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Body composition in childhood: effects of normal growth and disease

J. C. K. Wells
MRC Childhood Nutrition Research Centre, Institute of Child Health, 30 Guilford Street, London WC1N 1EH, UK

Body composition in children is of increasing interest within the contexts of childhood obesity, clinical management of patients and nutritional programming as a pathway to adult disease. Energy imbalance appears to be common in many disease states; however, body composition is not routinely measured in patients. Traditionally, clinical interest has focused on growth or nutritional status, whereas more recent studies have quantified fat mass and lean mass. The human body changes in proportions and chemical composition during childhood and adolescence. Most of the weight gain comprises lean mass rather than fat. In general, interest has focused on percentage fat, and less attention has been paid to the way in which lean mass varies within and between individuals. In the general population secular trends in BMI have been widely reported, indicating increasing levels of childhood obesity, which have been linked to reduced physical activity. However, lower activity levels may potentially lead not only to increased fatness, but also to reduced lean mass. This issue merits further investigation. Diseases have multiple effects on body composition and may influence fat-free mass and/or fat mass. In some diseases both components change in the same direction, whereas in other diseases, the changes are contradictory and may be concealed by relatively normal weight. Improved techniques are required for clinical evaluations. Both higher fatness and reduced lean mass may represent pathways to an increased risk of adult disease.

Body composition in childhood: Fat mass: Lean mass: Childhood disease: Nutritional programming

Children's body composition is an issue of increasing interest in several areas of medical research. Relatively rapid secular trends in weight relative to height throughout the general population are contributing to an increase in the prevalence of obesity in children. Growth of the fat-free mass (FFM) and its constituent tissues and organs is also attracting interest, in the contexts first of clinical care and second of nutritional programming as a pathway to adult disease.

Almost every childhood disease has the potential to impact on body composition. Even modest changes in activity level may influence traits such as body fatness, muscle mass or bone density, while more serious diseases may adversely affect organ and muscle function and hydration. Our ability to address these problems is dependent on a good understanding of several basic issues: the range of normal body composition; appropriate techniques with which to obtain data in health and disease; appropriate interpretation of such data given problematic confounding effects such as age, gender and size.

The present review will focus on the broadest aspects of body composition, body fatness and relative lean size. As recently highlighted by Reilly (2002), energy imbalance is common in paediatric diseases and may lead either to malnutrition or to excess weight gain. However, the identification of undernutrition or overnutrition is frequently hindered by the fact that both lean and fat may be affected by a disease state, and deficits or excesses in one component of weight may be concealed by changes in the other. Advances in the ability to measure and evaluate body composition are therefore required to underpin improvements in clinical practice.

Abbreviations: FFM, fat-free mass; FFMI, fat-free mass index; FM, fat mass; FMI, fat mass index.
Corresponding author: Dr J. C. K. Wells, fax +44 20 7831 9903, email J.Wells@ich.ucl.ac.uk

Methodologies

The gold standard for body composition assessment is cadaver dissection combined with chemical analysis. Any measurements conducted *in vivo* are of necessity imperfect, and there is the added constraint in children, especially in those who are sick, that measurement techniques must be acceptable. For the majority of the last century, body composition tended to be assessed through anthropometry, using measurements of weight, height and skinfold thickness. Since the mid-1980s rapid advances have been made in methodologies and there is now a variety of techniques acceptable for paediatric use. This progress has led not only to measurements being made more frequently, but also to a more diverse range of outcomes being investigated.

For many purposes, clinicians and researchers require a two-component model of body composition, in which body weight is divided into the FFM and the fat mass (FM). These are chemical components, with FFM in the present paper taken to be synonymous with lean mass. However, awareness that diseases and other environmental factors may influence more specific components has stimulated the development of more sophisticated approaches. Among the outcomes of interest are specific chemical compartments of the body (e.g. protein *v.* fat); functional tissues (e.g. organs *v.* muscles), or tissue properties (e.g. hydration of FFM).

