Dietary Intake Assessment: From Traditional Paper-Pencil Questionnaires to Technology-Based Tools

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Abstract. Self-reported methods of recall and real-time recording are the most commonly used approaches to assess dietary intake, both in research as well as the health-care setting. The traditional versions of these methods are limited by various methodological factors and burdensome for interviewees and researchers. Technology-based dietary assessment tools have the potential to improve the accuracy of the data and reduce interviewee and researcher burden. Consequently, various research groups around the globe started to explore the use of technology-based tools. This paper provides an overview of the: (1) most-commonly used and generally accepted methods to assess dietary intake; (2) errors encountered using these methods; and (3) web-based and app-based tools (i.e., Compl-eat™, Traqq, Dutch FFQ-TOOL™, and "Eetscore") that have been developed by researchers of the Division of Human Nutrition and Health of Wageningen University during the past years.

Keywords: Technology-based dietary intake assessment · App · Sensors · Biomarkers · FFQ · Recall · Food record · Dietary history

1 Assessing Dietary Intake: Why?

Scurvy was a major cause of disability and mortality among long-distance sailors for decades [1]. In 1497, the Portuguese explorer Vasco da Gama lead an expedition to India and reported that crew members with scurvy recovered days after eating fresh oranges. Yet, another 150 years passed before scurvy was finally acknowledged as being caused by malnutrition [1].

Fortunately, our understanding of how diet influences the human body evolved more rapidly during the past decades, and nutrient-related diseases considerably decreased. Accurate dietary assessment played an important role in these developments by generating quantitative information on the intake of foods, energy, and/or nutrients. The demand for quantitative information on dietary intake is still high, now more and more focusing on the exploration of diet-related determinants of today's challenges

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such as obesity and (age-related) non-communicable diseases (NCD) [2, 3]. More specifically, around 39%, 40%, 39% and 9% of the population is faced with one or more cardiometabolic risk factors, e.g., overweight [4], hypertension [5], hypercholesterolemia [6], and/or hyperglycaemia, respectively [7].

Consequently, many studies nowadays focus on the identification of modifiable dietary factors affecting the development of obesity and NCD risk. Nutritional epidemiologists for instance focus on potential associations between dairy consumption and body weight development or diabetes risk using data of large observational cohort studies [8, 9]. Dietary intake is estimated and included in the model as the exposure factor and various health parameters (e.g., body weight, waist circumference, fasting blood glucose and insulin and/or self-reported disease prevalence) are assessed and included in de model as the outcome. In addition, potentially relevant information is obtained on a large range of characteristics related to demographics, lifestyle, medical (family) history, etc. Subsequently, statistical modelling results in e.g., βs showing whether or not an increase in dairy intake is associated with an increase or decrease in body weight, or risk estimate indicating whether or not diabetes risk is associated with a certain dairy intake level (e.g., 2 glasses of milk per day) relative to a reference level (e.g., no milk consumption). Dietary intake assessment is also an important component of dietary intervention studies. By modifying the consumption of a nutrient, food or diet in a controlled way and monitoring the potential impact on a selected health parameter, intervention studies are key to provide more certainty on whether or not there is actual causality between a nutrient, product or dietary pattern and a certain health outcome [10]. Dietary assessment is also performed by various national organisations in order to monitor the intake of foods and nutrients of the general population, which serves the formulation and evaluation of food policy [11]. Finally, a very important non-research related application of dietary assessment is the health-care setting where it is used to prevent or treat diseases caused by malnutrition or disease-related malnutrition. Dietary assessment allows the health-care professional to diagnose and provide feedback on the nutritional status of the patient and to educate the patient to improve dietary habits.

2 Assessing Dietary Intake: How?

Currently, self-report methods are the most commonly used dietary assessment methods, which can be roughly divided in methods of recall and methods of real-time recording.

2.1 Methods of Recall

In research, 24-hour recalls and food frequency questionnaires (FFQ) are the most commonly used methods of recall. In the health-care setting, the dietary history method is the most commonly-used approach.

