Institute of Education

Diet – Opportunities for Data Collection

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Economic and Social Research Council

Contents

1. Introduction

The aim of this report is to identify opportunities for future data collection in the CLS cohorts to be enhanced by novel methods and linkages, specifically those relating to diet and expenditure. Such novel data collection may come from new tools and technologies (i.e wearables and smartphones), or through data new linkages (i.e consumer data or social media).

The focus of this current report is to identify new ways to assess dietary intake and expenditure. The findings of the report have been collated through a non-systematic rapid literature review. Multiple databases have been searched using key terms (i.e “dietary assessment”; “novel”, “innovative”, “methods”) with an initial focus on identifying systematic reviews and high quality reports summarising the current approaches used to measure dietary intake. Following this, a snow ball approach has been employed to identify additional relevant papers, including primary research articles. Searches of the grey literature have been carried out to further identify relevant information sources.

The first section of this report will outline what is meant by diet and expenditure, and what is intended to be measured. The second section will present the findings of this report, consisting of a review of the existing and traditional methods, use of biomarkers, innovative technologies, and statistical adjustments and finally presenting resources which have been developed to aid identification of the most appropriate tool or biomarker. The final section of this report will provide some concluding remarks on the methods available to assess dietary intake in the 21st Century.

What is Diet?

Diet is an important risk factor for numerous chronic diseases and has been heavily implicated in non-communicable disease mortality [1]. Diet has also been implicated in cognition [2], mental health [3] and quality of life [4] and therefore is considered an important area of investigation in longitudinal research, and especially in nutritional epidemiology.

Diet can be considered in a number of different ways that may be of interest for researchers. This may include looking at intake in terms of: a) micro and macro nutrients; b) energy intake and expenditure; c) dietary patterns; d) abiding to a specific diet; e) as monetary expenditure patterns. Each of these different approaches to viewing diet are outlined below, with example of the different research questions that may be addressed.

Macro and Micro Nutrients

Macronutrients are the main food groups we require (i.e fats, carbohydrates and proteins) and those nutrients that are needed in larger quantities (grams as opposed to micro- or milligrams). Macronutrients are broadly the groups which the UK government gives recommendations on through the “Eatwell Guide” [5]. The eatwell guide gives recommendations on includes 5 food groups, these being: fruit and vegetables (should make up over a third of food intake each day); starchy foods - advises to choose high fibre or wholegrain versions (should be the basis to meals and make up over a third of food intake); dairy and dairy alternatives; protein (emphasis on meat alternatives such as pulses, nuts, eggs and fish); and fats (limited to unsaturated oils and spreads). The eatwell guide also gives recommendation to limit foods high in sugars, salt and saturated fats, to drink at least 6-8 glasses of water a day, and to limit calories to 2000kcl a day for women, and 2500kcl for men.

Micronutrients on the other hand are required in smaller quantities, and are broken up into vitamins and minerals and are essential for bodily functioning and overall health. The UK government provides daily recommendations for Vitamin A, C and D, B vitamins, Folate, Riboflavin, Niacin and Thiamin. For minerals, daily recommendations are given for Iron, Calcium, Magnesium, Potassium, Zinc, Copper, Iodine, Selenium, Phosphorus, Chloride and Sodium [6].

It is worth noting, that although Public Health England gives guidelines on daily vitamin D intake, it is only occurs naturally and in small amounts in a few foods (oily fish, red meat, egg yolk and liver) and also in fortified food. It is more common for people to get vitamin D when it is naturally produced by the body as a result of direct exposure to sunlight on the skin. Despite this, vitamin D may still be of interest to investigate, but extra consideration should be taken to the time of year that data is collected as there will be seasonal variation in vitamin D levels.

By measuring macro- and micronutrients within large population studies, it is possible to investigate how different dietary components relate to disease outcomes. Additionally it would be possible to investigate the extent to which individuals are meeting government and international recommendations, and how intake patterns of micro and macronutrients differ between groups and across time (e.g., age or year of birth).

Energy Intake

Diet may also be assessed purely in terms of energy intake, which is defined as the total energy content of foods, as made up by the primary sources of dietary energy, these being carbohydrate, protein, fat and alcohol [7]. Energy intake is measured in kilojoule (kJ) or calories (kcal), with the recommended calorie intake for men and women in the UK is 2,500 kcal and 2,000 kcal respectively [5]. By focusing on energy intake, research would be looking less at the composition of the food and instead on the calories consumed. This may be of particular interest in fields of obesity research or energy balance, where interest lies in monitoring over or under consumption [8]. With this in mind, some focus to total energy intake and portions sizes should be made in dietary assessment.

Dietary Patterns

Additionally to intake, it may be of interest to focus on different dietary patterns and how these may relate to disease outcomes or other demographic characteristics. A dietary pattern is defined as the quantity, variety, or combination of different foods and beverage in a diet and the frequency with which they are habitually consumed [9]. The Mediterranean dietary pattern (characterised by high quantities of fruit, vegetables, legumes, nuts, grains and olive oil, moderate consumption of fish, and low consumption on meat, meat products and dairy [10]) has most frequently been studied and has been linked to a number of positive health outcomes, such as slower cognitive decline [11, 12], lower levels of depression[12], cardiovascular disease[13], and diabetes[14]. In UK studies, a number of different dietary patterns have been identified often through factor analysis, examples of these are “high fruit and vegetable”, “fast food”, “sweet”, “ethnic foods and alcohol” and “traditional” diets, characterised by different consumptions of food groups depending on the cohort and demographic [15-19].

Abiding to Specific Diets

Relating to dietary patterns, there may also be interest in looking at individuals who choose to abide to specific diet, especially those that restrict certain food items (i.e gluten or animal products). By examining special diets it would be possible to research how these relate to specific health outcomes and other demographic characteristics. Examples of such diets might include Mediterranean diet, gluten free, vegetarian or vegan diets, or diets for weight loss or health conditions.

Expenditure

Expenditure in reference to diet can refer to the physical monetary expenditure on food, which may be incredibly valuable data to have in large epidemiological studies. There are a number of interesting research questions that could be addressed by collecting data on how people spend their money on food. Research surrounding inequalities in obesity have often focused on the cost of a healthy diet, with it being argued that cheaper foods tend to be the least healthy, although the evidence to support this is mixed [20-22]. Additionally there may also be regional differences in the cost of foods and food choices, as well as cross cohort differences that may indicate changing preferences and food priorities between generations, that could be investigated by including measures of monetary expenditure on food.

2. Findings

Accurate measurement of dietary intake is a crucial underpinning to many areas of research, most notably in nutritional epidemiology. A number of difficulties arise when trying to measure dietary intake, with specific challenges arising when attempting to do this in large scale studies. Methods that rely on self-report face challenges with measurement error and underreporting, which may be exacerbated by factors such as presence of an interviewer and the interviewees characteristics (i.e their BMI, age, gender). Additionally, the majority of commonly used methods rely on food composition databases and tables to convert the reported intake into specific nutrients and energy. Inherent flaws in these tables (inaccurate conversions and limited food items) can in itself introduce measurement error [23]. Ability to keep such tables up to date is hindered by the constant expansion and development of the food market, and requires significant time and effort to insure they are in line with the current availability and consumption of food items. Specific challenges that exist include reformulation of products, changes to portion sizes, introduction and increase in popularity of new products - it was estimated that there were 42,000 items in the average supermarket in 2014 [23]).

