Clinical Paediatric Dietetics

EDITED BY

Vanessa Shaw

and

Margaret Lawson

Third edition

Blackwell
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Foreword

It gives me great pleasure to write the foreword for the third edition of *Clinical Paediatric Dietetics*. This edition clearly shows the diversity of areas paediatric dietitians work within, from clinical dietetics to community nutrition. The new structure recognises the important extent of the role dietitians play in the health care of sick infants and children.

Recognition should be given to The Paediatric Group of the British Dietetic Association for their evidence based and practical approach. Vanessa and Margaret should once again be sincerely congratulated for managing contributions from almost 40 dietitians with valued input from a significant number of others – a task that would overwhelm many.

The value of this book is recognised not only by dietitians but also by many other health professionals as an excellent source of reliable information to ensure optimal nutritional care is given to sick infants and children.

Dame Barbara Clayton DBE
Honorary Research Professor in Metabolism,
University of Southampton
Honorary President, The British Dietetic Association

Preface

The aim of this manual is to provide a very practical approach to the nutritional management of a wide range of paediatric nutritional disorders that may benefit from nutritional support or be ameliorated or resolved by dietary manipulation. The text will be of particular relevance to professional dietitians, dietetic students and their tutors, paediatricians, paediatric nurses and members of the community health team involved with children requiring therapeutic diets. The importance of nutritional support and dietary management in many paediatric conditions is increasingly recognised and is reflected in new text for this edition.

The authors are largely drawn from practising paediatric dietitians around the United Kingdom, with additional contributions from academic research dietitians and a psychiatrist. The text has been reorganised for this edition and includes a thorough review of the scientific and medical literature to support practice wherever available. The major part of the text concentrates on nutritional requirements of sick infants and children in the clinical setting. Normal dietary constituents are used alongside special dietetic products to provide a prescription that will control progression and symptoms of disease whilst maintaining the growth potential of the child. There is a new section on community nutrition including healthy eating throughout childhood. We acknowledge that the distinction between clinical dietetics and nutrition in the community is rather arbitrary since many clinical conditions are dealt with in the community, and the principles of healthy eating underpin many clinical interventions.

New topics have been added: nutrition support in critical care, autistic spectrum disorders, prevention of food allergy. There has been an expansion of the range of disorders and treatments described in many chapters, e.g. gastroenterology, liver disease, gut transplantation, cardiac conditions, fatty acid oxidation defects; and new recommendations and guidelines for parenteral nutrition, feeding preterm infants and assessing children with neurodisabilities.

Arranged under headings of disorders of organ systems rather than type of diet, and with much information presented in tabular form and with worked examples, the manual is easy to use. Appendices list the many and varied special products described in the text, together with details of their manufacturers. The appendices are not exhaustive, but include the products most commonly used in the UK. The most recent information and data has been used in the preparation of this edition, but no guarantee can be given of the validity or availability at the time of going to press.

Vanessa Shaw
Margaret Lawson

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Chapter 8, The Liver and Pancreas: Jane Ely
Chapter 14, Ketogenic Diet for Epilepsy: Jane Eaton
Chapter 18, Lipid Disorders: Anne Maclean
Chapter 22, Eating Disorders: Bernadette Wren and Bryan Lask
Chapter 25, Burns: Judith Martin

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Chapter 4, Parenteral Nutrition: Janice Glynn
Chapter 12, The Kidney: Janet Coleman
Chapter 13, The Cardiothoracic System: Marion Noble
Chapter 14, Food hypersensitivity: Christine Carter
Chapter 15, HIV and AIDS: Jayne Butler
Chapter 15, Immunodeficiency Syndromes: Dona Hileti-Telfer
Chapter 21, Refsum's Disease: June Brown
Chapter 25, Burns: Dearbhla Hunt
Chapter 30, Feeding Children with Neurodisabilities: Karen Jeffereys
Chapter 31, Obesity: Mary Deane

Part 1

Principles of Paediatric Dietetics

1 Nutritional Assessment, Dietary Requirements, Feed Supplementation

Vanessa Shaw & Margaret Lawson

Introduction

This text provides a practical approach to the dietary management of a range of paediatric disorders. The therapies outlined in Parts 2 and 3 describe dietetic manipulations and the nutritional requirements of the infant and child in a clinical setting, illustrating how normal dietary constituents are used alongside special dietetic products to allow for the continued growth of the child while controlling the progression and symptoms of disease. Nutrition for the healthy child and nutritional care most often provided in the community setting is addressed in Part 4.

Dietary principles

The following principles are relevant to the treatment of all infants and children and provide the basis for many of the therapies described later in the text.

Assessment of nutritional status

Assessment and monitoring of nutritional status should be included in any dietary regimen, audit procedure or research project where a modified diet has a role. There are a number of methods of assessing specific aspects of nutritional status, but no one measurement will give an overall picture of status for all nutrients. There are several assessment techniques, some of which should be used routinely in all centres while others are still in a developmental stage or are suitable only for research. Figure 1.1 outlines the techniques that can be used for nutritional assessment.

Dietary intake

For children over the age of 2 years food intake is assessed in the same way as for adults: using a recall diet history, a quantitative food diary over a number of days, a weighed food intake over a number of days or a food frequency questionnaire [1]. For most clinical purposes an oral history from the usual carers (or from the child if appropriate) will provide sufficient information on which to base recommendations. As well as assessing the range and quantity of foods eaten it is also useful to assess whether the texture and presentation of food is appropriate for the age and developmental level of the child. For instance, does the child use an infant feeding bottle or a cup; is the child able to self-feed or need a lot of help; is the food of normal consistency, as eaten by the family, or is it a smooth purée, chopped or mashed?