24-hour Recall

The 24-hour recall is an open-ended method to generate detailed information on all foods and drinks consumed during the previous 24 h (i.e., actual intake), usually starting with breakfast on the previous day. On the individual level, data of 2–3 24-hour recalls can be used to gain insight in the habitual intake of commonly consumed foods; ≥ 3 days are needed to capture the day-to-day variation of a variety of nutrients and foods that are episodically consumed such as vitamin A, vitamin C, cholesterol, and fish [12]. The required observation period for interviewees with a stable food pattern is usually shorter than the required observation period for interviewees with a varied food pattern due to less day-to-day variation. At our department, 24 h-recalls are often carried-out by trained dietitians, either face-to-face or by telephone. In general, the interview can be completed in approximately 30 min, whereas food coding by the dietitian requires another 30–60 min. Our dietitians perform the 24-hour recall according the multiple-pass method [13, 14]. Due to the workload related to this method it is expensive to use face-to-face or phone-based 24-hour recalls in research, which limits its use to small-scale studies. Fortunately, recent technological innovations lead to the development of various self-administered web-based 24-hour recalls all over de world. Obviously, it is of key importance that these new tools are just as accurate as the dietitian-guided recalls. So far, validation studies of web-based recalls show promising results, but also clues for further improvements [15–22].

Dietary History Method

The dietary history method is the most commonly used method in the clinic, but less often used in the research setting. Similar to the 24-hour recall, the dietary history is an open-ended method to generate detailed information (i.e., type and amount) of all foods and drinks consumed, and is usually performed by a dietitian. The difference between the two methods is the addressed time-window. Where the 24-hour recall focusses on the previous day, the dietary history aims to assess a typical weekly or monthly pattern. Therefore, a 24-hour recall or food record can be a first step of a dietary history, but additional information on foods, drinks, and meals consumed on other days is warranted to obtain insight in the habitual intake. Information on habitual intake can be obtained by requesting for alternatives for the foods reported during the 24-hour recall; this process may be supported by addressing time and location of food consumption, differences between week days and weekends, cooking methods, etc. Clearly, the dietary history is a comprehensive and time-consuming method and may require up to 30–90 min to complete depending on the aim of the interview [23]; the use of photographs, food models or food packages may aid the procedure. Perceptibly, interviewees with irregular eating patterns are a challenge [24].

Food Frequency Questionnaire

A Food Frequency Questionnaire (FFQ) is a fixed-food list - with or without portion size descriptions - inquiring for the consumption frequency of foods and beverages over the past month, past three months, or year (i.e., habitual intake). FFQs can be interviewer-based and self-administered. In general, an extensive FFQ that addresses macronutrients and the majority of the micronutrients can be completed in approximately 45 min. FFQs are primarily designed to rank interviewees according to their intakes and not to estimate absolute intakes. Nevertheless, in case of nutrients or foods with a large day-to-day variability (e.g., fish and alcohol), an FFQ may be more accurate than other methods also in terms of absolute intakes. Important benefits of an FFQ are that the administration and processing is very efficient. We can easily process several thousand FFQs at once and the output is relatively easy to convert to computer ready-data, making the FFQ a very practical method for use in large-scale studies. However, in contrast to a recall, dietary history or food record, the use of validated FFQs requires intensive preparation before it can be send to the interviewees. The first step involves the identification of food items that are contributing most to the relevant energy and nutrient intakes in the target population, which obviously depends on the research questions to be addressed. To identify these food items, researchers in the Netherlands currently use the results of the Dutch National Food Consumption Survey (DNFCS) [25] - collected through two 24-h recalls - and generally aim to cover at least 80% of the absolute intake level and between-person variability of each nutrient under study [26]. Thus, each FFQ is tailored depending on the research question(s) and the population of interest. It should be emphasized that this process requires the availability of detailed food consumption data for the population under study, which are not (yet) available for many low-and middle income countries [11]. The second step involves the validation of the FFQ, which is ideally performed using validated recovery markers/techniques such as urinary nitrogen (for protein), potassium, sodium, and doubly labelled water, which are able to estimate absolute nutrient intakes [27]. Blood carotenoids and *n*-3 fatty acids can be used to assess the relative validity (i.e. ranking) for the intake of fruit/vegetables and fish intake (concentration markers), respectively [28–30]. However, no other markers are available yet [31]. Although the duplicate portion technique could serve as an alternative method for the use of validated biomarkers [32], validation studies are often conducted using other self-reported dietary assessment methods (sharing correlated errors) as the reference method (e.g. 24 h-recalls, food records) [33]. Besides this validation step, FFQs also require continuous updating due to new research questions and continuously changing availability of products. Thus, all in all, the development and maintenance of FFQs is a skilled task, time-consuming, and expensive. Fortunately, also this research area substantially developed in terms of automatization during the past years [34–38].

