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# Dietary intake measurements

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## Abstract

*Objective:* To provide a concise summary of field and laboratory methods for the measurement of dietary intake with particular reference to the assessment of energy and protein intake and to the pitfalls and difficulties that may be encountered in practice when implementing the methods both in the field and under laboratory conditions.

**Keywords**
Dietary intake methods
Measurement error
Biomarkers
Energy
Protein
Habitual

## Review of basic concepts

*'It is easy to ask what people eat, but finding an answer can be a daunting task (Helsing, 1991)[1]'.*

### *What is dietary intake?*

Dietary intake is generally considered to include all foods and beverages (hereafter referred to as food) consumed by the oral route. Items that are not considered as foods such as dietary supplements and condiments, which contain energy and/or nutrients, should be, but are not always, included as part of dietary intake. When such items are omitted from assessments of dietary intake it is usually because of difficulties with identification, quantification or lack of information about their composition.

### *Why measure dietary intake?*

In many, but not all, instances the underlying purpose in measuring dietary intake, whether for an individual or for a group, is to obtain quantitative information on the amounts of energy and nutrients available for metabolism. This objective is indirectly met by measuring dietary intake.

This is because dietary intake is measured in terms of food intake and not in terms of energy and nutrient intake and because the amounts of energy and nutrients derived from measurements of food intake, at best, are the amounts of energy and nutrients found in food and not necessarily the amounts available to the individual for metabolism. Dietary intake measurements, therefore, only provide a guide to, and not a direct measure of, the amounts of energy and nutrients available for metabolism. They do, however, provide the best way of describing the actual food intake of both individuals and groups.

### *Day-to-day variation*

The food intake of individuals is not a static quantity. It varies both in type and amount from day to day, from week to week and from year to year. In general quantitative measurements of dietary intake can only be made over very short periods of time. This means that such measurements are unlikely to reflect the long-term *habitual* intake of individuals that for most purposes is the timeframe of interest.

When dietary intake data are used in order to assess the adequacy of energy or nutrient intake in relation to requirements it is important that short-term measurements are always adjusted for within-person variation in intake. This is possible, for group data, when at least 2 days of information are obtained from the same individuals. For assessment of relationships between nutrient intake and health status in individuals' long-term data on intake are always necessary. Methods designed to obtain a 'history' of intake over a longer period of time may relate to intake over the past month or the past year and can usually only provide semi-quantitative information on food and beverage intake.

### *One measurement – or many?*

Even a short-term measurement of dietary intake (24 hours) usually involves the collection of data for between 10 and 40 different food items each of which has to be described and its quantity measured or estimated. In effect a measurement of dietary intake represents not one but many related but essentially independent measurements.

A consequence of this situation is that different aspects of dietary intake are estimated with varying levels of precision and accuracy. Similarly, the precision and accuracy of estimates of energy and nutrient intake, obtained from a measurement of dietary intake, can also be expected to vary.

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### *Measurement error*

> *'There is not, and probably never will be, a method that can estimate dietary intake without error (Beaton 1994)[2]'.*

*The nature of error*

The fact that there is error in dietary measurements does not mean that dietary data should not be collected but simply that dietary data need independent validation and that it is important to determine the nature of the errors associated with dietary data in order that these can be taken into account in evaluating the data. Basically errors are of two types: random errors and systematic errors.

Random error increases the variance of the dietary estimates and consequently reduces their precision. The effects of random errors can always be reduced by increasing the number of observations. For example, the effect of day-to-day variation in food intake can be reduced by increasing either the number of days of observation on each individual or the number of individuals for whom data are collected.

In contrast the effects of systematic error cannot be reduced by increasing the number of observations. Systematic error arises from errors that are non-randomly distributed in a group or in the data from a given individual. For example, use of inappropriate nutrient composition data for some food items but not others will affect the food intake data for different individuals in different ways. Systematic errors lead to bias in the estimates of intake obtained.

*Precision/repeatability*

In the laboratory the precision of a method is given by the coefficient of variation of repeated determinations on the same sample made under the same conditions. In the context of dietary studies we determine whether the same method gives the same answer when repeated in the same individuals. The terms repeatability and reproducibility are commonly used to describe the precision of a method. It is important to note that it is possible for a method to have high precision (good repeatability) but yet not to provide an accurate (valid) estimate of intake.

