue. Future efforts should focus on combining technology-based dietary methods with the use of dietary biomarkers to help reduce and account for the impact of these biases.

Summary: Future research will be important in terms of strengthening methods used in the assessment and interpretation of dietary intake data in the context of overweight and obesity.

Introduction

Worldwide, the prevalence of obesity more than doubled between 1980 and 2014, with 1.9 billion adults with overweight and 600 million with obesity [1]. In Western countries approximately 23% of children and adolescents have overweight or obesity [2]. It is anticipated that 50% of adults worldwide will have overweight or obesity by 2030 if the incidence remains consistent [3]. This is concerning as excessive body weight and visceral fat mass are risk factors for chronic diseases including cardiovascular disease [4-6], type 2 diabetes [7-9], kidney disease [10-12], specific cancers [13-15] musculoskeletal disorders [16-18] and depression [19-22]. Major healthcare costs for individuals and societies are associated with the chronic disease management [23]. Risks related to poor dietary patterns are a major contributor to the global burden of disease and account for 11.3 million deaths and 241.4 million disability adjusted life years (DALYs) [24]. Therefore, improving nutrition is currently a worldwide public health priority [25, 26].

It is widely acknowledged that at a metabolic level, overweight and obesity is due to an energy imbalance in which energy intake exceeds energy expenditure over a prolonged time period [27]. However, there are reported discrepancies in the relationship between energy intake and body mass index (BMI) [28-30]. These findings highlight limitations within assessment and analysis of nutrient intakes. Estimating dietary intake typically relies on self-reported measures, including 24-hour food recalls, weighed and estimated food records and food frequency questionnaires (FFQs). A major limitation of these methods is mis-reporting of intake, which has been confirmed by studies measuring total energy expenditure using the doubly-labelled water (DLW) method versus self-reported energy intake [31-33]. Furthermore, the prevalence of under-reporting of energy intake is higher among those with overweight or obesity, especially females, and is thought to be influenced by social desirability bias [31, 34].

In recent years, technological advances have been integrated with traditional dietary assessment methods to improve nutrient intake estimates by standardising processes and reducing participant burden and potentially recall bias. The main types of technology being used include: online adaptations of well-established dietary assessment methods (e.g. web-based FFQs), image-based and -assisted methods (e.g. using smart-phone technology) and wearable devices [35]. Technology-based dietary assessment methods continue to evolve, with further evaluation required to elucidate acceptability, validity and reliability compared to traditional dietary assessment methods [35, 36].

Dietary biomarkers can provide an objective measure of dietary intake components and are recommended for evaluating the validity of dietary assessment methods which is discussed further in this review [37, 38]. Classes of biomarkers include recovery biomarkers (e.g. doubly labelled water) which exhibit a direct relationship with dietary intake, concentration biomarkers (e.g. plasma carotenoids) which correlate with intake but cannot be used as absolute measures of intake, and predictive biomarkers (e.g. urinary fructose) which show a dose-response relationship with intake. [39]. However, inter-individual factors including adiposity, age, sex, smoking status and physical activity levels potentially impact biomarker concentrations and hence validity and reliability [40]. Therefore, caution must be taken in the application and interpretation of results when using dietary biomarkers to ensure they are appropriate for the study population and nutrients analysed.

This review aims to provide an overview of traditional and technology-based dietary assessment methods and to discuss the considerations for interpreting the accuracy of dietary intake data in individuals with overweight or obesity. This will help researchers to strengthen the methodological aspects of future studies in which dietary intake will be measured and thereby contribute to higher-quality studies and strengthen the evidence-base used to inform dietary guidelines, as well as the development of policies and strategies targeting the prevention and management of overweight and obesity.

Traditional dietary assessment methods

Traditional self-reported dietary assessment methods can be grouped into two broad categories: prospective ‘real-time’ recording and retrospective ‘recall’ methods [41]. A summary of dietary assessment methods are provided in **Table 1**. There are a number of online methods and selection databases that can help guide choice appropriate dietary assessment methods and tools. These include:-

- ACAORN diet assessment method selection guide (http://anzos.com/acaorn/food-and-nutrition/)
- Diet Primer (https://dietassessmentprimer.cancer.gov/)
- DAPA Measurement Toolkit (http://www.measurement-toolkit.mrc.ac.uk/)
- Nutritools (https://www.nutritools.org/strengths-and-weaknesses)
- FAO Dietary Assessment: a resource guide to method selection and application in low resource settings (http://www.fao.org/3/i9940en/I9940EN.pdf).

Prospective methods

Prospective methods include weighed or estimated food records which records all food and beverages consumed within a pre-defined time period (i.e. usually 3 or 7 days) [42]. Recording at the time of the eating occasion is preferred to avoid reliance on memory [43]. Food records can collect quantitatively accurate dietary information [44] by using measurement aids such as scales or household measures (e.g. cups or tablespoons) or standard serving sizes (i.e. models or pictures) [43]. Food records require a high level of literacy, numeracy and motivation to frequently weigh, measure, estimate and record foods and beverages [42]. These demands can affect individual's adherence and usual eating behaviours (e.g. consume less or choose to eat foods that are easier to prepare and/or report) [45]. Food records also require extensive data entry of the food and beverage items into a computer program for nutrient analysis, with coding of item a tedious process that must be standardised to reduce coding errors, especially if the record is not collected electronically [43]. Therefore, food records are infrequently used in large-scale epidemiological studies [46].

Retrospective methods

Retrospective methods include 24-hour food recalls and FFQs [41]. Food recalls are usually interview-administered, in-person or by telephone, in which the individual recalls all foods and drinks consumed in the preceding 24-hours [43]. In contrast to food records, 24-hour food recalls occur after consumption, therefore the assessment method is less likely to alter the individual's dietary intake. Food recalls are less burdensome to the individual and therefore those who agree to complete recalls are more likely to be representative of the population [43]. However, 24-hour food recalls can have substantial researcher burden due to the extensive training required for interviewing and data entry, coding and analysis [47].

FFQs enable assessment of longer-term dietary intake (i.e. up to 12-months) in a cost-effective and timely manner [48]. Individuals report usual frequency of each food from a list of foods for a specific time period, but information regarding cooking methods and combination of foods in meals is rarely collected [43]. Some FFQs will collect usual quantities of food consumed (i.e. quantitative FFQs) or specify food portions using usual or common serving size data (semi-quantitative) with the use of photographs of various portions and household or standard units [41]. The FFQ has lower participant burden compared to other methods and can be administered to a large study sample [49]. Despite this, limitations of FFQs includes reporting errors related to incomplete food lists, inappropriate frequency options and portion sizes used [50] and potentially length of time taken to complete [42].