2.2 Methods of Real-Time Monitoring

Food Record

Food records are open-ended and generate detailed information (i.e., amount and type) on all foods and drinks consumed during the recording period. Similar to the 24-hour recall, a one day food record provides information on actual food and nutrient intake; 2–3 day food records provide information on the habitual intake of commonly consumed foods on the individual level. More days are needed to cover the nutrients and foods that are less commonly consumed [12]. The completion time of a one-day food record is approximately 30 min distributed over the day. In theory, multiple (i.e., 7 day) *weighed* food records are the most accurate self-reported dietary assessment method;

the so-called "gold standard" [39]. In case of weighed food records, the interviewee is instructed to weigh all foods and drinks consumed, ideally using scales with an accuracy up to 1 g. Following a demonstration on the weighing and reporting of consumed foods (i.e., food type such as white bread vs. whole-wheat bread, food brands, recipe details) the interviewee receives a simple notebook. A disadvantage of dietary records is that they are prone to reactivity bias, very intrusive for interviewees and also time-consuming and labour-intensive for dietitians due to the food coding. Weighed food records can be very useful in dietary studies, but weighed food records are not feasible for use in large-scale studies. The *non-weighed* food record largely follows the same procedure, but is less intrusive as food quantity is estimated, using e.g., standard portion-sizes and household measures. Obviously, this procedure requires more from the dietitian in terms of the interpretation of the portion size estimates and is thus less precise compared to the weighed food record. Fortunately, also for the food record, technological inventions have led to promising innovations, including the use of mobile devices. Whereas the more basic apps still collect dietary intake data through descriptive text [40], other apps are also exploring the potential of before and after photography, which provides additional information on consumed portion sizes and potentially undocumented foods [41].

Duplicate Portions

Similar to the 24-hour recall and food record, the duplicate portion method is open-ended and provides information on actual intake in case of a 24-hour collection period; ≥ 3 days may provide information on the habitual intake of commonly consumed foods and nutrients on the individual level. Distinct from the other methods, the duplicate portion method involves the collection of a second identical portion of all foods and drinks consumed - whether in combination with a weighed food record or not - in a cool box. Cool boxes are collected the following day; foods are weighed, homogenised in a blender, freeze dried and chemically analysed for nutrient composition [32, 42]. Clearly this method is very intrusive, labour-intensive and expensive, and therefore it is not often used. However, the duplicate portion method may be valuable when local food composition data are lacking, food composition tables do not contain information on specific compounds, validating other self-report dietary assessment methods or biomarkers, or exploring determinants associated with misreporting of dietary intake.

2.3 Nutrient and Food Calculations

Except for the duplicate portion method, average daily nutrient intakes for the 24-hour recall, dietary history, FFQ and food record are usually calculated by multiplying the consumption frequency with portion sizes (in grams) and nutrient content as indicated in the Dutch food composition table [43]. Note that, depending on the design of the FFQ, a weighed estimate of multiple food codes may be assigned to an item due to the fixed nature of the questionnaire.