*Accuracy/validity*

An accurate method is one that measures what the method intends to measure, i.e. the 'truth'. In the context of dietary studies 'the truth' represents the actual intake over the period of the study. For example, a valid dietary record is a complete and accurate record of all the food consumed over the period of the record. To be a valid record of *habitual* intake it also needs to reflect what would have been consumed if the individual had not been keeping a record. If the process of recording influenced what was eaten then the record is not a valid record of *habitual* intake over the period although it may be a true record of *actual* intake over the period.

Except for short-term dietary assessments that can be validated against direct observations of intake (made unknown to the respondent) it is not possible to determine the validity of a dietary method without the use of an independent (non-dietary) measure of intake.

## Laboratory methods of assessing dietary intake

Eating is an integral part of everyday life and consequently it is not possible to assess what people eat *habitually* under controlled or laboratory conditions. It is possible to measure accurately and precisely what people eat under such conditions but not what they would choose to eat if they were not placed in a laboratory situation.

### *Laboratory-based dietary studies*

In a laboratory study of dietary intake the individuals whose food intake is being assessed have access only to foods that have been prepared under known conditions and for which the energy or nutrient composition has been determined by chemical or other appropriate analytical methods. In such studies the individuals may 'live' in a metabolic facility for the period of the study or they may live at home and take their meals in the metabolic laboratory. In either case the amount of all foods provided to each individual is carefully measured and recorded prior to consumption and any food that is not eaten is also carefully measured and recorded.

This approach in assessing dietary intake enables precise estimation of the amounts of energy and nutrients that are ingested by an individual over a fixed period of time. Additional measurements are needed to determine the proportion of the ingested nutrients that is available for metabolism.

### *Analysis of foods consumed*

Determination in the laboratory, by chemical or other methods, of the energy and nutrient content of the food and beverages that have been consumed by an individual, can also be considered under the heading of laboratory methods. This approach allows accurate determination of the energy and nutrient content of the actual foods consumed by individuals eating their *habitual* diets. The accuracy of the food intake information on which the analysis is based is, however, not assessed by this approach.

There are three ways in which foods that have been consumed may be sampled for analysis. The first approach is to collect a duplicate portion of all foods consumed during the period of the dietary record. The second approach is to collect only samples of the food consumed for analysis. The third approach is not to sample the foods that have actually been eaten but to reconstruct a composite from the record of the foods that have been consumed during the period of the dietary record and to analyse this. For the latter approach to be effective the

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dietary record must provide adequate detail not only of the types of foods consumed but also details of the way in which they were prepared for consumption.

### *Markers of energy and nutrient intake*

It is now widely recognised that in order to assess the validity of any dietary assessment, including weighed records, it is necessary to compare the dietary data with one or more objective measures that reflect but are independent of food intake. For groups such measures may include food supply and/or expenditure data but at the individual level the measures are biochemical or physiological markers that reflect energy or nutrient intake. Measures that have been used for this purpose include energy expenditure, urinary breakdown products of protein, urinary sodium and potassium, plasma levels of vitamins and tissue levels of minerals and fatty acids[3].

The three measures most widely used as independent assessments of dietary intake are urinary nitrogen as a marker of protein intake, energy expenditure as measured by doubly labelled water to compare with energy intake (EI) in weight stable individuals and the ratio of EI to basal metabolic rate (BMR) to identify 'plausible' records of food intake. The EI/BMR ratio is not strictly a laboratory assessment of 'intake' but provides a way of comparing an estimate of intake with an independent but related measure, i.e. an estimate of BMR.

#### *Urinary nitrogen*

Similar to the 24-hour recall, a single 24-hour urine collection does not necessarily reflect what is *habitual*. However, urinary nitrogen excretion is less variable from day to day than dietary protein intake; and while around 2 weeks of food intake are needed to assess *habitual* protein intake, only eight 24-hour urine collections are needed to assess nitrogen excretion with the same level of confidence[4].

Although fewer 24-hour urine collections may be needed urine collections are, in general, no more acceptable to respondents than 24-hour food records, may be incomplete and require access to laboratory facilities. Nevertheless they can provide, subject to appropriate checks, a practical and independent assessment, of protein, potassium and sodium intake.

Correlations between urinary N and dietary N measured by food record are better (0.65–0.79) than between urinary N and dietary N measured by food-frequency questionnaire (0.15–0.24)[5].

