8. Thin adults

8.1 Introduction

8.1.1 *Background*

The nutrition and health of adults are of particular importance because it is this age group that is primarily responsible for the economic support of the rest of society. In industrialized countries, although an appreciable proportion of adults are still engaged in activities that require physical stamina and strength, economic productivity depends to a substantial degree on the intellectual and technical skills of the population. In non-industrialized societies, however, where agricultural work is the dominant economic activity, physical capacity and endurance are critical to the ability of adults to sustain the socioeconomic and cultural integrity of their community.

8.1.2 *Terminology*

The terms "stunting" and "wasting" are rarely applied to adults, except in a clinical context where particular individuals may be deemed to be so different in their stature or physical appearance from the rest of society that clinicians employ these descriptive terms without reference to defined cut-off points. Thus "wasting" is usually confined to adults who are ill (in a hospital setting) or enduring extreme conditions, e.g. famine.

Variability in adult weight is recognized as being linked with variation in adult height, which in turn reflects a number of environmental factors active throughout much of childhood. The term "underweight" in adult assessment has therefore been applied to individuals of low body weight relative to height; it is generally expressed in terms of body mass index.

Degrees of underweight have recently been defined as "chronic energy deficiency" (CED), categorized on the basis of BMI (*1*, *2*). The term CED was originally applied to adults who were not only underweight for their height but also constrained in their physical activity by inadequate food intakes (*1*); more recently the term has been defined simply in terms of specific levels of BMI (*2*). In this report, however, the condition of low BMI is termed "thinness" graded as mild (grade 1), moderate (grade 2), or severe (grade 3).

Other measures of size

In clinical practice and in population studies, simple additional or alternative measurements to weight and height have been sought. Arm circumference is one such measurement and has also been used together with more sophisticated estimates of muscle circumference obtained by adding a skinfold measurement; however, total circumference at the mid-point of the upper arm (MUAC) is preferred. Measuring MUAC has the advantage that it reflects the mass of just three tissues – bone, muscle, and fat – the last two of which are particularly sensitive to body weight gain or loss. Changes in arm circumference thus reflect more accurately the increase or decrease of tissue "reserves" of energy and protein (3) than body weight *per se*. By calculating mid-arm muscle circumference (AMC), a more specific measure of the more labile fraction of lean tissue can be obtained. The significance and usefulness of these measurements, used either alone or in association with BMI, are considered later in this section.

8.2 Biological and social significance of anthropometry

8.2.1 *Biological and social determinants of anthropometry*

The average stature of adults varies markedly from country to country. Environmental conditions and childhood nutrition interact with the genetic potential of the individual to determine increase in height and eventual attained stature. Differences in adult height therefore reflect long-term differences in the socioeconomic conditions of different groups in most developed and developing countries. However, as socioeconomic differences within a society attenuate, so the differences in adult height are reduced. The relationships between height and socioeconomic circumstances are more readily seen by monitoring the height of children.

Adult height usually declines with age. This reflects not only the steady, age-related decrease in the width of both the intervertebral discs and the lumbar vertebral bodies (see section 9) but also the impact of the greater height of better-grown younger cohorts. Thus, where socioeconomic impact on adult height has been small over the past 70 years, the differences between the heights of adults aged 20 and 60 years are also small. This contrasts with data on adults in Japan, for example, where there has been a marked secular increase in the height of children and where the discrepancy between the height of 20- and 60-year-old adults is substantial.

Table 37
Daily physical activity level of Rwandan women according to body mass index[a]

	Daily physical activity level[b]			
Body mass index	Monday–Friday	Saturday	Sunday	Average
≤ 17.0	1.51	1.51	1.44	1.50
17.1–17.5	1.57	1.55	1.48	1.55
17.6–18.6	1.63	1.59	1.52	1.61
18.7–23.8	1.67	1.66	1.57	1.65
23.9–26.1	1.69	1.67	1.58	1.67

[a] Data from François P, unpublished report to Food and Agriculture Organization of the United Nations, Rome, 1990.

[b] Expressed as multiples of basal metabolic rate. Average values obtained over a 1-year period.