The FFQ and food recalls are both prone to mis-reporting and this can be affected by an individual's personal characteristics (i.e. age, gender and BMI status). For example, the dietary intake of children when relying on their parents to be proxy reporters. Individuals with overweight and obesity are more likely to under-report their dietary intake [51] especially for foods considered less healthy (i.e. energy-dense, nutrient poor foods) [52-54]. In a review of studies using DLW in conjunction with self-reported energy intake, under-reporting in individual's with obesity was almost twice as high compared to those within a healthy weight range [55]. Dietary under-reporting may distort the association between dietary intake and health outcomes [56]. This is a major concern because this may mislead public policy and dietary recommendations for health [57].

Improving traditional dietary assessment methods

Recent endeavours have been directed towards improving existing traditional methods and developing technology-based instruments (e.g. wearable devices) to reduce burden and capture intake with greater accuracy [58, 59]. Greater efforts have also focused on improving study design and statistical methods to minimise error [60, 61]. Furthermore, intervention research needs to consider the potential for differential dietary reporting, when exposure to a dietary intervention influences how an individual reports their dietary intake, which may result in biased estimates of the intervention effect and reduced statistical power [62, 63]. For example, in The Women's Health Initiative Nutritional Biomarkers Study the prevalence of underreporting energy intake was approximately 5% higher in the intervention group (received group and individual nutrition intervention sessions and self-monitored fat, fruit and vegetable intake) than the comparison group [64]. Combining self-reported dietary intake with recovery biomarkers may be useful for minimising differential error, however further strategies are needed [65].

Technology-based dietary assessment methods

Given technology is now mainstream, there is potential for self-administered paper-based tools or interviewer-administered dietary assessment methods, to be modified to become accessible in an online format. For example, the self-administered web-based 24-hour recall eliminates the need for an interviewer and implements automated coding as food records are electronically linked to a nutrient database. Although the conversion of paper-based methods into web-based methods may have advantages, including faster completion and the collection of dietary intake from a broader population, it may not address dietary mis-reporting.

Image-based dietary assessment methods include the active collection of digital photographs or images, or passive collection by means such as wearable cameras, for assessing dietary intake [66]. This allows capture of all foods and drinks consumed including portions, removing some limitations of traditional dietary assessment methods including the ability to recall types and amounts of food consumed. Image-based methods are feasible given the availability of embedded cameras in personal digital assistants and smartphones, or through the use of wearable cameras [66]. These methods have been shown to reduce user-burden, with image-based applications on mobile phones found to be easier and more convenient to use than manually weighing and measuring foods every day [67].

Table 1. Summary of dietary assessment methods outlined by Collins et al., [68] and Food and Agriculture Organization (FAO) [69].

	Dietary assessment method	**Description**	**Information obtained**	**Strengths**	**Limitations**
Traditional dietary assessment method: prospective	Food records	Written accounts of an individual's food and beverage consumption during a pre-defined period (e.g. 3 or 7 days)	-Includes qualitative and quantitative information -Usual (long-term) intake is not captured if only a few days are recorded -Measures group mean intakes and distribution of individual intakes	-Measures actual or usual intake, depending on the number of days recorded -The gold-standard method for dietary assessment compared to other methods (when conscientiously completed) -Information is not reliant on the individual's memory -Provides exact serving sizes rather than estimations -Provides detailed diet and nutrient intake data -Can provide contextual information surrounding food consumption -Individuals can provide the recipes and manufacturing product information related to the foods they have consumed	-Expensive for equipment and staff training -High burden on individuals and researchers -Individuals require literacy and numeracy skills -Individuals need to be highly motivated -Individuals may alter their eating habits to make the reporting process easier -Reliability of food records decreases across time -Requires a suitable environment for weighing food
Traditional dietary assessment method: retrospective	Diet history	An in depth-interview either by phone or in person to assess an individual's dietary intake over a prolonged period of time (6-12 months). Often includes a 24-hour food recall.	-Provides comprehensive information (qualitative and quantitative) related to eating habits and patterns -Provides dietary intake information that is suitable for clinical use	-Comprehensive information of meal patterns, individual food consumed, portion size and cooking methods -Describe usual food or nutrient intake over a prolonged period -Assessment method does not influence the individual's eating habits	-Information is reliant on the individual's memory -The assessment method is not standardised, therefore it is difficult to make comparisons -High burden for researchers for data entry and coding -May not be suitable for young children and the elderly -Interviews can be time consuming to obtain sufficient information -Portion size estimation of past meals can be difficult -Interviewers require training
Traditional dietary assessment method: retrospective	Food recalls	A structured interview either by phone or in person to assess an individual's food and beverage consumption over the preceding 24 hours.	-Measures current (short-term) dietary intake. Several days of dietary recalls are requires to estimate usual intake. -Measures group or population means	-Individuals requires low literacy skills -Low burden on individuals - Assessment method does not influence the individual's eating habits -Can be used for a large sample size -Provide contextual information surrounding food consumption	-Information is reliant on the individual's memory -Interviewers require training -Interviews can be time consuming to obtain sufficient information -Multi-day recalls are require to obtain data that is representative of the individual's habitual intake

					-High burden on researchers for data entry and coding

Table 1.*(Continued)*

	Dietary assessment method	Description	Information obtained	Strengths	Limitations
Traditional dietary assessment method: retrospective	Food frequency questionnaires (FFQs)	Self-or interviewer administered questionnaire which assesses the individual's frequency of consumption of each food from a list regarding a specific time period (e.g. 1, 6 or 12 months).	-Measures usual (long-term) dietary intake -Collects less information about cooking methods and portion sizes consumed compared to other dietary assessment methods -Generally provides a higher estimate of dietary intake compared to food records and recalls -Diet rankings rather than quantifying absolute nutrient intake of individuals	-Assess the individual's usual dietary intake -Low burden on individuals -Simple and inexpensive to administer -Can also be self-administered via mail or internet -Can be used for a large sample size -Assessment method does not influence the individual's eating habits	-Does not give precise information on the estimated portion size consumed by the individual -Foods included in the FFQ are limited due to the categorical nature of frequency of response categories -Individuals require literacy skills -Individuals may misinterpret the questions -FFQs require adaptation and validation for specific populations
Technology-based dietary assessment method: image-based methods	Digital photographs/images	Individuals use a camera to capture images of their food and meals before and after consumption. The consumed serving size from the captured images is estimated by the images alone or comparing them to reference images of a known serving sizes.	-Can be incorporated with traditional dietary assessment methods or used as a stand-alone method to measure dietary intake -Can include quantitative and qualitative data -Provides dietary intake information in real-time which is independent of the individual's memory -Dietary under-reporting may occur if captured images are not of adequate quality or images of meals are not recorded and the information cannot be collected retrospectively -Images can be directly linked to food composition databases to quantify nutrient intake	-Low burden on individuals -Suitable for individuals with low literacy skills -Dietary intake data is not reliant on the individual's memory -Suitable for parents assisted dietary assessment in children	-Individuals may intentional or unintentionally not take images -Not all information can be captured with a single photograph/image -Estimating serving size can difficult in mixed dishes -Information about cooking methods cannot be captured