The assessment of milk intake for breast fed infants is difficult and only very general estimations can be made. Infants can be test-weighed before and after a breast feed and the amount of milk consumed can be calculated. This requires the use of very accurate scales (±1–2 g) and should be

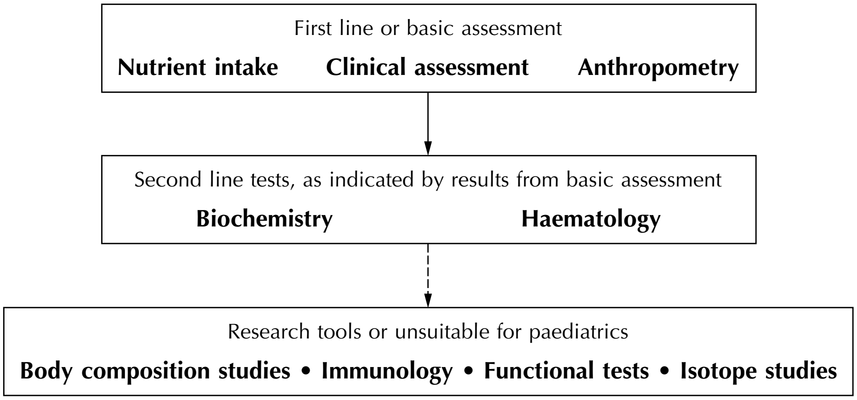

Figure 1.1 Nutritional assessment methods.

carried out for all feeds over a 24-hour period as the volume consumed varies throughout the day. Test-weighing should be avoided if at all possible as it is disturbing for the infant, engenders anxiety in the mother and is likely to compromise breast feeding. Studies have shown that the volume of breast milk consumed is approximately 770 mL at 5 weeks and 870 mL at 11 weeks [2]. In general, an intake of 850 mL is assumed for infants who are fully breast fed and over the age of 6 weeks, with additional intake from food at the appropriate weaning age. Estimation of food intake is particularly difficult in infants, as it is not possible to assess accurately the amount of food wasted through, for example, spitting or drooling.

Conversion of food intake into nutrient values for young children may involve the use of manufacturers' data if the child is taking proprietary infant foods and/or infant formula. The composition of breast milk varies and food table values may be inaccurate by up to 20% because of individual variation.

Assessment of the adequacy of an individual calculated nutrient intake for sick and for healthy infants and children is discussed in the section on Dietary Reference Values (see p. 10).

Anthropometry

Measurement of weight and height or length is critical as the basis for calculating dietary requirements as well as monitoring the effects of dietary intervention. Other anthropometric measurements are summarised in Table 1.1.

Head circumference

Head circumference is a useful measurement in children under the age of 2 years, particularly where it is difficult to obtain an accurate length measurement. After this age head growth slows and is a less useful indicator of somatic growth. A number of genetic and acquired conditions will affect head growth (e.g. neurodevelopmental delay) and measurement of head circumference will not be a useful indicator of nutritional status in these conditions. Head circumference is measured using a narrow, flexible, non-stretch tape. Details of a suitable disposable paper tape are available from the Child Growth Foundation (see p. 20). Measurement should be made just above the eyes to include the maximum circumference of the head, with the child supported in an upright position and looking straight ahead.

Weight

Measurement of weight is an easy and routine procedure using an electronic digital scale or a beam balance. Ideally, infants should be weighed nude and children wearing just a dry nappy or pants, but if this is not possible it is important to record whether the infant is weighed wearing a nappy, and the amount and type of clothing worn by older children. For weighing infants up to 10 kg, scales should be accurate to 10 g; for children up to 20 kg, accuracy should be ±20 g and over 20 kg it should be about 50–200 g. A higher degree of accuracy is required for the assessment of sick children than for routine measurements in the community. Frequent weight monitoring is important for the sick infant

Table 1.1 Anthropometric measurements.

Measurement	Derived indices	Comments
Head circumference	Head circumference for age	Easy to measure; useful up to the age of 2 years; useful as proxy for length increase; does not normally change rapidly Affected by medical condition; may not indicate nutritional status
Weight	Weight for age Weight for age z score	Easy to measure; useful on a day to day basis Does not differentiate between lean tissue, oedema and body fat
Length/height	Length/height for age Length/height for age z score Height age	Not easy to measure accurately – needs more than one person to measure; does not change rapidly Best overall indicator of nutritional wellbeing
	Weight for stature Body mass index (W/H^2) Body mass index z score	Useful for children with low height age BMI indicates relative weight for height, but does not differentiate between lean and fat tissue
Mid arm circumference	Mid arm circumference for age Mid arm circumference z score	Easy to measure; useful up to the age of 5 years Less likely to be affected by water retention or fat deposition than body weight
Skinfold thickness (SFT)	Triceps SFT for age	Difficult to measure accurately; unpleasant procedure for children Usually triceps only are used in children Distinguishes between lean and fat tissue
Waist circumference	Waist circumference for age	Easy to measure, although requires removal of clothes Distinguishes between high weight due to muscle bulk and that due to fat
Hip circumference	Waist : hip ratio	Easy to measure No standards for children

or child and hospitalised infants should be weighed daily if there are problems with fluid balance, otherwise on alternate days; children over the age of 2 years in hospital should be weighed at least weekly. Recommendations for the routine measurement of healthy infants where there are no concerns about growth are given in Table 1.2 [3]. If there are concerns about weight gain that is too slow or too rapid, measurement of weight should be carried out more frequently.

Height

Height or length measurement requires a stadiometer or length-board. Details of suitable equipment, which may be fixed or portable, are available from the Child Growth Foundation. Measurement of length using a tape measure is too inaccurate to be of use for longitudinal monitoring of growth, although an approximate length may be useful as a single measure (e.g. for calculating body mass index). Under the age of about 2 years supine length is measured; standing height is usually measured

Table 1.2 Recommendations for routine measurements for healthy infants and children.