Once adult stature has been achieved, biological impacts on height are limited to disease states, e.g. Cushing disease or ankylosing spondylitis, or to environmental processes that accentuate bone loss and osteoporosis.

In contrast to the effects on height, changes in nutritional intake and in health can have a major impact on body weight. Seasonal changes in food availability and in physical activity produce fluctuations in both average weight and the population distribution of weights, and any illness that induces anorexia, elevated metabolic rates, or preferential catabolic loss of lean tissue will also produce a fall in body weight. This makes the monitoring of adult weight or some alternative index of body mass a useful tool for assessing the impact of illness, food shortage, or unusual physical demands. Other factors, such as cigarette smoking and drug and alcohol dependence are also usually associated with lower body weight.

8.2.2 *Biological and social consequences of anthropometry*

Adult height has long been recognized as a predictor of work capacity, and formal studies now confirm this relationship. However, height and weight are closely correlated, and in practice work capacity is predicted better by total body weight than by height. The relationship between work capacity and height is therefore indirect. Women's height and weight also predict a variety of outcomes of pregnancy, such as dystocia and low birth weight (see section 3).

Individual adaptation

Individuals of low body weight change the allocation of time and energy to different productive and leisure-time activities. Data collected for the National Food Consumption and Household Budget Survey in Rwandan women[1] reveal that physical activity levels in women with BMI < 17.6 are significantly lower, and the length of time taken for rest each day greater, than those in heavier women (see Table 37). The women of lower weight allocate fewer days to heavy labour; an inverse relationship is thus apparent between BMI and the time allocated to heavy work. Obligatory work needs, however, are still met.

Studies in Ethiopia and in India also show very low levels of physical activity in adult men with BMI 18–19 and women with BMI 17–18 (*2*); work output is sustained at only 2–4.5 hours per day.[2] Men with a very low BMI (< 16) show even lower levels of activity.

[1] François P. Unpublished report to the Food and Agriculture Organization of the United Nations, Rome, 1990.

[2] See also:
Norgan NG et al. *The determinants of the biological impact of seasonality on energy nutritional status in a rural Karnataka (South India) agricultural cycle.* Unpublished report to International Food Policy Research Institute, Washington, DC, 1993.
Branca F et al. *Seasonality in agriculture: evidence of its nutritional impact. A case study in southern Ethiopia.* Unpublished report to International Food Policy Research Institute, Washington, DC, 1993.

During seasonal food shortages, adults reduce their energy intakes and increase their expenditure of energy on productive work; for example, to complete jobs such as planting and hoeing, individuals will adjust the time allocated to work and home activities, giving more time to work and expending less energy on home activities and leisure (*4*). This is an important form of behavioural adaptation, with a pattern that may be different in undernourished and well nourished individuals. When semi-starvation occurs without the need to maintain work output for survival, there is a considerable fall in spontaneous activity (*5*). However, if it is essential that some work be continued, there is a change in the activity pattern, with a substitution of low-cost for high-cost discretionary activities (*6*).

The nature of behavioural adaptation can vary. Guatemalan men with low muscle mass who were assigned substantial agricultural workloads took a significantly longer time to walk home after work, and spent about 3 hours/day in sleeping (during the daytime), sitting, playing cards, or other sedentary activities (*7*) (see Table 38). In contrast, better nourished, age-matched men did not sleep during the daytime, were active at home, and played soccer, thereby remaining physically active for a significantly greater proportion of the day.

The dramatic reduction in physical activity in conditions of acute energy deprivation is an important survival mechanism and seems to be induced by the process of weight loss. Thus, male volunteers in the USA who semistarved for 6 months to achieve a BMI of 16.5 (*5*) were far less active than African individuals with a similar BMI who had never achieved a BMI as high as the original US levels (20–25) or who had reduced their weight more slowly. Once weight is stabilized, however, and dietary energy is available for physical work, very thin individuals can maintain a certain amount of activity even if their work capacity and productivity are impaired. The distinctions, if any, between the extent of lethargy induced by weight loss *per se* and that associated with a low BMI have not been explored.