Objective methods can allow for more accurate measurement of intake as they do not rely on self-report and may overcome issues of participants being unable to accurately report portion size (i.e with duplicate meal methods or food records that require individuals to measure each component of food before eating). Additionally, methods that involve real-time data collection (i.e diet records/food diaries) can reduce levels of underreporting and overcome issues relating to recall. However, such methods may not prevent the participants altering their food consumption over the study period, and the methods themselves are time consuming, costly and increase both participant and researcher burden. This decreases the ability of such methods to scale up to larger studies, and may also reduce compliance rates among respondents. Therefore, when choosing and applying dietary assessment methods to large epidemiology studies, there is a play off between ease of which the method can be used or applied (in terms of ability to complete, distribute, financial cost and participant burden) versus the accuracy of the method, which may be enhanced by expensive, intrusive and time intensive methods.

A number of elements in this compromise can be addressed through novel methods and innovative techniques, which have been made more plausible with the expansion of the internet and mobile devices. Many of the advances that come with these techniques relate to the practicalities of data collection (i.e can be self-administered, can be completed irrespective of time or location, reduce participant burden, data saved automatically and automated nutrition calculations) and therefore allow for a large amount of dietary data to be captured. They may also improve measurement issues that are harder to achieve through traditional pen and paper methods. For example, easier real-time data collection reduces dependence on recall and participants are able to more accurately report portion size through use of scalable pictures. Research has also shown that participants prefer to use innovative techniques compared to traditional measures [23]. However, this does not necessarily directly translate to high compliance with only 16% of UK Biobank participants completing the Oxford WebQ questionnaire at all four data collection points [24]. Where there has been high completion rates of multiple assessments, accuracy in response tends to decrease as demonstrated by lower successive energy intakes [25, 26]. This again raises the compromise that needs to be made between achieving accuracy of measures and reducing burden to the participant. Successful uptake of new techniques may also be dependent on the technological literacy of participants, which may be different across demographic groups (i.e the elderly and very young). However, some technologies can overcome these constraints by having clear and specially designed user interfaces, and being adapted to touch screen devices.

Another issue relating to identifying the most appropriate method is the lack of true “gold standard”. No method is without its limitations and it is common for novel dietary measurement methods to be validated by against alternative self-report methods. Additionally, many tools for dietary assessment are created in a haphazard way and do not always provide validation studies or report the food database which under pin the technique [23]. Doubly-labelled water (DLW) is perhaps the closest there is to a gold standard validation tool, which measures total energy expenditure, which in turn can be used to calculate energy intake. However, DLW is unable to distinguish the origin of energy from different food groups, so can only be used to validate the accuracy of the reported energy intake. Other biomarkers have also been developed to try and measure different macro- and micronutrients, although again there is no single biomarker to capture the total diet, requiring multiple biomarkers to be used. On top of this, biomarkers are influenced by factors that do not effect traditional measures of intake, such as genetics, lifestyle/physiological factors (i.e smoking), interaction by other dietary factors, the sample taken and the method used to analyse it [27].

There are a wide range of methods available for dietary assessment, with multiple reasons for choosing each approach dependent on the target population, the goals of dietary assessment and the scale of data collection. Because of this complexity, a number of resources have been developed to help guide researchers to pick the most appropriate method. One in particular is Nutritools which sets out the best practice guidelines for identifying a method for dietary assessment [28, 29]. Both the Diet, Anthropometry and Physical Activity (DAPA) Measurement Toolkit and the Dietary Assessment Primer provide users with the information necessary to make informed decisions on their assessment method. For selecting biomarkers, The Food Biomarkers Alliance (FoodBAll) (foodmetabolome.org) is aimed at identifying novel biomarkers, databases and review papers on biomarkers for use in nutritional research. Similarly, the The Biomarkers of Nutrition for Development (BOND) program has aimed to harmonise decision making on the best biomarker for 6 nutrients (iodine, vitamin A, iron, folate, vitamin B12 and zinc).

Given the range of methods available for application in epidemiological studies, the below sections further outlines the different approaches: traditional methods, biomarkers, innovative technologies. Mention is also given to statistical adjustments that can be made during and after data collection, as well as to different resources that have been designed or can be used to aid decisions in dietary assessment.

Traditional Methods

Traditional dietary assessment methods, also known as pen and paper methods, can broadly be split into two categories. Those which collect real-time data and therefore tend to be more objective in their assessment of intake, and those that rely on recall and are subjective. Examples of real-time data collection methods include food records and duplicate diet approaches. Food records may either be obtained by trained staff who observe and record intake, or may be taken by the individual where the food eaten is documented at the time of consumption [30]. In weighted food records, participants are expected to weigh all the separate components of a meal and record the exact amounts consumed. In duplicate diet methods, two portions of the food consumed is prepared, with one being sent off for nutritional analysis [31]. Although such methods tend to be more accurate in estimating dietary intake, there is a tendency for individuals to alter their dietary patterns over the study period and therefore the results may not reflect usual intake. Additionally, such methods are very time consuming and have high participant burden (and high researcher burden if they are required to be present). Because of these limitations, such methods are less often used in large epidemiological studies (instead being built into validation studies), and retrospective recall methods tend to be favoured. In particular, there are two types of recall methods that are most frequently used in large epidemiological research, these being multiple 24-hour recalls and food frequency questionnaires (FFQ).

The 24 hour recall approach requires an individual to recall all food consumed in the previous 24 hours, which is often administered via a trained interviewer using an open-ended structured interviews, and can be done either in person or over the phone [32]. Typically, the interviewer will ask about food consumption over the last 24 hours (usually midnight to midnight on the previous day) and will be prompted for more details by the interviewer (for example, the preparation method or any additional condiments). Portion size will be estimated often using standard household measures, or photographs and models of different food portions. From these estimated portion sizes and using food composition tables, energy and specific nutrient intake can then be calculated.

Compared to real-time data collection, the 24 hour recall has the advantage that participants are unlikely to alter their intake, especially if the 24 hour recall is done with little prior notice [32]. Moreover, it only relies on short term memory compared to other recall methods such as diet histories that rely on memory spanning a longer period of time or FFQ that rely on generic memory. However, because of these short term qualities, the 24h recall may not capture habitual patterns. It will only measure the intake of the previous day and therefor may not be representative of usual intake. To overcome this, it is common for multiple 24 hour recalls to be administered (two to seven times being the suggested optimal number [31]), often at different points throughout the year so to capture seasonal variability. However, with increased administrations of the 24 hour recall, participant burden increases, risking lower completion of the dietary assessment. Additionally, the 24 hour recall usually takes between 20 and 30 minutes to complete [30], with an additional 30 minutes to code the responses [33] – given that a trained interviewer is often required to be present, this method is also costly and timely from the researchers perspective, and especially when applied to large population studies.