Weight	Length/Height	Head Circumference
Birth 2 months	Birth 6–8 weeks if birthweight <2.5 kg or if other cause for concern	Birth or neonatal period 6–8 weeks
3 months 4 months 8 months		
Additional weights at parent's request, not more frequently than 2 weekly under the age of 6 months, monthly 6–12 months 12–15 months	No other routine measurement of length/height	No other routine measurement of head circumference
School entry	School entry	

Source: After Health for all Children [3].

over this age or whenever the child can stand straight and unsupported. When the method of measurement changes there is likely to be a difference in length, and measurements should be made by both methods on one occasion when switching from supine length to standing height. Measurement of length is difficult and requires careful positioning of the infant, ensuring that the back, legs and head are straight, the heels are against the footboard, the shoulders are touching the baseboard and the crown of the head is touching the headboard. Two people are required to measure length – one to hold the child in position and one to record the measurement. Positioning of the child is also important when measuring standing height and care should be taken to ensure that the back and legs are straight, the heels, buttocks, shoulder blades and back of head are touching the measurement board and that the child is looking straight ahead.

Sick infants should be measured every month and older children whenever they attend a clinic. Healthy infants have a length measurement at birth (although this is notoriously inaccurate) and no further height checks are recommended until the pre-school check [3]. Whenever there are concerns about growth or weight gain a height measurement should be made more often, although there is little point in measuring height more frequently than every 3 months.

Body mass index

A body mass index (BMI) measurement can be calculated from the weight and height measurements: BMI = weight (kg)/height (m)^2. This provides an indication of fatness or thinness. In adults, body fatness is largely unrelated to age and high BMI measurements are related to health risks. In children, the amount and distribution of body fat is dependent on age, and does not appear to be related to health. At the extremes of centiles, BMI does not differentiate well between heaviness resulting from lean tissue (e.g. high muscle mass) and weight resulting from excess fat deposition, and further interpretation is necessary.

Proxy measurements for length/height

In some cases it is difficult to obtain length or height measurements (e.g. in very sick or preterm infants and in older children with scoliosis). A number of proxy measurements can be used which are useful to monitor whether longitudinal growth is progressing in an individual, but there are no recognised centile charts as yet and indices such as BMI cannot be calculated. In adults, arm span is approximately equivalent to height, but body proportions depend upon age and this measurement is not generally useful. Measurements of lower leg length or knee–heel length have been used and are a useful proxy for growth. For infants and small children, a kneemometer has been developed which displays knee–heel length digitally [4]. For older children knee–heel length is measured with the child in a supine position (if possible) with the knee bent at a 90° angle using a caliper with a blade at either end. One blade is fitted under the heel of the foot and the other onto the knee, immediately behind the patella, using the outside surface of the leg. Total leg length is rarely measured outside specialist growth clinics and is calculated as the difference between measured sitting height and standing height. A number of other measures have been used in children with cerebral palsy as a proxy for height, but numbers are too small for reference standards to be established [5]. Formulas for calculating height from proxy measurements are further discussed in Chapter 29.

Supplementary measurements

The measurement of weight and length or height forms the basis of anthropometric assessment. However, these measurements on their own do not indicate whether weight increments are due to lean and fat tissue, or whether weight gained is merely fat. Supplementary measurements that can be used include mid upper arm circumference (MUAC). This is a useful measurement in children under the age of 5 years, as MUAC increases fairly rapidly up until this age. Age related standards exist for children over the age of 1 year [6]. Increases in MUAC are more likely to comprise muscle and less likely to be affected by oedema than body weight. In order to fully differentiate between lean and fat, measurement of triceps skinfold thickness (TSF or SFT) is necessary. This can be an unpleasant procedure for young children, who are afraid of the skinfold caliper and may not remain still for long enough for accurate measurements to be taken. The equipment and technique are identical to those used in adults and the measurement is subject to the same observer

Table 1.3 Arm fat and arm muscle area.

$$\text{Arm muscle area (mm}^2) = \frac{[\text{MAC} - (\pi \times \text{TSF})]^2}{4 \times \pi}$$

$$\text{Arm fat area (mm}^2) = \frac{\text{TSF} \times \text{MAC}}{2} - \frac{\pi \times (\text{TSF})^2}{4}$$

MAC = mid arm circumference in mm^2
TSF = triceps skinfold thickness in mm

Worked example for a boy aged 6 years:
MAC = 180 mm (50th centile* for age)
TSF = 16 mm (95th centile* for age)

Arm muscle area = 1340 mm^2 (<5th centile* for age)
Arm fat area = 1238 mm^2 (90–95th centile* for age)
Although all measurements are within the normal range for age, this boy is severely depleted in muscle and may be depleted in all lean tissue

* Reference standards taken from Gibson [6].

error. Skinfold thickness is not used as a routine anthropometric measure but provides valuable data in research studies. Reference data for children over the age of 1 year are available [6] and the World Health Organization (WHO) will publish reference norms for children aged 1–5 in the near future. Arm muscle and arm fat area can be calculated and compared to reference data [6]. A calculation of arm fat and muscle area is shown in Table 1.3.

Measurement of the waist circumference can help distinguish between a high weight for age that is caused by high body lean tissue or high body fat. In general, children with a high weight for height or high BMI who have a high muscle bulk (usually resulting from sports training) will have a low waist circumference centile, while overweight and obese children will have a high waist centile. The waist : hip ratio in children has not proved to be a useful predictor of obesity in pre-pubertal children [7], and reference data do not exist at present for European children.

Growth charts

Measurements should be regularly plotted on the relevant centile chart using a dot rather than a cross or a circle. All children in the UK are issued with a growth centile chart as part of the personal child health record that is held by parents and completed by health care professionals whenever the child is weighed or measured. UK centile charts are available for weight, length/height, head circumference and BMI and the standard ones in use are based on the UK 1990 data [8]. These data were based on a cohort of infants who were largely formula fed during the first 6 months of life. The growth of breast fed infants differs from that of artificially fed infants, and breast fed infants tend to be longer and leaner at age 3 months [9]. Centile charts for fully breast fed infants are available from the Child Growth Foundation, and can be used for both breast and formula fed infants; however, they are based on a very small cohort of 120 infants who had solids introduced at a mean age of 15 weeks and only 40% were still receiving breast milk at 1 year of age. The WHO has produced growth charts based on a sample size of 8440 children for longitudinal and cross-sectional study from ethnically diverse populations across the globe [10]. These children were raised in optimal conditions including exclusive or predominant breast feeding for at least 4 months, introduction of complementary foods by 6 months of age and continued partial breast feeding to at least 12 months of age. These charts may be more suitable than the standard UK 1990 charts for infants and children who are recent immigrants to the UK.

