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Assessment tools in obesity — Psychological measures, diet, activity, and body composition

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Abstract

The global increase in the prevalence of obesity has led to an increased need for measurement tools for research, management and treatment of the obese person. The physical size limitations imposed by obesity, variations in body composition from that of normal weight, and a complex psychopathology all pose tremendous challenges to the assessment of an obese person. There is little published research regarding what tools can be used with confidence. This review is designed to provide researchers and clinicians with a guide to the current and emerging measurement tools specifically associated with obesity research and practice. Section 1 addresses psychological measures of well being. Sections 2, 3, and 4 focus on the assessment of food intake, activity, and body composition. All sections address basic challenges involved in the study and management of obesity, and highlight methodological issues associated with the use of common assessment tools. The best available methods for use in the obese both in research and clinical practice are recommended.

Keywords

Obesity; Psychometrics; Psychological tools; Dietary assessment; Body composition measurement

1. Introduction

The global increase in the prevalence of obesity has led to an increased need for measurement tools for research, management and treatment of the obese person. The physical size limitations imposed by obesity, variations in body composition from that of normal weight, and a complex psychopathology all pose tremendous challenges to the assessment of an obese person. The field of obesity research would benefit from having more uniform methods of assessment which would enable researchers for clinical and community-based studies, evaluation teams to assess intervention programs, and health

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professionals for counseling individuals. Standardized assessment methods support better comparison of health between different studies and across diverse populations. This is particularly important since the reported results are attributed value that drives policy, organization, and treatment.

2. Psychological assessment

2.1. Introduction

Psychological assessment measures are abundant in the field of obesity research, and are necessary to determine the psychological health of an obese patient before, during, and after treatment. In clinical practice, psychological assessment tools are important for determining the effectiveness of weight loss treatment. In a research setting, these tools are important for comparing the results of different weight loss programs, and understanding the connection between the physical and psychological problems associated with obesity. The field of obesity research would benefit from having more uniform methods of psychological assessment, which would allow for better comparison of psychological health between different studies and across diverse populations. The purpose of this section on psychological well-being is to address issues of tool validity in overweight and obese populations, highlight the most widely used tools in the field, and provide a reference for selecting the most appropriate method of assessment, depending on the context and purpose of the research.

2.2. Introduction to Quality of Life Assessment

The effects of obesity on quality of life (QOL) have been well studied, and the overall consensus is that obesity decreases QOL, and treatment improves QOL [1]. The main assessment tool used by researchers has been the questionnaire, and several authors have done extensive reviews on these questionnaires [2–5]. Questionnaires can be divided into general QOL questionnaires, which are not designed to examine the specific health problems associated with obesity, and obesity-specific QOL questionnaires. The questionnaires discussed in this review are the general Short Form-36, the obesity-specific Impact of Weight on Quality of Life, the Impact of Weight on Quality of Life — Lite, the Moorehead–Ardelt — II, the Weight Related Symptom Measure, the Obesity and Weight Loss Quality of Life questionnaire, and the Obesity Related Well Being questionnaire.

2.2.1. Short Form-36 (SF-36)—The Medical Outcomes Study SF-36 questionnaire is the most commonly used generic instrument for measuring QOL [4,6]. The SF-36 measures eight domains: i) physical functioning, ii) role limitations due to physical health problems, iii) bodily pain, iv) general health perceptions, v) vitality, vi) social functioning, vii) role limitations due to emotional problems, and viii) mental health. The SF-36 has excellent psychometric properties, has been validated across diverse populations with medical and psychiatric problems, and is easy to complete [4,6–8]. Although the SF-36 has been used in numerous studies with individuals who are overweight and obese, it is recommended that it be used in conjunction with an obesity-specific questionnaire [9–12]. BMI has been shown to be significantly associated with poor health related QOL using the SF-36, but this association is the strongest when measuring physical activity, not mental health, social functioning, role limitations due to emotional problems, or vitality. Also, the SF-36 is unable to distinguish between impairments due to BMI in mild and moderate physical activity versus intense physical activity [8]. Overall, the SF-36 does not measure disease-specific domains, lacks the sensitivity to detect small treatment effects, and further studies need to be done to assess the validity of each domain of the SF-36 with morbidly obese individuals [9,12]. However, the SF-36 is a very robust tool that can be used to compare QOL in obese individuals to the general population [7].

2.2.2. Impact of Weight on Quality of Life (IWQOL)/IWQOL-Lite—The IWQOL is a 74-item self-report questionnaire that was developed in a clinical sample of moderate to severe obese individuals, and assesses the affects of weight on QOL in eight areas: health, social and interpersonal life, work, mobility, self-esteem, sexual life, activities of daily living, and comfort with food [13]. The IWQOL is a psychometrically sound measure that has the ability to detect any post-treatment affects, which makes it a useful tool to use after clinical trials of antiobesity drugs, or after surgical treatments [14]. A shorter 31-item version, the IWQOL-Lite, has been developed that assesses QOL across five areas: physical function, self-esteem, sexual life, public distress, and work, and correlates well with the IWQOL, shows excellent psychometric properties, and has been validated in individuals with psychiatric disorders who are prone to obesity [15,16]. Because of its ease of use and its ability to detect changes in QOL associated with small changes in BMI, the IWQOL-Lite is the preferred method of assessment over the original questionnaire.

2.2.3. Moorehead–Ardelt Quality of Life Questionnaire — II (MA-II)—The MA-II is a one page obesity specific tool used as part of the Bariatric Analysis and Reporting Outcome System to measure postoperative outcomes in self-perceived QOL by using simple drawings to assess six areas: self-esteem, physical well-being, social relationships, work, sexual activity, and eating behavior [17–19]. The MA-II has been validated in gastric bypass patients who are morbidly obese, with a target population of morbidly and super obese individuals. It creates a standard for comparing QOL outcomes after the surgical treatment of severe obesity because it can be used for both pre and post intervention assessment [5]. The MA-II is an easy to use questionnaire that can be easily used for different cultures and populations. Specifically designed for morbidly obese patients who have undergone surgical operations, it takes into account complications that could arise from surgery and the potential for re-operation [17].

2.2.4. Weight Related Symptom Measure (WRSM) and Obesity and Weight Loss Quality of Life (OWLQOL)—Both the WRSM and the OWLQOL questionnaire were developed as culturally sensitive measures of QOL as development of the questionnaires involved qualitative input from six countries: the United States, the United Kingdom, France, Germany, Spain, and Italy [20]. The WRSM is a 20-item measure of the symptoms associated with obesity and obesity treatment, along with the degree to which each symptom “bothers the individual”. The OWLQOL is a 17-item measure of a person’s global evaluation of obesity and their effort to lose weight based on feelings that are unobservable to others. Both the WRSM and the OWLQOL are responsive to short and long-term reductions in weight loss, and are easy to complete questionnaires that are intended to be administered together and with other outcome measures [21].

2.2.5. Obesity Related Well-Being (ORWELL-97)—The ORWELL 97 questionnaire is an 18-item self-report measure that assesses QOL across three areas: symptoms, which include somatic symptoms and physical functioning; discomfort, which is defined as the effect of obesity on emotional status; and impact, which is defined as the effect of obesity on relationships and an individuals' social network. The ORWELL 97 proposes that symptoms of similar intensity can have a different impact depending on the individual, so respondents are asked about the occurrence, severity, and relevance of each impairment on the individual's own life. The ORWELL-97 has high test–retest reliability, good internal consistency, and can be used as a clinical measure with a wide population. But, in a preliminary study, weaknesses were found when trying to correlate BMI with sub-scores of the ORWELL-97. Also, women were found to have lower QOL because of the greater impact of being obese had on psychosocial complaints [22]. This suggests that further studies need to be done in order to determine how to interpret the sub-scores of the ORWELL 97.

2.3. Introduction to hunger assessment

Hunger, dietary restraint, and overeating have been well studied in the obese and questions still exist as to the differences between normal and obese individuals when it comes to these dimensions [23]. While other scales, such as the Restraint Scale and Eating Behavior Scales exist, the Three-Factor Eating Questionnaire will be discussed because it encompasses both hunger and dietary restraint, and is commonly used in the study of the obese [1]. More subjective measures of hunger include Visual Analog Scales and what is described as Pictorial Measures of hunger.

