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Research strategies in human biology: field and survey studies

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6 *Nutritional studies in biological anthropology*

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Nutritional studies in biological anthropology are varied in type. They may be directly concerned with nutritional factors and the way that they affect different aspects of human population biology or ecology, or they may be concerned with nutritional adaptation (Haas and Pelletier, 1990). Regardless, some knowledge is needed of nutritional state of either the whole community, or some sector of it. There are various ways in which this can be obtained, and this chapter will be concerned with the description and evaluation of methods that are likely to be of particular interest to anthropologists and human biologists. Details about sampling and analysis of data will not be considered, since these are discussed elsewhere in this book.

A number of volumes have been written about nutritional assessment; most have been concerned with identifying the role of nutritional factors in health problems (Jelliffe, 1966; Mason *et al.*, 1984; Jelliffe and Jelliffe, 1989; Gibson, 1990; Willett, 1990), whilst only two have considered the usefulness of nutritional studies in addressing anthropological problems (Johnston, 1987; Pelto *et al.*, 1989). A good starting point is therefore to consider the types of question that an anthropologist might ask, which would need some understanding of an individual's or population's nutritional state.

Anthropological questions

Nutritional assessment has been defined as the interpretation of information obtained from dietary, biochemical anthropometric and clinical studies, in determining the health status of individuals or populations as influenced by their intake and utilisation of nutrients (Gibson, 1990). For an anthropologist, this is not an end in itself; rather, knowledge of nutritional state based on current beliefs about nutritional assessment can be used to examine aspects of human adaptability and responses to stress under differing physical and cultural circumstances and environments. Further, the existence of nutritionally related health problems in communities and populations can be quantified and statistically analysed, allowing rigorous comparisons to be made between subgroups of a population,

or between populations. In this manner, anthropologists have examined nutritional factors as possible explanatory variables in studies of human biology and behaviour.

Amongst the nutrition-related questions that are of interest to biological anthropologists are the following: undernutrition, specific nutrient deficiencies, or obesity in relation to between-population differences in the utilisation of specific nutrients, socio-economic status, modernisation, and subsistence and disease ecology. In addition, there is considerable interest in the relationship between food intake, nutritional status, susceptibility to infectious disease, and the physical growth of children. With such broad areas of interest, the methods of nutritional assessment to be used will depend on the question in hand.

Nutritional assessment

Methods available for nutritional assessment vary in degree of complexity, expense and invasiveness. Some measures are easier or cheaper to make than others; this does not make their use any less sophisticated than more complex or more expensive methods, since the interpretation of nutritional data is always a complex matter.

Nutritional studies carried out by anthropologists can be divided into two main types: those concerned directly with food consumption, and those concerned with nutritional status. There are a number of techniques that can be used:

Food consumption:

- Twenty-four-hour recall
- Estimated food record
- Weighed food record
- Dietary history
- Food frequency questionnaire

Nutritional state:

- Anthropometric
- Body composition
- Biochemical
- Immunological
- Clinical

For the first type of study, it may be of interest to know about the types of food eaten by different sectors of a community, whether this differs across seasons, between age-groups, by gender or by reproductive status. Further, if such a study is sufficiently detailed, it may be possible to infer something about nutritional state from weights of foods eaten and the

nutrient content of those foods, and by comparing these with recommended daily allowances for nutrients in question. Studies of food and nutrient intakes are usually carried out in association with other types of nutritional assessment, however. For the second type of study, the methods vary in the extent to which they are direct measures of current nutritional state, or indirect measures of past nutritional state. Indirect measures involve the measurement of 'outcome variables', which are the results of past nutrition.

Dietary methods

There is no single, ideal method for gathering dietary intake data. There is no merit in using a more elaborate or expensive method than is needed to obtain the quality of data needed to meet the defined objective of the study. A broad generalisation is that the more detailed the desired data, the more time consuming and expensive is the method needed. No dietary method is free from error, the more detailed methods being subject to types of error different from the less detailed methods. Table 6.1 gives the uses and limitations of the more commonly used methods to assess the food consumption of individuals.

Of these methods, all except the food frequency questionnaire can be used to estimate nutrient intakes. The weighed food method is the most accurate, followed by that of estimated food record. The most appropriate method depends upon the information needed, however (Table 6.2). All of these methods involve errors, and some may affect the food consumption behaviours of the subjects during the period of study. Certainly, the more invasive the method, the more likely is behaviour to be modified.

A number of authors have examined between- and within-subject variation in nutrient intake, in attempts to estimate the number of days necessary to estimate true intakes (Beaton *et al.*, 1979; El Lozy, 1983; Sempos *et al.*, 1985; Willett *et al.*, 1985; Nelson *et al.*, 1989).

Black *et al.* (1983) have suggested a formula that uses within-subject CV to calculate the number of days of dietary measurement needed to estimate an individual's true intake of a nutrient, with a specified degree of error:

$$D = \frac{r^2}{1 - r^2} \times \frac{Sw^2}{Sb^2} \quad (6.1)$$

where D = the number of days needed per person, r = the unobservable correlation between the observed and true mean nutrient intakes of individuals over the period of observation, Sw = the observed within-

subject coefficient of variation, and Sb = the observed between-subject coefficient of variation.

Equation (6.1) can be used to calculate the minimum number of days of study needed to estimate the intakes of the nutrients of interest, at a chosen level of accuracy. Even if these calculations were carried out *post hoc*, they would be of value for the interpretation of the data collected. For example, if a seven-day weighed dietary intake study had been carried out, and the use of equation (6.1) at $r > 0.9$ showed that the minimum number of days of measured intake needed to estimate energy intake was five, whilst that for vitamin A was 12, then confidence could be expressed for the measurement of intake of the former nutrient but not the latter.

In addition to the problems associated with the use of the methods described in Table 6.1, there are other considerations, such as the sampling method and the need to disaggregate the data by age and sex, which can influence estimates of food and nutrient intake. Further, food preparation techniques can effect the nutrient composition of foods eaten, whilst the non-recording of non-food items of nutritional significance can result in errors of estimate. Table 6.3 gives a summary of the problems associated with these factors.