The FFQ is an alternative approach to measure dietary intake that overcomes some of the issues relating to the 24 hour recall approach. The aim of the FFQ is to identify the frequency of which certain foods are consumed, often with a close-ended list of foods and the option to then specify the frequency at which they are consumed. Therefore the FFQ is better able to capture usual dietary patterns compared to the 24 hour recall without relying on multiple completions and reducing participant burden. Additionally, the FFQ can be administered both by an interviewer, or can be self-administered reducing the cost and time for the researcher to collect the data (although the length of time to complete the FFQ is similar to that of the 24 hour recall [30]). The FFQ may also collect information on portion size, and again use known quantities or pictures to aid this. However, the ability of the FFQ to accurately assess energy intake is reduced compared to the 24 hour recall method due to the reduced specificity of the questions and answers. Additionally, the FFQ relies on generic memory resulting in greater potential to introduce error through recall bias.

An important element of an FFQ that directly influences how successful they are at capturing dietary information is the food list. It is important that this is comprehensive enough that it does not introduce measurement error. For example, errors from non-reporting where a food item is not listed, or where individuals substitute items in their answer to the closest available listed, which may have different nutritional qualities to the true item consumed. To ensure these errors are not introduced it is important that the items included in the food list are culturally specific and appropriate for the target population. It is common practice to either design a specific FFQ for the study or to adapt ones that already exist. With the advent of modern technology, a number of online resources have been developed that have created population specific food lists (i.e for the UK specifically).

Due to the strengths and weaknesses of both 24 hour recalls and FFQ, there is a tendency in epidemiological research to combine methods. This does not necessarily have to be limited to just the FFQ and 24 hour recall (although this is often the chosen combination), but may incorporate biomarkers, objective measures and other self-report methods. One method that is incredibly thorough in its evaluation of dietary intake is the diet history, which combines a 24 hour recall, 3 day food record and checklist of regularly consumed foods, along with an in-depth interview often lasting around 90 minutes [30]. Due to the complexity and thoroughness of this method it is rarely used in epidemiological studies, but may instead be used as a validation tool. On top of the complexity and despite allowing for a more accurate assessment of true intake, there are still issues that exist even when employing multiple different assessment methods. These ranging from recall bias, underreporting and inaccurate estimation of portion sizes, issues with the underlying food tables and practical issues of administrating. Some of these issues can start to be addressed through the use of alternative methods and innovative technologies.

Biomarkers

In order to try and objectively and accurately assess nutrient intake, there is some potential to use biomarkers, which should be independent of the error and biases that exist with self-report methods or those relying on food composition tables. Biomarkers can be considered as a biological specimen which provides information on either metabolism, specific nutrient intake or dietary component, or more general nutritional status [31]. Ideally, biomarkers would be objective indicators of dietary intake that are applicable to many populations, specific and sensitive [34]. However, in practice this is not always the case, although they may still have great functional use in informing us about the dietary intake of individuals understudy.

Because of the different aspects of diet that biomarkers can assess, they are often grouped into four non-mutually exclusive categories, these being: a) recovery; b) concentration; c) replacement; and, d) predictive biomarkers. Other classification systems also exists, one groups biomarkers according to the way they are measured, with two groups: biomarkers of dietary exposure and biomarkers of nutritional status. The former of these measures the intake of specific nutrients, food, food groups and so on. The latter measuring not just the intake but the way in which it has been metabolised, which may be affected by disease processes or interactions with other nutrients [35]. On top of this, they can be categorised by the time period of which they represent, with short term biomarkers reflecting dietary intake of over hours today (such samples normally come from urine, plasma or serum samples), medium term which represents dietary intake of weeks and months (this is normally ascertained from blood or adipose tissue), and long-term of over months to years (taken from nails, hair and teeth samples) [31].

i) Recovery Biomarkers

Recovery are based on known physiological balances between intake and expenditure, and when used provide a dose-response relationship with intake. As such, these biomarkers have the greatest potential as a validation tool as they are specific and not significantly affected by inter-individual differences in metabolism. There are only a few known recovery biomarkers, these being doubly-labelled water which measures total energy expenditure, and urinary nitrogen and potassium which measures protein and potassium respectively.

Perhaps the best known and most widely applied recovery biomarker is doubly labelled water (DLW) which is often considered the gold standard for measuring energy expenditure, and therefore may be used as a validation technique for other dietary assessment methods. In order to measure energy expenditure, individuals are given water made up of heavy hydrogen (^{2}H) and oxygen (^{18}O), from which expenditure of CO^{2} can be calculated as the oxygen isotope is lost as water and carbon [36]. As such can also be used as an accurate measure of energy intake in free-living weight stable participants. However, before being used to validate other methods of nutritional assessment, recovery biomarkers must first be calibrated in controlled settings [34]. Such processes can be very expensive, time consuming and complex. As such, use of recovery biomarkers in large epidemiological studies is limited and instead may be used in a sub-study population to act as a calibration tool for other methods.

ii) Concentration Biomarkers

Concentration biomarkers are highly correlated with dietary intake, but are affected by inter-individual variation that may be caused by things such as metabolism, age, gender, smoking status, weight and physical activity. Although concentration biomarkers do correlate highly with the nutrient under study, the correlation is expected to be less than that of recovery biomarkers, and they cannot provide an exact estimate of intake. Therefore concentration biomarkers have reduced suitability in validation studies, although they have been used in this way and agreement between other methods and concentration biomarkers deem the method more reliable. Examples of concentration biomarkers are fatty acids that are found in adipose tissues, serum vitamins, blood lipids and urinary electrolytes.

iii) Predictive Biomarkers

Predictive biomarkers are similar to recovery biomarkers in that they are time-dependent and sensitive to intake in a dose-response manner. However, they do not have the same recovery rate as other biomarkers such as DLW. Predictive biomarkers may therefore be useful in assessing measurement error in other methods. Although there is only one widely use predictive biomarker, this being urinary fructose and sucrose which is highly correlated with sugar despite very small fractions being present in the sample.

iv) Replacement Biomarkers

Replacement biomarkers are similar to that of concentration biomarkers, but are often used for compounds where the information available in food composition databases is unsatisfactory or not available. Replacement biomarkers can also be indicative of metabolic responses to dietary stimulus. Examples of these type of biomarkers include sodium, phytoestrogens, polyphenols or aflatoxin.