2.3.1. Three Factor Eating Questionnaire (TFEQ)—The TFEQ is a 51-item self-report measure that was developed to assess restrained eating to control body weight by measuring three domains of the psychological patterns of eating: dietary restraint, disinhibition, and hunger [24–27]. The TFEQ is useful to predict weight loss in clinical patients, to monitor progress during treatment, has good psychometric properties, and it is one of the most widely used tools to study eating in obese individuals [25,28]. However, further analysis has shown that the original three factor structure may not be replicated in obese individuals, so two shortened forms, the TFEQ-21 and the TFEQ-18, which measure cognitive restraint, uncontrolled eating, and emotional eating have been developed in an obese population [29–32].

2.3.2. Visual Analog Scales (VAS)—A VAS is a type of question that is used to rate hunger, satiety, and individual's own interpretation of their hunger sensations. To measure hunger, Visual Analog Scales were initially developed with six questions: i) How hungry do you feel? ii) How full do you feel? iii) How strong is your desire to eat? iv) How much to you think you could eat now? v) What is your urge to eat? and vi) What is your preoccupation with thoughts of food? Individuals answer these questions by making a single mark on a 100 mm straight line, where the two extreme answers to every question are anchored on opposite ends of the line. The use of VASs have been shown to be both reliable and valid, have been used extensively when studying obese individuals, not influenced by prior diet, and can be used to assess the effects of drugs, diet composition, and alterations in energy intake [33–38]. VASs are sensitive to experimental manipulations, can be used as a proxy for energy intake, are simple to use and interpret, and can be used to compare across populations. However, because individual differences in interpretations of the scale may arise, it is advised that researchers predominantly use VASs in studies with a within-subjects design that compares hunger before and after treatment because in a validity study, within subjects comparisons were more accurate and sensitive than between-subjects comparisons [35,36].

Traditional VASs use pen and paper, but because the researchers must physically measure responses, electronic appetite rating systems (EARS) have been developed. These use handheld electronic devises that individuals electronically mark their answers on lines presented on a screen. Although EARS increases the reliability of data collection, initial studies have shown that EARS produces responses with less variation, so EARS and pen and paper VASs should not be used interchangeably [36]. Overall, VASs are a very common method for measuring hunger and are helpful for measuring an individual's subjective hunger sensations.

2.3.3. Pictorial Measures—Pictorial Measures of hunger were first developed to assess the body areas associated with the sensations of hunger and the extent of these sensations [39]. Individuals are asked to outline on a drawing of a human body the area where they are experiencing hunger sensations, and the size of the outlined area should reflect the intensity of ones hunger sensations. This is an emerging tool that needs further validation and should be used in conjunction with other subjective measures of hunger. Although this pictorial instrument was tested using obese individuals, it was developed in normal weight subjects, and the bodies used in the measure are of normal weight [23]. Despite this, an initial study using this tool has found that physical aspects of hunger may be distinguished from overall global aspects of hunger [39]. This tool may also be more sensitive to extreme hunger, and increases in hunger during fasting may be better measured by using a pictorial instrument [23,39]. Overall, more testing is needed, but an initial study suggests that a pictorial measure could be useful in the study of obese individuals as an instrument that complements more traditional measures of hunger.

2.4. Introduction to sleep assessment

Obesity is associated with sleep disturbances, excessive daytime sleepiness, and obstructive sleep apnea (OSA). Obesity increases a person's risk for OSA 10-fold [40,41]. Subjective sleep assessment tools, such as polysomnography and actigraphy are commonly used as a way to quantify sleep disturbances. Questionnaires have also been commonly employed in the study of obese individuals, such as the Epworth Sleepiness Scale, St Mary's Hospital Sleep Questionnaire, VSH Sleep Scale, and the Pittsburgh Sleep Quality Index [42–45]. These tools have not been developed in the obese, but the best to use when studying sleep disorders of obese individuals. This review will cover the Epworth Sleepiness Scale, polysomnography, and actigraphy technology because of their validation and extensive use in the obese.

2.4.1. Epworth Sleepiness Scale—The Epworth Sleepiness Scale (ESS) is an eight-item measure of daytime sleepiness that asks individuals to rate on a scale how likely they would be to doze off or fall asleep in 8 situations [46]. The ESS is a simple test that has been found to be psychometrically sound among the general population, gives a retrospective report on dozing behavior, and high ESS scores have been significantly correlated with obstructive sleep apnea [47,48]. The ESS has been used extensively in obese individuals to study sleep disturbances, but may be more difficult to use in morbidly obese individuals [42,49,50]. However, the use of the ESS alone is not sufficient to diagnose obstructive sleep apnea or other sleep related disorders. It is recommended that morbidly obese individuals who have a high score on the ESS undergo polysomnography to further diagnose a sleep disorder.

2.4.2. Polysomnography—Overnight polysomnography is used to diagnose sleep-related breathing and respiratory disorders, including OSA. Before undergoing polysomnography, a full sleep history and physical examination are recommended. A full polysomnography includes an electroencephalography, electrooculography, chin electromyography, airflow, arterial oxygen saturation, respiratory effort, and electrocardiography. An anterior tibialis EMG can be used to help measure movement associated with arousal [51]. Overnight polysomnography is the gold standard for accurate diagnosis in obese individuals because of its reliability and its ability to accurately diagnose sleep disorders [51,52]. This tool can also measure sleep improvements after weight loss, and is recommended for use after substantial weight loss [51,53]. Despite these advantages, polysomnography is expensive, time consuming, often inconvenient, error could arise during instrument readings, data could be lost, and misclassification of patients could result because of night-to-night variability [41,51].

2.4.3. Actigraphy—Actigraphy is used to assess sleep/wake patterns via a movement detector, most commonly an accelerometer, which is worn on the wrist or ankle over a period of time [54–56]. Currently, there are different actigraph instruments on the market, and different algorithms used to determine sleep/wake patterns [57]. This lack of standardization poses a problem when comparing the results of sleep studies that use these different methods. Although there is a relationship between sleep duration and obesity as measured by an actigraph, actigraphy is not the gold standard for measuring sleep duration because it is not as accurate as polysomnography, it cannot distinguish the difference between different sleep disorders, and it likely overestimates sleep and underestimates wake [54,55]. For accurate readings, it is recommended that actigraphy measurements be supplemented with a sleep log. Also, actigraphy does not allow for routine diagnosis or assessment of severity of sleep disorders [58]. Despite these disadvantages, actigraphy can be used in an individual’s natural sleep environment, is feasible for use in large research studies, is cost effective, allows for study when polysomnography is not feasible, and it allows individuals to be tested for 24 h across multiple days [54,55].

2.5. Introduction to psychological well-being assessment

Individuals with obesity show a higher prevalence of psychiatric illness compared with the general population [1,59]. However, weight loss is associated with a reduction of depressive symptoms [60]. The most common method of psychological assessment is questionnaires designed for the general population. Described here are the questionnaires that are considered the gold standard for assessing depression, well-being, and self-esteem. These are the Beck Depression Inventory, the Center for Epidemiologic Studies Depression Scale, the General Well-Being Schedule, and the Rosenberg Self-Esteem Scale.

2.5.1. Beck Depression Inventory II (BDI-II)—The BDI-II is a 21-item measure that was initially developed in psychiatric patients to assess the intensity and the behavioral manifestations of depression [61,62]. The BDI-II is recommend in the study of obese individuals because of its widespread use with both obese and extremely obese populations, and because its items are not biased by obesity [4,60,63]. Advantages of the BDI-II are its ease of use, its ability to detect changes in depression over time and with treatment, and it is one of the most widely used, psychometrically valid self-report measures of depression [61,62,64]. However, the BDI-II is not designed to diagnose different types of depression or psychiatric illness [61].