Anthropologists carry out dietary studies on different units of human organisation, as shown in Figure 6.1. These levels include the individual, the household, band or community subgroup, the community, and the

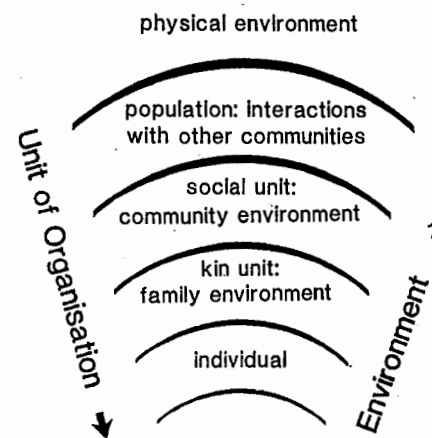


Figure 6.1. Nested character of human organisation and environment (after Foley, 1987).

Table 6.1. *Uses and limitations of commonly used methods to assess the food consumption of individuals*

Method and procedures	Uses and limitations
<p><i>Twenty-four-hour recall</i> Subject or caretaker recalls food intake of previous twenty-four hours in an interview. Quantities estimated in household measures using food models as memory aids and/or to assist in quantifying portion sizes. Nutrient intakes calculated using food composition data.</p>	<p>Useful for assessing average <i>usual</i> intakes of a large population, provided that the sample is truly representative and that the days of the week are adequately represented. Used for international comparisons of relationship of nutrient intakes to health and susceptibility to chronic disease. Inexpensive, easy, quick, with low respondent burden so that compliance is high. Large coverage possible; can be used with illiterate individuals. Element of surprise so less likely to modify eating pattern. Single twenty-four-hour recalls likely to omit foods consumed infrequently. Relies on memory and hence unsatisfactory for the elderly and young children. Multiple replicate twenty-four-hour recalls used to estimate <i>usual</i> intakes of individuals.</p>
<p><i>Estimated food record</i> Record of all food and beverages as eaten (including snacks), over periods from one to seven days. Quantities estimated in household measures. Nutrient intakes calculated using food composition data.</p>	<p>Used to assess <i>actual</i> or <i>usual</i> intakes of individuals, depending on number of measurement days. Data on <i>usual</i> intakes used for diet counselling and statistical analysis involving correlation and regression. Accuracy depends on conscientiousness of subject and ability to estimate quantities. Longer time frames result in a higher respondent burden and a lower co-operation. Subjects must be literate.</p>
<p><i>Weighed food record</i> All food consumed over defined period is weighed by the subject, caretaker, or assistant. Food samples may be saved individually, or as a composite, for nutrient analysis. Alternatively, nutrient intakes calculated from food composition data.</p>	<p>Used to assess <i>actual</i> or <i>usual</i> intakes of individuals, depending on the number of measurement days. Accurate but time consuming. Condition must allow weighing. Subjects may change their usual eating pattern to simplify weighing or to impress investigator. Requires literate, motivated, and willing participants. Expensive.</p>
<p><i>Dietary history</i> Interview method consisting of a twenty-four-hour recall of <i>actual</i> intake, plus information on overall <i>usual</i> eating pattern, followed by a food frequency questionnaire to verify and clarify</p>	<p>Used to describe <i>usual</i> food and/or nutrient intakes over a relatively long time period which can be used to estimate prevalence of inadequate intakes. Such information used for national food policy development, food fortification planning, and to identify food patterns associated with inadequate</p>

Table 6.1 (cont.)

Method and procedures	Uses and limitations
<p>initial data. Usual portion sizes recorded in household measures. Nutrient intakes calculated using food composition data.</p>	<p>intakes. Labour intensive, time consuming and results depend on skill of interviewer.</p>
<p><i>Food frequency questionnaire</i> Uses comprehensive list or list of specific food items to record intakes over a given period (day, week, month, year). Record is obtained by interview, or self-administered questionnaire. Questionnaire can be semiquantitative when subjects asked to quantify usual portion sizes of food items, with or without the use of food models.</p>	<p>Designed to obtain qualitative, descriptive data on <i>usual</i> intakes of foods or classes of foods over a long time period. Useful in epidemiological studies for ranking subjects into broad categories of low, medium, and high intakes of specific foods, for components or nutrients, for comparison with the prevalence and/or mortality statistics of a specific disease. Can also identify food patterns associated with inadequate intakes of specific nutrients. Method is rapid with low respondent burden and high response rate but accuracy is lower than other methods.</p>

From Gibson (1990).

Table 6.2. *The choice of method in relation to the information desired from dietary studies*

Desired information	Preferred approach
Actual nutrient intake over finite time period (e.g. in a balance study)	Chemical analysis of duplicate meals or calculated intake from weighed records
Estimate of 'usual' nutrient intake in free-living subjects	
Group average	One day intake with large number of subjects and adequate representation of days of week
Proportion of the population 'at risk'	Replicate observations of intake or diet history
Individual intake, for correlation or regression analysis	Multiple replicate observations on each individual
Group or individual pattern of food use, proportion of population with particular pattern	Food frequency questionnaire
Average use of a particular food or food group for a group	Food frequency questionnaire or a one-day intake with large number of subjects and adequate representation of days of the week

After Beaton (1982).

Table 6.3. *General problems associated with dietary studies*

Sampling	Is the sample of individuals representative of the group or groups under investigation? Can the sample be disaggregated for analysis to allow comparisons between age groups, sexes, households, or any other unit of study? Is the sampling period representative of habitual intakes over longer periods, such as across a year, or season?
Food preparation techniques	Various preparation methods such as peeling, drying, soaking, fermenting, boiling, baking and frying can have significant effects on the nutrient content of foods. The method of preparation should be recorded, to allow reasonable comparison with food composition tables.
Consumption of non-food items	Consumption of some non-food items, such as betel-nut, salt, spices, herbs and water may be of nutritional significance. When carrying out a study in alcohol-consuming groups, care should be taken to ensure that consumption is not under-reported.