Table 38
Allocation of time to activities among well nourished and undernourished rural Guatemalan men[a]

	Time (min) spent daily				Distribution of time (%)		
	walking to work	walking from work	daytime rest	nighttime sleep	Work	Other[b]	Daytime rest
Undernourished	25	40	173	530	27	24	12
Well nourished	20	22	0	498	16	50	0

[a] Modified from reference *7*.
[b] Apart from time devoted to sleeping or personal care activities.

Fluctuations in body weight during seasonal changes in food availability have a different impact on the body composition of adults of low body weight than on those of greater weight; the former group lose proportionally more lean tissue (see section 8.4.2) and are therefore compromised to a greater extent in their general health and work capacity. No formal assessment has yet been made of the degree to which the seasonal susceptibility to infection, lethargy, or work impairment is exacerbated in those of low body weight.

Societal changes in behaviour at low body weights

Energy deprivation with consequent weight loss has profound effects on societal behaviour (*8*). Much depends on the traditions of the society and whether the limitation on food supply is viewed as normal and expected, e.g. as a result of seasonal changes, or as abnormal and life-threatening. As food becomes increasingly scarce, communal activity tends to decline, men migrate in search of alternative employment, and food is hoarded by individual households rather than being shared. Innovative effort is selectively concentrated on preserving and diversifying food stocks, to the detriment of community facilities.

8.3 Anthropometry as an indicator of nutritional and health status

8.3.1 *Work capacity*

Physiological studies have shown that muscle mass is an important determinant of physical work capacity, measured and expressed as maximal oxygen consumption (VO_2 max.) during graded tests of increasingly severe physical intensity. In physically strenuous work, positive correlations have been found between work capacity and work performance: taller individuals with larger body and muscle mass have consistently been shown to have a higher work capacity and work performance than short individuals. However, when work capacity is expressed per kg body weight or per kg active tissue mass, the evidence is less clear. Thus, the overall size of an individual can be important: in heavy activities such as cane-cutting, logging, mining, and certain agricultural activities, the total weight of the body can also be used to power particular tasks, so that the heavier individual is again at an advantage (*9*). This is illustrated in Table 39, taken from studies conducted in India (*10*).

In studies of migrant agricultural labourers, Desai (*11*) was able to show deficits in work capacity that were associated with thinness and short stature.

8.3.2 *Work productivity*

Individuals of low body weight are more likely to fail to appear for work because of illness or exhaustion. Physical training can substantially improve work capacity, but inactivity leads to rapid and substantial reductions in the ability to sustain heavy work.

Table 39

Effect of body weight, height, and body mass index on productivity of male industrial workers[a]

	Productivity, expressed in productivity units		
Height (metres)	Body weight 40–50 kg[b]	Body weight 50–60 kg[b]	Body weight > 60 kg[b]
< 1.60	2875 (18.0)	3250 (22.0)	–
1.60–1.70	2850 (16.5)	3250 (20.0)	3750 (23.0)
> 1.70	–	3325 (19.0)	–

[a] Source reference *10*; used with the permission of the American Society for Clinical Nutrition.

[b] Figures in parentheses denote mean BMI of the group.

The link between low body weight and poor work productivity is complicated by the individual's motivation and health status. Determination to maintain work output can lead to thinner people sustaining hard work but at a higher proportion of their maximal oxygen capacity. The additional stress is then apparent as elevated heart rates at the same level of oxygen consumption and higher blood lactate levels resulting from the smaller muscle mass working harder. In a comparison of Brazilian adolescent boys (*12*), those with a mean BMI below 17 exhibited oxygen consumption levels and gross efficiency of work under the test conditions similar to those of their more affluent counterparts who were of mean BMI 20, but showed greater stress. Men from rural areas of Hyderabad, India, with BMI below 18.5 showed work capacities (expressed in body weight terms) and increments of mechanical efficiency similar to those of better nourished urban men (BMI >20). However, correcting the results for body weight differences revealed that the total work capacity of the lighter individuals was substantially lower than that of their urban counterparts; a similar workload had thus imposed a greater stress on those with low BMI (*13*).