Considerations

When choosing a biomarker it's necessary to consider a number of practical elements associated with the collections. This includes thinking about the specimen that is required to detect the biomarker, with different methods reflecting different lengths of intake [37]. Additionally, different specimens may have different burden to the participant. Biomarkers such as hair, nails, cheek cells and fingerprint blood spots are fairly easy to collect, whilst stool and urine samples may be more difficult to collect and methods requiring biopsies or full blood samples may be considered more invasive to the participant. There may also be differences in the way biomarkers need to be stored, and the risk of contamination which may be particularly high in hair and nail samples which may occur prior to the sample being taken. Additionally, the timing of the specimen collection is important in samples which reflect short term intake, especially those with diurnal variation, and should be standardised across collections. There may also be seasonal variation, which may either be due to seasonal variation in the diet, or to seasonality in external factors which effect the biomarker (vitamin D is produced in the body when exposed to sunlight, resulting in seasonal differences in 25-hydroxy vitamin D levels) [38].

Biomarkers have a lot of potential to be used in epidemiological studies, either as validation tools to be compared against other methods, or for specific investigation of the nutrient-disease relationship. For the latter, it is often concentration and replacement biomarkers that are used. It may therefore be of consideration to include such biomarkers in epidemiological studies alongside other methods. However, there are still limits in the ability of such biomarkers to be translated into absolute dietary intake as they are influenced by factors that would not affect traditional methods of measuring intake (i.e. inter-individual differences in metabolism, smoking, genetics, interactions with other diet related nutrients and so on). Recovery and predictive biomarkers may be very accurate and informative measures of total energy intake and other dietary components, but they are complex and costly to use. This may limit their ability to be applied to epidemiological studies on a large scale, but they may still be appropriate for use as a validation tool against the primary method, taken in a sub-sample of the study.

The Food Metabolome

Another field relating to biomarkers that has potential for research in nutritional epidemiology and dietary assessment is metabolomics, which involves the screening of small molecule metabolites that are found in bodily samples (blood, saliva, urine etc). The combined characteristics of the metabolites makes up the metabolome, which is essentially a “molecular fingerprint” [27, 39]. Research has found that a number of different factors effect an individual’s metabolome, with diet being one of the most important. This has resulted in a focus on the food metabolome which is part of the human metabolome that relates specifically to the digestion and biotransformation of foods. The food metabolome is incredibly complex with at least 25,000 known compounds from food contributing to it [40]. The complexity and diversity of the food metabolome makes it possible to relate variations to differences in diets, and may allow for more accurate identification and research into nutrient-disease relations. In particular, research in metabolomics has been incredibly important in the identification of new biomarkers, including those which are indicative of specific dietary patterns i.e vegetarian diets, Mediterranean diets [41].

Innovative technologies

With ever developing and increasingly widespread use of technology, there is also growing potential for this to be utilised in large studies to assess dietary intake. A report by the Office for National Statistics indicated that in 2018, 90% of UK households had internet access, with 78% of adults using mobile phones to do so making it the most popular method to access the internet [42]. This is with the exception of over 65’s who preferred tablet computers, but still favoured mobile phones when accessing the internet on the go [42]. Given the widespread acceptability of internet and mobile devices, utilisation of these in dietary assessment can transform the way in which data is collected and in some cases analysed.

There have been a number of reviews outlining the different methods available for dietary assessment using new technologies, and different ways in which this has consequently being classified. Perhaps one of the most extensive and widely sighted review is Illner et al (2012), who categorised the novel methods in to 6 groups, these being: i) Personal digital assistant (PDA); ii) mobile based; iii) interactive computer; iv) web based; v) camera and tape recorder; and, vi) scan and sensor based.

i. Personal Digital Assistants

A PDA is a handheld computer that has software installed that helps assess dietary intake, and can be used for real-time data collection [43]. In order for participants to use PDA they require training on how to use the device, this coupled with the extensive food lists that exist on PDA (ranging from 180 to over 4,000) raises the participant burden, with it being reported to be higher than that of traditional pen and paper methods [43]. Moreover, although PDA were the leading mobile technology for dietary assessment, this has quickly been surpassed by mobile phone based technologies with the development and common use of smartphones [44].

ii. Mobile Based Technologies

There’s great interest in the possibility of using mobile phones to collect dietary intake, due to the greater possibility of real-time data collection and the wide spread use of mobile phones, even among older generations. In Illner *et al’s* (2012) review, a major aspect of the mobile phone based technologies was the possibility of voice and photograph recording, with examples of these being the Japanese “Wellnavi”, the “Mobile phone food record” and the “spoken dietary record”. In each of these either verbal dietary records or photographs are taken (using a fiducial marker) and either sent to a dietician for analysis through the phone, or analysed by automated software.

However, perhaps the more common understanding of mobile based technologies now are those that have either been adapted from web applications for use on a portable device, or alternatively apps that have been specially designed for mobile phones. It is possible that either of these two may incorporate photo and voice recordings, but it is not an essential element of the mobile based technologies for dietary assessment. Additionally, another avenue that may be explored is the use of commercial apps for weight loss that may incorporate a tracking aspect of diet, examples of these include MyFitnessPal, My Meal Mate (MMM), DietSensor (the latter of which has a feature for barcode scanning), among others. However, it is important to note that as these apps are intended for use in weight loss and fitness tracking, there is possibility that even if only the food tracking elements are harnessed there may still be some bias introduced by individuals altering their diet during use or from independently accessing the weight loss features of the app.

Although the widespread use of smartphones mean that mobile based apps have great potential in dietary assessment, at current there are few apps that exist that have a strong theoretical basis or that have been appropriately validated. In an assessment of 800 health and fitness related apps only 28 were related to dietary intake and had feature that allowed for dietary intake to be recorded and tracked [45]. When 3 day dietary records were inputted into all the apps, although the mean differences from the diary was small (absolute energy difference 127kj (95% CI -45,299), percentage energy difference 1.9% (95% CI -0.5, 4.4), the variance between the apps was in some cases considerable (one app reported 1001kJ greater and another 700kJ lower energy intakes than the inputted food record) [45]. A separate review looking at the feasibility and validity of dietary apps reported in English language publications between 2001 and 2013 found that although acceptability by participants was high, there were no advances in terms of reliability or validity compared to conventional methods [46].

One app which seems to have greater reported underpinning evidence is My Meal Mate (MMM), which was designed using an evidence based behavioural approach [23], and includes features for diet monitoring including the option to take photos of food to help with recall at a later point [46]. In a validation study of 50 volunteers, there was high correlation comparing the means of 2 days of MMM with 24 hour recall ($r=0.69–0.86$; $P<0.001$), but this was lower when looking at the mean over 7 days ($r=0.64–0.75$; $P<0.001$) [47]. Moreover, there was wide limits of agreement between the MMM and the 24 hour recall at the individual level, but reasonable agreement at the population level, which can be best explained by variance in the ability to estimate portion size [47]. However, these limits of agreement at the individual level were still smaller than those reported by studies using PDA [46], and there have been demonstrated preferences for and increased adherence to MMM compared to more traditional pen and paper methods over a 6 month study period [48].