Table 6.4. *Food consumption patterns in different populations*

Country	Group	Pattern
Britain, USA, Australia, Canada	Wage-earners and salaried workers	Five-day work-day pattern of food consumption, two-day week-end pattern of consumption. Low seasonal variation in foods eaten; greater seasonal variation in lower socio-economic classes than in higher socio-economic classes.
Papua New Guinea, Senegal, Kenya, Namibia	Groups practising traditional subsistence methods	Seasonal variation in types and amounts of different foods eaten. It is likely that hunter-gatherers and pastoralists experience greater variation than agriculturalists; amongst agriculturalists, it is likely that wealthier households show less seasonal variation than poorer households.
Chad, Cameroun, Gambia	Groups practising traditional subsistence methods	Seasonal post-harvest gorging practised by some, or all, sections of the community.

population. In general, it is better to collect data at lower levels of organisation if at all possible, since such data can be aggregated once collected. Thus, if all members of a sample of households have been included, and collection has been at the individual level, then the data can be aggregated in various ways; the data might be expressed by age group and sex, or it might be aggregated by household, to allow between household comparisons. It is not possible, however, to infer the intakes of individuals from data collected at the household level, because it cannot be assumed that food will be divided either equitably or equally within the household (Wheeler, 1988). The choice of the sampling period is an important consideration in carrying out dietary studies. Human groups exhibit a number of different food consumption patterns; some of these are given in Table 6.4.

Very few groups show no variation in quantity or types of foods eaten either from day to day, or across seasons. Worldwide, patterns of food consumption are almost universally related to the patterns of subsistence. In an industrialised country such as the United Kingdom, there is less variation in types and amounts of food eaten during the usual five-day working period than there is during the two days of the week-end. Indeed, the patterns of consumption may be dramatically different between the two periods, with greater amounts of more expensive foods being eaten on Sunday, and sometimes large amounts of alcohol being consumed on Saturday. In Papua New Guinea, Ningerum horticulturalists show no variation in intake of energy and protein across seasons, but enormous differences in the sources of those nutrients (Ulijaszek, 1985). In Senegal, Serere pastoralists show seasonal variation in energy intake, and in types of foods used (Rosetta, 1988). This is related to the type of agro-pastoralism that these people practise. Mixed horticulturalists in Chad and Cameroun (de Garine and Koppert, 1990), and agriculturalists in the Gambia (Fox, 1953) engage in post-harvest gorging to a greater and lesser extent, respectively. Dugdale and Payne (1986) have shown this practice in the latter group to be a good strategy of food storage.

Seasonal variation in the types of foods eaten does not necessarily mean that energy intake also varies; in some studies it has been shown to be the same (Ulijaszek, 1985). It is more likely that the intake of other nutrients will vary, however, since different foods have different nutrient profiles.

In carrying out a food consumption survey, it is important to obtain some sort of representativeness of the sampling period. For studies in Britain, a sample period of seven days has been suggested, to take account of the difference between work-days and the week-end. Studies

using such a period are thus believed to be representative of longer time frames. In developing countries, seasonality may suggest that sampling be carried out at different times of year, representative of the different seasons. Generalising from data that have not taken into account seasonal bias can be dangerous. Lee's (1965) study of the !Kung is instructive in this regard. In carrying out a dietary study at a time of year when the high energy, high protein staple mongongo nut was in season, Lee found that intakes of both these nutrients to be high. Lee's data have been used in support of the 'original affluent society' argument put forward by Sahlins (1972), although it has since been argued that nutritional returns for the !Kung are less good at other times of year, when mongongo nuts are less available (Wilmsen, 1978), and when there is the likelihood of energy nutritional stress (Bentley, 1985).

Without carrying out prior investigations, it is often difficult to determine the most appropriate sampling period. There are various ways of arriving at some approximation. Ethnographic, social and nutritional literature may give some clues as to variation in dietary patterns; alternatively, researchers and government officials who have worked with the population of interest may be able to provide important information. If a group is involved in industrial work, this can give some idea of likely day-to-day variation in food intake, whilst rainfall figures for a district in the tropics can give an indication of the extent of climatic seasonality, which can be translated into seasonality of food intake.

Food preparation techniques can affect the nutrient composition of foods eaten, and these are summarised in Table 6.5. If the intention is to examine nutrient intakes from weighed or recalled dietary data, then care should be taken to note how food is prepared, in order to match the description as closely as possible to those given in the food composition tables. Failure to do so could lead to some gross inaccuracies.

The water content of the food can also affect the calculated nutrient content of the diet, particularly when the consumption of one food supplies the majority of the dietary energy intake. A gross difference in water content between that of the consumed food and that of the published value used to calculate the nutrient intake could lead to enormous inaccuracies in estimated nutrient intakes. For example, 19 samples of sweet potato analysed by Norgan *et al.* (1979) varied enormously in their energy and protein contents. When corrected for differences in water content, the coefficient of variation between samples was reduced from 39% to 33% for protein content and from 24% to only 2% for energy.

In some populations, the consumption of non-food items could be of

Table 6.5. *The effect of food preparation techniques on the nutrient composition of foods*

Technique	Example	Possible effects
Peeling	Milling of grain; peeling of potatoes and vegetables	Loss of protein and vitamins which are concentrated in the outer layers of the food; greater concentration of carbohydrate per unit of food stuff in the case of cereals
Drying	Drying of fruits, fish, for storage	Loss of ascorbic acid and B vitamins
Pickling or salting	Vegetables, meat	Loss of vitamins; addition of some minerals in large quantities
Soaking	Soaking of cassava to remove cyanide; reconstitution of dried foods	Loss of water-soluble vitamins due to leaching
Sprouting	Sprouting of mung beans, alfalfa	Increase in ascorbic acid content; greater digestibility of protein
Fermenting	Production of tofu, beancurd, shoyu, from soya beans; production of idli from fermented rice and lentil flour	Increased availability of protein
Boiling	Boiling of potatoes and vegetables	Some destruction of vitamins by heat; loss of water-soluble vitamins due to leaching
Baking	Potatoes, tubers in general, meat	Some destruction of vitamins by heat
Frying	Meat, vegetables	Energy content of food greatly increased due to the addition of fat

nutritional significance. In particular, alcoholic beverages contain energy, and in the case of some traditionally prepared drinks, other nutrients too. Subjects consuming even only small amounts of alcoholic drink that are not reported may have their energy intakes significantly under-reported. Another example is the use of betel-nut as a stimulant. Slaked lime (calcium hydroxide) is needed to liberate the narcotic from the nut, and is frequently chewed with the nut. Swallowing only small amounts of this lime in the course of chewing can contribute substantial quantities of calcium to intake; this could easily be missed by the dietary recorder. Further, habituated betel-nut chewers swallow the chewed substance rather than spit it out. Where this happens, betel-nut could also