As no individual *in vivo* technique measures chemical composition of the body directly, it is necessary to incorporate theoretical assumptions. These assumptions range from being relatively specific and reliable (e.g. assumed constancy of a specific chemical component) to being more general and less reliable (e.g. assumed constancy of the entire FFM). The extent to which theoretical assumptions detract from data depends on two issues: (1) the extent of biological variability between individuals in a given property; (2) whether an assumed property is appropriate for a given population (e.g. a specific age-group or disease state).

Arguably the best approach at present is to use a multi-component model. The four-component model measures body weight, body volume, total body water and bone mineral content, from which the masses of fat, protein, water and mineral may be calculated (Fuller *et al.* 1992; Wells *et al.* 1999). In addition, the density and hydration of FFM are quantified. The model can be applied in children aged ≥5 years, using ^{2}H dilution, air-displacement plethysmography and dual-energy X-ray absorptiometry, although accuracy of the latter two techniques in younger children is still being assessed. It could be improved further in some patient groups by the addition of bromide dilution for the estimation of extracellular water. The model has minimal dependence on assumed constancy of tissue properties, assuming only constant osseous:non-osseous mineral (Fuller *et al.* 1992). The simpler three-component model omits the measurement of bone mineral content by dual-energy X-ray absorptiometry and assumes constant protein:mineral in fat-free dry tissue. Such an assumption may, however, be inappropriate in some disease states.

Using four-component model data as a reference, other simpler techniques can be evaluated. The most successful two-component technique appears to be ^{2}H (Wells *et al.* 1999; Werkman *et al.* 2000), although it is inappropriate when hydration is altered. Dual-energy X-ray absorptiometry is prone to error due to its inability to measure soft tissue overlying bone, while the accuracy of densitometry, whether through hydrodensitometry or plethysmography, is limited on account of between-subject variability in the density of FFM (Wells *et al.* 1999). Predictive techniques, such as bioelectrical impedance analysis for the prediction of body water, and skinfold thickness measurements, have greater error due to between-subject variability in body proportions. The accuracy of skinfold prediction equations varies according to the fatness of the subject (Reilly *et al.* 1995; Wells *et al.* 1999). However, although simple bioelectrical impedance equations currently suffer from the same limitation (Wells *et al.* 1999), more sophisticated approaches may allow considerable refinement of this technique in the future. Data on regional body composition may be obtained (Fuller *et al.* 2002), and using multi-frequency instrumentation both hydration and tissue masses may be studied simultaneously (De Palo *et al.* 2000). Both dual-energy X-ray absorptiometry and bioelectrical impedance potentially offer improvements over BMI in epidemiological work by providing discrete, although imperfect, indices of relative fatness and lean size.

Expression of body composition data

Traditionally, clinical interest has focused on: (1) growth, represented by height and weight; (2) nutritional status, represented by weight adjusted for height (ideally BMI); (3) body fatness, with FM expressed as percentage weight. It is becoming clear that nutritional status is too general an index for both clinical and epidemiological research on body composition, and that even percentage fat is problematic when applied to body composition data. BMI, although highly correlated with fatness (Pietrobelli *et al.* 1998), is a poor index in individuals because it does not distinguish fat from lean. Fig. 1 demonstrates that children aged 8 years may have varying extents of of body fatness for a given BMI value, according to the fat:lean within their weight.

Percentage fat is similarly problematic as an index of fatness, because values are inadvertently influenced by relative lean size. Fig. 2 illustrates three hypothetical children of identical height. Compared with subject A, subject B has greater percentage fat because of greater absolute FM. Compared with subject B, however, subject C has greater percentage fat despite having identical FM, merely because B has greater FFM.

The implication of these graphs is that both fat and lean require independent adjustment for size, leading to discrete indices of relative FM and FFM deposition. Adjustment for size is particularly important in children, given that maturational status exerts its own effects on body composition.