Age related centile charts for BMI have been developed [11] and indicate how heavy the child is relevant to their height and age. Waist circumference centile charts are also available for British children over the age of 3 years [12]. Some medical conditions have a significant effect on growth, and where sufficient data exist, for instance in Down's syndrome, Turner's syndrome and sickle cell disease, separate growth charts have been developed for these conditions [13], and are available from the Child Growth Foundation.

Evaluation of anthropometric measurements

There are a number of problems associated with accurate plotting on charts that can lead to inaccuracies in monitoring. Charts may give time increments in months or may require the decimal age to be calculated using the decimal age calendar on the centile charts, and it is important to check which type of chart is being used. In a clinic or a centre where a number of people are involved in plotting measurements, agreement should be reached over whether values that fall between centiles should be rounded up or rounded down. Variations in procedures can result in relatively large errors, particularly in infants, and deviations from centiles can be missed. When assessing height it is important to take parental height into consideration, and the genetic height potential for the child can be approximately estimated using the mid-parental height +7 cm for boys, and the mid-parental height –7 cm for girls. This calculation is not appropriate if either parent is not of normal stature. The UK 1990 growth charts give example calculations for adult height potential. (For definitions of obesity and failure to thrive see Chapters 29 and 31.)

It is difficult to assess progress or decide upon targets where a measurement falls outside the centile lines: either <0.4th centile or >99.6th centile. Amended weight charts showing up to ±5 standard deviations for monitoring children with slow weight gain are available [14]; details from the Child Growth Foundation. 'Thrive lines' have also been developed to aid interpretation of infants with either slow or rapid weight gain. The 5% thrive lines define the slowest rate of normal weight velocity in healthy infants. If an infant is growing at a rate parallel to or slower than a 5% thrive line, weight gain is abnormally slow. The 95% thrive lines define the most rapid rate of normal weight gain in healthy infants and weight gain that parallels or is faster than the 95% thrive line is abnormally rapid [14]. Thrive lines are in the form of an acetate sheet which overlays either the standard A4 weight centile charts or charts in the personal child health record. Acetates are available from the Child Growth Foundation.

There are a number of methods of overcoming problems in plotting onto charts, which involve converting the weight and height into a finite proportion of a reference or standard measurement. Calculation of the standard deviation score (SDS) or z score for length/height, weight and BMI gives a numerical score indicating how far away from the 50th centile for age the child's measurements falls. A child on the 0.4th centile will have a SDS of –2.65 SD. A child on the 99.6th centile will have a SDS of +2.65 SD, while a measurement that falls exactly on the 50th centile will have a z score of 0. Because of the distribution of the data, calculation of z scores by hand is extremely laborious. A computer software program is available from the Child Growth Foundation that will calculate z scores from height, weight and age data. The z score is also used when comparing groups of children of different genders or ages, when a comparison of the measurements themselves would not be useful.

The calculation of height for age, height age and weight for height are useful when assessing nutritional status initially or when monitoring progress in children who are short for their chronological age. Table 1.4 shows examples of calculations for these measurements. Calculation of height age is necessary when determining nutrient requirements for children who are much smaller (or larger) than their chronological age (see p. 12).

A number of methods of classification of malnutrition have been used in developing countries. The Waterlow classification [15] may be of use when assessing children in the UK with severe failure to thrive. An adaptation of the classification is shown in Table 1.5. The WHO defines malnutrition as moderate if the weight for age z score is less than

Table 1.4 Height for age, height age and weight for height.

Worked example – six-year-old girl with cerebral palsy referred with severe feeding problems

Visit 1 Decimal age = 6.2 years
Height = 93 cm (<0.4th centile)
Weight = 10 kg (<0.4th centile)
50th centile for height for a girl aged 6.2 years = 117 cm

$$\text{Height for age} = \frac{93}{117} = 79.5\% \text{ height for age}$$

Height age is the age at which 93 cm (measured height) falls on 50th centile = 2.7 years
50th centile for weight for 2.7 years = 14 kg

$$\text{Weight for height} = \frac{10}{14} = 71\% \text{ weight for height}$$

Visit 2 (after intervention) Decimal age = 6.8 years
Height = 95.5 cm (<0.4th centile)
Weight = 12 kg (<0.4th centile)
50th centile for height for age 3.1 years = 121 cm

$$\text{Height for age} = \frac{95.5}{121} = 79\% \text{ height for age}$$

Height age = 3.1 years
50th centile for weight for age 3.1 years = 14.5 kg

$$\text{Weight for height} = \frac{12}{14.5} = 82.7\% \text{ weight for height}$$

Conclusions: the child has shown catch-up weight gain – weight for height has increased from 71% to 83%. She has continued to grow in height, but has not had any catch-up – her height continues to be about 79% of that expected for her chronological age

Table 1.5 Classification of malnutrition.

Acute malnutrition (wasting)	Chronic malnutrition (stunting ± wasting)
Weight for height	Height for age
80–90% standard – grade 1	90–95% standard – grade 1
70–80% standard – grade 2	85–90% standard – grade 2
<70% standard – grade 3	<80% standard – grade 3

Source: After Waterlow [15].

–0.2 and severe if the weight for age z score is less than –0.3 [16].

Clinical assessment

Clinical assessment of the child involves a medical history and a physical examination. The medical history will identify medical, social or environmental factors that may be risk factors for the development of nutritional problems. Such factors include parental knowledge and money available for food purchase, underlying disease, changes in weight, food allergies and medications. Clinical signs of poor nutrition, revealed in the physical examination, only appear at a late stage in the development of a deficiency disease and absence of clinical signs should not be taken as indicating that a deficiency is not present. Typical physical signs associated with poor nutrition that have been described in children in western countries are summarised in Table 1.6. Physical signs represent very general changes and may not be caused by nutrient deficiencies alone. Other indications such as poor weight gain and/or low dietary intake are needed in order to reinforce suspicions, and a blood test should be carried out to confirm the diagnosis.