2.5.2. Center for Epidemiologic Studies Depression Scale (CES-D)—The CES-D was developed from previous questionnaires for use in large population based epidemiological studies. It is a 20-item self-report scale designed to measure the frequency and duration of the major symptoms associated with depression, including depressed mood, feelings of guilt and worthlessness, feelings of helplessness and hopelessness, psychomotor retardation, loss of appetite, and sleep disturbance [65]. The CES-D has been validated in diverse populations, so it is appropriate to use when studying obese individuals in a large epidemiological setting [66,67]. Although the CES-D is brief, a 10 item short form, the CESD-10 has been developed in healthy older adults [68]. The short form is not as widely used as the longer, 20 item scale, and only one study has used the CESD-10 in overweight individuals [69]. The CES-D is easy to complete, and has been used extensively in epidemiologic studies and in ethnically diverse samples, which allows for the comparison of scores across populations [67,70]. However, the scale is not designed for the clinical diagnosis of depression, to differentiate between different types of depression, nor to interpret individual scores [65,70].

2.5.3. General Well-Being Schedule (GWB)—The GWB is an 18-item self-administered questionnaire that has been validated in and is widely used in medical research on obesity, and is recommended for measuring subjective feelings of psychological well-being [71–73]. The GWB emphasizes an individual's inner personal state, rather than external conditions that could affect well-being. Six subscales: anxiety, depression, general health, positive well-being, self-control, and vitality have been identified, but have not been validated in all populations [71,72]. The GWB is easy to complete and avoids references to physical symptoms of emotional distress, which can lead to problems in interpretation [71]. Because of its relatively low test–retest reliability, it is recommended for use in large population studies, and not in determining individual changes in well being. Alternate forms include the 10-item Psychological Mental Health Index, and a version incorporated into the Rand Mental Health Inventory [74].

2.5.4. Rosenberg Self-Esteem Scale (RSE)—
The RSE scale is a 10-item self-report psychological screening tool that measures global self-esteem by assessing whether a person has a favorable or unfavorable attitude toward oneself [75,76]. The RSE scale is widely used across a variety of populations, including the obese and morbidly obese, because of its excellent psychometric properties [59,71,77,78].

2.6. Introduction to perceived body image assessment

Williamson and O'Neil define body image as the cognitive perception of one's body size and appearance, and the emotional response to that perception. Body image is less accurately estimated by obese individuals, and obesity is associated with a preoccupation with one's body weight [1]. Various technological methods of body image assessment exist, including using video, computers, and distorted mirrors [79–82]. This review will cover questionnaires, because they are easier to use, are currently more commonly used, and are well validated. These include the Body Shape Questionnaire, the Multidimensional Body-Self Relations Questionnaire, and the Body Image Assessment for Obesity.

2.6.1. Body Shape Questionnaire (BSQ)—
The BSQ is a 34-item self-report measure of body shape dissatis faction, especially the construct of "feeling fat" by assessing distress with, and frequency of preoccupation with body shape and size [78,83,84]. It is a useful measure of weight and shape concerns in diverse clinical samples of obese and morbidly obese individuals, has good psychometric properties, and is easy to complete [78,83,85–88]. Short versions of the BSQ have been developed, but are not validated in nor used extensively in the obese [89,90].

2.6.2. Multidimensional Body-Self Relations Questionnaire (MBSRQ)—
The MBSRQ is a 69-item self-report measure that is one of the most widely used tools to assess body image. It measures the evaluation of one's appearance, health and illness, fitness, body satisfaction, weight attitude, and weight status, and assessing the cognitive, behavioral, and affective components of body image [91,92]. The two subscales frequently used in the study of obese individuals are the Appearance Evaluation (AE) subscale and the Body Areas Satisfaction (BAS) subscale [92–94]. The MBSRQ is an excellent tool for the use with obese individuals, but an analysis does show the questionnaire's weakness in being able to compare different age and gender groups [91,92].

2.6.3. Body Image Assessment for Obesity (BIA-O)—
The BIA-O is an extension of the original Body Image Assessment (BIA). The BIA defines body image dissatisfaction as the discrepancy between self-perceived and ideal body size estimates. The measure presents individuals with nine silhouettes ranging in body size and asks them to determine which most accurately depicts their current body size and ideal body size. However, the original BIA silhouettes depicting overweight individuals were not large enough to use with an obese population [95]. The BIA-O added an additional nine silhouettes, so the 18 silhouettes ranged from very thin to very obese. The developers also added an additional

question concerning a reasonable body size that would be realistic to maintain over a long period of time. After completing the BIA-O, two measures of body size dissatisfaction can be determined: current body size minus ideal body size and current body size minus realistic body size. The BIA-O has been found to be a valid and reliable tool in individuals with a BMI of up to 50, can be used to determine the relative cause of body dissatisfaction, and is valid in ethically diverse populations. Disadvantages of the BIA-O include its interpretability because it can only be used in the context of BMI, ethnicity, and gender, and the fact that male silhouettes do not distinguish between increasing size due to fat or due to muscularity [95,96].

2.7. Conclusion

This review of the psychological assessment tools in the obese shows that while many objective tools and subjective questionnaires exist, few are well-validated and used extensively in obese populations. While each tool has its flaws, the tools presented in this review are recommended for researchers and clinicians going forward as more interest develops in the measurement of psychological health of obese individuals. Choosing well-validated and widely used measures allows for a better comparison of research methods and results. When choosing which method of assessment to use, researchers and clinicians should consider the population they are studying, the purpose and goals of their research, and what specific aspects of psychological health they are assessing. With the increase in prevalence of obesity, measuring the psychological health of this population will continue to be vital in determining proper treatments and their efficacy.

3. Dietary intake

3.1. Introduction

Dietary intake assessment is an influential measure in research and clinical communities. Whether employed by researchers for clinical and community-based studies, evaluation teams to assess intervention programs, or by health professionals for counseling individuals, the reported results are attributed value that drives policy, organization, and treatment. Many resources provide descriptions and discussions on the most widely used methods [97,98]. The purpose of this section on dietary intakes assessment is to address issues of tool validity in overweight and obese populations, highlight new technologies emerging in the field, and provide an easy to reference table for selecting the most appropriate methods for a variety of contexts.

Table 1 presents the results of a literature review on dietary intake assessment tools used in overweight and obese populations. The chart follows the general evolution of the field, starting with classic methods involving written records and manual data input, to the newest automated technologies still in development. The purpose of this chart is to serve as a useful inventory by outlining the advantages and limitations specifically related to assessment in overweight and obese populations. In pursuit of the most valid measurement, many researchers have studied variations or combinations of traditional methods. A column of recommendations shares those techniques less widely used, provides suggestions for implementation, and highlights additional sources and areas of investigation. Italicized items highlight the impact of weight status on tool performance.

3.2. Conclusion

No measure has perfect construct validity. Selection of a dietary assessment method in any study must balance between greatest validity and feasibility [113]. The sources of bias in dietary intake assessment tools continue to be explored, and new methods promise to move the field forward. Even for tools that have been validated against the gold standard DLW, external validation in overweight and obese populations remains fragile. An unannounced multi-pass 24-hour recall (in person or over the phone) with portion size estimation aids, collected for 3–8 days, including a Sunday is a recommended method for assessing dietary intake of overweight and obese individuals. The recall should be conducted by staff highly trained in the tool methodology and interpersonal communication to encourage accurate reporting. Use of ancillary tools to screen for high risk of low-energy reporting is advised. Preemptive strategies to reduce low-energy reporting may include motivational training to increase social desirability of reporting certain foods. Statistical analyses may be used to identify and address misreporting. But for researchers working with overweight and obese populations, strategic triangulation of methods provides the greatest confidence in true reporting of dietary intake.

4. Physical activity

4.1. Introduction

Physical activity (PA) assessment is the measurement of movement intensity, type, duration, or frequency [149]. Assessment in free-living obese individuals is important for the study of disease, weight management, and associated interventions [150]. Researchers and clinicians should consider participant interference and burden, the need for contextual data, data objectivity, and time and cost requirements when selecting a method to assess physical activity [151].