A simple approach divides BMI into its fat and lean components (Van Itallie *et al.* 1990):

$$\text{BMI} = \text{weight}/\text{height}^2 = \text{FFM}/\text{height}^2 + \text{FM}/\text{height}^2.$$

It is helpful to conceptualise these indices, termed the FFM index (FFMI) and the FM index (FMI), using a cylinder model. Logic suggests that, on average, taller

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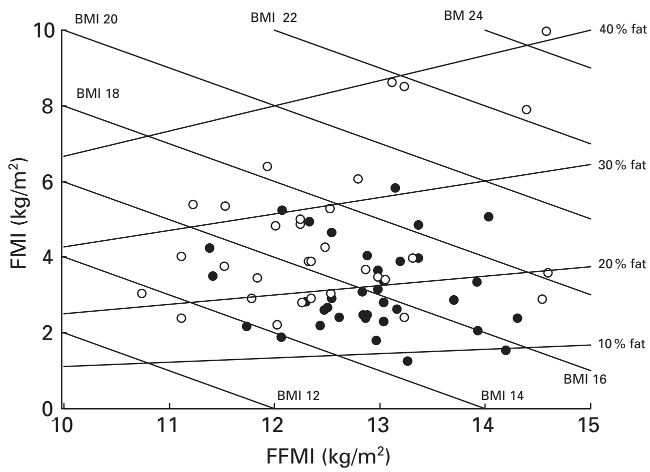

Fig. 1. A Hattori chart (Hattori *et al.* 1997) for children aged 8 years, plotting fat-free mass (FFM) index (FFMI; FFM/height^2) *v.* fat mass (FM) index (FMI; FM/height^2). Diagonal lines represent constant values for BMI and percentage fat. A given BMI value may embrace varying proportions of fat and lean, as may a given value for percentage fat. (●), Boys; (○), girls.

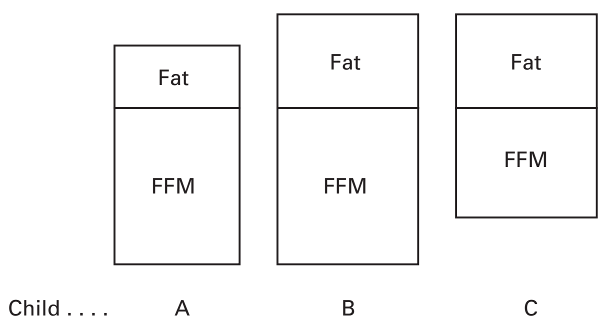

Fig. 2. Data for three hypothetical children of identical height. Child B differs from both child A and child C in percentage fat, in the first case because absolute fat mass is different, but in the second case because absolute lean mass is different. FFM, fat-free mass.

subjects will tend to have both greater FFM and greater FM, represented by greater cylinder length. The previously mentioned approach adjusts for length, to allow between-subject comparisons of cylinder volume. The approach is convenient, since both indices are expressed in the same units as BMI, kg/m^2.

However, this adjustment is based on the relationship between weight and height, not on the separate relationships of FFM and FM with height. FFM and FM will not have identical relationships with height if they differ in between-subject variability. Separate adjustments may therefore be required to establish the appropriate approach for each component of weight.

An analysis in 8-year-old children found that while FFM is normalised by dividing by height^2, FM is normalised by dividing by height^6 (Wells *et al.* 2002*a*). As it is a sub-optimal adjustment for height, FMI retains a correlation with height, *r* 0·38. Nevertheless, the magnitude of this correlation indicates that only 7·5 % of the variation in FMI is attributable to variation in height as opposed to variation in fatness (Wells *et al.* 2002*a*). For most purposes, the simpler FMI and FFMI are acceptable, and provide the opportunity to evaluate variation in fat and lean independently of size. Only if comparing two groups or two individuals who are markedly different in height is the simpler FMI likely to introduce significant bias.

This approach, of expressing data in the form of FFMI and FMI, is used throughout the remainder of the present paper. Both FFMI and FMI *v.* age may be plotted to show gender-specific size-adjusted development in both fat and lean (Wells, 2001). Once reference data are available, measurements may also be converted to z-scores for evaluation of relative changes over time.