Food and nutrient intake, anthropometric measurements and clinical examination and history form the basis of routine nutritional assessment. None of these are diagnostic tests and can only predict which nutrients may be deficient and which children need further investigation. If a nutrient deficiency (or excess) is suspected as a result of the first line assessment tools, then confirmation using other objective measures should be sought.

Biochemistry and haematology

Methods of confirming suspicion of a nutritional problem include analysis of levels of nutrients or nutrient-dependent metabolites in body fluids or tissues, or measuring functional impairment of a nutrient-dependent metabolic process.

The most commonly used tissue for investigation is the blood. Whole blood, plasma, serum or blood cells can be used, depending on the test. Tests may be static (e.g. levels of zinc in plasma) or may be functional (e.g. the measurement of the activity of glutathione peroxidase, a selenium-

Table 1.6 Physical signs of nutritional problems.

Assessment	Clinical sign	Possible nutrient(s)
Hair	Thin, sparse Colour change – 'flag sign' Easily plucked	Protein and energy, zinc, copper
Skin	Dry, flaky	Essential fatty acids B vitamins
	Rough, 'sandpaper' texture	Vitamin A
	Petechiae, bruising	Vitamin C
Eyes	Pale conjunctiva	Iron
	Xerosis Keratomalacia	Vitamin A
Lips	Angular stomatitis Cheilosis	B vitamins
Tongue	Colour changes	B vitamins
Teeth	Mottling of enamel	Fluorosis (excess fluoride)
Gums	Spongy, bleed easily	Vitamin C
Face	Thyroid enlargement	Iodine
Nails	Spoon shape, koilonychia	Iron, zinc, copper
Subcutaneous tissue	Oedema Over-hydration	Protein, sodium
	Depleted subcutaneous fat	Energy
Muscles	Wasting	Protein, energy, zinc
Bones	Craniotabes Parietal and frontal bossing Epiphyseal enlargement Beading of ribs	Vitamin D

dependent enzyme, as a measure of selenium status). Although an objective measurement is obtained from a blood test, there are a number of factors that can affect the validity of such biochemical or haematological investigations. Age specific normal ranges need to be established for the individual centre unless the laboratory participates in a regional or national quality control scheme. Recent food intake and time of sampling can affect levels and it may be necessary to take a fasting blood sample for some nutrients. Physiological processes such as infection, disease or drugs may alter normal levels. Contamination from exogenous materials such as equipment or endogenous sources such as sweat or interstitial fluid is important for nutrients such as trace elements, and care must be taken to choose the correct sampling procedure. A fuller review of the subject is given by Clayton & Round [17]. A summary of some biochemical and haematological measurements is given in Table 1.7.

Urine is often used for adult investigations, but many tests require the collection of a 24-hour urine sample and this is difficult in babies and children. The usefulness of a single urine sample for nutritional tests is limited and needs to be compared with a standard metabolite, usually creatinine. However, creatinine excretion itself is age dependent and this needs to be taken into consideration. Hair and nails have been used to assess trace element and heavy metal status in populations, but a number of environmental and physiological factors affect levels and these tissues are not routinely used in the UK. Tissues that store certain nutrients, such as the liver and bone, would be useful materials to investigate, but sampling is too invasive for routine clinical use.

Other tests

A number of other tests that are indicative of nutritional status may provide useful information but are not available routinely. Measurement of body composition using isotope dilution or imaging techniques is particularly useful for the clinical dietitian as most methods of assessment do not indicate whether growth consists of normal ratios of fat and protein or whether excess amounts of adipose tissues are being accumulated. Body composition measurements are described by Ruxton *et al*. [18]. The use of bioimpedance (BIA) in assessing body composition in adults has increased since the development of relatively inexpensive and user friendly equipment ('Body Fat Analysers'). However, this method assumes a constant state of hydration, which has shown not to be true for obese individuals. In addition the method has not been validated for use in children and young people under the age of 18 years [19].

Tests that are not routinely carried out but that may be useful research tools are summarised in Table 1.8.

Expected growth in childhood

The 50th centile birthweight for infants in the UK is 3.5 kg. There is some weight loss during the first 5–7 days of life while feeding on full volumes of milk is established; birthweight is normally regained by the 10th to 14th day. Thereafter, average weight gain is as follows:

- 200 g per week for the first 3 months
- 150 g per week for the second 3 months
- 100 g per week for the third 3 months
- 50–75 g per week for the fourth 3 months

Increase in length during the first year of life: 25 cm.

During the second year, the toddler following the 50th centile for growth velocity gains approximately 2.5 kg in weight and a further 12 cm in length. Average growth continues at a rate of approximately 2 kg per year and 10 cm per year, steadily declining to 6 cm per year until the growth spurt at puberty.

Dietary Reference Values

The 1991 Department of Health Report on Dietary Reference Values [20] provides information and figures for requirements for a comprehensive range of nutrients and energy. The requirements are termed dietary reference values (DRV) and are for normal, healthy populations of infants fed artificial formulas and for older infants, children and adults consuming food. DRVs are not set for breast fed babies as it is considered that human milk provides the necessary amounts of nutrients. In some cases, the DRVs for infants aged up to 3 months who are formula fed are in excess of those that would be expected to derive from breast milk; this is because

Table 1.7 Biochemical and haematological tests.