#### *Doubly labelled water method*

The doubly labelled water method (DLW) is described elsewhere in this report. Its use in the field of dietary assessment is based on the following relationship:

$$\text{Energy expenditure(EE)} = \text{Energy intake(EI)} \pm \text{change in body energy reserve}$$

Over periods when there is no, or only minimal, change in the body energy reserve the DLW method allows, for the first time, assessment of energy expenditure (and by equivalence energy intake) in free-living subjects over a period of one or more weeks. The method involves minimal inconvenience to the subject and has a high level of accuracy and precision. Under controlled conditions the DLW method gives a small overestimate of 2–3% when compared with whole body calorimetry and under field conditions the bias is not expected to exceed 5%[6–7].

A number of investigators have compared self-reported dietary EI with energy expenditure determined by DLW. In these studies, differences between the measured EI and expenditure have varied from −44% to +28% in different population groups[8]. This large range of variation confirms the need to include an independent assessment of EI in all dietary studies to ascertain the level of bias applicable to the particular group under study since it is not readily predicted on the basis of gender, age and body mass index.

The main advantage of the DLW method is that it makes minimal demands on the respondents and does not in any way interfere with their normal daily activities and therefore with the *habitual* level of energy expenditure. Its main disadvantage, at this time, is its cost and the need for access to sophisticated laboratory equipment for mass spectrometric analysis. The method is, therefore, not yet available for use on a routine basis for validation of dietary intake data in respect of EI.

#### *EI/BMR ratio*

Because of the current cost limitations of the DLW method the EI/BMR ratio has been used as an alternative approach in comparing EI from dietary studies with an independent estimate of 'expected' energy requirements. The relevant relationship in this case is:

$$\text{EI:BMR} = \text{EE:BMR (physical activity level or PAL)}$$

EI/BMR is used to determine whether a reported level of EI is a 'plausible' estimate of the actual diet during the measurement period (i.e. likely to represent habitual diet) based on an equation developed by Goldberg and colleagues[9]. This equation calculates the 95% confidence limits of agreement between EI:BMR and PAL allowing for variation in EI, BMR, and PAL and also for the length of the dietary assessment period and the number of observations.

For a group, if the mean reported EI:BMR is below the lower 95% confidence limit for the specific study period and sample size, then this is an indication of bias towards

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under-estimation of EI. Identification of individual under-reporters is much more difficult since reported EI can deviate quite markedly from energy expenditure before it falls outside the limitations of the methods. To improve the identification of individual under-reporters it is necessary to have additional information to enable subjects to be classified into different levels of activity[10].

## Field methods for assessing dietary intake

Most methods used to measure dietary intake are field methods in the sense that the information is obtained either at the home of the individual concerned or from an individual who is free-living and not subject to laboratory restrictions.

It is possible to classify the most commonly used field methods for measuring dietary intake in a number of different ways. For the purpose of this report the methods are classified into those that record intake as it occurs (records) and those that recall intake after it has occurred (recalls).

Irrespective of the specific method used to obtain the information on food and beverage intake all dietary assessments involve the five basic steps illustrated in Fig. 1[11]. The figure also illustrates the main variations possible for each method and the sources of error that may operate at each step.

### *Records*

Dietary records can be of several types:

- Records can be descriptive or quantitative.
- If quantitative the amounts can be estimated in household measures, by photographic means or by actual weighing of all the foods consumed over the period of the record.
- The person who records the intake may be the person whose intake is being recorded or it may be an external observer.
- The information on food intake can be converted to nutrient intake by means of food composition tables, by analysis of samples of the foods consumed or by laboratory analysis of a duplicate diet.

#### *Menu record*

The simplest form of dietary record is a menu record. This type of record only records the types of food consumed and the frequency with which they are consumed but not the quantities in which they are consumed. Since it requires relatively little input from the respondent it is possible for such a record to be kept for a longer period of time than one that requires quantities to be measured or estimated. Menu records are mainly useful for determining food intake patterns over time and for assessing compliance with dietary advice. Their principal disadvantage is that it is not possible to use them to derive an estimate of nutrient intake without additional information on portion size.

#### *Estimated record*

Estimated records require the respondent (or another person) to record all food consumed over a specified period of time, generally for between 1 and 7 days. Unless the record involves analysis of a duplicate portion, the foods consumed must be described in sufficient detail to allow the investigator to select an appropriate food from tables of food composition or for laboratory analysis.