Normal growth

It has been recognised for many decades that the body is chemically immature at birth (Widdowson, 1950) and undergoes marked changes in composition throughout the period of growth. At birth, for example, approximately 80 % of lean tissue is water, declining to approximately 75 % at the end of the first decade (Fomon *et al.* 1982) and further to 72–73 % by adulthood (Schoeller, 1996). Similar changes occur within FFM, e.g. in protein:mineral and intracellular:extracellular water (Fomon *et al.* 1982). Using data relating to birth, 6 months and 9–10 years, age-related trends in body composition were derived within this age period by Fomon *et al.* (1982) to provide a provisional reference child.

The traditional interpretation of these data in terms of fat and lean is that there is a steady increase in FFM throughout growth, while there is a marked peak in body fatness in infancy, followed by a rapid decline and then a steady increase towards the adult value. Fig. 3 illustrates both BMI and percentage fat *v.* age over the period from birth to 10 years, using data from the reference child. It is interesting that although both genders show a 'U'-shaped curve for BMI between 1 and 10 years, only in the reference girl does percentage fat increase again in the second half of childhood.

Few studies have followed the development of fatness over time, whereas many studies, mostly cross-sectional but some longitudinal, have followed the trend of BMI *v.* age. The ubiquitous finding of the 'U'-shaped pattern has led to the increase in BMI following its nadir in mid-childhood being termed the adiposity rebound (Rolland-Cachera *et al.* 1984). Recent analyses, however, have demonstrated that the majority of the increase in BMI from mid-childhood onwards can be attributed to increasing FFM, rather than FM, relative to height. Fig. 4 illustrates FFMI *v.* FMI, using the same data from 1 to 10 years. Girls do increase FMI between 6 and 10 years, but the effect of this increase on BMI is less than that of FFMI. In boys FMI remains stable between 6 and 10 years, whereas FFMI increases consistently (Wells, 2000). Similar findings have been reported in adolescents, where increases in BMI can again be attributed largely to FFM rather than fat (Maynard *et al.* 2001).

BMI remains a useful tool by which to identify excess weight gain, as rapid increases in individual children can be attributed to fat rather than lean. Those children who climb more steadily through the BMI centiles might also be depositing fat rather than lean. Nevertheless, insufficient

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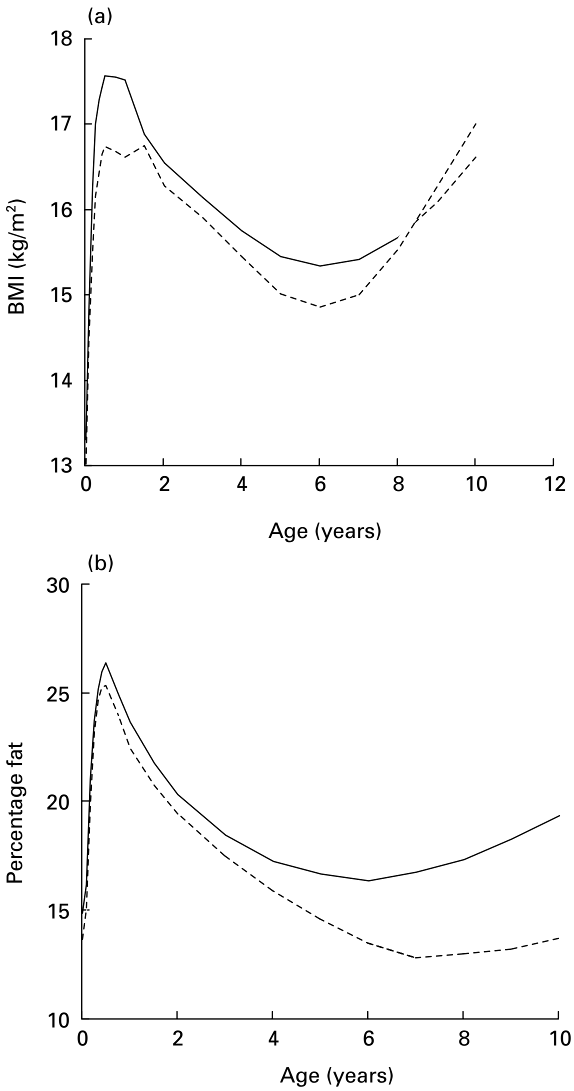

Fig. 3. Changes in (a) BMI and (b) percentage fat in the reference child (Fomon *et al.* 1982) between birth and 10 years. (——), Males; (– – –), females.