Nutrient	Test	Normal values in children	Comments
Biochemical tests			
Protein	Total plasma protein Albumin	55–80 g/L 30–45 g/L	Low levels reflect long term not acute depletion
	Caeruloplasmin Retinol binding protein	0.18–0.46 g/L 2.6–7.6 g/L	Low levels indicate acute protein depletion, but are acute phase proteins which increase during infection
Thiamin	Erythrocyte transketolase	1–1.15	High activity coefficient (>1.15) indicates thiamin activity coefficient deficiency
Vitamin B_{12}	Plasma B_{12} value	263–1336 pmol/L	Low levels indicate deficiency
Riboflavin	Erythrocyte glutathione reductase activity coefficient	1.0–1.3	High activity coefficient (>1.3) indicates deficiency
Vitamin C	Plasma ascorbate level	8.8–124 μmol/L	Low levels indicate deficiency
Vitamin A	Plasma retinol level	0.54–1.56 μmol/L	Low level indicates deficiency
Vitamin D	Plasma 25-hydroxy cholecalciferol level	30–110 nmol/L	Low level indicates deficiency
Vitamin E	Plasma tocopherol level	α tocopherol 10.9–28.1 μmol/L	Low levels indicate deficiency
Copper	Plasma level	70–140 μmol/L	Low levels indicate deficiency
Selenium	Plasma level Glutathione peroxidase activity	0.76–1.07 μmol/L >1.77 μmol/L	Low levels indicate deficiency Low levels indicate deficiency
Zinc	Plasma level	10–18 μmol/L	Low levels indicate deficiency
Haematology tests			
Folic acid	Plasma folate Red cell folate	7–48 nmol/L 429–1749 nmol/L	Low levels indicate deficiency Low levels indicate deficiency
Haemoglobin	Whole blood	104–140 g/L	Levels <110 g/L indicate iron deficiency
Red cell distribution width	Whole blood	<16%	High values indicate iron deficiency
Mean corpuscular volume	Whole blood	70–86 fL	Small volume (microcytosis) indicates iron deficiency Large volume (macrocytosis) indicates folate or B_{12} deficiency
Mean cell haemoglobin	Whole blood	22.7–29.6 pg	Low values indicate iron deficiency
Percentage hypochromic cells	Whole blood	<2.5%	High values (>2.5%) indicate iron deficiency
Zinc protoporphyrin	Red cell	32–102 μmol/mol haem	High levels indicate iron deficiency
Ferritin	Plasma level	5–70 μg/L	Low levels indicate depletion of iron stores Ferritin is an acute phase protein and increases during infection

Table 1.8 Other tests.

Measurement	Method
Body composition	Total body potassium using ^{40}K Total body water using water labelled with stable isotopes (^2H_2O, $H_2{}^{18}O$, $^2H_2{}^{18}O$) Ultrasound Bioelectrical impedance Computerised tomography Dual X-ray absorptiometry
Functional tests	Muscle strength using dynamometer to assess protein energy malnutrition Taste acuity to assess zinc status Dark adaptation test to assess vitamin A adequacy These tests require the co-operation of the subject and none have been used extensively in children
Immunological tests	Leucocyte function, delayed cutaneous hypersensitivity reaction These tests are affected by infection and are age dependent There is no reference data for children and immunological tests are not normally used as a measure of nutritional status in paediatrics

of the different bioavailability of some nutrients from breast and artificial formulas.

It is important to remember that these are recommendations for groups, not for individuals; however, they can be used as a basis for estimating suitable intakes for the individual, using the Reference Nutrient Intake (RNI). This level of intake should satisfy the requirements of 97.5% of healthy individuals in a population group. A summary of these DRVs for energy, protein, sodium, potassium, vitamin C, calcium and iron is given in Table 1.9. The DRVs for other nutrients may be found in the full report. The WHO has recently published new recommendations for energy intakes that are lower than those formerly used [21]. A number of other bodies, including the European Union, have also published estimated requirements which include children, and these have been summarised [22].

When estimating requirements for the individual sick child it is important to calculate energy and nutrient intakes based on actual body weight, and not expected body weight. The latter will lead to a proposed intake that is inappropriately high for the child who has an abnormally low body weight. In some instances it may be more appropriate to consider the child's height age rather than chronological age when comparing intakes with the DRVs as this is a more realistic measure of the child's body size and hence nutrient requirement. An estimation of requirements for sick children is given in Table 1.10.

Fluid requirements in the newborn

Breast feeding is the most appropriate method of feeding the normal infant and may be suitable for sick infants with a variety of clinical conditions. Demand breast feeding will automatically ensure that the healthy infant gets the right volume of milk and hence nutrients. If the infant is too ill or too immature to suckle (the suck–swallow–breathe sequence that allows the newborn infant to feed orally is usually well developed by 35–37 weeks' gestation), the mother may express her breast milk; expressed breast milk (EBM) may be modified to suit the sick infant's requirements. If EBM is unavailable or inappropriate to feed in certain circumstances, infant formula milks must be used (Table 1.11). After the age of 6 months, a follow-on milk may be used (Table 1.12). These milks are higher in protein, iron and some other minerals and vitamins than formulas designed to be given from birth and may be useful for infants with a poor intake of solids or who are fluid restricted. Organic infant formulas and follow-on milks are also available.

Low birthweight and preterm infants

Chapter 6 gives a full account of the special requirements of these babies.

Infants over 2.5 kg birthweight

Fluid offered per 24 hours: 150–200 mL/kg. On the first day, if bottle fed, approximately one-seventh of the total volume should be offered, divided into eight feeds and fed every 2–3 hours. The volume offered should be gradually increased over the following days to give full requirements by the

Table 1.9 Selected dietary reference values.