Table 6.6. Methods for estimating energy expenditure in largely free-living populations

Method	Sources of error	Measurement error	Feasible duration	Range of activities	Invasiveness
Intake-balance	Small changes in body composition over intake measurement period	2%	24-360+ h	Total daily EE only	High
Douglas bag or portable respirometer	Leaks and gas diffusion from sampling bags	2-5%	0.1-1.0 h	Moderate to high	Moderate to high
Oxylog	Turbine flow meter	2-5%	0.1-0.5 h	Moderate to high	Moderate to high
Doubly-labelled water ($D_2^{18}O$)	Assumed steady state, known evaporative water losses and isotope fractionation rates, known isotope flux between CO_2 , H_2O and other pools	2-6%	72-7200 h	Total daily EE only	Low
Heart rate monitoring	Low or extreme high levels of activity	5-10%	12-72 h	Total daily EE only	Low

EE = energy expenditure.
After Garrow and Blaza (1982).

make an important contribution to protein intake. In studies where trace element intakes are of interest, the consumption of substantial quantities of water, in one form or another, could make important contributions to intakes of calcium or magnesium. In studies of hypertension, the consumption of salt, often disregarded in dietary studies, is of particular interest.

Validation of dietary studies can be carried out by using biochemical markers; these are biochemical indices which give a predictive response to a given dietary component (Bingham, 1984). Examples include twenty-four-hour urinary nitrogen and 3-methyl-histidine excretion as markers of total protein and meat intake, respectively. Although the use of such markers may appear attractive, often single measurements are not adequate to provide accurate estimates of the excretion of the dietary component, however. In addition, standard methods have yet to be widely accepted.

Interpretation of energy intake data will often require estimates of energy expenditure or change in body energy stores. Methods in body composition analysis (see below) enable the latter variable to be studied. In some respects, however, energy studies form a special field in their own right. As with any type of inquiry, the theory of hypothesis to be tested will determine the nature and range of appropriate methods.

Several recent publications review thoroughly the principles underlying techniques of calorimetry (McLean and Tobin, 1987; Blaxter, 1989; Collins and Spurr, 1990) and labelling studies (James, Haggerty and McGraw, 1988; Prentice, 1990). The range of methods likely to be used in human anthropological studies, with an indication of their advantages and limitations, is given in Table 6.6. These methods fall broadly into two groups: those suitable for obtaining estimates of average 24-hour energy expenditure, and those that are appropriate for measuring energy expenditure over periods shorter than one hour.

In general, measurement error falls in the range 2-5%. All methods have been used on free-living populations under non-Western conditions, and have been subject to cross-validation trials by simultaneous measurements on humans, in which the standard of reference has usually been the intake-balance method (Kwarkwarf *et al.*, 1989), the Douglas bag (McNeill *et al.*, 1987; Wenzel *et al.*, 1990), or the whole-body room calorimeter (Seale *et al.*, 1990; Soares *et al.*, 1989).

Equations for predicting basal metabolic rate (BMR) from body weight, with or without other variables, have also been derived. The FAO/WHO/UNU (1985) report, *Energy and Protein Requirements*, advises use of Schofield's (1985) equations. These, however, have been

Table 6.7. *Uses and limitations of commonly used methods to assess the nutritional state of individuals*

Method	Uses and limitations
<p>Anthropometry A combination of measurements including length, height, weight, arm circumference, biceps, triceps, subscapular and suprailiac skinfold thicknesses made on a number of subjects, either cross-sectionally or longitudinally by one or several observers. Comparisons made with standards of variable against age, or accepted cut-offs to judge nutritional state.</p>	<p>Used cross-sectionally in obtaining group estimates of nutritional state, by comparing values for anthropometric measurements with cut-offs obtained from an accepted 'ideal' population. Used longitudinally to assess changes in nutritional state of individuals across time. Limitations include the determination of cut-offs from 'ideal' populations, and defining 'ideal' populations for comparison; some measures are dependent upon knowing the age of children; poor cross-measurement validity of some variables (for example, weight for height and arm circumference). Anthropometry cannot be used to determine the state of a group or individual with respect to specific nutrients.</p>
<p>Body composition Skinfold thicknesses, densitometry, plethysmography, isotope dilution, total body potassium, ultrasound, bioelectrical impedance.</p>	<p>Used to estimate the relative size of different physiological body compartments in order to use them as possible explanatory variables in studies of human functions that are influenced by nutritional state (for example, work output and work capacity, reproductive ecology). Used directly in the study of undernutrition and obesity. All methods apart from skinfold thickness measures and bioelectrical impedance are laboratory-bound.</p>
<p>Biochemistry Measurement of nutrients or their metabolites in biological fluids or tissues, including blood and blood cells, hair, fingernails, urine. Measures of changes in blood components or enzyme activities which are dependent on a given nutrient.</p>	<p>Used to obtain direct measures of specific nutrient status. Tests vary in complexity and cost; some can be carried out in the field, whilst others require specialised laboratory procedures. In the latter case, problems of preservation, transport and storage of samples may arise.</p>
<p>Immunology Delayed cutaneous hypersensitivity, secretory IgA, leucocyte antigenic challenge, complement C3.</p>	<p>Used to measure interactions between undernutrition and infection. Tests cannot detect deficits of individual nutrients.</p>
<p>Clinical examination Physical examination of individual's skin, eyes, hair, mouth, size and shape of parotid and thyroid glands.</p>	<p>Used in identifying extreme pathologies of undernutrition. Some signs are not specific to a deficiency of a single nutrient. Inadequate training in examination techniques or poor standardisation of criteria for judging a sign to be present can lead to inconsistencies in assessments.</p>

From Chandra (1983), Gibson (1990), Telford (1966), Shephard (1991), Weiner and Lourie (1981).

shown to overpredict measured BMR in a wide range of non-Western populations by between 1 and 22% (Henry and Rees, 1991). Thus there is a strong case for recommending direct measurement of BMR in field studies of such groups.