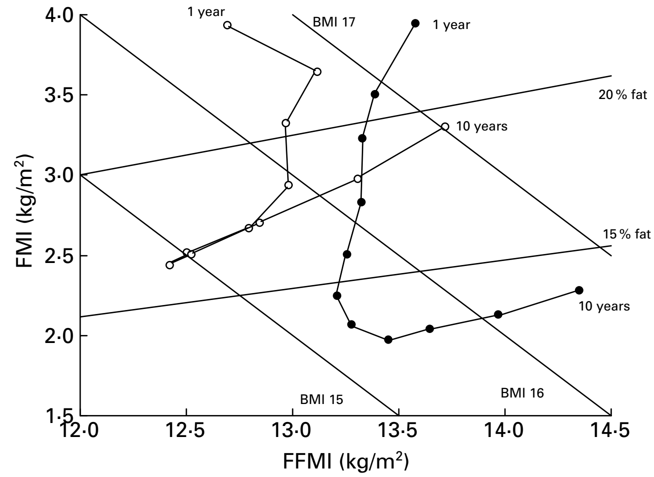

Fig. 4. A Hattori chart of the reference child (Fomon *et al.* 1982) between 1 and 10 years of age, illustrating gender differences in the proportion of BMI that is fat and lean at different ages. FMI, fat mass index (fat mass/height²); FFMI, fat-free mass index (fat-free mass/height²). (●), Boys; (○), girls.

attention has been directed to how FFM develops in individual children over time, and there is a need to improve understanding of how body build and frame size develop and track over time.

Likewise, little attention has been directed to cross-sectional variability in lean size. In the subjects shown in Fig. 1, the SD of FFMI and FMI are 0·70 and 1·13 kg/m^2 in boys, and 1·01 and 1·96 kg/m^2 in girls, indicating that variability in lean size is over half that in fatness in both genders at 8 years.

However, there is still a dearth of studies characterising these changes in sufficient detail, and the predictions of Fomon *et al.* (1982), supported by similar work (Lohman, 1989), remain widely used as reference data despite giving mean values only. Adolescence has rarely been considered (Haschke, 1983*a,b*), which is surprising given the marked changes in size that accompany puberty. New reference data are required that represent contemporary children throughout the period of growth, based on measured values rather than predicted values. Such data are needed not only to describe the broad changes in fat and lean, but also to describe the changing properties of FFM with age.

Childhood body composition and adult disease

Human growth appears to be characterised by three distinct phases, termed infancy, childhood and adolescence (Karlberg *et al.* 1987). The contributions of these phases to final size are thought to be additive, such that deficits in growth that occur in one phase tend not fully to be recovered subsequently, even if the environment improves. Whereas childhood and adolescent growth in FFM is mainly under hormonal regulation, the first growth phase covering fetal and infant life is environmentally regulated, with nutrition the major limiting factor. Organ growth is largely completed during this first phase, even though body size increases substantially in later phases (Bogin, 1996).

Epidemiological work has demonstrated associations between poor early growth and several adult diseases such as stroke, CHD and type 2 diabetes (Barker, 1998). More recently, attention has also focused on the role of childhood growth patterns in this association. Rather than small size itself predisposing to later disease, there is increasing evidence that it is the disparity between early and later size that is important (Lucas *et al.* 1999). As small infants tend to show catch-up growth, they are inherently prone to such disparity. However, infants of normal size at birth who gain excess weight in childhood also show elevation in risk factors for adult disease (Fewtrell *et al.* 2000). The implication is that any mismatch between early organ development and later body size increases disease risk, and the disparity is merely greatest in those born small who have subsequently risen most through the growth centiles.