Age	Weight* kg	Fluid ml/kg	Energy (EAR) kJ/d	Energy (EAR) kJ/kg/d	Energy (EAR) kcal/d	Energy (EAR) kcal/kg/d	RNI Protein g/d	RNI Protein g/kg/d	RNI Sodium mmol/d	RNI Sodium mmol/kg/d	RNI Potassium mmol/d	RNI Potassium mmol/kg/d	RNI Vitamin C mg/d	RNI Calcium mmol/d	RNI Iron µmol/d
Males															
0–3 months	5.9	150	2280	480–420	545	115–100	12.5	2.1	9	1.5	20	3.4	25	13.1	30
4–6	7.7	150	2890	400	690	95	12.7	1.6	12	1.6	22	2.8	25	13.1	80
7–9	8.9	120	3440	400	825	95	13.7	1.5	14	1.6	18	2.0	25	13.1	140
10–12	9.8	120	3850	400	920	95	14.9	1.5	15	1.5	18	1.8	25	13.1	140
1–3 years	12.6	90	5150	400	1230	95	14.5	1.1	22	1.7	20	1.6	30	8.8	120
4–6	17.8	80	7160	380	1715	90	19.7	1.1	30	1.7	28	1.6	30	11.3	110
7–10	28.3	60	8240	–	1970	–	28.3	–	50	–	50	–	30	13.8	160
11–14	43.1	50	9270	–	2220	–	42.1	–	70	–	80	–	35	25.0	200
15–18	64.5	40	1 1510	–	2755	–	55.2	–	70	–	90	–	40	25.0	200
Females															
0–3 months	5.9	150	2160	480–420	515	115–100	12.5	2.1	9	1.5	20	3.4	25	13.1	30
4–6	7.7	150	2690	400	645	95	12.7	1.6	12	1.6	22	2.8	25	13.1	80
7–9	8.9	120	3200	400	765	95	13.7	1.5	14	1.6	18	2.0	25	13.1	140
10–12	9.8	120	3610	400	865	95	14.9	1.5	15	1.5	18	1.8	25	13.1	140
1–3 years	12.6	90	4860	400	1165	95	14.5	1.1	22	1.7	20	1.6	30	8.8	120
4–6	17.8	80	6460	380	1545	90	19.7	1.1	30	1.7	28	1.6	30	11.3	110
7–10	28.3	60	7280	–	1740	–	28.3	–	50	–	50	–	30	13.8	160
11–14	43.8	50	7920	–	1845	–	42.1	–	70	–	80	–	35	20.0	260
15–18	55.5	40	8830	–	2110	–	45.4	–	70	–	90	–	40	20.0	260

EAR, Estimated average requirement; RNI, Reference nutrient intake.
* Standard weights for age ranges [20]

Table 1.10 General guide to oral requirements in sick children.

	Infants 0–1 year (based on actual weight, not expected weight)	Children
Energy	High: 130–150 kcals/kg/day (545–630 kJ/kg/day) Very high: 150–220 kcals/kg/day (630–920 kJ/kg/day)	High: 120% EAR for age Very high: 150% EAR for age
Protein	High: 3–4.5 g/kg/day Very high: 6 g/kg/day 0–6 months, increasing to maximum of 10 g/kg/day up to 1 year	High: 2 g/kg/day, actual body weight It should be recognised that children may easily eat more than this
Sodium	High: 3.0 mmol/kg/day Very high: 4.5 mmol/kg/day A concentration >7.7 mmol Na/100 mL of infant formula will have an emetic effect	For severely underweight children, initially an energy and protein intake based on weight, not age, is used
Potassium	High: 3.0 mmol/kg/day Very high: 4.5 mmol/kg/day	

Table 1.11 Infant milk formulas.

Whey based	Casein based	Manufacturer
Aptamil First*	Aptamil Extra*	Milupa Ltd
Cow & Gate Premium*	Cow & Gate Plus*†	Cow & Gate Nutricia Ltd
Farley's First Milk	Farley's Second Milk	HJ Heinz Co Ltd
SMA Gold	SMA White	SMA Nutrition

All formulas contain nucleotides and beta-carotene.
* Contains prebiotics.
† Does not contain long chain polyunsaturated fatty acids.

Table 1.12 Follow-on milks suitable from 6 months.

	Manufacturer
Farley's Follow-on Milk	HJ Heinz Co Ltd
Forward	Milupa Ltd
Progress	SMA Nutrition
Step-up, Next Steps*	Cow & Gate Nutricia Ltd

* From 9 months.

seventh day of life, or sooner if the infant is feeding well. Breast fed infants will regulate their own intake of milk. Bottle fed babies should also ideally be fed on demand.

Fluid requirements in the first few weeks

The normal infant will tolerate 4-hourly feeds, six times daily once a body weight of more than 3.5 kg is reached. By the age of 3–6 weeks (body weight approximately 4 kg), the infant may sleep longer through the night and drop a feed. A fluid intake of 150 mL/kg should be maintained to provide adequate fluids, energy and nutrients. Infants should not normally be given more than 1200 mL of feed per 24 hours as this may induce vomiting and, in the long term, will lead to an inappropriately high energy intake. Sick infants may need smaller, more frequent feeds than the normal baby and, according to the clinical condition, may have increased or decreased fluid requirements. Breast fed infants will continue to regulate their own intake of milk and feeding pattern.

Fluid requirements in older infants and children

Once solids are introduced around 6 months of age (p. 525) the infant's appetite for milk will lessen. For the older infant aged 7–12 months fluid requirements decrease to 120 mL/kg, assuming that some water is also obtained from solids. At 1 year, the child's thirst will largely determine how much fluid is taken.

Very few authorities publish fluid requirements for healthy populations. European recommendations for fluid intakes are summarised [22]. Table 1.13 gives recommendations in the USA [23].

If all a child's nutrition comes from feed and there is no significant contribution to fluid intake from foods, then fluid requirements may be estimated using the following guideline:

Table 1.13 Recommended intakes of water by age group.

	Total water intake per day, including water contained in food	Water obtained from drinks per day
Infants 0–6 months	700 mL, assumed to be from human milk	
7–12 months	800 mL from milk and complementary foods and beverages	600 mL
Children 1–3 years	1300 mL	900 mL
4–8 years	1700 mL	1200 mL
Boys 9–13 years	2400 mL	1800 mL
Girls 9–13 years	2100 mL	1600 mL

Source: Adadpted from USA dietary recommendations [23].

Body weight	*Estimated fluid requirement*
11–20 kg	100 mL/kg for the first 10 kg + 50 mL/kg for the next 10 kg
20 kg and above	100 mL/kg for the first 10 kg + 50 mL/kg for the next 10 kg + 25 mL/kg thereafter

Worked example for a child weighing 22 kg:

100 mL/kg for the first 10 kg	= 1000 mL
+ 50 mL/kg for the next 10 kg	= 500 mL
+ 25 mL/kg for the final 2 kg	= 50 mL
Total	= 1550 mL
	= 70 mL/kg

It is important to remember that not all of this fluid needs to be given as feed if nutritional requirements are met from a smaller volume; the remaining fluid requirement may simply be given as water. Estimates of fluid requirements using this guideline and standard body weights for age groups are given in Table 1.9.