Assessment of nutritional state

A variety of means exists for assessing nutritional state, including anthropometric, body composition, biochemical, immunological and clinical methods. Table 6.7 gives the uses and limitations of methods that are likely to be of use to anthropologists.

Of these, anthropometry, and the measurement of body composition from skinfold thicknesses, are the most widely used methods, because of their cheapness and the portability of the equipment needed. The other methods have been used less often, either because of difficulties of acquiring expertise or laboratory resources, as with clinical and biochemical assessment, respectively, or for logistical reasons, such as the need to transport specimens of body fluids across long distances. Immunological assessment has been little used by either anthropologists or nutritionists, since the methods available are rather new.

Again, the method of choice depends on the question in hand. If a generalised view of the nutritional status of a population, community or group is required, then the measurement of one or more anthropometric variables, such as height, weight or arm circumference, may be adequate. If more subtle effects are to be examined, such as the metabolic changes associated with low protein nutritional status, then one or more biochemical measures might be more appropriate. Immunological tests are likely to be the best measures of functional effects of the interaction between undernutrition and infection. Clinical assessments are only really useful if serious deficiencies of certain nutrients are likely to be found in a substantial proportion of the group being studied.

Anthropometric assessment

Anthropometric assessment is the most widely used because measurement is simple, and, once equipment has been bought, there is no further outlay. Most anthropometric equipment is portable, and measurements can be made in remote geographical regions. Problems associated with anthropometry include measurement error and interpretation of data.

Although nutritional classifications for children exist using anthropometry alone (Waterlow *et al.*, 1977), for adults, a two variable classification has been recommended by James, Ferro-Luzzi and Waterlow (1988) for the assessment of undernutrition. This incorporates body mass

BOX 6.1. Training in anthropometric measurement

Measurement error exists, even when there is only one trained observer doing all the measuring. Studies in which more than one observer is employed will incorporate both within- and between-observer errors. Since measuring techniques are usually learned by instruction from an expert or supervisor, there is a need to determine when a trainee is ready to perform the measurement accurately. When comparing repeat measurements of a trainee and a trained observer, the differences between the two should be within respectable bounds. Zerfas (1985) has recommended a scheme for evaluating measurement error among trainees. Differences should be consistently below 5 mm for height and arm circumference, 0.1 kg for weight, and 0.9 mm for skinfold thickness before a trainee is deemed as having reached an acceptable level of proficiency. In addition, there should be no systematic bias in measurement between observers. The length of time taken to reach these levels of proficiency varies between trainees; for most, one morning spent in carrying out repeat measurements is enough.

The accuracy of collected anthropometric data can be evaluated by using two error estimates: the technical error of measurement (TEM) and coefficient of reliability (*R*) (Mueller and Martorell, 1988; Frisancho, 1990). The TEM is obtained by carrying out a number of repeat measurements on the same subject by the same observer, to obtain intra-observer TEM, and (where applicable) the different observers, for inter-observer TEM. Intra-observer TEM, and inter-observer TEM involving only two observers, can be obtained by entering the differences into the equation:

$$\text{TEM} = \sqrt{(\sum D^2/2N)} \quad (1)$$

where *D* is the difference between measurements, and *N* is the number of individuals measured. If more than two observers are involved, TEM can be calculated using the formula:

$$\text{TEM} = \sqrt{\{\sum_1^N [(\sum_1^K M(n)^2) - (\sum_1^K M(n)^2/K)]/N(K-1)\}} \quad (2)$$

where *N* is the number of subjects, *K* is the number of determinations of the variable taken on each subject, and *M*(*n*) is the *n*th replicate of the measurement, where *n* varies from 1 to *K*. Acceptable TEMs vary with the measurement taken, and with age (Ulijaszek and Lourie, in press). The table gives maximum acceptable TEMs for height, arm circumference, triceps and subscapular skinfold thicknesses by age group, at two levels of reliability. Ideally, TEM should be lower than the values given for a reliability coefficient of 0.99 (Ulijaszek and Lourie, in press).

(continued)

Maximum levels for technical error of measurement at two levels of reliability for either intra- or inter-observer error

Age group (years)	Measurement (males)					Measurement (females)				
	Height (cm)	Sitting height (cm)	Arm circumference (cm)	Triceps skinfold (mm)	Subscapular skinfold (mm)	Height (cm)	Sitting height (cm)	Arm circumference (cm)	Triceps skinfold (mm)	Subscapular skinfold (mm)
Reliability = 0.95										
1-4.9	1.03	0.40(a)	0.31	0.61	0.43	1.04	0.34 ^a	0.30	0.65	0.47
5-10.9	1.30	0.35	0.52	0.97	0.87	1.38	0.36	0.54	1.05	1.08
11-17.9	1.69	0.30	0.75	1.45	1.55	1.50	0.29	0.78	1.55	1.74
18-64.9	1.52	0.30	0.73	1.38	1.79	1.39	0.31	0.98	1.94	2.39
65+	1.52	0.30	0.74	1.29	1.74	1.35	0.32	0.98	1.86	2.27
Reliability = 0.99										
1-4.9	0.46	0.18(a)	0.14	0.28	0.19	0.47	0.15 ^a	0.13	0.29	0.21
5-10.9	0.58	0.16	0.23	0.43	0.39	0.62	0.16	0.24	0.47	0.48
11-17.9	0.76	0.13	0.33	0.65	0.69	0.67	0.13	0.35	0.69	0.78
18-64.9	0.68	0.13	0.33	0.62	0.80	0.62	0.14	0.44	0.87	1.07
65+	0.68	0.13	0.33	0.58	0.78	0.60	0.14	0.44	0.83	1.02

^a2-4.9 years.

From Ulijaszek and Lourie (in press).

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Table 6.8. Assessment of undernutrition in adults, from body mass index (BMI) and physical activity level (PAL)

BMI	PAL	Presumptive diagnosis
>18.5	—	Normal
17.0-18.5	>1.4	Normal
	<1.4	CED grade I
16.0-17.0	>1.4	CED grade I
	<1.4	CED grade II
<16.0	—	CED grade III

CED = Chronic energy deficiency, Grad I = mild; II = moderate; III = severe.