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Nutritional programming represents a relatively new angle on childhood body composition, with alterations to both fat and lean components representing potential pathways between early environment and adult disease. Both catch-up growth in lean size and excess fatness may increase disparity between metabolic capacity determined early in life and subsequent metabolic load.

Thus, the main effect of childhood obesity on population health is potentially not its immediate impact during childhood, but its persistence over time into adulthood. Studies conflict in their assessment of whether childhood obesity status is maintained. Several studies focusing on BMI status support the hypothesis, whereas recent studies suggest that BMI tracking may relate more to body build than to fatness (Wright *et al*. 2001). However, obesity appears much easier to acquire than to lose, and the tendency of obesity to persist in contemporary children may be greater than in previous more active generations.

The idea that childhood FFM might be related to later disease risk is less well researched, but of increasing interest. Recent work has highlighted the differential adaptation of different components of body weight to undernutrition in early life. Compared with normal-weight infants, growth-retarded infants were found to preserve their fat stores and organs at the expense of muscle tissue (Yajnik, 2001). In separate studies of catch-up growth, compensatory increases in height appear not to be supported by matching increases in weight (Norgan, 2000). Work from a variety of animal species suggests that such catch-up growth represents a short-term adaptation, achieved at the cost of reduced cellular robustness in later life (Metcalfe & Monaghan, 2001).

The development of both FM and FFM may, therefore, have important implications for later health. Increases in fatness, achieved through over-nutrition, and compensatory increases in FFM, achieved through catch-up growth, may each increase disparity between metabolic capacity and load. As discussed later, many hospital patients may be at increased risk for both such pathways to disease.

Secular trends in the general population

Advances in the measurement of body composition are relatively recent, and evaluations of secular trends in the prevalence of obesity are mainly restricted to data on BMI, although skinfold thickness data have also been reported. Studies from many Western countries have consistently shown an increase in BMI over recent decades, reflected in an increase in the number of children classified as obese (Bundred *et al*. 2001; Chinn & Rona, 200; also, see Wang & Wang, 2002).

Although the validity of BMI as an index of fatness in a population depends on its relationship with both fat and lean components of weight, this issue has received minimal investigation. If the relationship between BMI and body composition varies between populations, or within them over time, then the interpretation of changes in BMI as equivalent changes in fatness will be misleading. The possibility that children have changed in relative lean size over recent decades is not implausible, given the trend towards lower activity levels.

A recent analysis comparing 1990s children from Cambridge, UK against the reference child (Fomon *et al*. 1982) found that the Cambridge children had significantly lower FFM and significantly greater FM for their height ($P<0{\cdot}005$ for both genders in both cases; Wells *et al*. 2002*b*). The study allowed for the first time an assessment of the increase in fatness, as opposed to BMI, and indicated that average increases in FMI were 23 % in boys and 35 % in girls.

The limitation of this analysis is of course the quality of the reference data, which may not be a good representation of body composition of children in previous decades. Nevertheless, variation in the BMI–fatness relationship is now well documented in adults (Deurenberg-Yap *et al*. 2000), and two further studies have reported trends in fatness of children that are not matched by equivalent changes in BMI. A previous analysis of US adolescents demonstrated stability of BMI but an increase in triceps skinfold thickness over the period 1966–80 (Flegal, 1993). A recent comparison of Spanish children studied in 1980 and 1995 (Moreno *et al*. 2001), likewise, showed a trend towards increasing central fat distribution in pre-pubertal children, independent of changes in BMI over the same period. These studies focus more on fat distribution rather than the total amount of fat, but nevertheless indicate that trends in BMI are not identical to those in fatness.

The possibility that children are building up lower levels of FFM during childhood due to lower activity levels requires further investigation, as such changes could have their own implications for adult disease risk. Although quantitative data are scarce, changes in lifestyle imply that UK children are substantially less active than formerly. This factor is the most likely cause of a reduction in FFM, since exercise stimulates muscle growth (Torun & Viteri, 1994). A previous study of weight gain in Scottish children has also suggested that FFM deposition is reduced and fat deposition increased, compared with the reference child (Ruxton *et al*. 1999). Reduced FFM deposition developing from mid-childhood onwards may have implications for osteoporosis as well as physical work capacity in adulthood.