Other aforementioned apps that may be considered either now or in future data collections are MyFitnessPal (MFP) and Diet sensor. Diet Sensor is a relatively new app that is designed with the aim of achieving weight loss. It has features that allow for tracking of food intake, including audio options to dictate food consumption and the option to purchase a connectable scale for accurate measure of portion sizes [49]. DietSensor automatically analyses the nutritional information from the food inputted, as well as having the option to scan bar codes of food purchased which could also be utilised to measure monetary expenditure on food [49]. Despite these promising features, DietSensor has not been tested in any formal validation studies. However, Diet Sensor cites scientific literature which has been used in its design along with the involvement of doctors and dieticians, and therefore may be a promising application for use in epidemiological studies in the future.

MFP is arguably one of the most popular and publically available fitness app, and also incorporates elements of behaviour change theory into its design, along with features that allow for self-monitoring of dietary intake [50]. MFP therefore has a lot of potential to be used in the CLS cohorts as it is likely that some cohort members may already be familiar with and using the app, which may improve ease of use. Additionally it may be possible to harness data from it that has already been collected. A recent validation study comparing MFP to paper based food records demonstrated that MFP had good relative validity, especially for energy (Adjusted mean difference (kJ)= −56.04 (s.d 851.82) p=0.61, r=0.70 p<0.001) and fibre (Adjusted mean difference (g)= −0.46 (s.d 4.08) p=0.12, r=0.63 p<0.001), although significant differences did exist in regards to carbohydrate (Adjusted mean difference (g)= −25.41 (s.d 22.41) p<0.001), lipid (Adjusted mean difference (g)= −10.94 (s.d 8.65) p<0.001) and protein (Adjusted mean difference (g)= −10.92 (s.d 8.10) p<0.001) intake [51]. Overall MFP tended to underestimate dietary intake compared to traditional pen and paper methods, resulting from an inadequacy of the underlying database [51].

iii. Interactive Computer Technologies

Interactive computer based technologies assess dietary intake from the recent or distant past, but may adopt a multi-media approach to do so such as animations, audios, photos, use of colour, touch screens and pop up functions [43, 52]. Interactive computer based technologies are often modelled off traditional pen and paper methods, and may be similar to web based technologies in their use of probing, coding and calculating intake through multiple media and direct transfer of data – however, they differ in that they often require less programming than the web-based methods [52]. Similar to PDA’s being surpassed by mobile based technologies, many interactive computer based methods have largely been overtaken by web-based assessment methods, which although are very similar are accessible regardless of time or location.

iv. Web-based Technologies

Of the innovative technologies, web-based methods are perhaps the most advanced and widely used in epidemiological research. They are very similar to interactive computer technologies, measuring dietary intake over either a short or long period of time and modelled of traditional methods, but require a greater amount of programming and are characterised by various different software components [52]. Because they are web-based, the software is accessed online instead of at the desktop computer, allowing data collection irrespective of time and place as long as there is satisfactory internet connection.

Different methods may be adopted in the way they collect data from participants to help increase the accuracy of information collected through web-based tools, one such method is the multiple automated pass method (AMPM) which has been developed by the US department of agriculture. The method is a five-step, multiple-pass technique with the first step involving an unaided and unstructured recall of items from an extensive list of food and drinks [53]. The following three steps are structured and involving memory cues, followed by a final probe step of unstructured recall with additional memory cues [53]. This method has been incorporated into the Automated Self-Administered 24-Hour (ASA24) Dietary Assessment Tool, a self-administered 24 hour recall which has been designed for use in the US and Canada, and has been adopted into over 5,100 studies since its release in 2009. Although the ASA24 is not designed for use in the UK, INTAKE24 is an online multipass 24-hour recall that is based on the AMPM method and was initially developed for UK use in 11-24 year olds, but with expansion to older age groups [54].

There are multiple different web based tools available, with the most relevant for applications in UK epidemiological (or those which are well established in nutritional epidemiology i.e ASA24) detailed in Table 1. Of the tools listed, Oxford WebQ has previously been used in

Table 1: Web-based tools for assessment of dietary intake

Online Tool	Country	Features	Time to complete	N of food items in Database	Validation Studies Available
Oxford WebQ	UK	Web-based 24 hour dietary assessment, designed for repeated administration in large prospective studies. Self-administered, with automated nutrient calculations. Used in UK biobank, Million Women Study, CLS cohorts.	12.5 minutes	206 foods and 32 dinks split into 21 groups.	Comparison against interviewer administered 24 hour recall in 116 participants, spearman's rank correlation for the 21 nutrients obtained on Oxford WebQ was 0.6 with majority between 0.5 and 0.9. Difference in energy intake was +12kJ (+3kcal), with all nutrients except carotene and B12 vitamins no more or less than 10% different [33]. Other validations planned (REC reference 14/LO/0293): a) Comparison of dietary estimates in the National Diet and Nutrition Survey; b) Comparison with biomarkers and myfood24.
MyFood24	UK	Online 24-hour recall, can also be used as a food diary. Self-administered or interviewer administered. Large number of food items for participant selection, both generic and branded. Uses standard portion sizes, food weighting and photographs. No training required. Data output as Microsoft excel file, requiring further analysis in statistical package.	19 minutes (+/- 7)	45,000	When compared to interviewer administered 24 hour recall, mean difference of −230 kJ (−55 kcal) (95 % CI −490, 30 kJ (−117, 7 kcal); P=0·4) in energy intake, with limits of agreement ranging from (3336 kJ (−797 kcal)) lower and (2874 kJ (687 kcal)) higher [55]. Further comparison with interview administered multiple pass 24 hour recall and biomarkers found attenuation from biomarkers in both self-report methods (attenuation factors of 0.2-0.3 for myfood24), but comparability of myfood24 with interviewer administered [56].
INTAKE24	UK	Open source, self-administered, online 24 hour recall. Based on AMPM.	13 minutes, dependent	2,800	Comparison with interviewer led 24 hour recall in 180 individuals aged 11 to 24 (split into two age groups), repeated on four occasions for each individual.