3 True vs. Measured Diet: Sources of Measurement Error

Studies exploring diet–disease associations often show mixed findings [44, 45]; varying from null associations, beneficial associations to adverse associations. Inconsistencies may relate to various factors, including study population (e.g., healthy vs. health-compromised population), variation in the exposure (e.g., population with high intakes of a certain food or nutrient vs. population with a low intake) or outcome (e.g., low vs. high prevalence of a certain disease) under study, the covariates considered (e.g. inadequate vs. satisfactory correction for covariates) or the applied statistical approach (e.g., may affect statistical power to detect potential associations). Methodological issues related to the assessment of the exposure (i.e., dietary factor) are also commonly discussed. Indeed, it is indisputable that above described methods have their limitations that introduce measurement error, which can be "intake-related" (reflecting the correlation between the error and true intake) or "person-specific" (errors related to the interviewee's personal characteristics) [46]. Besides, errors can be systematic/differential or random/non-differential [46]. To be more specific, a shared factor for all methods of recall (i.e., recall, dietary history and FFQ) is its sensitivity to memory-related bias. To illustrate, dietary estimates obtained by dietary history have been shown to overestimate the consumption of healthy foods and underestimate the consumption of snacks, drinks and alcoholic beverages (e.g., socially desirable responses). Moreover, although the dietary history aims to obtain information on the habitual diet, the estimated diet may be more likely to reflect the past 7 days rather than the diet over a longer period. Other shared sources of errors for these three methods as well as the *non-weighed* food record include the inaccurate estimation of portion sizes and errors in food composition tables. An additional source of measurement error for the FFQ is the large supply of available foods, which cannot be fully reflected in a fixed-food list. Additionally, reporting's obtained through food record as well as duplicate portion method may be influenced by the fact that interviewees are made aware of their habits while recording/collecting. To limit this source of error it is therefore important to emphasize that interviewees should not change their usual intake at the time of recording/collecting (reactivity bias). The duplicate portion method is least influenced by abovementioned sources of error: there is no memory-related bias, no bias due to errors in food consumption tables, and errors in portion sizes are also unlikely. Still, interviewees may forget to collect foods resulting in underestimated food intakes [32]. So in the end, dietary assessment will give you more or less an indication of what people eat, but it is very difficult to get a very precise estimate.

4 Assessing Dietary Intake: Which Method to Use?

The dietary assessment method to choose eventually depends on your research question and target population [47]. To select the most appropriate and cost effective method for a specific research question it is important to weigh the benefits and the weaknesses, e.g., available tools, resources and expertise, interviewee burden, researcher burden, costs, and validity and reproducibility. Considerations may relate to the range of foods or nutrients of interest, how the data will be analysed and presented (i.e., group vs. individual level and absolute intakes vs. relative intakes), and to the targeted time-frame (i.e., actual vs. habitual intake and recall vs. real-time recording). In terms of the target population important considerations may relate to the sample size, age of the interviewees (e.g., young children and older adults may experience difficulties when working with some of the tools), educational level/literacy, motivation, ethnicity, disabilities (e.g., vision or hearing problems), country, and available resources and expertise (e.g., internet access or not, availability of dietitians).

5 Innovations

It may be clear that each tool has it strengths and it weaknesses. Up to 15–20 years ago, above presented methods were completely paper-pencil based, which shifted more and more towards web-based and smartphone-based tools throughout the past decade. The current pace of technological development is very valuable to improve our methods, i.e., reduce sources of error, increase user-friendliness, and decrease workload of dietitians and/or researchers. Due to the absence of a dietitian/researcher, data obtained through web-based/smartphone-based tools are for instance expected to be less biased by social desirable answers. Web-based and smartphone-based tools are also assumed to be less burdensome for the interviewees as they can complete the dietary assessment at a time and location that is convenient for them.