BMI remains the most practical way in which to compare broad changes in obesity within and between populations. However, the analyses mentioned earlier imply that epidemiological work should ideally measure body composition directly, rather than through proxy measurements, in order to quantify variation in fatness as opposed to weight.

Effects of diseases

Research on body composition in paediatric patients remains constrained by the twin requirements that techniques be both acceptable and able to accommodate the increased chemical variability in tissues that occurs in diseases. Until recently, disease states have remained comparatively unexplored, and although interest is rapidly increasing as a result of technological advances, clinical practice is still dominated by assessment of nutritional status alone. However, the importance of addressing this area is emphasised by reports that it exerts a marked influence on clinical outcome in the longer term. Advances in nutritional management underlie the substantial increases in longevity achieved in patients with cystic fibrosis (Reilly *et al*. 1997), while poor nutritional status is associated with post-operative growth failure in patients who have received a liver transplant (Kelly, 1997) and with increased risk of mortality in patients with HIV (Miller *et al*. 1995). Measurements of specific aspects of body composition offer the potential to achieve marked improvement in both the characterisation of disease states and the assessment of alternative management strategies.

Given the extraordinary diversity of paediatric diseases, the present article aims merely to illustrate the concepts described earlier by highlighting the general pattern of changes in relative fat and lean deposition. Briefly, patients may have either high or low FFM compared with healthy children and, reasonably independently, high or low fatness. This pattern is shown schematically in Fig. 5, together with examples of disease states that conform to this categorisation. It should be clear that some diseases exert common effects on both components of weight (e.g. anorexia, obesity), whereas in others the effects diverge. Improving understanding of these patterns is predicted to improve dietetic management, as energy requirements should ideally be based on lean size rather than weight.

Childhood eating disorders

Studies of adult patients with anorexia nervosa have shown that both fat and protein stores are depleted relative to those of control women (Russell *et al*. 1994). However, very few studies have considered early adolescence, when growth rate would normally be rapid. Furthermore, the independent effect of bulimia nervosa on body composition has also received little attention.

In a recent study (Nicholls *et al*. 2002) of pre- and peripubertal children with eating disorders, body composition was measured using skinfold thickness measurements. Such measurements are predicted to measure body composition with bias in most patient populations, and the results should therefore be considered preliminary. However, comparisons of SD scores to some extent overcomes biases in absolute values, and the results were found to be similar regardless of the equation used to convert raw measurements into final values. The study therefore provides a useful starting point for further investigations.

Children with anorexia nervosa, mainly girls, were found to have broadly comparable deficits in FM and FFM (Nicholls *et al*. 2002). In contrast, there was no evidence that girls with bulimia nervosa differed in their body composition from the reference children.

This study highlights the value of expressing data on fatness independently from lean size. Reduced fatness is important in such patients because of the suggested role of fat stores in regulating the onset of puberty and the resumption of menses (Frisch, 1984). The reduced lean mass may also have implications for diseases such as osteoporosis and, possibly, type 2 diabetes. Importantly, a study of adults with anorexia found that re-feeding was more successful at restoring fat than lean (Iketani *et al*. 1999).

Fat-free mass \ Fat mass	Low	High
Low	Anorexia	Chronic lung disease
High	Cancer	Obesity

Fig. 5. Simple categorisation of paediatric patients emphasising that fat and/or lean components of weight may be increased or decreased relative to that of healthy children.

Cancer

Few diseases lead to increases in fat-free dry tissue mass. In cancer, however, tumour masses may reach $>10\ \%$ of the total body weight, and hence may confound evaluations of weight relative to height. A study of paediatric patients with cancer using measurements of upper arm circumference and triceps skinfold thickness found that although weight relative to height was comparable with that of controls, the arm measurements were significantly lower ($P<0{\cdot}001$) and in some patients were below the fifth centile for both mid upper arm circumference and triceps skinfold thickness, indicating marked malnutrition (Oguz *et al*. 1999). The most extreme results were found in patients with intra-abdominal solid tumours.