		Images used to calculate portion size, high tolerance to spelling mistakes, automated coding of nutrition. Accessible on multiple devices including mobiles and tablets.	on interface		Tendency to underestimate by 1% with limits of agreement 49% lower and 93% higher. Difference in energy intake was -142 kJ (-34 kcal) in the 11-16 year olds and -108kJ (-26kcal) in the 17-24 year olds [57].
Food4Me	7 European countries including UK	Online FFQ, with 157 food items. Designed from EPIC-Norfolk FFQ (130 food items) with input from 7 other EU countries (an additional 27 food items). Uses standardised photographs to help with reporting of portion size.	Not reported	157 items grouped into 11 categories	Comparison against the EPIC Norfolk printed FFQ in 113 participants, mean age 30. Difference energy intake was 2828 kJ (+676 kcal) higher than the paper FFQ. Correlations for specific food groups were between 0.41 and 0.90, with highest agreement for alcohol (93%) and lowest for polyunsaturated fatty acids (77%) [58]. Validation against 4-day weighted food diary in 49 participants (mean age 27) found non-significant differences in energy between Food4Me (2115.2 kcal (SD 809.1)) and the weighted food diary (1936.9 kcal (SD 505.8)), and found moderate agreement between the two methods with less than 5% of cases falling out of the limits of agreement [59].
ASA24	USA and Canada	Self-administered 24 hour recall, using the validated automated multiple pass method (AMPM). Participants guided through completion with an animated guide. Requires standard computer monitor and high-speed internet connection.	24 minutes average, range of 17-34 minutes.	10,000	Compared with true intake and plate waste from three meals, and interview administered AMPM. Performed well although the interviewer administered AMPM performed slightly better on true intakes for matches, exclusions, and intrusions. Difference in energy intake was -2kJ (-0.5 kcal) 95% CI 987, -992 kJ, 236, -237 kcal [60].
NANA	UK and USA	Touch-screen computer based self-administered food record, designed for use in older adults. Also contains features to assess cognition and physical activity.	Not reported	1,200	Validation in 40 individuals aged 65 and over, use at three 7-days periods, at 4 week intervals, compared to a 4-day food diary. Found good relation with dietary intake (energy, carbohydrates and protein) although slightly lower estimation with NANA – difference in

	Both participants and researchers need training for use.		energy between NANA and food diary was -250 kJ, 95% CI -1711,1212 (-60 kcal, 95% CI -409, 290) [61]. Validation in 94 individuals aged 65-89 against a 4 day estimated food diary and biomarkers (Blood and 24 hour urine, only taken in 76 of the participants). Reasonable agreement between NANA and the food diary for energy and macronutrient intake, with correlations ranging from 0.879 ($p<0.001$) for energy and 0.750 ($p<0.001$) for protein. Correlations in both NANA and the food diary with urinary urea and dietary protein (NANA: r 0·466, $P<0·0001$), and correlations only in NANA for plasma ascorbic acid and dietary vitamin C intake (r 0·294, $P<0.028$) [62].

the CLS cohorts, as well as UK biobank and the Million Women's Study. Taking only 12.5 minutes to complete on average, this is much faster than a traditional 24 hour recall which typically takes 30 minutes to complete and an additional 30 minutes to code the data [33]. Although a 24 hours recall, the format of which participants report their food intake is similar to an FFQ by recording frequency of consumption of 21 food groups, with the Oxford WebQ being previously described as a hybrid method because of this feature [23]. Oxford WebQ records portion size through specified servings, with additional descriptions for foods which don't have a standard serving sizes, for example cheese. Participants are then expected to adjust their reported portion relative to the standard serving size. This contrasts to other methods such as INTAKE24, myfood24, food4me and ASA24 among others, which utilise photographs to measure portion size, especially for foods which don't have a standard serving size [23].

In validation studies comparing Oxford WebQ to interviewer administered 24 hour recall among 116 men and women, Oxford WebQ was found to reasonably capture similar food items and to report similar nutrients. The spearman's rank correlation for the 21 nutrients obtained on Oxford WebQ was 0.6 with majority between 0.5 and 0.9, and the difference in energy intake was +12kJ (+3kcal), with all nutrients within 10% more or less than the interviewer administered, with the exception of carotene and B12 [33]. Oxford WebQ has also been shown to be reasonably acceptable for use, with 66% of participants completing the survey in the UK biobank at least once, and higher completion rates went sent during the week [24]. However, only 16% of individuals completed the Oxford WebQ survey on all 4 assessments over a 16 month period, raising issues regarding the play off between increased participant burden at risk of reduced accuracy in dietary assessment. There have been plans for further validation of the Oxford WebQ with biomarkers and myfood24, another web-based 24 hour recall designed for use in the UK (REC reference: 14/LO/0293).

Myfood24 is an online tool that has been developed by the Nutritional Epidemiology Group in the School of Food Science & Nutrition at the University of Leeds, with the aim of supporting academic research into dietary intake[63]. Myfood24 has a number of features which makes it stand out compared to other online tools, primarily the size and scope of the underlying food database. The current version of the UK food composition database has roughly 3,300 generic items. However, myfood24 has developed a new comprehensive food composition database containing ~ 50,000 products [23, 63]. The process by which this was developed was to use "Back of Pack" data from branded food and to match it to the generic database, to create a fully comprehensive database of the foods available in the UK. This database is continuously updated to account for the changeability of the UK food systems, with it being estimated that 10,000 new products are introduced each year whilst other are discontinued, and many other products only being available at certain times of year due to seasonal demands [63].

Because of this large database, myfood24 uses a search strategy to complete the dietary assessment, with additional formatting to ensure the ease of which items can be selected and that accurate assessment is made i.e ensuring most popular foods displayed first, common synonyms and misspellings, prompting for common accompaniments, and clarification of serving sizes. Other benefits of myfood24 is the ability to be used both prospectively and retrospectively, and to either be self-administered or interviewer led. The tool also has real-time feedback on nutrient intake and removes the need for extensive coding following completion of the survey. Additionally, myfood24 has the option for customisation in the researcher area of the tool, allowing for project specific logos and text and the ability for researchers to send out tailored invitations, reminder emails and prompts [23].

In comparison with interviewer led 24-h multiple-pass recall among British adolescents aged 11-18, there was a mean difference of −230 kJ (−55 kcal) (95 % CI −490, 30 kJ (−117, 7 kcal); P=0·4) in energy intake, with limits of agreement ranging from 39% lower and 34% higher than the interview administered. Myfood24 proved to have good agreeability for classifying individuals into tertiles of energy intake, and additionally had high agreement between day 1 and day 2 when compared to the interviewer administered, indicating that myfood24 has potential in epidemiological studies to collect data of comparable accuracy to that of interview administered 24 hour recall [55]. A more recent validation study of myfood24 comparing it against an interviewer administered multiple-pass 24-h recall, as well as a number of biomarkers, found myfood24 to attenuate nutrient intake (0.19 (95% CI 0.10, 0.29)) comparative to the biomarkers, but overall was comparable to the interviewer administered method which also attenuated intake (0.32 (95% CI 0.21, 0.43) [56].

v. Camera and Tape Recorder

Camera and tape recorder technologies measure dietary intake through either visual or verbal records of consumption, along with plate waste, which is then analysed to calculate nutritional intake. Given these methods only require the user to take photos of their meals, such methods have the potential to reduce burden on the participant compared to other methods or real-time recording. Among camera based methods, two main approaches exist, those requiring input from a researcher to calculate nutrition, and those not requiring human input [44]. Methods that don't rely of photos by a dietician include products such as DietCam which automatically estimates the nutrient content through photos taken on a smart phone [64], reporting an 84% accuracy of recognition on regularly shaped foods [65].