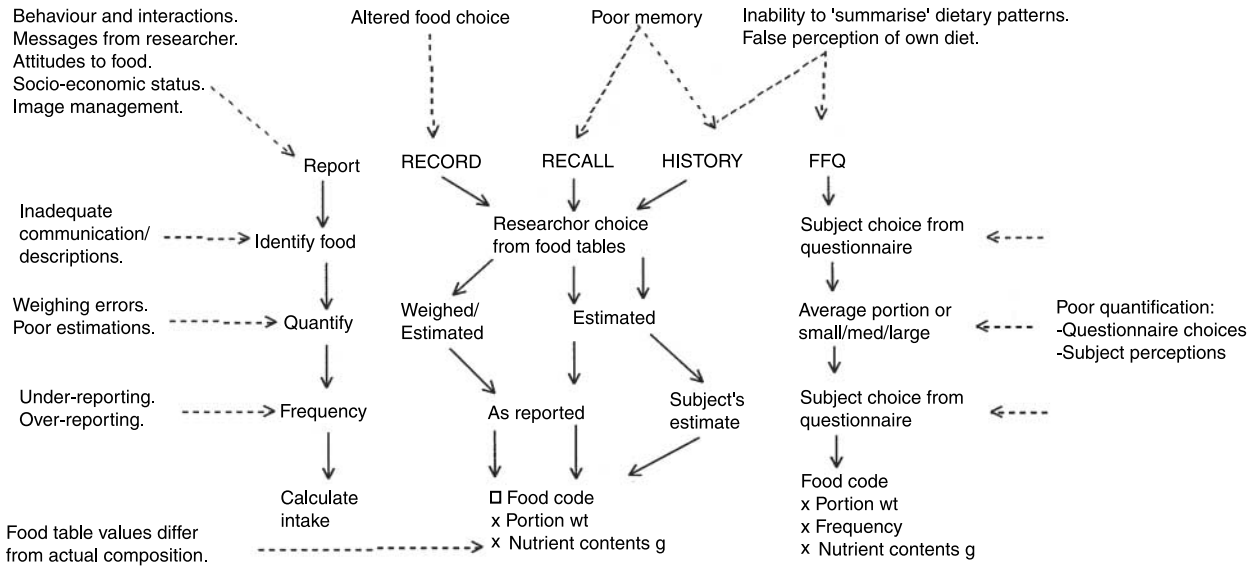


**Fig. 1** The process of dietary assessment (Source: Black, 1999)[11]

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The record must also provide information on the amounts of the foods that have been consumed. This may be done in terms of the measures usually used in the household (jugs, cups, bowls, spoons) in which the data are being collected or by means of a set of standard measures. If the former approach is used the household measures need to be calibrated by the investigator. In addition to household measures two-dimensional representations of different shapes may also be used to assist the investigator to convert area and volume descriptions to estimates of mass.

An alternative approach to quantitation is for respondents to photograph the food to be consumed, prior to consumption. A reference plate of known size or other reference object is included in the photograph to allow subsequent estimation of portion size from the photographic record.

The principal advantage of records estimated in household measures is that they involve less disruption to normal eating patterns than the weighing of food and as a result have less effect on usual food habits. Estimating rather than weighing the foods consumed leads to a loss of precision but the magnitude of this effect is not well documented[12].

*Weighed record*

A weighed record can be either a record of food as it is consumed (*weighed inventory*) or a much more detailed record of the weights of ingredients, final cooked weights of prepared foods, the weights of foods eaten and any plate waste (*precise weighing method*). The latter approach is used when tables of food composition contain little information on mixed dishes and when it is possible for the information to be collected by the investigator. Weighed records kept by the respondent usually use the weighed inventory method and are kept for periods of only 1–4 days because of the high respondent burden involved.

Weighed records have the potential to provide the most accurate description of the types and amounts of the foods actually consumed over a specified period of time. However, weighing all food is time-consuming and the method requires a high level of cooperation from respondents. In most individuals the method probably affects the amounts and kinds of food eaten. While the method may accurately reflect *actual* intake during the record-keeping period, this intake may not reflect *habitual* intake.

### *Recalls*

Dietary recalls can be of several types:

- Recalls can be quantitative, semi-quantitative or in terms of frequency.
- If quantitative the amounts consumed can be described in household measures, by reference to photographs or three-dimensional food models, or simply in terms of small, medium or large portions.
- Recalls can relate to specified (yesterday) or to indefinite periods of time.
- Recalls can refer to short (e.g. 24 hours) or to extended periods of time such as the previous year or longer.
- The information on food intake may or may not be converted to nutrient intake. If converted to nutrient intake it may be presented in terms of categories (e.g. high, medium or low) rather than as absolute estimates of intake.