4.2. Doubly labeled water (DLW)

DLW estimates total energy expenditure through measured excretion of isotope-labeled water. DLW is the most accurate and objective measurement for assessing physical activity in free-living individuals, and has been used extensively in obese populations [151]. Greater underestimation of energy expenditure has been shown in the obese than nonobese using this method [152], but the accuracy in obese populations still remains greater than other methods of PA assessment. DLW has a low participant burden, but the high cost of this method limits its use to small studies.

4.3. Heart rate (HR) monitoring

Estimating energy expenditure and PA through HR monitoring is a popular alternative to more expensive methods. Minute-by-minute HR data is inexpensive, convenient, noninvasive, and versatile, and provides information on the frequency, intensity, and duration of free-living PA [150]. HR monitoring underestimated energy expenditure in a small group of obese women, but was not quite significant compared to DLW. Standard calculations of activity energy costs must be modified in obese populations to account for the increased basal metabolic rate and energy costs of moving greater mass [153]. HR calculations provide unreliable estimates of energy expenditure at the individual level, but provide an acceptable estimate of total energy expenditure and associated patterns of PA when applied to a group [54,55]. Combination with accelerometry may improve precision [151].

4.4. Accelerometry

Accelerometry measures the intensity and duration of movement through sensors attached to the body. Known linear relationships between accelerometry counts and energy cost allow for the classification of PA by intensity [150]. Single unit accelerometers, usually placed on the waist, are small, non-invasive, and give minimal discomfort to subjects, including the obese [154]. Consistent and secure placement on the body is important to limit variance, which may be challenging in the extremely obese. Accelerometers are limited in ability to detect activity of the extremities, bicycling, or swimming [155]. Four days of ≥6 h wear time/day optimized reliability and sample size in a study of overweight and obese adults using a triaxial accelerometer on the hip [155]. Accelerometry, using a DLW-validated instrument, is the indicated method for the assessment of habitual frequency, intensity and duration of PA of both obese and non-obese individuals [151,154].

4.5. Introduction to questionnaires

Questionnaires are the most widely used method to assess PA, but few have been studied in the obese [156]. The use of questionnaires to predict individual energy expenditure is largely dependent on subject compliance and ability to correctly estimate time spent in activities of varying intensities [157]. In general, questionnaires have low reliability and validity but are useful for ranking individuals by activity level [151]. Obesity is correlated with overestimation of daily PA in individuals [156] making this method particularly problematic in obese populations. Questionnaires vary in their measurement of activity domains, time frame of recall, and expression of result [156].

4.5.1. Baecke Questionnaire—The Baecke questionnaire contains 16-items and a simple scoring system for calculation of an activity index. It is valid and reliable for assessing physical activity patterns in work, sport, and leisure in the general population [158] and has been used in studies with the obese [156]. Identification of misreporting can be difficult because the index results cannot be easily compared with energy expenditure measurements from other methods [156].

4.5.2. International Physical Activity Questionnaire (IPAQ)—The IPAQ is a 31-item questionnaire available in 21 languages, in telephone or self-administered format. Domains of assessed PA include household and yard work, occupational activity, self-powered transport, leisure-time activity, and sedentary activity. The IPAQ was validated in a 12-country study with reasonable measurement properties for monitoring population levels of physical activity among adults, and results at least as good as other established PA surveys [159]. The IPAQ produces higher estimates of physical activity compared to a shorter version described below [159]. No studies examining the impact of weight status on the questionnaire accuracy were identified.

4.5.3. Short 7-day IPAQ (IPAQ-S7)—

The IPAQ-S7 is a 9-item questionnaire designed primarily for surveillance and comparison between populations. It is available in telephone or self-administered formats and provides results based on current recommendations for moderate and vigorous activity. The IPAQ-S7 is generally preferred by respondents and interviewers over the full-length IPAQ. There is no difference in reliability and validity between the short and long IPAQ forms [159]. The 7-day IPAQ may lead to overestimation of physical activity in obese populations, and needs further investigation before validity is established [156].

4.5.4. Physical Activity Recall Questionnaire (PAR-Q)—

The PAR-Q is designed to estimate habitual PA [109], and can estimate energy expenditure using metabolic equivalent calculations [157]. Fourteen-items assess duration of sleep, moderate, hard, and very-hard intensity PA. Though studied in general populations with obese individuals [157], the impact of weight status has not been reported. In a small, but general population, the PAR-Q significantly overestimated energy expenditure compared to DLW. Awarding a lower intensity to hard- and very-hard activity may reduce overestimation with this tool. The PAR-Q is therefore not recommended for estimation of individual or small group energy expenditure, but may be appropriate for large epidemiological studies.

4.6. Behavioral observation

Direct behavioral observation by trained observers is a possible method for small samples of short durations, when contextual information is particularly important. The many disadvantages make the use of this method now rare. These include an extensive time requirement, potential bias with presence of observer, and subjective classification of activity and intensity. No validation studies with DLW have been completed [151].

5. Body composition

5.1. Introduction

The human body is composed of fat and fat free compartments and body composition assessment involves the accurate measurement of one or many of these compartments. Body composition can be assessed at the molecular, cellular, and tissue levels [160] using several different methods. Evaluating body composition of obese individuals is necessary both in research and clinical practice [161] to determine health as well as disease risk. It is well known that high amounts of body fat are associated with a greater risk of developing type 2 diabetes, cardiovascular disease, cancer, and renal failure [162]. However, assessing body composition in the obese is challenging because obesity is marked by an increase in body fat and changes in body composition different from that of a non-obese person. There is an increase in total body hydration and a relative expansion of the extracellular water (ECW) component compared to intracellular water. Due to these physiological changes the assumptions used to assess body composition in normal weight individuals, including density of tissues, concentrations of water and electrolytes, biological interrelationships between body tissues and distributions do not apply for obese persons [162] and can affect the accuracy of body composition tools [163]. The goal of this section is to review what methods are available to researchers and clinicians and to identify which are the best options to assess body composition in the obese population.

5.2. Body Mass Index (BMI)

BMI is a proportion of height to weight (weight in kilograms/height in meters squared) and is the most widely used measure for determining the prevalence of obesity [164]. A BMI above 30 kg/m^2 is classified as obese, with sub-classifications of Class I 30–34.9, Class II 35–39.9, and Class III≥40 [165]. There is extensive national reference data for BMI [164], and because it is thought to correlate highly with percent body fat (%BF), BMI is considered an accurate indicator of body composition [166,167]. However, in obesity BMI and %BF do not have a strong correlation. Obesity is identified as >25% BF in men, and >30% BF obese in women [168]. When BMI is compared with these parameters, more than 50% of individuals who have body fat outside the %BF cutoffs do not have a BMI>30 [164]. BMI is an acceptable tool for screening for obesity and tracking weight over time. However, since it does not separate body compartments into fat-free mass and fat mass [169] or identify the distribution of fat [170] it should not be used to further assess body composition in the obese beyond classifying the level of obesity.

5.3. Anthropometrics

Anthropometry is the most basic method for assessing body composition and is used to determine body mass, size, shape, and level of fatness [160]. Measurements include height, weight and circumferences of the waist, hip, head, and neck measured with a flexible quilting tape. Body composition is assessed using these variables in standardized regression equations [171]. Anthropometric measurements are considered easy, safe, and inexpensive for assessing obesity [171]. However accuracy is dependent on the skills and training of the person taking the measurements [172] and can vary from observer to observer [173]. Specific limitations of anthropometry in the obese include the inability to distinguish subcutaneous fat from visceral adipose tissue, which is helpful to assess disease risk [160,174] and accuracy may be lowered in the severely obese, due to difficulties finding the actual waistline or drooping abdominal fat can interfere with hip measurement [161].