5.1 Compl-eat™

New technological opportunities allowed us to develop a self-administered Dutch web-based dietary 24-hour recall tool, entitled Compl-eat™ [22]. Contrary to the traditional method, the web-based tool is not guided by a research dietitian. At 6.00 AM, the interviewee receives an invite to complete the recall through e-mail; the invite remains effective until midnight that same day. The tool is introduced by two short instruction videos explaining how to: (1) select food items from the food list (2 min 16 s) and (2) report details (type and amount) of the consumed foods (2 min 26 s). Portion sizes can be reported in commonly-used household measures, standard portion sizes or in grams/litres. Compl-eat™ does not contain images. Identical to the traditional 24 h-recall, interviewees are requested to report their dietary intake of the previous day, starting in the morning after waking up till the next morning. Moreover, comparable to the traditional 24 h-recall, the web-based tool is based on the multiple-pass method, ensuring proper guidance while reporting the consumed foods [13, 14]. Compl-eat™ contains an extensive food list based on the Dutch food composition table (NEVO) [43], including most commonly-used synonyms as well as previously entered foods and recipes. This food list is flexible and can be easily modified in order to be tailored to specific research questions or updated to include new food items. In theory, this food list can be replaced with non-Dutch food lists. Compl-eat™ also comprises a recipe module, which facilitates the reporting of a complete dish by selecting or modifying a standard recipe. Besides, the interviewee has the option to enter all ingredients of an original recipe in combination with the consumption amount of the meal. Yield and retention factors (i.e., retained weight and nutrients after cooking) are automatically taken into account. Interviewees also have the possibility to include notes to clarify their input. After each eating occasion, interviewees receive prompts to report on commonly omitted foods (i.e., sugar and/or milk in coffee/tea, oils and fats used in the preparation of dishes, snacks/candies and fruits). Generally, all web-based 24-hour recalls are checked by research dietitians for completeness, unusual portion sizes and notes entered by the interviewee. Identified errors and notes are processed according to a standardised protocol, using standard portion sizes and recipes. Interviewees are not contacted for clarifications. Examples of errors include the report of 125 cups of coffee instead of one cup of 125 g. Notes may relate to a food consumed, but could not be identified in the food list. The computation module of Compl-eat™ subsequently calculates food, food groups, and energy and nutrient intakes where different output formats can be selected. Interviewees require on average 40–45 min to complete the web-based recall (including login time, watching the instruction videos and entering the food items), which is 10–15 min more compared to the traditional recall method. However, the dietitians can process the recalls in 5-10 min, whereas approximately 90 min are needed to complete the interview and coding according to traditional method.

5.2 Traqq

Recently, the development of the app called "Traqq" was initiated. Traqq can serve as a recall and food record, and can be used to collect data on one or more pre-specified full days. Besides, Traqq can be programmed to send random notifications over a longer period of time. In case of the food record module, interviewees are able to enter consumed foods throughout the day. In case of the recall module, the interviewee receives a notification on the smartphone prompting to complete the recall. By ticking the notification/opening the app, the interviewee obtains access to an extensive food list based on the Dutch food composition Table (1463 items) with additional synonyms (1019 items) [43]. If desired, this food list can be adjusted to fit different research purposes. Following the selection of a food item, the interviewee is prompted to select a portion size. Portion sizes can be reported in household measures (e.g., cups, spoons, glasses), standard portion sizes (e.g., small, medium, large), and weight in grams. Traqq also contains a "My Dishes" option where the interviewee can select all ingredients of an original recipe in combination with the quantity of the meal consumed. Yield and retention factors (i.e., retained weight and nutrients after cooking) are automatically taken into account. The recall closes after submission of the entered foods; data are stored on a secured server. The validation study of Traqq is currently ongoing with the first results expected early 2020. Screenshots of Traqq are displayed in Fig. 1.

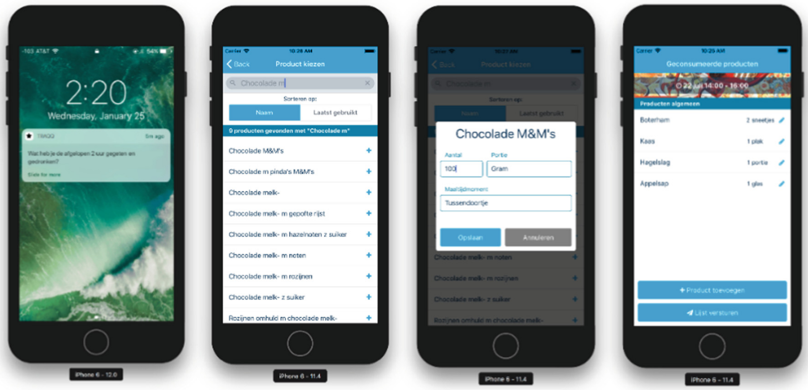

Fig. 1. Screenshots of Traqq.