*24-hour recall*

The 24-hour recall is the most widely used method for obtaining quantitative recall data. The period of recall can be longer than 24 hours but is usually restricted to this length of time because of the difficulties that individuals have in being able to recall, in sufficient detail, what and how much food was eaten over longer periods of time.

A 24-hour recall is usually conducted by means of an interview during which the respondent is asked to provide a recall of all food eaten, most often, over the previous 24 hours. Traditionally, food intake has been reviewed chronologically but more recently a 'multiple pass' technique has been described which is considered to provide better cues for respondents' cognitive processes than chronological cues[13,14]. First the respondent provides a list of all foods eaten on the previous day using any recall strategy they desire, i.e. not necessarily in chronological order. The interviewer then obtains a more detailed list by probing for additions to these foods and by giving respondents an opportunity to recall food items initially omitted from the list. Finally, the interviewer reviews the list of foods to allow yet further reports of foods and eating occasions to be added if appropriate.

Recalls conducted by means of a face-to-face interview usually use aids such as food photographs or models to help the respondent with the task of describing the amount consumed. In telephone interviews respondents may be provided with photographs of food portions and two-dimensional pictures of areas and volumes to assist with quantitation.

The main advantages of the 24-hour recall are that it generally has a higher response rate than recording methods, can provide detailed information on food intake and is suitable for use in face-to-face, telephone and computer assisted interviews. The principal disadvantages are that the method cannot provide information on *habitual* intake, unless it is repeated on multiple occasions, and it may not be suitable for some groups who are unable to describe food eaten from memory.

*Diet history*

The diet history method does not involve recall over a specific period of time, rather it attempts to obtain a

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semi-quantitative picture of typical or *habitual* intake as reflected by intake in the immediate past. As first proposed by Burke[15] in the 1940s, the method had several components:

- An interview to obtain usual diet.
- A cross-check of this information by food group.
- A 3-day record of food intake in household measures.

The 3-day record is now seldom used as a regular component of a diet history. During the interview the investigator attempts to construct the respondent's pattern of intake over a period such as a typical week or fortnight and if appropriate any seasonal variations. Often a recall of intake on the previous day is used as the starting point for elaborating the usual variations in meal pattern and food intake. A diet history interview generally takes at least an hour and requires an interviewer with the skills to help respondents recall their intake freely and fully in a non-judgemental atmosphere. Information on the usual size of food proportions is obtained with the aid of food models or photographs in the same way as for a 24-hour recall. The dependence of the diet history on both respondent and interviewer skills may make the results less comparable between individuals than those obtained from other methods and for this reason it is often considered more appropriate to categorise diet history data (e.g. as high, medium, low) than to present them as absolute intakes.

The main advantage of the diet history method is that, if successfully carried out, it can provide an estimate of *habitual* intake for individuals. Its principal disadvantages are the time and skills required by both interviewers and respondents and the semi-quantitative nature of the data obtained.

*Food-frequency questionnaire*

A food-frequency questionnaire is basically a list of foods with a selection of options for reporting how often each food is consumed. Typical options include: daily; 3–4 times per week, 1–2 times per week, 1–2 times per month, <1 per month and never.

Respondents indicate the most appropriate frequency option for each of the foods on the list by marking the appropriate column in the questionnaire. The food list may contain only a few items or it may contain up to 200 items. The length of the list depends largely on the focus of the questionnaire. A questionnaire designed to capture a high proportion of total EI will necessitate a much longer list than a questionnaire designed to capture the same proportion of total calcium intake.

Food-frequency questionnaires are almost always designed for self-completion. This is because they were developed primarily as a practical and cost-effective way of collecting long-term dietary intake data from large numbers of respondents. When appropriately designed such questionnaires can be optically scanned to save time both on data entry and checking procedures.

Some food-frequency questionnaires attempt to quantify the frequency information by obtaining additional data on portion size. This information may be obtained by asking respondents to indicate if their usual portions are large, medium or small relative to those eaten by others; by asking them to describe their usual portion size in terms of a standard portion described on the questionnaire or by reference to a picture atlas of food portions[16,17].

Food frequency questionnaires provide a relatively inexpensive and standardised way of collecting information from a large number of individuals. Their main disadvantages lie in the lack of detail that can be obtained about foods, the semi-quantitative nature of the data, and the large random errors. The latter most likely reflect the complex nature of the task that respondents completing a food frequency questionnaire are asked to perform.