From James, Ferro-Luzzi and Waterlow (1988).

index (BMI; weight divided by height squared), and physical activity level (PAL; total daily energy expenditure divided by basal metabolic rate). This is presented in Table 6.8. The authors suggest using energy intake measures to estimate physical activity level, assuming that subjects are in energy balance, and that intake equals expenditure. If this is not available, amendments to this classification may be needed.

Body composition

Body composition measures are useful for estimating body fatness or leanness. The most common method is the use of skinfold measurements to estimate body density from regression equations of skinfolds against body density. Such equations have been derived from studies in which the skinfolds of a large number of subjects have been correlated with their body density as estimated by a 'gold standard' method, such as densitometry or isotope dilution. Although a large number of prediction

BOX 6.2. Calculation of body fatness and fat-free mass from anthropometry

Fat-free mass (FFM) can be calculated in the following manner:

$$\text{FFM} = \text{body weight} - [\text{body weight} \times (\% \text{body fat}/100)] \quad (1)$$

A typical calculation of percentage of body fat and FFM is as follows:

Data: adult New Guinean male, aged 24 years
Weight = 58.4 kg

Skinfold thickness:

Biceps = 3.4 mm
Triceps = 5.2 mm
Subscapular = 8.8 mm
Suprailiac = 7.3 mm
Total (skinfolts) = 24.7 mm

For a 24-year-old male, body density is calculated using the following formula from Durnin and Womersley (1974):

$$\begin{aligned} \text{Density (g/cm}^2\text{)} &= 1.1631 - 0.0632 \times \log_{10}[\Sigma(\text{skinfolts})] \quad (2) \\ &= 1.1631 - 0.0632 \times \log_{10}(24.7) \\ &= 1.075 \text{ g/cm}^2 \end{aligned}$$

$$\begin{aligned} \text{Fat percentage} &= [(4.95/1.075) - 4.5] \times 100 \\ &= 10.47\% \end{aligned}$$

$$\begin{aligned} \text{FFM} &= \text{body weight} - (\text{body weight} \times (10.47/100)) \\ &= 58.4 - (58.4 \times 0.1047) \\ &= 52.3 \text{ kg} \end{aligned}$$

Such values of fat percentage and FFM may not be typical of Western countries, where individuals other than athletes are generally heavier and fatter than in Papua New Guinea, where body weights are low and fat percentages below 10 are not unusual (Ulijaszek *et al.*, 1989).

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equations have been developed in this way (Sloan, 1967; Durnin and Womersley, 1974; Jackson and Pollock, 1974; Jackson *et al.*, 1980), only a few have been validated across different populations. The equations of Durnin and Womersley (1974) have been found to be appropriate for Indian men (Jones *et al.*, 1976), Chilean men (Apud *et al.*, 1977), and younger New Guinean adults (Norgan *et al.*, 1982), but not Eskimos (Shephard *et al.*, 1973). Further, the predictive equations derived from measurements of non-pregnant, non-lactating women have been found to be appropriate for lactating women, despite differences in patterns of fat deposition (Butte *et al.*, 1985).

The percentage of body weight as fat can be calculated using one or other of the following equations:

$$\text{Fat percentage} = [(4.950/\text{density}) - 4.5] \times 100 \quad (6.2)$$

(Siri, 1956)

$$\text{Fat percentage} = [(4.570/\text{density}) - 4.142] \times 100 \quad (6.3)$$

(Brožek, 1965)

These formulae give good estimates of body fatness, as compared with other methods (Jones and Lourie, 1981), with precision of estimate varying between 3% and 9% when compared with densitometry. The formulae over-estimate the body fatness of women above the age of 60 years by 2-3%, however (Deurenberg *et al.*, 1989). This is because of age-related changes in fat-free body mass, which are greater in females than in males.

Fat-free mass (FFM) consists of skeletal tissue (bone and cartilage), muscle, skin and viscera. Changes in FFM in an individual over time are in large part due to changes in muscle mass, both skeletal and smooth. It can be calculated as shown in Box 6.2.

Another way in which body composition can be estimated in the field is by the use of equations that predict FFM from weight and height measures (Hume and Wyers, 1971), or percentage of fat from BMI (Black *et al.*, 1983). The equations for adults (from Hume and Wyers, 1971) are as follows:

$$\text{Men: FFM} = 1.39 \times (0.297 \text{ kg} + 0.193 \text{ cm} - 14.01) \quad (6.4)$$

$$\text{Women: FFM} = 1.39 \times (0.184 \text{ kg} + 0.345 \text{ cm} - 35.27) \quad (6.5)$$

Here, the calculation in parentheses represents the estimation of total body water; it is assumed that water counts for 0.7194 of FFM, so the reciprocal of this, 1.39, is used to estimate FFM from total body water. The Black *et al.* (1983) equations are:

$$\text{Men: Fat percentage} = (1.281 \times \text{BMI}) - 10.13 \quad (6.6)$$

$$\text{Women: Fat percentage} = (1.481 \times \text{BMI}) - 7.0 \quad (6.7)$$

A method that has gained recent popularity is the bioelectrical impedance method (BEI), which depends upon the differences in electrical conductivity of fat-free mass and fat. The technique measures the impedance of a weak electrical current ($800 \mu\text{A}$; 50 kHz) passed between the right ankle and right wrist of an individual. The impedance is proportional to the length of the conductor, and indirectly proportional to the cross-sectional area. The length of the conductor is usually a function of the height of the subject. The FFM can be calculated using a formula of the form:

$$\text{FFM} = A + (B \times (H^2/R)) \quad (6.8)$$

where A and B are constants, H is height, and R is resistance, or the square of impedance. A number of predictive equations have been developed (Kushner and Schoeller, 1986; Khaled *et al.*, 1988), by relating BEI measures to a 'gold standard' method of estimating body composition, either isotope dilution or densitometry. The applicability of any of these equations to a diversity of populations has yet to be determined, however. Caution is urged in the use of this method, since it has been found that two equations that are used with commercially available instruments under-estimate and over-estimate FFM as determined from an isotope dilution method by an average of 4.7% and 8.1% respectively (Pullicino *et al.*, 1990). In the same study, prediction equations using skinfold thicknesses, weight/height, and body mass index gave under-predictions of only 2.6%, 4.1% and 2.8% respectively. The BEI method may well become an important one for anthropologists in the future, however, when appropriate equations are available.