5.3 The Dutch FFQ-TOOL™

The Dutch FFQ-TOOL™ is a data-driven web-based computer system developed to generate (Fig. 2) and process tailored FFQs (Fig. 3) - i.e., for nutrients of interest and population under study - by standardized, reproducible, relatively fast and flexible procedures [38]. The FFQ-tool has three main functionalities, i.e., 'selection of food items', 'question generation', and 'nutrient and food calculations'. The selection of food items is a semi-automated process. The FFQ-tool uses data from the DNFCS [25] to tailor the FFQ to the nutrients and population of interest, which is comparable to the procedure used to develop paper-based FFQs. Generally, researchers aim to cover about 80% of the absolute intake level and 80% of the between-person variability of each nutrient under study [48, 49]. The FFQ-tool indicates to which extent an item contributes to the total intake or the variation in intake for the nutrient(s) of interest for each aggregation level. Depending on the research question, the researcher subsequently selects the most suitable aggregation level and related food items. Thereafter, the selected food items are automatically translated to standard questions. Once the FFQ is completed, food, and energy and nutrient intake is computed through the computation module of the FFQ-TOOL™, which is facilitated by attached (Dutch) food composition tables.

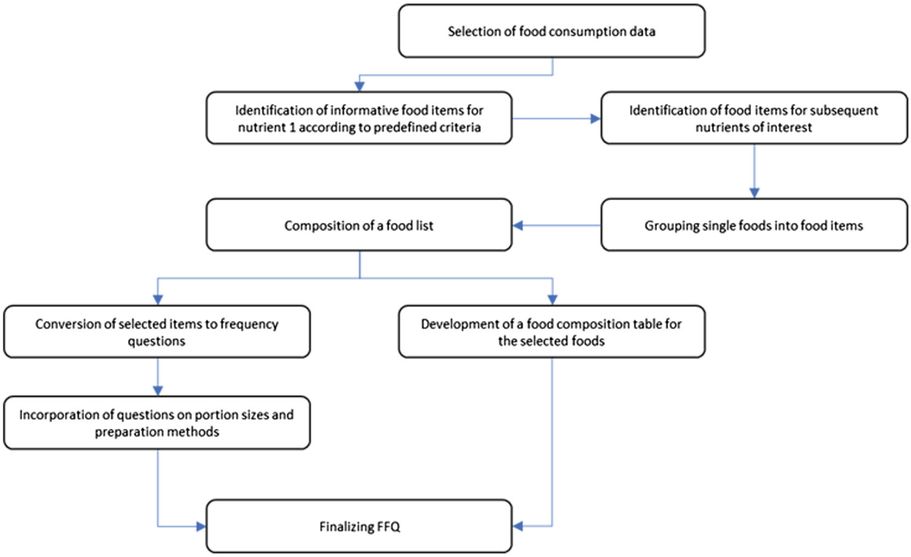

Fig. 2. Overview of the Dutch FFQ-TOOL^{TM} to develop and process FFQs. Figure adapted from PhD-thesis Marja Molag entitled "Towards Transparent Development of Food Frequency Questionnaires. Scientific basis of the Dutch FFQ-TOOL^{TM}: a computer system to generate, apply and process FFQs" [38].

5.4 Eetscore

The "Eetscore" is a self-administered web-based screener to assess habitual diet quality during the previous month. In contrast to above described methods and associated tools, the "Eetscore" is a relatively short FFQ specifically developed to fulfil the demand for a shorter and less burdensome questionnaire. It is not the primary aim to obtain quantitative food or nutrient intakes when administrating the "Eetscore". The "Eetscore" can be completed in approximately 10–15 min and therefore interviewee and researcher burden as well as the associated costs are relatively low. The "Eetscore" is also the only tool providing immediate personal dietary advice after submission of the questionnaire. However, if desired, the "Eetscore" can also be administered without the advice module. The "Eetscore" is based on the Dutch Health Diet-index (DHD-index). The DHD-index was developed in 2012 [50] by the Division of Human Nutrition and Health of the Wageningen University and based on the Dutch dietary guidelines of 2006 [51]. The first version of the Eetscore FFQ was developed in 2015 and called the Dutch Healthy Diet-FFQ (DHD-FFQ), reflecting the nine (nutrient-based) dietary components of the DHD-index [50]. In 2017, the DHD-index was adapted to the Dutch dietary guidelines 2015 [52] – which are food-based instead of nutrient-based - and called the Dutch Healthy Diet 2015-index (DHD15-index) [53]. The DHD15-index includes fifteen components, including vegetables, fruit, whole-grain products, legumes, nuts, dairy, fish, tea, fats and oils, coffee, red meat, processed meat, sweetened beverages and fruit juices, alcohol, and salt. For each component an