## Which method of dietary assessment?

It is not possible to decide which method of dietary assessment to use until the purpose of a study has been clearly defined. The purpose for which the data are being collected governs both the kind of information that is needed and the time for which it needs to be collected from each individual. The purpose of the study also determines the level of precision that is needed in order to meet the study objectives and therefore the size of the sample. Both the method and sample size have major implications for the human and economic resources required for the study.

### *Group comparisons*

When dietary data are collected in order to describe the diet of a group for comparison with another group or groups, it is possible to use either a short-term method such as a 24-hour recall or record, or a long-term method such as food records obtained over several days, a diet history or a food frequency questionnaire. The choice of method in this situation will depend on the importance of obtaining a representative sample, the level of precision required and the resources, both human and economic, that are available. Usually the most efficient approach is to measure the diet of as many individuals as possible for a single day[18]. This is the approach usually adopted for national surveys. In such surveys both high response rates and detailed quantitative information are important because the dietary information is used for a wide variety of purposes[19].

### *Prevalence*

If the purpose of the dietary study is to determine the proportion of individuals in a population or population sub-group who are 'at risk' of dietary inadequacy or excess, then a single day of information on each individual

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is no longer adequate because what is required is a reliable estimate of the distribution of *habitual* intake for the group. In order to determine the distribution of *habitual* intake for a group at least 2 (preferably not consecutive) days of information are required from each individual. Alternatively if several days of information are available from each individual they can be used to derive a mean intake for each individual and from this the distribution of average intakes for the group.

In large surveys, e.g. national dietary surveys, where it may not be possible to obtain more than 1 day of intake from most of the population, the data necessary for statistical adjustment for within-person variation can be obtained from representative sub-sample(s) of the population and applied to the 1-day intake data for the groups represented by the sub-samples[20,21].

While the use of statistical techniques, to remove the effect of day-to-day variation in intake can greatly improve estimates of the proportion of individuals above/below cut-off levels of interest, it is important to note that this type of adjustment does not enable the actual 'at risk' individuals to be identified.

### *Individual diets*

When the purpose of a study is to assess the diet of specific individuals it is necessary to obtain dietary information over at least a week and preferably longer. In studies or situations where information on the usual pattern of food intake rather than precise quantitative information on nutrient intake is required, e.g. in clinical practice the diet history is often used for this purpose. Because a diet history requires time, a skilled interviewer and respondents with the ability to describe their *habitual* diet from memory it is not a method that is readily applied to large randomly selected samples of the population.

Long-term information about an individual can also be obtained using multiple 24-hour recalls, or 24-hour food records, over an appropriate period of time, e.g. to allow for seasonal variation. The minimum number of days needed to obtain an estimate of energy or nutrient intake, with a specified level of confidence, differs for different nutrients. A reliable estimate of EI, which tends to show less day-to-day variation than other nutrients, can be obtained over a shorter period of time (a few days) than an equally reliable estimate of vitamin A intake (several weeks), for which intake is much more variable from day to day[22]. For this reason dietary assessment alone is usually not adequate to provide reliable estimates of *habitual* intake, in individuals, for nutrients with high day-to-day variability in intake.

### *Epidemiological studies*

Epidemiological studies that include dietary assessments are generally concerned with establishing whether specific dietary components or types of foods contribute to the occurrence, development or prevention of specific conditions. The conditions may be short-term, e.g. food poisoning or chronic conditions, e.g. cardiovascular disease that develop over an extended period of time. In the case of short-term conditions such as food poisoning the focus of the dietary assessment is also short-term, e.g. foods eaten in the preceding 12–48 hours and presents no particular problems with recall.

In the case of chronic conditions the information on diet also needs to be long-term. Moreover the studies usually involve large numbers of individuals who are often widely distributed geographically. Food-frequency questionnaires were specifically developed to address these needs in a practical way[23] since they can be delivered by mail, completed in less time than a diet history, processed electronically and repeated at regular intervals. They can also be readily modified to obtain information on intake for varying periods of time.

The accuracy of the information obtained from food-frequency questionnaires clearly depends very largely on the ability of respondents to answer the questions accurately, but is not easy to assess[24]. Comparisons of nutrient intake data from food-frequency questionnaires with similar data obtained by other dietary methods often show only limited agreement at the individual level and lower precision than multiple short-term recalls or records[25–27]. For this reason it may be preferable to restrict the use of food-frequency questionnaires to providing information on the long-term intake of a limited number of foods/food groups rather than to use them to derive quantitative estimates of nutrient intake for individuals.

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