5.4. Skin fold thickness (SKF)

SKF is a tool used to assess body fat stores by measuring subcutaneous fat in specific locations on the body. The most common sites of measurement are the bicep, tricep, subscapular, and supra-iliac [175,176]. SKF measurements are incorporated into regression equations to predict total body fat [169,177]. SKF has limits in the general population including observer variability, elasticity of fat and skin tissue (which vary with age and between individuals), and discomfort the participant may feel during measurements [178]. All of these limitations are applicable to the obese population. Furthermore, the thickness of adipose tissue in obese participants make it difficult to raise a skinfold that will provide an accurate measure [177]. The calipers used to measure SKF are often too small [177], especially when used on the abdominal and thigh folds of obese participants [177]. Larger calipers are available [162] but are much more difficult for the researcher to use due to their width, and consequently have a greater risk of error [162]. If a participant has edema, it further complicates the accuracy of SKF, because the degree of compression of the caliper can differ from location to location, resulting in uneven and inaccurate measurements [178]. Finally, SKF accuracy in the obese is related to the prediction equation used. Most of the current equations were developed in normal weight individuals, and have not been validated in the obese [161].

5.5. Bioelectrical impedance analysis (BIA)

BIA measures the body impedance using electrodes that are connected from one leg to the other, or to the arm, to form a circuit for the current to pass through. The impedance measure is used to predict total body water (TBW) and fat-free mass (FFM) and fat mass is calculated from the difference between weight and FFM. Different tissues offer varying resistance, with adipose tissue a poor conductor of the current because of its' low water content [179]. Muscle tissue, which has higher water content, offers less resistance and is able to better conduct the current [179]. Body composition assessment by BIA is attractive because it requires little equipment, is inexpensive, noninvasive [180], and has no weight or height restrictions [181]. The method is safe, and there is no risk from frequent measurements [163]. Single frequency BIA (SF-BIA) should not be used for body composition assessment in the obese because the theory that the human body is a single cylinder with constant resistivity cannot be applied to the obese [181]. In addition, the frequency of the current applied (50 kHz) in SF-BIA is not high enough to penetrate all tissues [182]. Segmental BIA (tetra- and eight-polar-BIA) recognizes the human body is complex in shape and combines several impedance measures together for a more accurate assessment [181]. However, segmental-BIA has been found to significantly overestimate %BF in obese adults [181]. Multi frequency-BIA (MF-BIA) allows multiple frequencies to assess fluid distribution [181]; low electric frequencies (e.g. 1 or 5 kHz) measure ECW and high frequencies (e.g. 100, 200, or 500 kHz) measure TBW [183]. MF-BIA has been found to overestimate %BF in the overweight and obese groups [181], significantly underestimate both total and truncal fat in obese women [184], and offer accurate estimates of TBW and ECW in women with a BMI up to 48.2 kg/m^2 [185]. More research needs to be conducted to determine an agreement on the use of MF-BIA in the obese before recommendations can be made.

Prediction equations developed in normal-weight subjects for BIA are based on the assumption that the hydration of FFM is a constant factor of 73.2% [182]. However, in obesity this hydration of FFM has found to be higher (approximately 77.5%) [161,186–188]. The different body build of obese also affects the accuracy of BIA, as obese subject typically have a trunk that is short, and large in diameter, leading to a different body water distribution form lean individuals [182]. As a result of these variances found in obesity, when prediction equations developed in non-obese populations are used to assess body composition in obese participants, they underestimate body fat [177,182,183,189,190]. Fatness-specific BIA equations, developed by Segal et al. have been validated for use in the obese [191] and more recently developed prediction equations specifically for the obese population are more accurate for prediction of body fat [192] and have been discussed in detail elsewhere [192–195].

5.6. Bioimpedance spectroscopy (BIS)

BIS assesses body composition by measuring TBW, differentiating between ECW and intracellular water (ICW) [196] by using a range of frequencies (5–1000 kHz) [183]. The method is noninvasive and inexpensive [197]. For an accurate BIS measurement, the participants' limbs must be completely away from the body such that they are not touching the trunk. This can be difficult in extreme obesity, leading to an overestimation of fluid volumes and BIS has been found to overestimate TBW and ECW [198]. At this time, the method has proven to be inaccurate when used to assess body composition in the obese [88,101].

5.7. Dilution technique

In the dilution technique, deuterium labeled water (^2H_2O) is used to obtain a measure of TBW to calculate an individual's FFM [161,193]. A known dose of isotope, based on the individual's weight, is provided for the participant to drink [199]. TBW volume can be assessed from the dilution spaces of the ^2H_2O and then converted to kilograms using the conversion factor of 0.99336 (density of water at normal body temperature) [161]. The technique is limited to use in research because of its cost, time needed [98] required specialized equipment, and highly trained personnel [161], that make it unrealistic for routine clinical use. When the technique is used in an obese participant, there is an underestimation of FFM and overestimation of fatness [161] because of the high hydration found in obesity. For normal-weight individuals the average proportion of TBW in FFM is 73%, but in the obese it may be as high as 80%. This percentage increases with an increase in adiposity leading to more inaccurate measures. Population specific values for FFM hydration should be determined to further enhance the accuracy of the dilution technique.

The addition of Intravenous Sodium Bromide with the deuterium dilution technique to determine ECW provides a more accurate measure of ECW. ECW is calculated from the increase in bromide concentration between baseline and mean post dose blood samples and the amount of bromide injected after applying appropriate correction factors [161]. Studies have shown that bromide is able to equilibrate within a four hour period in the extracellular space in severe obesity [161].

5.8. Total body potassium (TBP)

Measuring potassium, the most abundant intracellular ion, with a whole-body counter [200] allows researchers to calculate body cell mass. Body cell mass is the metabolically active portion of the human body; quantifying it allows researchers to assess FFM and metabolism [160,200]. Measuring TBP over time in the obese has been found to be an acceptable method to monitor weight [200], but potassium content of FFM may be affected by hydration related changes, specifically in severe obesity [161]. This method is not recommended for assessment of body composition because of high price of the counter [200] and lack of strong support for accuracy.

5.9. Hydrostatic weighing

Hydrostatic weighing, also known as hydrodensitometry, estimates body composition by combining body weight, body volume, and residual lung volume. The original hydrodensitometry method requires complete submersion. However hydrostatic weighing without head submersion has also been developed [202] with comparable accuracy [189]. Hydrostatic weighing is impractical in clinical settings [189]. The test is time consuming [203], labor intensive [160], and often involves difficult maneuvers such as holding breath underwater and is highly reliant on participant performance [192]. Although hydrostatic weighing is done in the obese, the test may also cause discomfort and apprehension for some individuals [161] due to physical and technical constraints. Given the many disadvantages of this method hydrodensitometry, is not a widely recommended method for measuring body composition in obese participants.

5.10. Air Displacement Plethysmography (ADP)

ADP measures body volume by measuring air displacement. The machine used is a dual-chamber unit with a testing chamber for the participant to sit in and a reference chamber which holds the breathing circuit, electronics, and pressure transducers [181,204,205]. The tool is highly sensitive to changes in body volume, is valuable for trending small changes in body composition, is quick to perform, has low participant burden [206], and is noninvasive [181]. The ADP method is validated in the obese, including the extremely obese patients with BMI over 40 [161,206,207]. Obese participants are able to easily learn and perform the correct breathing techniques needed for accurate measurement [206]. For measurement, participants must wear minimal, tight fitting clothing (ideally a swimming suit) and a swimming cap to compact the participants' hair [192]. The clothing requirement for the ADP may limit its use in the moderate to severely obese and in certain ethnic groups. However, its ease and speed make ADP a favorable option for measuring body composition in the obese.

5.11. Dual Energy X-ray Absorptiometry (DEXA)

DEXA is a scanning technique that measures bone mineral, fat tissue, and fat-free soft tissue. Participants must lie completely still on the DEXA machine platform while X-rays at a high and low energy levels are passed over the body [201,208]. DEXA can be used to determine abdominal obesity [209] and is useful in predicting intraabdominal fat in obese men and women [210]. DEXA also provides assessment of regional body composition in allowing for the identification of gynoid or android obesity [211]. Limitations of DEXA include its high cost, need for trained technicians, and dedicated facilities [212]. In obese participants, the DEXA scan is sensitive to difference in body thickness resulting in an overestimation of body fat [201]. As the tissue gets thicker, especially over 20 cm, there is an increased degree of beam hardening, which involves the preferential attenuation of the lower energy X-rays [208]. The instrument itself may also limit its use for measuring body composition of obese individuals, Traditional DEXA scan tables can only hold up to 300 lb and the width of the scanning area, average of 60 cm, does not accommodate the obese or severely obese [160,161,213]. It has been demonstrated that an accurate whole-body composition assessment can be predicted from a half-body scan for participants who are too large to fit on the traditional DEXA scan table [214]. A recently developed iDXA half body analysis, that is able to hold up to 400 lb with an increased scanning width of 66 cm, and scanning height of 46 cm, has been shown to provide body composition analysis for fat-mass, non-bone lean mass, and percent fat that is comparable to whole-body analysis [213].