Table 1.*(Continued)*

	Dietary assessment method	Description	Information obtained	Strengths	Limitations
Technology-based dietary assessment method: image-based methods	Mobile-phone based	Individuals use the camera on their mobile phone to capture images of the food and beverages consumed. The individual or researcher can identify and estimate the volume of food and beverages consumed from the captured images.	-Can be incorporated with traditional dietary assessment methods or used as a stand-alone method to measure dietary intake -Electronic short-term dietary assessment -Can provide real-time dietary intake data -Can include quantitative and qualitative data -Dietary under-reporting may occur if captured images are not of adequate quality or images of meals are not recorded and the information cannot be collected retrospectively -Images can be directly linked to food composition databases to quantify nutrient intake	-The technology is widely used -Suitable for individuals with low literacy skills -Higher quality control of data due to reduced time delay and real-time responses -Dietary intake data is not reliant on the individual's memory	-It is expensive and time-consuming to develop the application and software -Mixed dishes are difficult to analyse -Data storage is limited -Training is required for administration, data collection and analysis -Digital data transfer requires specific security infrastructure
Technology-based dietary assessment method	Web-based technologies	Individuals report their food and beverage consumption over a pre-defined period using a web-based data collection system.	-Can be incorporated with traditional dietary assessment methods or used as a stand-alone method -Short-or long-term dietary intake	-Automated data collection method reduces labour costs -Standardised process increases levels of quality control -Suitable for a large study sample -Provides interactive audible and visual aids -Individuals can provide dietary information at any time or location -Can include different countries and languages	-Individuals require literacy skills -Software needs to be adapted to specific populations -Individuals require internet access -Security infrastructure is required for storage of the individuals data -There is potential for non-response bias

Table 1.*(Continued)*

	Dietary assessment method	**Description**	**Information obtained**	**Strengths**	**Limitations**
Technology-based dietary assessment method	Wearable-devices	Individuals wear a sensor device that records biological movements (i.e. swallowing, chewing) and/or visual data related to an eating occasion.	-Monitor short-term dietary intake with the influence of subjective influences in manual reports (e.g. individual's motivation, memory and desirability) -Provides information on the individual's food selection, eating behaviours, nutrient intake, digestion process -Estimate volume/weight of the individual's dietary intake	-Objective dietary assessment -Low burden on individuals	-Only been used in controlled settings to date -Application is restricted to a small sample size

By comparison, image-assisted methods include prospective active or passive capture of images collected in similar manner to image-based methods. However, these methods are used in conjunction with traditional dietary assessment methods, such as food records or 24-hour food recalls, rather than stand-alone [66]. A combination of methods may improve the accuracy of data collection, although studies in larger, more diverse samples are needed [66].

Intra- and inter-individual variability with which food is prepared, served and consumed, adds levels of complexity to automating the identification and quantification of foods contained in images collected in free-living settings. As a result, approaches to the analysis of images collected for dietary assessment vary from manual or automated [70, 66]. However, with continuing advancements in computer vision techniques and camera technologies the field is quickly progressing the automation of the image analysis [70]. Interestingly, willingness to use an image-based food record collected via a mobile device has been reported to be greater amongst individuals (n=73) with overweight or obesity, including the use of this method for relatively long durations (≥14 days) to collect dietary intake data [71]. However, 41.5% of participants reported changing eating behaviour as a result of using the mobile device [71] which is not ideal when assessing intake as a opposed to self-monitoring intake where reactivity and associated positive changes to intake are encouraged.

The use of wearable sensors to passively monitor and assess intake is another emerging area of technology-based dietary assessment. These devices aim to discretely collect more objective data without the need for any or minimal user input from various sensors worn on the body. Examples include devices on the wrist to detect hand-to-mouth gestures, and sensors on the neck and/or face to detect sounds or movements associated with chewing and swallowing of food, including the addition of a camera for image capture [70, 72]. A wrist-worn sensor for monitoring hand-to-mouth gestures associated with bites has been shown to be more accurate at estimating total energy intake in a controlled setting compared to estimations made by the individual [73]. Similarly, a device comprising sensors for detecting chewing and body movement worn on a pair of glasses showed high accuracy for detecting food intake in a laboratory setting [74]. A version of this system has also been tested in a free-living setting and was found to have a higher accuracy at detecting eating compared to when participants self-reported using a food diary [75]. Such information provides important insights into eating behaviours and the effect on associated food intake, offering possible targets for dietary intervention strategies.

However, to-date most wearable devices have been studied in laboratory settings and therefore, the acceptability and accuracy when worn in free-living settings requires exploration [72]. For example, wearable devices used for dietary assessment, in particular approaches that do not contain a camera, have challenges relating to accurate identification of food type from the collected sensor data [72].

Dietary biomarkers

Dietary biomarkers are chemical or biological markers analysed from biological material, commonly blood or urine, related to specific dietary exposures [77]. Specific dietary factors associated with overweight and obesity that can be assessed using biomarkers include intakes of total energy, protein, fatty acids, fruit and vegetables, sugars and fibre [40].

Doubly labelled water which is tagged with isotopes, such as deuterium, can be recovered in urine to objectively measure total energy expenditure (TEE) and is 99% accurate if participants are weight stable during the assessment period [78]. Accurate TEE measurement is valuable in determining the influence of genetic, metabolic and endocrine factors on weight status relative to energy consumption alone [79-81]. Dietary assessment methods that are reported to most closely approximate DLW estimates are the weighed food record and 24-hour recall methods. With estimations of energy intake, have been shown to be improved with a technology component such as images from a camera when compared to more traditional methods [78].

Accurate assessment of dietary protein is important in improving understanding of obesity management because increased dietary protein relative to carbohydrate and fat as part of an energy-restricted diet is an evidence-based approach to obesity management [82]. Increased protein intake increases nitrogen excretion, as does greater body size and higher levels of physical activity. Metabolomic biomarkers of meat consumption (carnosine), chicken (anserine) and fish (trimethylamine-N-oxide) are of interest as animal products are a predominant source of protein in the diet of most affluent populations [83].