Behavioural differences are also apparent at work. In a study of Guatemalan men, two groups undertook heavy standardized agricultural tasks such as woodcutting, land clearing, and hoeing for 3–6 days. The group with a smaller lean body mass and muscle mass were able to do the same amount of work as the better nourished group, but took considerably more time to complete it (397 ± 123 min/day compared with 235 ± 40 min/day) and performed the tasks at a less intense level (4.6 ± 0.8 $kcal_{th}$/min compared with 5.1 ± 0.2 $kcal_{th}$/min)[1] (*7*). A similar

[1] 1 cal_{th} = 4.184 J.

slowing of work in men with low BMI was observed in Kenyan road-workers (*14*). Thus there seems to be a continuous gradient in work capacity and productivity that is linked to body weight, and particularly to lean tissue and muscle mass. This is reflected in the differences in work output at different values of BMI (Table 40) reported in a study of Colombian men (*15*).

8.3.3 *Mortality at low body weight*

Developed countries

In attempting to define a level of weight or BMI below which impairments become apparent, an analysis of mortality data might be appropriate, since the link between body weight and mortality has been used extensively in defining the importance of overweight. In a series of studies in industrialized societies, the relationship between weight and mortality has been shown to be J-shaped, with an increase in mortality among adults with relatively low BMI (19–20). Systematic analysis of 25 major studies (*16*) showed two principal sources of bias in this relationship between thinness and excess mortality. The first was failure to control for cigarette smoking, which is strongly associated with low body weight because it reduces appetite and increases the body's metabolic rate. Moreover, smoking is a major risk factor: mortality rates are high among smokers. The second source of bias was the failure to eliminate early mortality from the analysis of thin adults, many of whom may have already been ill when measured and therefore more likely to have lost weight and died.

Information derived from the Build and Blood Pressure Study (*17*) provides strong supporting evidence for weight loss in the early years following inception of life insurance policies being due to pre-existing disease (*18*). Even the extensive Framingham Study was unable to show any increased risk among underweight individuals, after adjustment for early deaths of non-smokers (*19*). In a study by the American Cancer Society (*20*), a similar trend towards better survival over time was also observed among thin individuals.

Table 40
Reduction in aerobic work capacity associated with low BMI in Colombian men

		VO_2 max.	
Category	BMI	litres/min	ml/kg per min
Controls	24.0	2.8	47
Mild malnutrition	21.3	2.1	41
Moderate malnutrition	20.0	1.9	35
Severe malnutrition	17.7	1.0	28

In the Honolulu Heart Programme Study (*21*), mortality rates among men aged 45-68 years were highest in the lightest and heaviest quintiles. Deaths in the heaviest quintile were caused primarily by coronary heart disease, whereas those in the lightest two quintiles related to cancer and "other causes". When BMI at age 25 (median value 19.8) was used to predict future mortality, men in the lightest quintile had the lowest mortality in middle age, provided that they did not lose weight (*19*). This has been confirmed in other studies on thin, non-smoking men who were not suffering from any clinical disorder (*22, 23*). Among non-smoking women in the USA, with no pre-existing diseases (such as coronary artery disease, stroke, cancer), the relationship between BMI and fatal and non-fatal coronary artery disease in all five quintiles is direct and proportional to BMI, with the lightest quintile having a BMI <21. It may be concluded that, after selection of non-smokers and exclusion of early deaths, the relationship between BMI and mortality in industrialized societies is no longer J-shaped.

Since all the mortality studies were conducted in economically developed countries and involved predominantly white "middle-class" adults, it is unknown whether the results are applicable to other racial or ethnic groups. Moreover, most studies have been conducted only on men.

In developed countries, unintentional weight loss has a profound impact on subsequent morbidity and mortality. In a prospective study of 91 patients with involuntary weight loss, for example, 25% died during the first year following the initial visit by the researchers (*24*). In patients with cancer, weight loss is directly related to early mortality as well as responsiveness to treatment (*25*), and weight loss has long been used to estimate surgical risk (*26-28*).

In previously healthy individuals who voluntarily semistarve themselves, low BMI is compatible with life. In one study, volunteers semistarved for 24 weeks and attained a BMI of 16.5; none died (*5*). However, the sample size was small. Moreover, volunteers lost only 15% of their lean tissue, and the critical figure seems to be close to 50%. In an analysis of men and women with anorexia nervosa, the BMI of dying women was about 11 and of men about 13 (*29*). Thus, in highly favourable environments, where the chances of opportunistic infections are low, survival is compatible with very low BMI.