5.12. Computerized Tomography (CT) scan

CT scan uses an X-ray beam to produce cross sectional images of the body, allowing differentiation between measured muscle mass, visceral organ volumes [176], and measures of visceral adipose tissue in overweight and obese patients [160,195]. CT scans at the whole body level involve high radiation exposure [160]. Single cross sectional images taken at specific abdominal locations can be used to assess total body adiposity, visceral adipose tissue as well as skeletal muscle mass in healthy adults and are a more cost effective option and reduce radiation exposure [222,223]. However, when compared to multi-slice imaging, the reference method [210], the single slice method is not as accurate in detecting small changes in abdominal adiposity [224], because fat loss in the abdominal region is not uniform and should not be used to assess total abdominal fat loss [223]. It is also important to note that, single abdominal slice images provide good estimates of total body adiposity, visceral adiposity and skeletal muscle in group studies [224,225], but have limited applicability at the individual level due to individual variation [210]. A computer aided non-contrast CT can detect pericardial fat and thoracic fat, a risk factor for atherosclerosis [226]. CT can also be used to quantify fat content in skeletal muscle, but in the obese this can be more difficult due to higher levels of adipose tissue surrounding muscle [227]. Although CT and magnetic resonance imaging (MRI) are currently the best methods for analyzing regional adiposity these machines are expensive [195] and are usually limited to the hospital setting [176]. The high risk, combined with high cost, make the CT scan an unattractive option for routine clinical use for assessing body composition [169] in all participant populations.

5.13. Magnetic Resonance Imaging (MRI)

MRI is a technique of generating images from interactions between the nuclei of hydrogen atoms in the body and magnetic fields generated by the MRI machine. Protons from the various tissues in the body resonate differently. The MRI recognizes these differences, generating an image of the tissues. The generated image can be used to measure body composition [176] and to examine regional fat distribution. MRIs can accurately differentiate between fat and muscle in all populations [228], measure intramyocellular lipids in skeletal muscle [215], and quantify total body lipid [176]. MRI and MRS (magnetic resonance spectroscopy) are used clinically for detection and quantification of hepatic fat, [215,216], helping to diagnose fatty liver disease [217] and type 2 diabetes [218]. More recent studies have found that single slice images at a predetermined area of the abdomen allow for a fast and reliable estimation of visceral and total adipose tissue [219]. This is particularly important in the context of assessing risk factors for diabetes. However, while single slices may be useful for cross sectional estimation of volumes of relevant fat tissue compartments it is important to note that single slice imaging may not be sensitive or accurate in detecting small changes in abdominal adiposity [223]. Additionally, visceral adipose tissue is composed of subcompartments that are largely different both in metabolic and functional properties and the traditional CT and MRI protocols are not capable of separating all of the compartments, specifically intraperitoneal from intraabdominal [220]. While technical advances are clearly needed in this area the interpretations of current scans should come with a clear definition of the type of viceral adipose tissue.

There are no known long-term side effects from MRIs so they can be used for large coverage and repeated tests [221]. Use in the obese was previously limited by the size of the MRI machines, which were not able to accommodate large body sizes [160]. The developments of open-configuration MRI scanners have helped resolve this problem [161]. MRI is a good option for assessing body composition in the obese.

5.14. Near-Infrared Interactance (NII)

NII measures body fat by assessing the absorption of infrared light. The amount of absorption and reflection of the infrared light is related to the composition of the underlying tissue [186]. A signal penetrates underlying body tissue up to 1 cm, usually on the bicep and total body fat can be calculated by a prediction equation [201]. Error from using only one site on the body to measure body fat is likely [201]. The prediction equations used for this method have been found to underestimate body fat with increasing adiposity [201] leading to an underestimation of %BF in the obese [186]. This underestimation may be a result of the NII beam being affected by the irregularities in the fat–muscle junction and fat layering with increased adiposity [186]. NII has not been validated in the obese.

5.15. Three-Dimensional Photonic Scanning (3DPS)

In 3DPS a scanner captures body surface topography [229] measuring surface geometry using digital techniques [230]. The different 3DPS techniques that have been successfully developed for assessing body composition include photogrammetric technique, laser technique, and stereovision technique [229,231,232]. A scanner generates millions of points over a scan field, and then software connects the dots creating a 3-D body image including values on total and regional body volumes [231]. Measurements of waist and hip circumference, sagittal abdominal diameter, segmental volumes, and body surface area [232] are generated in seconds [231]. %BF can be calculated using a prediction equation [231]. 3DPS accurately measures body shape, including in the obese [229,231], and is attractive for use because it is safe to use frequently, requires no special conditions, and does not require intensive technical support [229]. Participants must wear tight fitting clothes and stand still for 10 s [231]. Monitoring the body shape measurements of obese individuals over time can help track patients weight gain or loss overtime, and the photonic scanner is able to display within person change over time [229]. 3DPS is a good option to use for both clinical and research assessment of body composition [229], with practical use in public health as well [232].

5.16. Quantitative Magnetic Resonance (QMR)

QMR is an emerging method for body composition assessment. The tool measures differences in nuclear magnetic resonance properties of hydrogen atoms to divide signals originating from fat, lean tissue, and free water [233]. The test, originally developed and tested on mice [234], has recently been adapted and scaled for human use. QMR is able to detect small changes in fat mass superior to DEXA and four-compartment models [233,235] but when quantifying total fat mass, there is some discrepancy when compared to the four-compartment model [233]. The method it is quick (less than 3 min) [233] and has been shown to have promise for body composition assessment in the obese.

5.17. Multi-compartment methods

Multi-compartment models account for the fact that the human body is composed of different compartments including fat mass and fat free mass (water, muscle, protein, bone, minerals). Combinations of two, three, four, or more of the previously discussed methods to measure body composition are often used in a multi-compartment model. They are considered the reference for body composition, and therefore must avoid major assumptions and have maximal precision [236]. Many single body composition assessments are based on assumptions, like the assumption of standard hydration or FFM density and the assumption of constant hydration in fat-free soft tissues in DEXA [236]. The most basic two-compartment (2-C) methods are based on major assumptions like the water or potassium constancy in FFM [236]. A three-compartment model allows for improvement over a two-compartment model, because it does not rely on these assumptions of standard hydration or FFM density [237]. Three-compartment models may combine ADP, BIA and TBW and has been developed in moderate to severely obese [161]. Four-compartment methods include measurements of fat, water, mineral, and protein, for example combining the measurements from ADP, deuterium oxide (TBW), and DEXA (bone mineral mass) [238]. Multi-compartment models are useful for measuring body fat in the obese. However, multi-compartment methods rely on the accuracy of the different measurements that are combined and an error in one of the measurements will result in an inaccurate body composition assessment.

5.18. Conclusion

This review of the different tools shows that there are several options for assessing body composition in the obese. Many of the tools and methods reviewed have their limitations and should be used with caution. Emerging methods have more promise for accurate assessment and need to be validated for use in the obese. When choosing a method for assessing body composition, researchers or clinicians should consider what resources they have available, their budget, and the goals of their assessment. With the increasingly large number of obese people in the world, body composition assessment will continue to be important in both in identifying the most effective treatments of obesity and in the evaluation of patients’ health.

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Table 1

Dietary intake measurement tools for use in the overweight and obese population.