Excess dietary fat intake is associated with higher weight status or weight gain [84]. Although it is not currently possible to quantify total dietary fat intake using biomarkers, the concentration of long-chain polyunsaturated fatty acids including omega-3, omega-6 and trans-fatty acids in plasma, red blood cell membranes and in subcutaneous fat are potential indicators of relative fatty acid intake. Fatty acid biomarkers therefore have the potential to assist obesity research by differentiating how different types of fatty acid influence metabolism and adiposity [85].

Consumption of fruit is associated with a reduced risk of obesity and weight gain and consumption of vegetables is associated with reduced risk of weight gain [84]. Plasma carotenoids are considered a reliable concentration biomarker of fruit and vegetable intake, with a reported dose–response relationship between intake and appearance in plasma [86]. Adjustment of plasma concentration for BMI is necessary as increasing BMI is associated with lower carotenoid concentration due to the antioxidant role of carotenoids in the body [87]. Obesity is a proinflammatory condition in which excessive adipose tissue results in elevated levels of proinflammatory cytokines and creates a higher demand for antioxidant nutrients to counteract this effect [88]. Accumulation of carotenoid pigments from fruits and vegetables in all layers of the skin contribute to the level of yellow skin colouration, which can be objectively measured by skin reflectance spectroscopy, a non-invasive alternative method to quantify relative fruit and vegetable intake [89].

Consumption of three to five serves per day of cereal foods (mainly wholegrain) is associated with a reduced risk of weight gain [84]. Evidence is accumulating that imbalances in the intestinal microbiota, in addition to other major factors such as diet and host genetics, contributes to obesity and metabolic dysfunction [90]. Human studies have shown that obesity and metabolic dysfunction are characterized by a profound dysbiosis [90].

Alkylresorcinols (AR) from the bran fraction of grains are a proposed biomarker for wholegrain intake [91]. Plasma AR is possible biomarker of intake over the short (i.e. hours) to medium (i.e. 2-3 months) term, with red blood cells suggested as a longer term indicator of whole grain intake [91]. Urinary AR metabolites may provide a comparable but less invasive indicator of wholegrain intake [92]. Wholegrain consumption patterns in populations with overweight and obesity requires additional research because of the known diet-obesity relationship, in particular the increasing awareness of the role of the microbiome in obesity.

Consumption of sugar sweetened beverages is associated with increased risk of weight gain in adults and children and a reduction in total sugar consumption prevents increases in measures of body weight and/or body fat [84]. While a range of sugar sub-types exist, sucrose and fructose are of interest as a fraction of dietary sucrose and fructose are excreted in urine, in amounts that are proportional to consumption, which can be measured as a biomarker under controlled conditions with multiple 24-hour urine samples. This method is able to detect changes in sucrose and fructose intakes, classify an individual as a high or low sugar consumer and is suitable for those with obesity [85]. The ratio of carbon stable isotopes, carbon-13 and carbon-12 can also be used to predict urinary sucrose and hence is a suitable biomarker of sugar intake [85]. The major limitation of urinary sucrose and fructose is the capability to only reflect short-term intake (i.e. 24-hours). Further research is needed to develop a longer term biomarker of total sugar intake that is reflective of habitual intake [40].

Advances in laboratory techniques and information technology combined with improved understanding of metabolism and the dietary metabolome means that identification and quantification of dietary biomarkers is likely to make substantial contributions to measuring intake and interpreting the contribution of dietary patterns to the prevention and treatment of obesity in the future.

Interpreting the accuracy of dietary intake data

The previous sections have discussed the strengths and limitations of traditional, technology-based methods and dietary biomarkers within dietary assessment. This section highlights further considerations for interpreting the accuracy of dietary intake data. Lissner [93] and Collins et al., [68] have identified key issues and provided recommendations in interpreting dietary data in the context of overweight and obesity, as summarised in **Table 2**. While these reviews [93, 68] were published during periods when traditional forms of dietary assessment predominated, the considerations raised remain relevant, despite the increasing development and use of technology-based methods and dietary biomarkers.

Innovative technologies used in food and energy intake assessment have been addressed in a previous narrative review which includes information about the validity and reliability of these technology-based tools [94]. This review concluded that although these technologies can facilitate recording of food/energy intake with greater accuracy than participants' individual estimates, caution should be exercised when using these technologies as they continue to be refined [94]. For example, images in combination with traditional recall methods (i.e. image-assisted dietary assessment) [95] and web-based food records [96], have been validated to assess energy intake in adults affected by overweight and obesity and compared with their energy expenditure assessed by DLW [95, 96]. These validation studies demonstrated that the accuracy for assessing energy intake with these technology-based tools was very high (overestimated mean, standard deviation (SD) energy intake by 6.8% (28%) [95] or comparable with traditional dietary assessment methods (mean, (SD): reporting accuracy was 79.6% (14.1%)) [96]. However, these studies were conducted with specific groups of young adults (mean, (SD): 22.9 (3.2) years old) [95] and women (mean, (SD): 34.5

(11.3) years old) [96] and therefore cannot be assumed to have the same level of accuracy for assessing total energy intake in children, young-middle aged men, or older adults affected by overweight or obesity. Furthermore, as traditional forms of dietary assessment continue to be used, it is important to be aware that only some methods and tools have had their validity tested for use in individuals with overweight or obesity (e.g. Walker et al., [97]; Hise et al., [98], Hill et al.,[55]).

When interpreting the accuracy of dietary intake data, in epidemiological or intervention studies, it is good practice to source reliability and validation studies associated with the dietary assessment methodology or tool and to identify key participant characteristics in those studies (e.g. age, gender, BMI status, ethnicity). This evidence will inform whether the selected methodology/tool is appropriate for use in individuals with overweight and obesity. Additionally, the STrengthening the Reporting of OBservational studies in Epidemiology extension for nutritional epidemiology (STROBE-nut) [37] and the Consolidated Standards Of Reporting Trials Patient Reported Outcomes (CONSORT-PRO) [99] statements and checklists, can assist with planning studies, or interpreting the results of studies, that respectively aim to examine diet as a factor in the epidemiology or management of overweight and obesity. Specifically, these tools can assist with identifying sources of bias or error in measuring dietary intake.

Table 2. Summary of recommendations for interpreting the accuracy of dietary intake data outlined by Lissner [93] and Collins et al., [68].