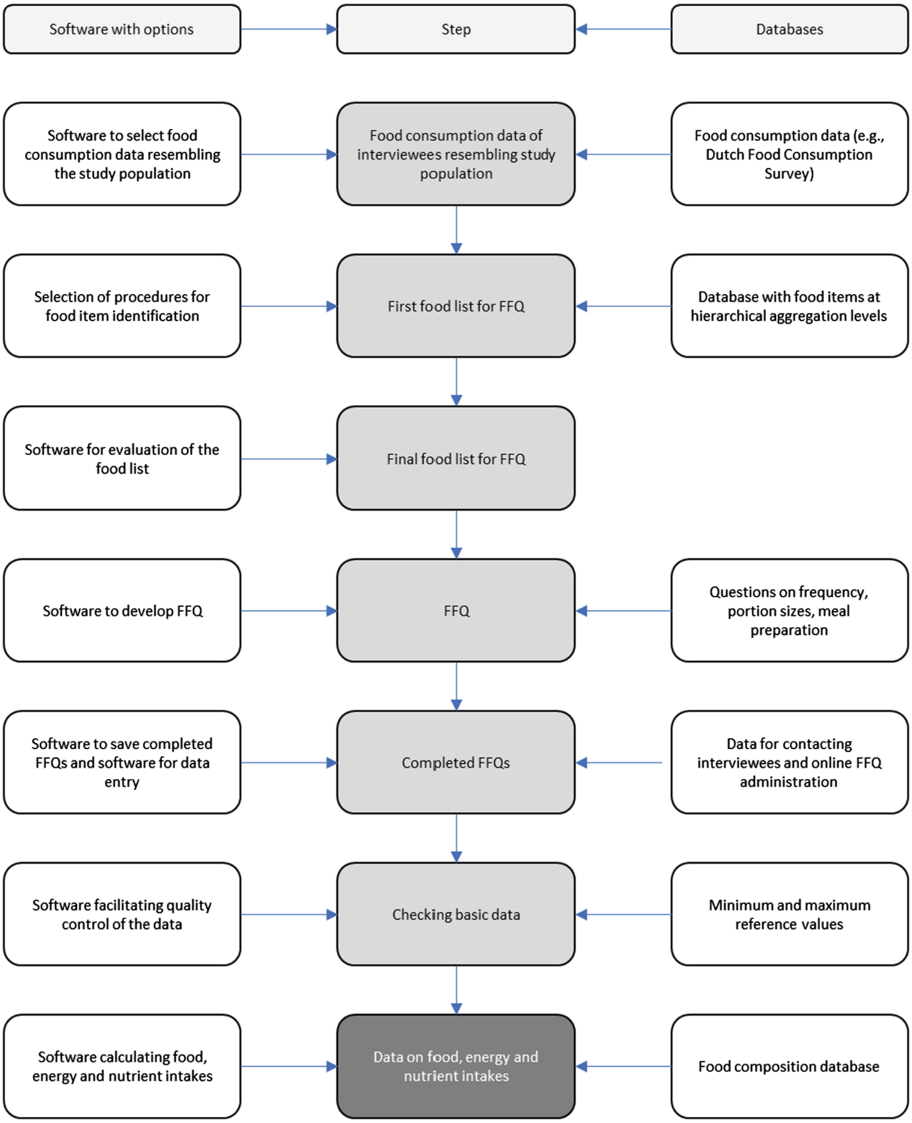

Fig. 3. Software and databases in the Dutch FFQ-TOOL™ to generate and process FFQs. Figure adapted from PhD-thesis Marja Molag entitled "Towards Transparent Development of Food Frequency Questionnaires. Scientific basis of the Dutch FFQ-TOOL™: a computer system to generate, apply and process FFQs" [38].