Method and examples	Studied in obese	Advantages	Limitations	Recommendations
Classic tools				
I. 24-hour recall Interviewer administered recall of exact food intake during the previous day	Yes [99–101]	• Appropriate for low-literacy populations [98] • Low participant time burden [98] • Relatively inexpensive [98]	• *Underreporting of energy intake associated with higher BMI* [102] • *Significant misreporting by obese in ethnic populations* [99] • Requires trained staff or interview and data analysis [98]	• May be conducted in person or over telephone [103] • Unannounced recall reduces potential for altered consumption patterns • *Additional financial incentive for accurate reporting does not improve intake among obese* [101] • Portion size estimation aids may help reduce misreporting
24-h multi-pass method 4–5 stage recall using probe questions and portion size estimation aids	Yes [102,104–107]	• *Validated measure of group intake among overweight and obese men and women in controlled environment* [105,107] • *Recommended for estimating energy intake during treatment and follow-up in the obese* [108]	• *Accurate record of mean energy intake within general population, but unable to detect additional energy requirements related to obesity* [102] • *Significantly lower correlations with true energy and protein intakes in the obese than non-obese* [102]	• First recall associated with highest misreporting [109] • 3 days of recall including Sunday optimal [109] • *8 days of recall, including Sunday, recommended for small cohort of obese participants to minimize random error* [106] • *Combination with food frequency questionnaire (FFQ) may improve bias with respect to obesity* [102] • *Energy adjustment procedures may improve ranking of obese individuals for protein intake* [102]
II. Food record Participant recorded multi-day record of exact food intake.	Yes [110,111]	• Accounts for daily intake variation if > 1 day • Weight changes during recording period may identify misreporting	• *Under-reporting of energy intake associated with higher BMI independent of recording time length* [110] • Not appropriate in low-literacy populations [98] • Participant may change normal food intake due to social bias or convenience [98] • Potential error in quantifying portion sizes [98]	• One day record per participant appropriate for determining average intake of group, if all days of week equally represented [98] • *Motivational training and confrontation with prior underreporting resulted in reduced underreporting rates in a population of overweight and obese women, though one-third of the participants continued to underreport* [111]

Method and examples	Studied in obese	Advantages	Limitations	Recommendations
			• Data quality declines with recording time • High staff burden for data entry	
Weighed food record All food and food waste weighed and recorded	Yes [112]	• Greatest precision estimating usual intake of individuals [98]. • Reduced portion size estimation error • Weighed records correspond most closely to biomarkers in normal weight participants [113]	• *Significant underreporting observed among overweight individuals* [97] • Not appropriate in low-literacy populations [98] • Participant may change normal food intake due to social bias or convenience [98] • Limited use in large cohort studies due to high participant burden and access to weighing scales by all participants [113]	• *Observer weighed records with 24-h snack recall valid measure among obese participants in institutional setting* [112]
III. Food Frequency Questionnaires (FFQ) Interviewer or participant administered; frequency of categorized food intake over specified time period. Portion-size data can be converted to estimate energy and nutrient intake		• Most practical and economical method in large epidemiologic studies [114] • Appropriate for low-literacy populations if interviewer administered • Valuable for ranking individuals by usual nutrient intake [98]	• Must be cultural specific • Validity for estimating long-term intake not established [98]	• *Statistical correction methods based on energy expenditure and body weight can reduce measurement error* [115] • *Using a picture-sort method to administer FFQ may reduce underreporting in low-literacy obese participants* [116] • Reviewing questionnaire with participant may increase validity, but cost-efficiency must be strongly considered [117]
III. Food Frequency Questionnaires (FFQ)		• Low staff burden for data entry with electronic scan [98] • Lower participant burden than other classic methods [98]		• Block questionnaire, Willett questionnaire, and Diet History Questionnaire comparable when adjusted for total energy intake [114]
Block 2005 FFQ	No	• Food lists may be tailored to target certain nutrients or foods, or groups of people by region, gender, age, ethnicity, or language [118]	• Used in overweight and obese populations, but no studies reporting impact of weight status	• 30–40 min completion time [118]
110-items with pictures for portion size estimation. Available in				• Brief Block Questionnaire (70 questions) appropriate for ranking individuals by energy and nutrient intake [118]

Method and examples	Studied in obese	Advantages	Limitations	Recommendations
paper-based electronic scan or web-based formats				• Short *Block Screeners (7–50 questions) for fat, sugar, fiber and fruit/vegetable intake may be useful for clinician assessment of dietary habits associated with weight loss, but are not validated in the obese* [108]
Willett FFQ 126 items; questions ask consumption frequency of given portion size. Available in paper-based electronic scan	No	• Provides option for open-ended additions to food list	• Used in overweight and obese populations, but no studies reporting impact of weight status • Weakest in assessing absolute intake compared to Block and DHQ in general population [114]	• Adjusting for total energy intake improves correlation with multiple 24-hour recalls [119]
Diet History Questionnaire (DHQ) 124-items with portion size and dietary supplement questions. Available in paper-based electronic scan or web-based formats	Yes [102]	• Most valid assessment of energy and nutrient intake compared to Block and Willett questionnaires in diverse weight status population [114]	• Weaker correlations between energy expenditure and reported energy intake in obese than nonobese groups [102] • Does not adequately measure energy or protein intake in obese groups [102]	• Detected significant portion of extra energy requirements in obese women, but not in obese men [102] • 60 min completion time [120]
IV. Direct Visual Estimation Food selections and plate waste estimated by trained observers in comparison to weighed reference portions	No	• Validated method for measuring food intake [121] • Low participant burden	• Requires highly trained staff • Vulnerable to participant altering eating habits • Results limited to observed meals; unknown prediction of 24-hour food intake or usual food intake [121]	• Most effective in cafeteria or institutional settings [121]
Digital Photography Food selections and plate waste recorded with digital video camera. Computer images viewed by trained observers and compared to weighed reference portions.	No	• Validated method highly correlated with weighed foods [121] • Portion size evaluation less hurried and may be validated by a second observer [121] • Low participant burden • May be less vulnerable to social desirability bias than direct visual estimation	• Requires highly trained staff • Quality of data dependent on picture quality • Results limited to meals of observation	• Best suited for cafeteria or institutional settings [121]
Information and communication technologies				

Method and examples	Studied in obese	Advantages	Limitations	Recommendations
V. Computer-based assessments		• May enhance communication through pictures [122] • Standardized question sequence [122] • Provides immediate feedback [122] • Automatic analyses decreases staff burden [122] • Self-administered formats decrease participant burden	• May limit population by requiring computer literacy and access to internet	• *Overweight respondents may prefer completing assessment in own home, social desirability bias related to food and/or the interviewer may be decreased due to limited face-to-face contact* [123]
USDA Automated Multi-Pass Method (AMPM) Computer-assisted, interview-administered multi-pass 24-hour recall	Yes [105,107,124]	• *Assessed mean energy intake within 10% of mean actual intake among overweight and obese women* [105] • *Accurately assessed energy, protein, carbohydrate, and fat intake in a population of men regardless of BMI* [107]	• *Inconsistent results among overweight and obese* [105,107,124] • Requires large samples for accuracy [124] • Normal weight and overweight women significantly overestimated energy, protein, and carbohydrate intakes [105]	
DietAdvice Participants self-report dietary intake on website.	Yes [125]	• Among participants with metabolic syndrome, no relationships were found between age, gender or BMI and accuracy of reporting [125] • Computerized dietary assessment may encourage patients to report with less bias than in a verbal dietary assessment when compared with the literature [125]	• Among participants with metabolic syndrome, 32% under-reported energy intake compared to predicted basal metabolic rate; 22% over-reported intake [125] • Participants were classified as mis-reporters based on predicted basal metabolic rate [125]	
Uses Australian food list.			• No validation studies with comparison to other methods available.	
MyPyramid tracker USDA web-based diet and physical activity record with targeted nutrition education	No	• Respondent completes on own time • Provides reports on intake compared to 2005 Dietary Guidelines	• *Recommends food intake patterns based on estimated energy requirements of healthyweight individuals* [127]; *therefore may not be appropriate for the obese* • One validation study in group of university students compared to a 1-day diet record [128]	• Recommended that readability, navigation, and cultural tailoring be improved [129]