Key issues	Recommendations
Method selection	Dietary intake assessment methods need to be validated in the population of interest (i.e. people affected by overweight or obesity) [93]. The method of ‘triads’ in assessing dietary intake (i.e. use of a biomarker and two other methods of dietary assessment) could be used more commonly, budget permitting, to determine the validity of reported dietary intakes [68].
Sources of biases	Consider potential measurement errors induced by various sources of bias (e.g. participation or non-response bias) [93, 68], repeated measure bias [68], social desirability and social approval bias [93, 68], Hawthorn effect [68], recency bias [68], and food and/or nutrient specificity in under-reporting [93]. Specific strategies for minimising these biases are described elsewhere [93, 68].
Random error	Consider random sources of measurement error (e.g. within-subject variation in daily dietary intake) [68].
Correction of measurement error	Using statistical techniques to correct measurement error should be approached with caution [93]. A statistician experienced in the correction of measurement error in dietary data should be consulted [68].

Recommendation and research priorities

Improvements in technology have facilitated improved capacity for, and accuracy of dietary assessment [85]. Importantly, they have also assisted in the provision of automated, personally tailored feedback on dietary patterns, food and/or nutrient intakes [85]. Smartphone technology can simultaneously decrease all aspects of participant and researcher burden. Technology is also proving useful in broadening availability and accessibility in developing countries, where dietary assessment has historically been very limited due to language, literacy, numeracy and cultural barriers. However, further research is needed to assess dietary intake using tools that are population-specific and culturally appropriate, given the increasing prevalence of obesity, type 2 diabetes and specific diet-related cancers in developing countries are rising in line with the adoption of more westernised dietary patterns.

Semi-automated 24-hour food recalls have decreased researcher burden, as participant responses are automatically linked to a nutrient database. Automated processes, such as the Automated Self-Administered 24-hour (ASA-24) dietary recall, have also resulted in a more standardised approach to data collection using the 24-hour food recall method [100, 101]. However, variations in administration and reporting of 24-hour food recalls can limit the comparisons between studies (e.g. number of weekend and weekdays, forgotten food approach). It is therefore recommended that tools such as the ASA-24 be used wherever available and using a standardised approach. Research into possible adaptations so that the tool can be used in different countries or cultures, and linked to other food databases, needs to be prioritised.

In population groups with overweight and obesity, the issue of participant burden in reporting dietary intake is overlaid by potential under-reporting biases related to social desirability. A further layer of complexity may be added if parents are affected by overweight or obesity and report on behalf of children with overweight or obesity. Passive capture methods (e.g. wearable devices) and the use of biomarkers may be relatively more useful when assessing dietary intake of those with overweight or obesity, as they minimise the risk of under-reporting bias [85].

Future research priorities in this dynamic field include:

1. Continued advancement in automation of recording and analysis of dietary data to lower individual and researcher burden and standardise process to reduce error

2. Continued improvements in the sensitivity and specificity of software associated with food identification and quantification from images, and associated analysis platforms (e.g. nutrition databases)
3. Increased sensitivity and specificity of biomarkers used within validation studies of dietary intake and to facilitate a reduction risk of bias and inform development of calibration equations to improve data accuracy
4. Further research into links between dietary intake and associated metabolic impact (e.g. microbiome and metabolome).

Conclusion

Recent endeavours have focussed on the application of technology-based dietary assessment methods to reduce participant burden and standardise data collection, analysis and interpretation. Despite the advantages of these methods, researchers need to consider the potential for dietary mis-reporting related to social desirability bias, especially in populations with overweight and obesity. Combining technology-based dietary assessment methods with the use of nutritional biomarkers may be a useful approach for minimising the risk of mis-reporting bias. Development of calibration equations to more accurately estimate intake are recommended, although further research on this approach is required. Improving the methodologies used in future studies that assess dietary intake will be an important component in strengthening the evidence base that informs the policies and programs targeting management of overweight and obesity.

References

1. Development Initiatives. Global Nutrition Report 2017: Nourishing the SDGs. Bristol, UK: Development Initiatives; 2017

2. Ng M, Fleming T, Robinson M, Thomson B, Graetz N, Margono C et al. Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the Global Burden of Disease Study 2013. The Lancet. 2014;384(9945):766-81.

3. Dobbs R, Sawers C, Thompson F, Manyika J, Woetzel JR, Child P et al. Overcoming obesity: an initial economic analysis. McKinsey global institute; 2014.

4. Huang Y, Xu M, Xie L, Wang T, Huang X, Lv X et al. Obesity and peripheral arterial disease: A Mendelian Randomization analysis. Atherosclerosis. 2016;247:218-24.

5. Cronin O, Morris DR, Walker PJ, Golledge J. The association of obesity with cardiovascular events in patients with peripheral artery disease. Atherosclerosis. 2013;228(2):316-23.

6. Cao Q, Yu S, Xiong W, Li Y, Li H, Li J et al. Waist-hip ratio as a predictor of myocardial infarction risk: A systematic review and meta-analysis. Medicine. 2018;97(30):e11639.

7. Babu GR, Murthy GVS, Ana Y, Patel P, Deepa R, Neelon SEB et al. Association of obesity with hypertension and type 2 diabetes mellitus in India: A meta-analysis of observational studies. World journal of diabetes. 2018;9(1):40-52.

8. Giraldez-Garcia C, Franch-Nadal J, Sangros FJ, Ruiz A, Carraminana F, Goday A et al. Adiposity and Diabetes Risk in Adults with Prediabetes: Heterogeneity of Findings Depending on Age and Anthropometric Measure. Obesity (Silver Spring, Md). 2018.

9. Son YJ, Kim J, Park HJ, Park SE, Park CY, Lee WY et al. Association of Waist-Height Ratio with Diabetes Risk: A 4-Year Longitudinal Retrospective Study. Endocrinology and metabolism (Seoul, Korea). 2016;31(1):127-33.

10. Kim YJ, Hwang SD, Oh TJ, Kim KM, Jang HC, Kimm H et al. Association Between Obesity and Chronic Kidney Disease, Defined by Both Glomerular Filtration Rate and Albuminuria, in Korean Adults. Metabolic syndrome and related disorders. 2017;15(8):416-22.

11. Garofalo C, Borrelli S, Minutolo R, Chiodini P, De Nicola L, Conte G. A systematic review and meta-analysis suggests obesity predicts onset of chronic kidney disease in the general population. Kidney international. 2017;91(5):1224-35.

12. Herrington WG, Smith M, Bankhead C, Matsushita K, Stevens S, Holt T et al. Body-mass index and risk of advanced chronic kidney disease: Prospective analyses from a primary care cohort of 1.4 million adults in England. PloS one. 2017;12(3):e0173515.