Developing countries

Evidence on the relationship between low BMI and mortality in developing countries is extremely scarce, although recent data for Indian men (*30*) show a progressive increase in mortality rates below a BMI of 18.5, with an almost threefold higher rate after 10 years for those with BMI below 16 (Table 41).

Clearly these men could have been ill before being measured, so it is difficult to assign any causal significance to the relationships. Nevertheless, if it can be assumed that immune competence is compromised in those

Table 41
Annual death rates in Indian men monitored over a 10-year period[a]

Initial BMI	≥ 18.5	17-18.49	16-16.99	< 16.0
Annual death rate (deaths/1000)	12.1	13.2	18.9	32.5

[a] Based on data from reference *30*.

with a low BMI, susceptible low-weight individuals may succumb to the prevalent life-threatening diseases. More prospective epidemiological studies in this field are needed in the developing world.

8.3.4 *Morbidity and low body weight*

Developed countries

Malnutrition among adults in hospitals and nursing homes is common in many developed countries (*31-35*), and the prevalence of significant malnutrition may exceed 25%. Two forms of malnutrition may be seen: adult marasmus, and the malnutrition associated with low serum albumin, which is analogous to kwashiorkor in children. Both of these adult conditions are almost invariably secondary to disease. Hypoalbuminaemic malnutrition usually results from the metabolic effects of injury, inflammation, or infection, rather than from dietary protein deficiency, and the cause is usually clinically obvious. Marasmic individuals or those with significant weight loss also react badly to injury and infection, and have a poorer outcome than normal individuals. They develop longer and more severe episodes of hypoalbuminaemia and associated immune incompetence (*36*). The marasmic patient in a healthy environment, however, is not particularly susceptible to infection unless he or she is malnourished. By contrast, hypoalbuminaemia is a sign, as in developing countries, that the body is responding to infection and therefore losing more lean tissue, particularly muscle, than fat. Measurement of serum albumin levels is thus a valuable simple tool for assessing the overall health status of the individual patient.

Developing countries

There has been little research on the links between low body weight or BMI and episodes of illness in adults in developing countries. Table 42 summarizes the prevalence of "sickness events" according to five classes of BMI among women in Rwanda.[1]

The number of days per year spent in illness increases dramatically in individuals whose BMI is below 18.6. Table 42 also presents data on the number of days per year spent in bed (where 16 hours extra in bed is considered as equivalent to one whole day in bed); this number was disproportionally higher in those with low BMI. A study in Bangladesh (*37*)

[1] François P. Unpublished report to the Food and Agriculture Organization of the United Nations, Rome, 1990.

Table 42

Body mass index and sickness events in women in Rwanda[a]

BMI range	No. of days ill per year	Percentage of days per year with sickness events	Equivalent days in bed[b]
≤ 17.0	77	20	40
17.1–17.5	58	16	40
17.6–18.6	29	8	12
18.7–23.8	14	4	7
23.9–26.1	14	4	7

[a] Data from François P, unpublished report to the Food and Agriculture Organization of the United Nations, Rome, 1990.

[b] Equivalent day = 16 hours of daytime spent in bed.

Table 43

Proportion of adults of different body mass index spending time ill in bed in Brazil in 1989[a]

	Proportion (%) of adults spending time ill in bed			
	Men		Women	
BMI range	5–7 days	8–14 days	5–7 days	8–14 days
< 16.0	1.0	< 0.1	5.1	4.5
16.0–16.9	1.0	2.8	2.2	2.9
17.0–18.4	1.4	1.6	0.4	0.8
18.5–19.9	0.6	0.5	0.6	0.9
20.0–24.9	0.4	0.6	0.8	0.6
25.0–29.9	0.5	0.6	1.1	0.6
≥ 30	0.1	< 0.1	1.1	0.9