Supplementing feeds for infants with faltering growth or who are fluid restricted

Supplements may be used to fortify standard infant formulas and special therapeutic formulas to achieve the necessary increase in energy and protein required by some infants. Expressed breast milk can also be fortified using a standard infant formula powder in term babies (Table 1.14) or a breast milk fortifier in preterm infants (see p. 80). Care needs to be taken not to present an osmotic load of more than 500 mOsm/kg H_2O to the normal functioning gut, otherwise an osmotic diarrhoea will result. If the infant has malabsorption, an upper limit of 400 mOsm/kg H_2O may be necessary. Infants who are fluid restricted will need to meet their nutritional requirements in a lower volume of feed than usual and the following feed manipulations can also be used for these babies.

Concentrating infant formulas

Normally, infant formula powders, whether whey and casein based formulas or specialised dietetic products, should be diluted according to the manufacturers' instructions as this provides the correct balance of energy, protein and nutrients when fed

Table 1.14 Examples of energy and nutrient dense formulas for infants per 100 mL.

	Energy		Protein	CHO	Fat	Na	K	Osmolality	P : E
	kcal	kJ	(g)	(g)	(g)	(mmol)	(mmol)	(mOsm/kg H_2O)	ratio
12.7% SMA Gold	67	280	1.5	7.2	3.6	0.7	1.8	294	9.0
15% SMA Gold	79	330	1.8	8.5	4.3	0.8	2.1	347	9.0
EBM + 3% SMA Gold	84	353	1.7	8.9	4.9	0.7	1.8	–	8.1
SMA High Energy	91	382	2.0	9.8	4.9	1.0	2.3	415	8.8
Infatrini	100	420	2.6	10.3	5.4	1.1	2.4	310	10.4
15% C&G Premium + Maxijul to 12% CHO + Calogen to 5% fat	100	420	1.6	12.0	5.0	0.9	2.1	–	6.4

P : E, protein:energy; EBM, expressed breast milk.

at the appropriate volume. However, there are occasions when, to achieve a feed that is denser in energy, protein and other nutrients, it is necessary to concentrate the formula. Most normal baby milks in the UK are made up at a dilution of approximately 13%. By making the baby milk up at a dilution of 15% (15 g powder per 100 mL water), more nutrition can be given in a given volume of feed, e.g. energy content may be increased from 67 kcal (280 kJ) per 100 mL to 77 kcal (325 kJ) per 100 mL and protein content from 1.5 g per 100 mL to 1.7 g per 100 mL. Similarly, special therapeutic feeds that are usually made up at a dilution of, say, 15% may be concentrated to a 17% dilution. This concentrating of feeds should only be performed as a therapeutic procedure and is not usual practice. Table 1.14 shows an example of a 15% feed.

The protein : energy ratio of the feed should ideally be kept within the range 7.5–12% for infants (i.e. 7.5–12% energy from protein) and 5–15% in older children. In order for accelerated or 'catch-up' growth to occur, it is necessary to provide about 9% energy from protein [24]. In some clinical situations it is not possible to preserve this protein : energy ratio as carbohydrate and fat sources alone may be added to a feed to control deranged blood biochemistry, for example. In these situations it is important to ensure that the infant is receiving at least the RNI for protein.

If infants are to be discharged home on a concentrated feed the recipe may be translated into scoop measures for ease of use. This will mean that more scoops of milk powder will be added to a given volume of water than recommended by the manufacturer. As this is contrary to normal practice the reasons for this deviation should be carefully explained to the parents and communicated to primary health care staff.

Nutrient-dense ready-to-feed formulas

There are two nutrient-dense ready-to-feed formulas available for hospital use and in the community, Infatrini and SMA High Energy (Table 1.14). They are nutritionally complete formulas containing more energy, protein and nutrients per 100 mL than standard infant formulas. They are suitable for use from birth and are designed for infants who have increased nutritional requirements or who are fluid restricted. They obviate the need for carers to make up normal infant formulas at concentrations other than the usual one scoop of powder to 30 mL water.

Energy and protein modules

There may be therapeutic circumstances when energy and/or protein supplements need to be added to normal infant formulas or special formulas without necessarily the need to increase the concentration of the base feed. Sometimes a ready-to-feed formula does not meet the needs of the individual child. Energy and protein modules and their use are described.

Carbohydrate

Carbohydrate provides 4 kcal/g (16 kJ/g). It is preferable to add carbohydrate to a feed in the form of glucose polymers, rather than using mono- or disaccharides, because they exert a lesser osmotic effect on the gut. Hence, a larger amount can be used per given volume of feed (Table 1.15). Glucose polymers should be added in 1% increments each 24 hours (i.e. 1 g per 100 mL feed per 24 hours). This will allow the point at which the infant becomes intolerant (i.e. has loose stools) to the concentration of the extra carbohydrate to be identified. Tolerance depends on the age of the infant and the maturity and absorptive capacity of the gut. As a guideline, the following percentage concentrations of carbohydrate (g total carbohydrate per 100 mL feed) should be tolerated if glucose polymer is used:

- 10–12% carbohydrate concentration in infants under 6 months (i.e. 7 g from formula, 3–5 g added)
- 12–15% in infants aged 6 months to 1 year
- 15–20% in toddlers aged 1–2 years
- 20–30% in older children

If glucose or fructose needs to be added to a feed where there is an intolerance of glucose polymer, an upper limit of tolerance may be reached at a total carbohydrate concentration of 7–8% in infants and young children.

Fat

Fat provides 9 kcal/g (37 kJ/g). Long chain fat emulsions are favoured over medium chain fat emulsions because they have a lower osmotic effect on the gut and provide a source of essential fatty