13. Dong Y, Zhou J, Zhu Y, Luo L, He T, Hu H et al. Abdominal obesity and colorectal cancer risk: systematic review and meta-analysis of prospective studies. Bioscience reports. 2017;37(6).

14. Aune D, Navarro Rosenblatt DA, Chan DS, Vingeliene S, Abar L, Vieira AR et al. Anthropometric factors and endometrial cancer risk: a systematic review and dose-response meta-analysis of prospective studies. Annals of oncology : official journal of the European Society for Medical Oncology. 2015;26(8):1635-48.

15. Hidayat K, Du X, Chen G, Shi M, Shi B. Abdominal Obesity and Lung Cancer Risk: Systematic Review and Meta-Analysis of Prospective Studies. Nutrients. 2016;8(12).

16. Feng J, Chen Q, Yu F, Wang Z, Chen S, Jin Z et al. Body Mass Index and Risk of Rheumatoid Arthritis: A Meta-Analysis of Observational Studies. Medicine. 2016;95(8):e2859.

17. Silverwood V, Blagojevic-Bucknall M, Jinks C, Jordan JL, Protheroe J, Jordan KP. Current evidence on risk factors for knee osteoarthritis in older adults: a systematic review and meta-analysis. Osteoarthritis and cartilage. 2015;23(4):507-15.
18. Reyes C, Leyland KM, Peat G, Cooper C, Arden NK, Prieto-Alhambra D. Association Between Overweight and Obesity and Risk of Clinically Diagnosed Knee, Hip, and Hand Osteoarthritis: A Population-Based Cohort Study. Arthritis & rheumatology (Hoboken, NJ). 2016;68(8):1869-75.
19. Luppino FS, de Wit LM, Bouvy PF, et al. Overweight, obesity, and depression: A systematic review and meta-analysis of longitudinal studies. Archives of General Psychiatry. 2010;67(3):220-9.
20. de Wit LM, van Straten A, van Herten M, Penninx BWJH, Cuijpers P. Depression and body mass index, a u-shaped association. BMC Public Health. 2009;9(1):14.
21. Mulugeta A, Zhou A, Power C, Hypponen E. Obesity and depressive symptoms in mid-life: a population-based cohort study. BMC psychiatry. 2018;18(1):297.
22. Martin-Rodriguez E, Guillen-Grima F, Martí A, Brugos-Larumbe A. Comorbidity associated with obesity in a large population: The APNA study. Obesity Research & Clinical Practice. 2015;9(5):435-47.
23. Kent S, Fusco F, Gray A, Jebb SA, Cairns BJ, Mihaylova B. Body mass index and healthcare costs: a systematic literature review of individual participant data studies. Obesity Reviews. 2017;18(8):869-79.
24. Forouzanfar MH, Alexander L, Anderson HR, Bachman VF, Biryukov S, Brauer M et al. Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks in 188 countries, 1990-2013: a systematic analysis for the Global Burden of Disease Study 2013. Lancet. 2015;386(10010):2287-323.
25. United Nations. Open Working Group proposal for Sustainable Development Goals. New York, US: United Nations; 2014.
26. Hawkes C, Popkin BM. Can the sustainable development goals reduce the burden of nutrition-related non-communicable diseases without truly addressing major food system reforms? BMC Medicine. 2015;13:143.
27. World Health Organization (WHO). Obesity: preventing and managing the global epidemic. Report of a World Health Organization Consultation (Technical Report Series). Geneva, Switzerland World Health Organization; 2000.
28. Scarborough P, Burg MR, Foster C, Swinburn B, Sacks G, Rayner M et al. Increased energy intake entirely accounts for increase in body weight in women but not in men in the UK between 1986 and 2000. British Journal of Nutrition. 2011;105(9):1399-404.
29. Yancy WS, Wang C-C, Maciejewski ML. Trends in energy and macronutrient intakes by weight status over four decades. Public health nutrition. 2014;17(2):256-65.
30. Brown RE, Sharma AM, Ardern CI, Mirdamadi P, Mirdamadi P, Kuk JL. Secular differences in the association between caloric intake, macronutrient intake, and physical activity with obesity. Obesity Research & Clinical Practice. 2016;10(3):243-55.
31. Scagliusi FB, Ferriolli E, Pfrimer K, Laureano C, Cunha CS, Gualano B et al. Characteristics of women who frequently under report their energy intake: a doubly labelled water study. Eur J Clin Nutr. 2009;63(10):1192-9.
32. Schoeller DA. How accurate is self-reported dietary energy intake? Nutrition reviews. 1990;48(10):373-9.
33. Pfrimer K, Vilela M, Resende CM, Scagliusi FB, Marchini JS, Lima NK et al. Under-reporting of food intake and body fatness in independent older people: a doubly labelled water study. Age and ageing. 2015;44(1):103-8.