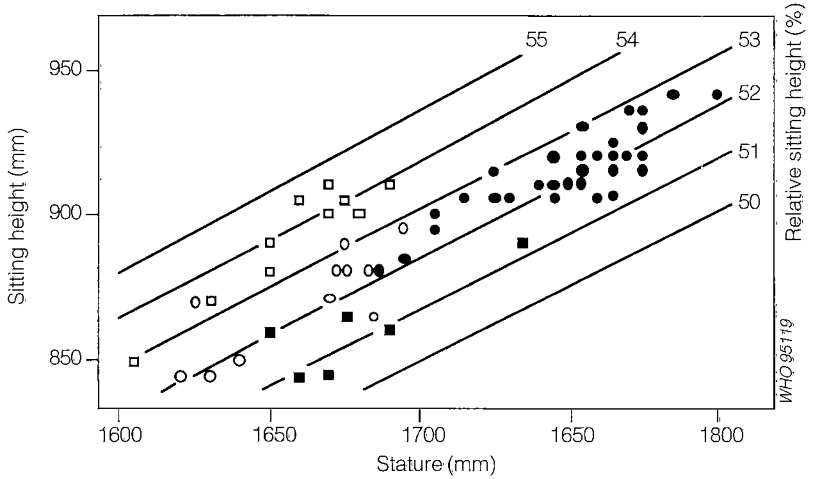
[a] Reproduced from reference *38* with the permission of the publisher.

showed that the percentage of men who failed to work because of illness also increased with declining BMI, and a Brazilian study (*38*) showed a U-shaped relationship between reported illness and BMI (Table 43).

This trend is particularly evident for individuals with BMI below 17. In the very large Brazilian sample a gradient effect for those who have spent 8–14 days in bed in the previous two weeks is still evident at a BMI below 18.5. Whether this signifies the effect of disease on low body weight or vice versa can be clarified only by careful and extensive prospective studies, but it seems obvious that in the less developed countries individuals with BMI below 18.5 are at some extra risk, which increases if BMI falls below 17.0.

Figure 58

Ethnic differences in the relationship between average sitting height and average stature in samples of adult men[a]



Key to samples:

- ● = European (including samples of predominantly European descent)
- ○ = Indo-Mediterranean
- □ = Western Pacific
- ■ = African

[a] Reproduced from reference *40* by kind permission of the publisher, Taylor & Francis.

8.4 Interpretation of anthropometry

8.4.1 *Considerations of body shape*

Individuals with low body weight are usually of short stature, and allowance should be made for this in assessing overweight (see section 7) and underweight. Since BMI is independent of height, it is a more appropriate measurement for most populations than weight alone (*39*). Problems arise, however, in adults whose shape differs from the norm, particularly those whose legs are shorter or longer than might be expected for their height.

The most common index of shape is the Cormic index, which is defined as the ratio of sitting height (crown-rump length) to height (*SH*/*H*) (*40*). It provides a measure of the relative length of the trunk and the legs and varies between individuals and groups; ethnic differences exist in both size and Cormic index. A typical ratio in those of predominantly European and Indo-Mediterranean[1] descent is 0.52–0.53, but populations in Western Pacific regions have values of 0.54, and African populations somewhat lower values of 0.51 to 0.52 (Fig. 58).

[1] Includes countries of the eastern Mediterranean region and the Indian subcontinent.

The Cormic index in women seems to be approximately 0.005 higher than that in men, although this is not well attested in the literature. In different populations, a BMI difference of 1 corresponds to a 0.01 difference in the *SH/H* ratio (*41*). Australian Aborigines have long legs and a BMI 2.0 units lower than Europeans, but the same sitting height and overall body weight. Similarly, South American people tend to have short legs relative to the length of the trunk, with a high ratio of sitting height to height and a higher BMI for their weight than European and Indo-Mediterranean people. Care should therefore be taken in groups and individuals with unusual leg length to avoid classifying them inappropriately as thin or overweight.

There is a linear, but only very moderate, correlation between BMI and height; correlation coefficients range between -0.01 and 0.23 in different ethnic and sex groups (*42*). BMI may therefore be considered as essentially independent of height. It should be noted, however, that, for values of height below 1.50 m or above 1.90 m, a strong non-linearity between BMI and height has been reported (*42*). Interpretation of BMI values for the very tall and the very short should thus be cautious, as the values would be height-biased.