Of the former, the Remote Food Photography Method (RFPM) is an example where images are sent to a Food Photography Application and then analysed through comparison with an images of food portions to estimate intake [66]. The RMPM has been validated against doubly labelled water in thirty adult participants [67] and among thirty-nine minority pre-schoolers (aged 3 to 5 years old) [68]. Although the RFPM method compared well to doubly labelled water among the adult participants (only underestimating energy intake by 3.7% when provided with customised prompts), among the pre-schoolers there was a tendency for the method to underestimate calorie intake by 222kcal/d (-15.6%, P<0.0001) regardless of intake. Some camera based methods, such as the Microsoft SenseCam – a wearable camera attached to the chest recording consumption throughout the day- are intended for use alongside other methods of assessment such as food records to help improve recall [44, 69]. Use of the SenseCam alongside a 24-hour recall was shown to improve recall, with increased self-reported energy intake when provided with pictures to aid the recall [70].

vi. Scan and Sensor

With scan and sensor technologies, participants would either scan the barcodes of food which then automatically calculates nutritional information, or through a wearable technology which itself can collect dietary data [44, 52]. Wearables that are intended to be the primary source of data collection have the potential to reduce participant burden and issues with self-report. An example of a wearable that has been designed in this way is the eButton which is a small electrical multi-sensor device that is attached to the participant's chest, and is able to record food intake through camera, microphone and other sensory methods [43, 71]. The camera take photos sporadically at 2-4 second intervals, which are stored on the memory card and transferred automatically by email to the dietician [71]. Portion size can then be estimated through two different methods, either using automated image analysis using fiducial markers when the participants eat in their own home (measurements of the markers are made prior to wearing the eButton), or when food is eaten away from the home, the eButton emits lights to create a referent in the visual field of the camera that allows for portion size calculations [72]. Although a promising technology, the ability for eButton to accurately calculate portion size is questionable with the error rate at 30% for foods of regular shape and significantly larger for irregular shaped food [73]. In an assessment of feasibility and inter-coder reliability in thirty 9-13 year old children, there was agreement between the two dietitians assessing in terms of calorie intake, but not with the dieticians and the parent-children dyads, and a number of feasibility problems were raised during use [74].

Another example of a scan and sensor technology is Tellspec, a food sensor using near-infrared spectroscopy - a method involving identification of compounds based on reflected wavelengths. Using machine learning and bioinformatics Tellspec is able to identify the ingredients and composition of different foods, including dairy, gluten, soy, calories, fats, protein, fibres, carbohydrates, sugars and glycaemic acid, with plans to expand this list [75]. The primary intended use of Tellspec as outlined on their website is to identify food contaminants or to help people make healthy choices about the foods they consume [76]. However, the ability to scan and analyse foods that are consumed has clear potential to be utilised in epidemiological studies for accurate and non-biased assessment of dietary intake. However, to date there is no formal peer-reviewed validation studies using Tellspec, although a number of conference abstracts exist outlining Tellspecs ability to correctly determine different food compositions [77, 78]. On top of this, the cost of Tellspec is high and the burden on participants if expected to scan every food item is large, which at current may make it a costly and impractical tool for use in large cohort studies.

Considerations

There are clearly a number of advantages in using novel technologies to assess dietary intake, such as easier and cheaper dissemination (not reliant on interviewers administering them), reduced data processing and in some cases automated nutrition assessment, automated collection of qualitative information such as time and date, and ability to complete dietary assessment irrespective of location or time. Depending on the technology used, there may also be less reliance on the respondent memory (i.e with methods that involve pictures or real-time assessment of food intake). There may also be ability to reduce measurement error, for example by having scalable pictures to more accurately determine portion size.

Nevertheless, there are a number of general points to bear in mind when selecting a technology. Firstly, it is important to ensure that the technology is designed in a way that makes it easy to use and navigate, especially across different generations and levels of technological literacy. This means for that the interface should be clear and easy to navigate and the process which the assessment is completed is logical. The usability of the technology should also be considered from the researcher's point of view, which can ease the process of data collection and analysis. Another general point to consider, is in those technologies which require individuals to select foods from a pre-defined list should ensure the process to which participates are able to identify foods is made as easy as possible. Individuals are less likely to comply with dietary assessment or complete them accurately if the methods to do so are lengthy and complicated (i.e having to scroll through exhaustive lists or navigate through unclear or nonsensical categorisations). If new technologies are able to optimise the processes for participants to select food items, it may also help to reduce measurement error by allowing for larger food lists without being off putting to the participant when faced with a vast number of food items.

Just like traditional pen and paper methods to increase accuracy and reduce measurement error it is important for assessment methods to have extensive and appropriate food lists for the population under study. However, this increased accuracy can only be ensured if the food composition databases that underlie the calculations of total energy and specific intake of macro and micro nutrients, are kept up to date and are as equally extensive in food items as the lists used. Myfood24 is an example of a new technology with an extensive food database, which is regularly updated to keep in line with current food availability in the UK [23, 63].

If new technologies are able to effectively improve usability they may also be able to increase completion rates (i.e they may reduce time taken to complete assessment, can include pictures or interactive aspects which is easier to use in low literacy populations). It is important to remember though that greater compliance is not necessarily guaranteed and especially over multiple administrations, as was demonstrated by the use of Oxford WebQ in the UK biobank [24]. Although participants generally tend to favour newer technologies to assess diet [48], and compliance is high on a single round of assessment (66% completed in first administration of Oxford WebQ in UK biobank), this can drastically decreases over multiple administrations (16% by fourth administration). In order to achieve high completion rates it may be necessary to send reminders to complete the assessment and to provide and strong and clear rational as to the importance of completing the dietary assessment. Additionally, even if completion rates are maintained over multiple assessments, this may be at risk of decreased accuracy. Multiple applications of automated 24 hour recall had high compliance, but reduced energy with each additional survey, indicating that the higher participant burden reduced the accuracy to which individuals were reporting their intake [26].

Other general points to consider in regards to completion of dietary assessment is the population to which the new technology is aimed at and how appropriate it is for the target population. As previously stated, differences exist between generations regarding their use of technology, which over 65’s preferring use of tablets [42]. Therefore, in order to maintain response rates across different studies, it may be worth using a method which has applications for different devices (i.e tablets, desktops and smartphones). Alternatively, different applications could be used based on the age group for which they are aimed, with INTAKE24 initially being designed for use in 11-24 year olds and the Novel Assessment of Nutrition and Ageing (NANA) tool being designed specifically for older populations, to be completed on touch-screen computers [62]. Moreover, in low technology literate groups, having applications which are based on touch screen or have use of pictures may also help to maintain response.

Additionally, many novel techniques are still under development, have not yet established the theoretical groundwork behind their design or lack validation. These latter two points are especially true for apps which have been developed for commercial use. Development of such applications specifically for use in longitudinal research would require large up-front investment and extensive work on developing them in line with established theory. Additionally they would need piloting and validating, which all in all would be a lengthy and costly process.