34. Hebert JR, Ma Y, Clemow L, Ockene IS, Saperia G, Stanek IIIEJ et al. Gender Differences in Social Desirability and Social Approval Bias in Dietary Self-report. American Journal of Epidemiology. 1997;146(12):1046-55.
35. Cade JE. Measuring diet in the 21st century: use of new technologies. The Proceedings of the Nutrition Society. 2017;76(3):276-82.
36. Illner AK, Freisling H, Boeing H, Huybrechts I, Crispim SP, Slimani N. Review and evaluation of innovative technologies for measuring diet in nutritional epidemiology. International journal of epidemiology. 2012;41(4):1187-203.
37. Lachat C, Hawwash D, Ocké MC, Berg C, Forsum E, Hörnell A et al. Strengthening the Reporting of Observational Studies in Epidemiology – nutritional epidemiology (STROBE-nut): An extension of the STROBE statement. Nutrition Bulletin. 2016;41(3):240-51.
38. Bingham SA. Biomarkers in nutritional epidemiology. Public Health Nutr. 2002;5(6a):821-7.
39. Freisling H, van Bakel MM, Biessy C, May AM, Byrnes G, Norat T et al. Dietary reporting errors on 24 h recalls and dietary questionnaires are associated with BMI across six European countries as evaluated with recovery biomarkers for protein and potassium intake. The British journal of nutrition. 2012;107(6):910-20.
40. Hedrick VE, Dietrich AM, Estabrooks PA, Savla J, Serrano E, Davy BM. Dietary biomarkers: advances, limitations and future directions. Nutrition journal. 2012;11:109.
41. Naska A, Lagiou A, Lagiou P. Dietary assessment methods in epidemiological research: current state of the art and future prospects. F1000Research. 2017;6:926.
42. Thompson FE, Subar AF, Loria CM, Reedy JL, Baranowski T. Need for technological innovation in dietary assessment. Journal of the American Dietetic Association. 2010;110(1):48.
43. Thomson FE, Subar AF. Chapter 1 - Dietary Assessment Methodology. In: Coulston AM, Boushey, Carol J, Ferruzzi Mario G,, editor. Nutrition in the Prevention and Treatment of Disease Third ed.: Academic Press 2013. p. 5-46.
44. Gibson RS. Principles of nutritional assessment. Oxford university press, USA; 2005.
45. Rebro SM, Patterson RE, Kristal AR, Cheney CL. The effect of keeping food records on eating patterns. Journal of the Academy of Nutrition and Dietetics. 1998;98(10):1163.
46. Willett W. Nutritional epidemiology. Oxford University Press; 2012.
47. Cullen KW, Watson K, Himes JH, Baranowski T, Rochon J, Waclawiw M et al. Evaluation of quality control procedures for 24-h dietary recalls: results from the Girls Health Enrichment Multisite Studies. Preventive medicine. 2004;38:14-23.
48. Shim J-S, Oh K, Kim HC. Dietary assessment methods in epidemiologic studies. Epidemiology and health. 2014;36.
49. Brouwer-Brolsma EM, Brennan L, Drevon CA, van Kranen H, Manach C, Dragsted LO et al. Combining traditional dietary assessment methods with novel metabolomics techniques: present efforts by the Food Biomarker Alliance. Proceedings of the Nutrition Society. 2017;76(4):619-27.
50. Wong JE, Parnell WR, Black KE, Skidmore PM. Reliability and relative validity of a food frequency questionnaire to assess food group intakes in New Zealand adolescents. Nutrition journal. 2012;11(1):65.
51. Madden JP, Goodman SJ, Guthrie HA. Validity of the 24-hr. recall. Analysis of data obtained from elderly subjects. Journal of the American Dietetic Association. 1976;68(2):143-7.
52. Bingham S, Cassidy A, Cole T, Welch A, Runswick S, Black A et al. Validation of weighed records and other methods of dietary assessment using the 24 h urine nitrogen technique and other biological markers. British Journal of Nutrition. 1995;73(4):531-50.

53. Goris AH, Westerterp-Plantenga MS, Westerterp KR. Undereating and underrecording of habitual food intake in obese men: selective underreporting of fat intake. The American journal of clinical nutrition. 2000;71(1):130-4.
54. Heitmann BL, Lissner L. Dietary underreporting by obese individuals--is it specific or non-specific? Bmj. 1995;311(7011):986-9.
55. Hill RJ, Davies PS. The validity of self-reported energy intake as determined using the doubly labelled water technique. The British journal of nutrition. 2001;85(4):415-30.
56. Westerterp KR, Goris AH. Validity of the assessment of dietary intake: problems of misreporting. Current opinion in clinical nutrition and metabolic care. 2002;5(5):489-93.
57. Svendsen M, Tonstad S. Accuracy of food intake reporting in obese subjects with metabolic risk factors. The British journal of nutrition. 2006;95(3):640-9.
58. Thompson FE, Subar AF, Loria CM, Reedy JL, Baranowski T. Need for technological innovation in dietary assessment. Journal of the American Dietetic Association. 2010;110(1):48-51.
59. O'Sullivan A, Gibney MJ, Brennan L. Dietary intake patterns are reflected in metabolomic profiles: potential role in dietary assessment studies. The American journal of clinical nutrition. 2011;93(2):314-21.
60. Freedman LS, Schatzkin A, Midthune D, Kipnis V. Dealing with dietary measurement error in nutritional cohort studies. Journal of the National Cancer Institute. 2011;103(14):1086-92.
61. Prentice RL, Huang Y. Measurement error modeling and nutritional epidemiology association analyses. The Canadian journal of statistics = Revue canadienne de statistique. 2011;39(3):498-509.
62. Kirkpatrick SI, Collins CE, Keogh RH, Krebs-Smith SM, Neuhouser ML, Wallace A. Assessing Dietary Outcomes in Intervention Studies: Pitfalls, Strategies, and Research Needs. Nutrients. 2018;10(8).
63. Natarajan L, Pu M, Fan J, Levine RA, Patterson RE, Thomson CA et al. Measurement error of dietary self-report in intervention trials. Am J Epidemiol. 2010;172(7):819-27.
64. Neuhouser ML, Tinker L, Shaw PA, Schoeller D, Bingham SA, Horn LV et al. Use of recovery biomarkers to calibrate nutrient consumption self-reports in the Women's Health Initiative. Am J Epidemiol. 2008;167(10):1247-59. doi:10.1093/aje/kwn026.
65. Keogh RH, Carroll RJ, Tooze JA, Kirkpatrick SI, Freedman LS. Statistical issues related to dietary intake as the response variable in intervention trials. Statistics in medicine. 2016;35(25):4493-508.
66. Boushey CJ, Spoden M, Zhu FM, Delp EJ, Kerr DA. New mobile methods for dietary assessment: review of image-assisted and image-based dietary assessment methods. The Proceedings of the Nutrition Society. 2017;76(3):283-94.
67. Rollo ME, Ash S, Lyons-Wall P, Russell AW. Evaluation of a Mobile Phone Image-Based Dietary Assessment Method in Adults with Type 2 Diabetes. Nutrients. 2015;7(6):4897-910.
68. Collins CE, Watson J, Burrows T. Measuring dietary intake in children and adolescents in the context of overweight and obesity. Int J Obes 2010;34(7):1103-15.
69. Food and Agriculture Organization of the United Nations (FAO). Dietary Assessment: A resource guide to method selection and application in low resource settings. Rome, Italy FAO 2018
70. Hassannejad H, Matrella G, Ciampolini P, De Munari I, Mordonini M, Cagnoni S. Automatic diet monitoring: a review of computer vision and wearable sensor-based methods. International journal of food sciences and nutrition. 2017;68(6):656-70.