Method and examples	Studied in obese	Advantages	Limitations	Recommendations
		• Provides targeted nutrition education and immediate feedback [126]	• Researcher must manually aggregate data if used for group • Available in Spanish, but with little cultural Tailoring [129]	
NutritionQuest See Block FFQ; online or offline format for self- or interviewer-administration	No			
Web-Pictorial Diet History Questionnaire See DHQ; includes pictures for portion size estimation	No			• Comparable repeatability and validity to the paper-DHQ, but did not improve the relationship of the DHQ to other food intake measures [130]
VioScreen/FFQ	No	• Web-based version of the Women's Health Initiative (WHI) FFQ, which produces nutrient estimates similar to those obtained from 4-day diet records, 24-hour recalls, and other FFQs [131]	• WHI FFQ used in overweight and obese populations, but no studies reporting impact of weight status	• See 'Graphical Food Frequency System' in Emerging Technologies section
Self-administered web-based 131-item FFQ with pictures for portion-size estimation		• Customizable system adapts for regional/ethnic food patterns, languages, font sizes, and target nutrients [132] • Provides optional behavioral feedback to participant [132]	• No usability or validation studies reported for web-based version.	
Food Recall Checklist (FoRC) 121-item self-administered web-based food checklist with pictures for estimating portion size	No	• Quicker and more cost-effective to implement and analyze than food record • 7.4 min mean daily recording time [133] • Potential as useful alternative for assessing group mean intakes [133]	• Recently developed tool studied in small university population [133] • Not recommended for assessing individual intake [133] • Median energy and alcohol intakes significantly lower; median fruit, vegetable, and breakfast cereal intake significantly higher compared to food record [133]	
VI. Personal Digital Assistants (PDA)	Yes [134]	• Provides data comparable to 24-h recall and to an observed, weighed meal [134]	• Does not appear to produce more valid data than paper-based approaches [135]	• Half of error in caloric estimation attributable to portion size estimation [134]

Method and examples	Studied in obese	Advantages	Limitations	Recommendations
DietMatePro		• Meal records can be saved to facilitate entry of similar foods [134]	• Primary sources of error similar to classic food record methods: subjects must select the appropriate foods, record all foods consumed, and accurately estimate portion sizes accurately [134]	• Average 8.5 min recording time per meal [134]
Participants record all food intake in program on PDA with automatic analysis		• Can remind users to record meals [134] • Real-time feedback to participant and to researcher [134]	• *Suggested validity for monitoring food intake in weight management and obesity studies* [134]	
Wellnavi PDA, camera, and mobile phone card. Participants photograph before and after meal, send photo to research staff for analysis	Yes [136]	• Low participant burden [137] • *No greater rate of underreporting by obese women compared to nonobese women* [136]	• Estimated significantly lower nutrient intake than weighed diet record, except for a few nutrients [136] • *Significant underreporting by obese men compared to nonobese men* [136] • Requires highly trained staff for analysis of photographs to estimate daily nutrient intake [136]	• Low tool performance attributed to poor digital photo quality [136]
CalorieKing Participants record all food intake and physical activity in program on PDA or through website	Yes	• Provides automatic nutrient analysis, estimates target nutrient intakes, and charts progress over time [138] • CalorieKing Professional Dashboard allows compilation of group data [138]	• *Prevalence of underreporting in an overweight and obese population did not improve compared to other methods of dietary intake assessment* [139] • Requires membership fee	• Use in populations comfortable with PDA use may improve rates of underreporting[139]
Nutrition biomarkers				
VII. Doubly Labeled Water (DLW)	Yes [140]	• *Gold standard measurement of energy expenditure in free-living conditions, including overweight and obese* [140]	• Assumes participant or group is weight stable (energy expenditure= energy intake) [98]	• Consideration of the dose enrichment ratio or exclusion from study must be given for participants traveling considerable distance (>500miles) from study site during weeks prior to dose [98]
Measurement of total energy expenditure through oral dose of isotope labeled water		• Low participant burden [140]	• Requires sophisticated technology and highly trained staff [140] • Very expensive [140]	• Body composition are important associated measurements for determination of energy balance [98]

Method and examples	Studied in obese	Advantages	Limitations	Recommendations
VIII. Urinary nitrogen excretion Measurement of protein intake through 24-hour urine collection	Yes[141]	• Valid indicator of dietary protein intake in free-living populations; useful for identifying misreporting [141] • Tends to classify underreporters same as DLW [98]	• Assumes participant or group has stable muscle mass and weight [98,113] • Applies universal correction factor for nitrogen loss through skin and feces, but actual loss may have wide variability due to fiber intake and exercise [98] • Requires participant to collect urine during recording period	• Eight 24-hour complete urine collections needed to estimate individual protein intake within 5% [98] • Must confirm urinary collection is complete using external marker, such as tablets of para-aminobenzoic acid (PABA) [141]
Emerging technologies				
Automated self-administered 24 h dietary recall (ASA24)	No	• Available at no cost to researchers, clinicians and teachers [142]	• Vulnerable to participant altering eating patterns	• Currently available for use with limited analysis capabilities of individual foods and daily total nutrients. Future plans include analysis reports in Pyramid equivalents, supplement use, a Spanish version for respondents, and optional modules to assess supplement intake, salt intake, with whom each meal was eaten, television viewing while eating, and where food was obtained [142]
Internet-based multi-pass 24 h recall		• Respondent completes on own time or at time scheduled by researcher [142] • Uses validated photographs to estimate portion size [143] • Generates automatic analyses and reports of nutrient intake [142]	• Users must be very computerliterate and have high-speed internet access [142]	
Graphical Food Frequency System (GraFFS) Pictorial, touch-screen FFQ with automatic reporting and tailored behavioral intervention. See VioScreen/FFQ	No	• Customizable system adapts for regional/ethnic food patterns, languages, font sizes, and target nutrients [144] • Provides interactive behavioral feedback to participant [144]	• See Limitations of FFQ • Validation study in progress [144]	• Currently not available for use
Mobile Food Intake Visualization and Voice Recognizer (FIVR) Participant photographs before/after food intake	No	• Real-time translation to dietary intake data [145] • Immediate feedback to participant expected to reduce reporting error [145]	• Automatic calculation of food consumed requires three quality photographic images [145]; quality of data dependent on photograph quality	• Currently not available for use

Method and examples	Studied in obese	Advantages	Limitations	Recommendations
with mobile phone and records intake with voice recognition software		• May be appropriate for low-literacy populations with adequate photography training	• Vulnerable to participant altering eating patterns • Requires staff to resolve discrepancies with automatic translation [145]	
Mobile Phone Food Record (mpFR) Digital photography and image analysis software	No	• Automatically translates cell phone images into dietary intake data [146] • Participants age 11 −18 agreed software was easy to use [146]	• Quality of data dependent on photograph quality • Vulnerable to participant altering eating patterns	• More than one instruction in use may improve accuracy [146] • Currently not available for use
Wearable Device for Dietary Assessment Wearable video camera, earphone, microphone, accelerometer, global positioning system, skin-surface electrodes, and flash drive takes continuous data collection	No	• Low participant burden with less intrusive data collection • Allows collection of supportive and complementary data including eating location, cooking techniques, and physical activity [147] • May be less vulnerable to participant altering eating patterns • Includes privacy protection mechanisms [147]	• Quality of data dependent on identification of eating episode and quality of image [147] • High staff burden for food identification and analysis [147]	• Data analysis software in development; currently not available for use [147]
Vicon Revue	No	• Low participant burden with less intrusive data collection	• Not studied as a dietary assessment tool	• Originally designed as a memory aid tool and most widely studied in participants with cognitive impairments [148]
Wearable digital camera, temperature sensor, motion detector, accelerometer, compass, and flash drive takes continuous digital photographs		• Allows collection of supportive and complementary data: eating location, cooking techniques, and physical activity • May be less vulnerable to participant altering eat patterns		

Italicized items highlight the impact of weight status on tool performance.