A final point to consider, is that although new technologies are able to overcome a number of the practical issues relating to collecting dietary data, many of the methods are based upon traditional pen and paper methods and therefore are still not able to address issues of self-report bias and underestimation of intake. Even technologies which facilitate use of real-time data collection, therefore helping to overcome issues relating to recall, cannot prevent the participant altering their intake alongside the assessment period. This is similarly true for other methods, such as scan and sensor technologies or camera and recorder technologies, which have the ability to reduce underreporting. Some of these issues may be addressed through use of multiple methods in calibration studies, and energy adjustments.

Calibration and Energy Adjustments

Errors are inherent to dietary assessment methods, regardless of the technique used. The measurement error can be systematic or random, with the former representing issues with the measurement technique that routinely miscalculate intake, and the latter are errors that occur at the individual level and fluctuate around the true intake. Validation studies can be used to try and measure the extent and structure of these errors, whilst calibration studies may be adopted to calculate a correction factor.

Calibration study, can be incorporated into epidemiological study by having a sub-group of participants undergo additional assessments of intake, using a reference method that is considered more accurate but may be difficult to use in the whole sample. For example, this may be biomarkers such as DWL, urinary nitrogen or potassium, or alternatively could be a very thorough self-report method such as the diet history method. This can then be used to “calibrate” the self-report method through estimation of the correction (attenuation) factor [31]. This approach works on the assumption that the reference method also has error, but this error is firstly independent to true intake, and secondly that the reference methods error is independent to the intake calculated from the compared method [25].

Because of the tendency for individuals to underreport their true intake, and this varying by method used, there is an argument for energy adjustment to be applied to the measurements acquired. In both the Observing Protein and Energy Nutrition (OPEN) study [79] and the US Validation Studies Pooling Project [80, 81] which compared traditional measures of assessment with biomarkers, found the measurement errors to be improved when energy adjustments were made. The rate of miss-reporting in OPEN was shown to be related to intake and on the number of the administration, with a tendency for greater underreporting with higher intake and additional questionnaires [31]. It is possible that some of the measurement error can be addressed through new technologies where the methods of measuring intake and estimation of portion size are improved. However, there is still value in considering the need for energy adjustments and calibration, giving support to the incorporation of multiple methods to assess the degree of error.

Resources to Guide Selection of Dietary Assessment Tool

There is a wide range of methods and tools available for dietary assessment, ranging from traditional pen and paper methods, to biomarkers, to innovative techniques. Even within these groups, there are more divergences in the approaches available, and even more tools within these approaches. Choosing the correct technique, whether it be a single method or a combination of tools, requires researchers to consider the population it is targeting, what element or multiple elements of diet is being assessed, and the extent of the data collection taking place. Because of the many nuances that exist both in the aims of dietary assessment and in the tools available, a number of resources have been developed to help document the techniques and tools available, with the aim of guiding researchers to choosing the most appropriate method for their research goal.

One such resource is the Diet, Anthropometry and Physical Activity (DAPA) Measurement Toolkit (https://dapa-toolkit.mrc.ac.uk/), supported by both the NIHR and the UK MRC among others. The DAPA tool-kit is a free online resource, designed for use by researchers to help select the most appropriate methods to assess either diet, anthropometry of physical activity. It is not with the aim of promoting one single technique, but instead provides comprehensive information to end-users on the tools available and their appropriateness in different settings [38]. This is similar to the Dietary Assessment Primer (https://dietassessmentprimer.cancer.gov/) provided by the NIH National Cancer Institute [82]. Both tools also aims to improve user's ability to interpret and use existing data relating to dietary techniques, allowing the user to then reach their own decision on the most appropriate technique for their current research or study. DAPA does not provide information on innovative techniques (The Dietary Assessment Primer provides some, although it is not extensive), but instead focuses on the merits of different traditional reporting methods and dietary biomarkers. The "method selector" in DAPA (https://dapa-toolkit.mrc.ac.uk/diet-individual-analysis-decision-matrix) is a particularly useful tool for rapid assessments of the different qualities of traditional subjective and objective approaches. Set out in a simple table, it provides direct comparison on a number of different qualities of the methods, including the costs, burdens, dietary elements assessed and risk of introducing bias.

Nutritools (https://www.nutritools.org/) is another resource that aims to guide users in choosing the best available tool for dietary assessment given their study characteristics and research goals [29]. Nutritools is a UK MRC funded resource, developed by DIET@NET, a partnership of academics across 8 UK universities with the aim of improving the collection and comparability of dietary data [23, 28]. Part of the development of Nutritools included setting out best practice guidelines, determined by a Delphi technique involving the contribution of 57 experts from across the globe [28]. These best practice guidelines are available on their web-page, along with a "Tool Library" providing detailed information on the tools available including features, considerations and validation studies [29]. Unlike DAPA and the Dietary Assessment Primer, there is a greater focus on emerging technologies, making it an incredibly useful resource going forward in collecting data on dietary intake.

Resources that have been developed that may prove useful when selecting biomarkers are The Food Biomarkers Alliance (FoodBAll) (foodmetabolome.org) and The Biomarkers of Nutrition for Development (BOND) program. FoodBall is a JPI-funded project involving collaboration of multiple experts in the field of metabolomics who help maintain the page. The aim of FoodBall is to aid and document the discovery and validation of biomarkers for food intake, and provide updates in the field of food metabolomics [83]. The FoodBall website documents those biomarkers which have been validated in population studies, biomarkers which can be used as surrogates for foods and food groups, and tentative biomarkers [40]. Finally, the Biomarkers of Nutrition for Development (BOND) program run by the National Institute of Child Health and Human Development at US Department of Health and Human has developed six reviews harmonising decision making on the best biomarker for 6 nutrients [84, 85]. These reviews are for iodine, vitamin A, iron, folate, vitamin B12 and zinc [86-91].

3. Conclusions

The opportunities for collecting dietary data in the CLS cohorts is vast, and with the advent of modern technology the possibilities to asses intake in novel and innovative ways is ever expanding. Many of the methods that exist today and utilise technology - such as PDA's, web based, interactive computer and mobile based technologies - still incorporate elements of the traditional pen and paper methods but are presented in a new format. Other novel technologies such as scan and sensor, and camera and tape recorder technologies have developed new ways to measure and assess dietary intake. It is important to note however, that even within these categories of new technologies there is considerable overlap, as different elements and approaches to dietary intake are incorporated into each other.

Additionally to approaches utilising technology, development in the field of metabolomics and biomarker discovery has opened up the possibility to objectively measure elements of dietary intake. Some biomarkers may be feasible to incorporate into large studies depending on the specimen required and the method used to analyse it. However, many biomarkers are currently impractical and/or costly when used on a large scale, but there is potential to incorporate them into sub-studies to act as a calibration tool for other assessment methods.

Choice of dietary assessment should be influenced by several different factors relating to the study and aim of data collection. Incorporation of multiple methods may result in dietary assessment that is closer to the true intake, but may be limited by costs and time. Equally, multiple administrations of the same method may place unnecessary burden on the participant and result in decreased accuracy of reporting or decreased response rate. Utilising available resources that provide up-to-date information about the currently available methods and their validation is good starting point to determine the most suitable method.

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