71. Kerr DA, Dhaliwal SS, Pollard CM, Norman R, Wright JL, Harray AJ et al. BMI is Associated with the Willingness to Record Diet with a Mobile Food Record among Adults Participating in Dietary Interventions. Nutrients. 2017;9(3):244.
72. Vu T, Lin F, Alshurafa N, Xu W. Wearable Food Intake Monitoring Technologies: A Comprehensive Review. Computers. 2017;6(1):4.
73. Salley JN, Hoover AW, Wilson ML, Muth ER. Comparison between Human and Bite-Based Methods of Estimating Caloric Intake. J Acad Nutr Diet. 2016;116(10):1568-77.
74. Farooq M, Sazonov E. A Novel Wearable Device for Food Intake and Physical Activity Recognition. Sensors (Basel, Switzerland). 2016;16(7):1067.
75. Doulah A, Farooq M, Yang X, Parton J, McCrory MA, Higgins JA et al. Meal Microstructure Characterization from Sensor-Based Food Intake Detection. Frontiers in Nutrition. 2017;4(31).
76. Mattfeld RS, Muth ER, Hoover A. A comparison of bite size and BMI in a cafeteria setting. Physiology & behavior. 2017;181:38-42.
77. Biesalski HK, Dragsted LO, Elmadfa I, Grossklaus R, Muller M, Schrenk D et al. Bioactive compounds: definition and assessment of activity. Nutrition (Burbank, Los Angeles County, Calif). 2009;25(11-12):1202-5.
78. Burrows T, Rollo M, Ho YY. What is the validity of dietary assessment methods in adults when comparatively validated by double labelled water (DLW) as an objective reference measure for energy intake (EI) (In-press) Journal of the Academy of Nutrition and Dietetics. 2018
79. Palmnäs MSA, Kopciuk KA, Shaykhutdinov RA, Robson PJ, Mignault D, Rabasa-Lhoret R et al. Serum Metabolomics of Activity Energy Expenditure and its Relation to Metabolic Syndrome and Obesity. Scientific Reports. 2018;8(1):3308.
80. Ravussin E, Bogardus C. Relationship of genetics, age, and physical fitness to daily energy expenditure and fuel utilization. The American journal of clinical nutrition. 1989;49(5):968-75.
81. Goran MI, Beer WH, Wolfe RR, Poehlman ET, Young VR. Variation in total energy expenditure in young healthy free-living men. Metabolism: clinical and experimental. 1993;42(4):487-96.
82. Jensen MD, Ryan DH, Apovian CM, Ard JD, Comuzzie AG, Donato KA et al. 2013 AHA/ACC/TOS guideline for the management of overweight and obesity in adults: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines and The Obesity Society. Circulation. 2014;129(25 Suppl 2):S102-38.
83. Cheung W, Keski-Rahkonen P, Assi N, Ferrari P, Freisling H, Rinaldi S et al. A metabolomic study of biomarkers of meat and fish intake. The American journal of clinical nutrition. 2017;105(3):600-8.
84. National Health and Medical Research Council (NHMRC). A Review of the Evidence to Address Targeted Questions to Inform the Revision of the Australian Dietary Guidelines. Canberra, ACT NHMRC; 2011.
85. Rollo ME, Williams RL, Burrows T, Kirkpatrick SI, Bucher T, Collins CE. What Are They Really Eating? A Review on New Approaches to Dietary Intake Assessment and Validation. Current Nutrition Reports. 2016;5(4):307-14.
86. Burrows TL, Williams R, Rollo M, Wood L, Garg ML, Jensen M et al. Plasma carotenoid levels as biomarkers of dietary carotenoid consumption: A systematic review of the validation studies. Journal of Nutrition & Intermediary Metabolism. 2015;2(1):15-64.
87. Burrows TL, Warren JM, Colyvas K, Garg ML, Collins CE. Validation of overweight children's fruit and vegetable intake using plasma carotenoids. Obesity (Silver Spring, Md). 2009;17(1):162-8.

88. Makki K, Froguel P, Wolowczuk I. Adipose tissue in obesity-related inflammation and insulin resistance: cells, cytokines, and chemokines. ISRN inflammation. 2013;2013:139239-.
89. Pezdirc K, Hutchesson MJ, Whitehead R, Ozakinci G, Perrett D, Collins CE. Fruit, Vegetable and Dietary Carotenoid Intakes Explain Variation in Skin-Color in Young Caucasian Women: A Cross-Sectional Study. Nutrients. 2015;7(7):5800-15.
90. Tilg H, Adolph TE. Influence of the human intestinal microbiome on obesity and metabolic dysfunction. Current opinion in pediatrics. 2015;27(4):496-501.
91. Landberg R, Aman P, Friberg LE, Vessby B, Adlercreutz H, Kamal-Eldin A. Dose response of whole-grain biomarkers: alkylresorcinols in human plasma and their metabolites in urine in relation to intake. The American journal of clinical nutrition. 2009;89(1):290-6.
92. Aubertin-Leheudre M, Koskela A, Marjamaa A, Adlercreutz H. Plasma alkylresorcinols and urinary alkylresorcinol metabolites as biomarkers of cereal fiber intake in Finnish women. Cancer epidemiology, biomarkers & prevention : a publication of the American Association for Cancer Research, cosponsored by the American Society of Preventive Oncology. 2008;17(9):2244-8.
93. Lissner L. Measuring food intake in studies of obesity. Public Health Nutr. 2002;5(6a):889-92.
94. Archundia Herrera MC, Chan CB. Narrative Review of New Methods for Assessing Food and Energy Intake. Nutrients. 2018;10(8).
95. Ptomey LT, Willis EA, Honas JJ, Mayo MS, Washburn RA, Herrmann SD et al. Validity of energy intake estimated by digital photography plus recall in overweight and obese young adults. J Acad Nutr Diet. 2015;115(9):1392-9.
96. Hutchesson MJ, Truby H, Callister R, Morgan PJ, Davies PS, Collins CE. Can a Web-based food record accurately assess energy intake in overweight and obese women? A pilot study. Journal of human nutrition and dietetics : the official journal of the British Dietetic Association. 2013;26 Suppl 1:140-4.
97. Walker JL, Ardouin S, Burrows T. The validity of dietary assessment methods to accurately measure energy intake in children and adolescents who are overweight or obese: a systematic review. Eur J Clin Nutr. 2018;72(2):185-97.
98. Hise ME, Sullivan DK, Jacobsen DJ, Johnson SL, Donnelly JE. Validation of energy intake measurements determined from observer-recorded food records and recall methods compared with the doubly labeled water method in overweight and obese individuals. The American journal of clinical nutrition. 2002;75(2):263-7.
99. Calvert M, Blazeby J, Altman DG, Revicki DA, Moher D, Brundage MD et al. Reporting of patient-reported outcomes in randomized trials: the CONSORT PRO extension. Jama. 2013;309(8):814-22.
100. Subar AF, Kirkpatrick SI, Mittl B, Zimmerman TP, Thompson FE, Bingley C et al. The Automated Self-Administered 24-hour dietary recall (ASA24): a resource for researchers, clinicians, and educators from the National Cancer Institute. J Acad Nutr Diet. 2012;112(8):1134-7.
101. National Cancer Institute, The Institute for Nutrition and Physical Activity. ASA24-Australia (2016). VIC: Australia National Cancer Institute; 2016