In addition to these methods, there is a range of laboratory-based techniques, both old and new. These have not been discussed here, since the concern is with field techniques. For further information, the reader is advised to consult the excellent book by Shephard (1991) *Body Composition in Biological Anthropology* and review articles by Lukaski (1987) and Sjostrom (1989).

Biochemical assessment

Although there is a wide range of biochemical tests available for measuring nutritional state (Table 6.9), two are more widely used than any others. These are plasma albumin, which is used to estimate protein nutritional state, and blood haemoglobin, which is used as a measure of

iron deficiency, the globally most common mineral deficiency. Before considering the estimation of these two variables, some general aspects of biochemical testing of nutritional state will be considered.

Biochemical tests in the field usually involve either the measurement of a nutrient in biological fluids or tissues, or the measurement of the urinary excretion rate of the nutrient, or a metabolite of it. Tissues and body fluids that have been used include blood, urine, hair, saliva, semen, amniotic fluid, fingernails and skin. The most commonly used of these are urine and blood. It should be noted that the collection of bodily fluids or tissues might seem a bizarre or strange activity in some societies; a person attempting such collections might be suspected of being a sorcerer, and attract hostility as a result. The purpose of the collection should be made very clear to the subjects of the investigation, and no attempt should be made to undertake collection without their consent.

It is clearly impractical to attempt to measure everything, even if it is possible to collect large amounts of sample. In the case of blood, subjects are usually loath to part with more than a few millilitres, if at all. The intended examination of urine allows the collection of large volumes for analysis; it is usually not practical to collect large volumes from each individual because of problems of storage and transport, however. Further, for some analyses, 24 hour urine samples are needed, and there may be poor compliance as a result of the prolonged sampling period. Subjects may be amused or appalled that someone should want them to collect something in a bottle that they might consider unclean.

Hair samples have sometimes been used to determine status of certain trace elements, such as zinc, manganese and iron. These are easy to take, store and transport, but are easily contaminated. The recommendation then is to keep biochemical testing to a minimum; that is, to focus only on the nutrients of specific interest.

There are a number of factors that may confound the interpretation of biochemical tests, so care should be taken to ensure that all samples are collected under standardised conditions. These factors include the following: sample contamination, diurnal variation, physiological state (pregnancy, lactation), infections and inflammations, physical exercise taken prior to measurement, recent dietary intake, recent intake of medicines, present weight gain, present weight loss, and accuracy, precision, sensitivity and specificity of the analytical method. Clearly, the collection, analysis and interpretation of biochemical nutritional information is not a light undertaking. Further information on biochemical measurement can be found in the very useful text on nutritional assessment by Gibson (1990).

Table 6.9. Biochemical methods for assessing nutritional status

Nutrient	Method	
	Principal	Supplementary
Protein	Urinary creatinine	Serum insulin-like growth factor 1
	Serum albumin	Serum amino-acid ratio
	Serum transferrin	
	Thyroxine-binding prealbumin	
	Urinary hydroxyproline	
Vitamin A	Serum retinol Serum carotene	
Vitamin B1 (thiamine)	Urinary thiamine	Serum pyruvate
	Erythrocyte transketolase	Serum lactate
Vitamin B2 (riboflavin)	Urinary riboflavin	Erythrocyte riboflavin
	Erythrocyte glutathione reductase	
Niacin	Urinary N'-methylnicotinamide and N'-methyl-2-pyridone-5-carboxylamide	Fasting serum free tryptophan
Vitamin B6	Erythrocyte aminotransferase activities	Tryptophan load test
	Serum pyridoxal-5'-phosphate	Kynurenine load test
	Urinary 4-pyridoxic acid excretion	
Folic acid	Serum folate	Bone marrow morphology
	Erythrocyte folate	
	Haemoglobin	
	Haematocrit	
	Erythrocyte count	
Vitamin B12	Serum B12	Deoxyuridine suppression test
	Erythrocyte B12	
Vitamin C (ascorbic acid)	Serum ascorbic acid	Urinary ascorbic acid
	Leucocyte ascorbic acid	Salivary ascorbic acid
Vitamin D	Serum 25-hydroxyvitamin D concentrations	Serum calcium and inorganic phosphate
	Serum alkaline phosphatase	
Vitamin E	Serum tocopherol	
	Erythrocyte tocopherol	
	Platelet tocopherol	
	Erythrocyte haemolysis	
	Breath pentane	
Sodium	Urinary sodium	
	Serum sodium	
Iron	Haemoglobin	Bone marrow morphology
	Haematocrit	

Table 6.9 (cont.)

Nutrient	Method	
	Principal	Supplementary
Iron (cont.)	Erythrocyte count	
	Serum iron	
	Total iron-binding capacity	
	Transferrin saturation	
Calcium	Serum calcium	
	Serum ionised calcium	
Iodine	Urinary iodine	
	Serum thyroxine	
	Serum 3,5,3'-triiodothyronine	
Zinc	Serum zinc	Oral zinc tolerance
	Erythrocyte zinc	
	Leucocyte zinc	
	Urinary zinc	
	Hair zinc	

From Passmore and Eastwood (1986); Gibson (1990).

Despite reservations, biochemical tests are useful in demonstrating low reserves of nutrients in individuals who do not show clinical signs of specific deficiencies. Samples of urine and blood can easily be collected by field workers if the subjects have no objection, but analyses usually have to be carried out in a distant laboratory. Planning and discussion are therefore needed between field staff and laboratory workers before the study begins, so that transport, storage and quality control are all acceptable, and the study feasible.

For the purposes of nutritional assessment, Gibson (1990) has classified the body's protein stores into two types: somatic, and visceral. Somatic protein is principally composed of skeletal muscle, whilst visceral protein includes the liver, kidneys, pancreas, heart, gastrointestinal tract, serum proteins, erythrocytes, granulocytes and lymphocytes. Somatic protein status has quite a different meaning from visceral protein status, and they are measured by different methods.