interviewee can score from 0 to 10; the total score of the DHD15-index ranges from 0 to 150. The scoring depends on the component type, which can be an adequacy component, moderation component, optimum component, qualitative component and ratio component. Adequacy components are foods which require an intake level above a certain cut-off level, including vegetables, fruit, wholegrain products, legumes, nuts, fish and tea. Moderation components are foods that need to be avoided, including red meat, processed meat, sweetened beverages and fruit juices, alcohol, and salt. Optimum components are foods that have been shown to reach an optimal level of intake that is considered most healthy (i.e., n-shaped), namely dairy. Qualitative components are foods of which the type matters, i.e., preferably filtered coffee and not unfiltered coffee. In case of ratio components, the scores depend on the replacement of less healthy products by more healthy alternatives, i.e., grain products and fats and oils. In addition to these 15 components of the DHD15-Index, the "Eetscore" comprises one additional component, i.e., the unhealthy choices component. The unhealthy choices component was added based on the guidelines of the Netherlands Nutrition Centre aiming to get insight in dietary intake beyond the Dutch dietary guidelines [54]. Similar to the other methods, the "Eetscore" is likely to be biased by memory-related error. At present, the "Eetscore" is considered adequate for use for interviewees with a Dutch food pattern aged 19 to 69 years. Besides, several patient-specific versions as well as versions suitable for individuals with a lower socio-economic-status and children are being developed, but these have not been tested yet.

5.5 Sensor-Based Wearable Dietary Assessment Methods

Sensor-based wearable dietary assessment tools are assumed to overcome many of the measurement error related to the self-report nature of the above described dietary assessment tools. In current literature, the detection of food intake using sensor-based technology has been most extensively described, primarily focussing on the detection of food intake via sounds of chewing and swallowing (acoustics) [55–58], wrist/arm motion (inertial) [59–61], skeletal muscle activity and skull vibrations (physiological) [62], and/or change in electric charge in response to chewing and swallowing (piezoelectric) [63]. Sensor-based food type classification appears to be more challenging than food intake identification and has been explored less extensively. Amft and colleagues tested the accuracy of sound-based recognition for apple, potato chips, and lettuce and showed a 94% average accuracy of food classification based on chewing sequences; the mean weight prediction error was lowest for apples (19.4%) and largest for lettuce (31%) (acoustic) [64]. The use of pictures and/or videos (visual) may seem a more straightforward approach in this field [65], but correct automatic identification of foods is also still a huge challenge due to the large variety of available foods, complexity of many prepared foods, and diverse conditions to capture the foods (e.g., lighting, position) [66]. In terms of portion size estimation, the use of camera's is developed somewhat more [66–68]. Still, current methods do not allow the use of sensors for detailed quantification of food, energy and nutrient intake for use in nutrition and health research yet. Therefore, in future studies we aim to contribute to this work by piloting various independent sensors to examine whether the combination of two or more sensors can provide a valuable addition to the currently used dietary assessment methods.

5.6 Biomarkers

Finally, even though not directly related to the technology-based work described above, work within the division of human nutrition and health also focusses on the identification of nutritional biomarkers as a complementary or alternative measure of dietary intake. Biological markers for dietary intake are considered more objective than the self-reported dietary intake methods, e.g., not affected by memory, social desirability and/or errors in food composition tables. As mentioned earlier, there are few well-validated nutritional biomarkers, but metabolomic techniques now provide a unique opportunity to measure up to thousands of metabolites at once providing valuable information on the food metabolome using a variety of body tissues [31, 69, 70].

6 Conclusion

The methods to assess diet substantially enhanced during the past decades, predominantly in terms of cost- and time-effectiveness, labour-intensiveness and interviewee and researcher burden. However, novel tools still share various methodological issues with the traditional self-report methods. New technology-based opportunities will help to further improve current tools (e.g., by updating app-based recalls such as Traqq with photo, video and/or chat functionalities to facilitate better food identification and portion size estimations), develop new wearable sensor-based tools to quantify food, energy, and nutrition intake, identify novel biomarkers, and potentially even integration of the various approaches.

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