This study illustrates how apparently-normal relative weight may conceal clinically important alterations in body composition. Further studies in such populations are important for describing the changes in FFM in more detail, as such alterations are predicted to influence energy requirements. In a male infant with disseminated myofibromatosis, increased FFM due to tumours was indeed associated with increased total energy expenditure (Wells *et al*. 2003).

Although increased fat-free dry tissue mass is rare, many disease states result in oedema, which may similarly confound evaluations of nutritional status based on weight relative to height. Where oedema is present, two-component models of body composition are unlikely to provide meaningful data. Investigation of the distribution of total body water between different pools is predicted to be more informative.

Artificial ventilation

Artificial ventilation is required in a variety of long-term intensive care patients, such as those with chronic lung disease and spinal injury. In contrast to acute patients, chronically-ventilated patients are not inevitably bed-bound, and may have moderate levels of physical activity. However, they are predicted to have reduced energy requirements compared with healthy children, partly because of the reduced energy cost of breathing and partly because their mobility is constrained by the ventilator. Furthermore, some

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patients with spinal cord injury or conditions affecting muscle function have negligible mobility.

In an ongoing study body composition and total energy expenditure have been measured in twelve patients with a variety of disease states. The cross-sectional data imply that, relative to healthy subjects, these patients initially have extreme deficits in FFM, which decrease with age, particularly in those with chronic lung disease (tracheo-bronchomalacia) whose condition usually improves. In contrast, average body fatness is higher than that of reference subjects, with the patients with chronic lung disease again showing less extreme values. The energy requirements of these patients are not markedly different from normal when expressed relative to FFM, but relative to weight tend to be lower than average, except for those with chronic lung disease in early infancy (Wells *et al*. 2002).

If the energy requirements of these patients are based on weight, their energy requirements in early infancy are underestimated and growth may be constrained, but thereafter they are overestimated because of the deficits in FFM, leading to increases in fatness. Paradoxically, many of these patients have extremely low BMI SD scores yet above average fat SD scores, e.g. the patients with congenital myasthenia who have approximately 40 % fat (Wells *et al*. 2002*c*). This combination of reduced FFM and high FM may prove to be common in other paediatric patient groups, and further studies are underway to explore this hypothesis.

Obesity

Obesity is defined as an excess of body fatness, but remains categorised on the basis of BMI. Where data on fatness are incorporated into its classification, they tend to be expressed as percentage fat, and thus still ignore changes in lean size. This factor is important, given that exercise regimens to promote weight loss may affect FFM as well as FM.

Adults with high levels of fatness also tend to have high FFM. However, from Fig. 1 it is apparent that this is not always the case in young children, and that some individuals, especially girls, may have high FMI but average FFMI values. This scenario may occur to a more extreme extent in some patients. Thus, although obesity may involve increases in both components of weight, categorisation based on relative weight alone risks failing to identify all those with high levels of fatness.

The future

The present review has discussed the total amounts of fat and lean relative to body size. Increasingly, interest is likely to focus on their regional distribution, and in turn on the size of specific organs. The ability to distinguish muscle and organ masses is important for energy requirements, as organ tissues have higher energy requirements per unit weight. Fat distribution may have important implications for later obesity status and type 2 diabetes, and is known to be altered both by diseases and by some management strategies (for example, see Brambilla *et al*. 2001).

A further issue meriting attention is that of body shape, which represents a pathway between body composition and psychology. Some adolescent patients may reduce compliance with dietetic management through attempting to conform to idealised body images. Concern with shape is also a defining component of some eating disorders. Body shape can now be measured objectively through photonic scanning (Wells *et al*. 2000), and the body composition implied by idealised female body shape has also been investigated (Wells & Nicholls, 2001). Research in this area may potentially improve treatment success in the future.

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