Somatic protein status is a measure of skeletal muscle mass, and can be estimated by measuring the excretion of urinary creatinine. Creatinine is derived from the catabolism of creatine phosphate, a high-energy metabolite found mainly in muscle, and its output is significantly related to muscle mass (Cheek, 1968). Somatic protein status of a subject can be

estimated using measures of their creatinine excretion in relation to expected levels of excretion. This is the creatinine:height index (CHI), and it is expressed thus:

$$\text{CHI}(\%) = 100 \times (\text{measured daily excretion/ideal daily excretion for height}) \quad (6.9)$$

Cut-offs for CHI that are suggestive of deficits in body muscle mass are 60–80% of standard (moderate deficit), and less than 60% (severe deficit) (Blackburn *et al.*, 1977).

Visceral protein status can be assessed by measuring total serum protein, serum albumin, transferrin, thyroxine-binding pre-albumin, or retinol-binding protein. Of these, the most commonly used is serum albumin, total serum protein being a rather insensitive measure.

Serum albumin is a reasonable measure of longer-term visceral protein status, since it has a half-life of fourteen to twenty days. Although it has been used as an index of low protein intake, there are various other factors that can affect its level. These include: 1. reduced protein synthesis resulting from inadequate energy intake, or electrolyte, iron, zinc or vitamin A deficiency; 2. altered metabolism due to trauma, stress of infection; and 3. altered distribution of albumin in body fluids in pregnancy (Jeejeebhoy, 1981). Thus, the interpretation of low serum albumin is made difficult; a further difficulty is that serum albumin levels may be elevated in some cases of semi-starvation (James and Hay, 1968), and are elevated in the acute phase of infection. The value of this test is as an index of marginal kwashiorkor, and for the identification of malnourished children susceptible to oedema (Whitehead *et al.*, 1971; Alleyne *et al.*, 1977).

Iron deficiency anaemia is common throughout the world, and there are a number of ways in which this can be estimated in the field. Iron in the body exists as three components: 1. integrally bound to molecules with oxygen-binding or enzymic function; 2. transport iron; 3. storage iron. Usually, levels of the oxygen-carrying molecule haemoglobin are measured as a marker of the exhaustion of iron stores in the liver, and declining levels of circulating iron. There are a number of devices that can be used to determine haemoglobin levels; these vary in cost, accuracy and convenience. A number of such devices are listed in Jelliffe and Jelliffe (1989).

Immunological tests

Tests of immunocompetence cannot be used to detect specific nutrient deficiencies. Rather, they may measure an individual's ability to mount

Table 6.10. *Tests of immunocompetence*

Test	Comments
Lymphocyte count	In malnutrition, the number of lymphocytes is reduced. Levels said to represent undernutrition: 900–1500 cells/mm ³ (moderate); <900 cells/mm ³ (severe).
Thymus-dependent lymphocytes	Reduction in total number of T-cells in undernutrition. Results expressed as number of T-cells per microlitre of whole blood, and compared with in-house standards for healthy subjects.
Delayed cutaneous-hypersensitivity	Skin test reactivity to specific antigens (purified protein derivative, mumps, trichophyton, <i>Candida albicans</i> , dinitrochlorobenzene) is reduced in undernutrition, and when subject is experiencing infectious sepsis.
Secretory IgA	Salivary levels reduced in undernutrition.
Complement C3	Serum C3 is low in undernourished subjects; decreases further with infection.

an immune response to an antigenic challenge; this may be reduced by the combined stresses of nutritional deficiency and infectious disease (Chandra, 1983). Alternatively, they may measure components of the immune system that are impaired by undernutrition. Nearly all aspects of the immune system can be impaired by nutritional deficiency, although only a limited number of tests are currently available. These are summarised in Table 6.10.

Clinical assessment

This method is only useful in detecting the advanced stages of nutritional depletion and it is based on the examination of epithelial tissues, especially the skin, eyes, hair, and mouth, or of organs near the surface of the body, such as the parotid and thyroid glands (Jelliffe, 1966). Although inexpensive, it requires skill. Further, some of the signs used lack specificity. Indeed, most signs of malnutrition are not specific to the lack of one nutrient, and can often be produced by various non-nutritional factors. Thus, care is needed when attempting the clinical assessment of nutritional status.

Details of clinical assessment are given in Jelliffe (1966), Jelliffe and Jelliffe (1989) and Gibson (1990), and illustrations of various nutritional pathologies are shown in McLaren (1981), Jelliffe (1966) and Jelliffe and Jelliffe (1989).

Standardisation of definition is important to minimise subjectivity in assessment. Researchers intending to carry out such assessments are directed to McLaren's (1981) excellent *Colour Atlas of Nutritional Disorders*, where such definitions are presented in association with colour photographs of the conditions described. If more than one investigator is to carry out the assessment, it is important that the definitions of the signs be available in written form for all investigators. Further, instruction and practical visual training is needed prior to undertaking the work to ensure uniformity of examination technique, and of judgement.

Clinical assessments should not be graded into such categories as 'low', 'medium', 'high', or 0, 1, 2, 3, 4, or -, +, ++, +++, because this increases the level of subjectivity. It is often time-consuming to attempt to differentiate degrees of severity of the signs observed. A record of 'positive' or 'negative' is more realistic. An example of the reporting of clinical signs is given in Box 6.3.

BOX 6.3. Assessment of clinical signs of malnutrition in refugee children from Irian Jaya

In 1985, indigenous people from Irian Jaya, Indonesia, fled across the border into Papua New Guinea. Ulijaszek and Welsby (1985) assessed clinical signs of malnutrition in a number of refugee children at this time.

Age group (years)	Sign	Refugees	Villagers
0-4.9		(N = 155)	(N = 26)
	Oedema of wrists and ankles	9	0
	Sparse hair	21	4
	Discoloured hair	15	4
	Moon face	23	0
5-12		(N = 32)	(N = 13)
	Oedema of wrists and ankles	0	8
	Sparse hair	9	0
	Discoloured hair	9	0
	Moon face	16	0

The table shows that the extent of clinical nutritional deficiency was greater in the younger age group than in the older one, and that clinical signs were not entirely absent from children in a nearby village, who could be taken as a control group.

Reference

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Conclusion

A number of techniques for the assessment of nutritional status have been described and in some cases, evaluated. It should be clear to the reader that nutritional assessment is not a simple matter, and that careful thought and preparation should be undertaken prior to undertaking such work. Despite reservations, nutritional assessment techniques form an important part of the battery of methods that human biologists and biological anthropologists use in examining human adaptability and ecology.

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