8.4.2 *Low body weight and body composition*

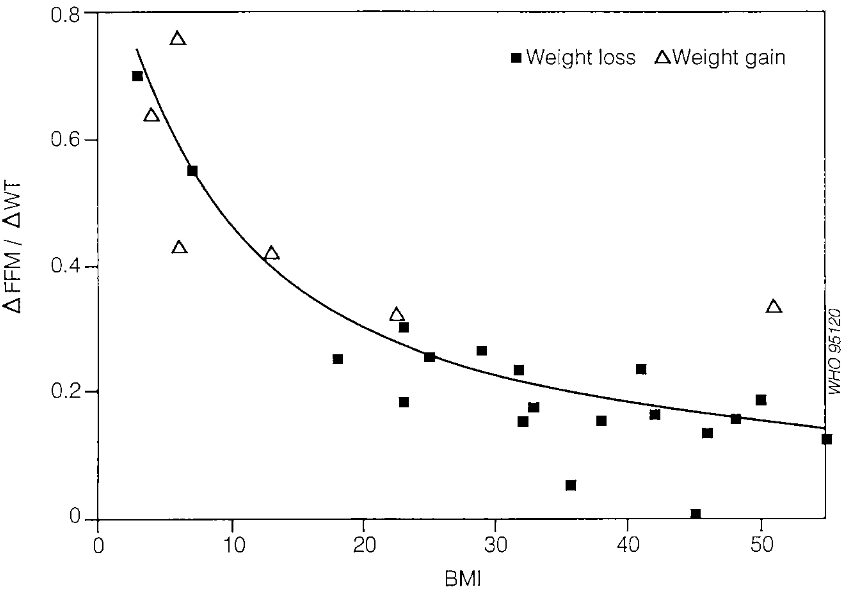
The body can be considered as composed of two compartments – the energy-dense fat tissue, and the lean body mass, which consists largely of muscles and visceral organs plus supporting tissues. For their height, women's bodies have a higher percentage fat content and a lower muscle mass than men's, and women's urinary creatinine-height index (*43*) is lower than that of men.[1] When weight is lost, both adipose tissue and lean tissue (muscle) are used for fuel, but the proportion of lean tissue lost depends on the amount of fat stored (*44*): the greater the mass of adipose tissue, the smaller the loss of lean tissue on starvation. Ferro-Luzzi, Branca & Pastore (*45*) have described this relationship. Because women have a greater fat mass but smaller muscle mass than men of equivalent weights, they lose less lean tissue; Fig. 59 shows this preferential loss of fat in women and the increasing amounts of lean tissue lost as body weight and BMI fall.

The proportion of lean tissue, and specifically muscle tissue, in the body is determined by both genetic and environmental factors. Ethnic differences are apparent, with Papua New Guinean men and women having higher values of lean body mass (LBM) and a smaller percentage of fat than Ethiopians or Indians (*1, 46*). Whether the LBM of adult Ethiopians or Indians is affected by early nutritional conditions is unclear; there has been insufficiently detailed analysis of LBM of, for example, well nourished Indian children growing on the NCHS 50th

[1] Defined as the individual's 24-hour urinary creatinine excretion as a fraction of the value for a normal individual of the same height.

Figure 59

Proportion of body weight lost (or gained) represented by lean tissue according to body mass index at the beginning of the weight loss (or gain) period[a]



Δ FFM / Δ WT = (change in fat-free mass)/(weight change)

[a] Adapted from reference *45* with the permission of the publisher.

percentile and well nourished Indian adults with a BMI of 22–23. Under nutritional stress, populations with a smaller body fat mass lose more LBM and can thus be expected to lose weight more rapidly than others.

Training with isometric techniques leads to hypertrophy of muscle, a feature of body-builders and of athletes involved in sports that require the application of intense power over short periods of time (e.g. weight-lifters, sprinters). Isotonic training, on the other hand, leads to very modest changes in muscle mass, although some increase in mid-arm muscle circumference (AMC) can be observed in most athletes compared with non-athletes. Deconditioning is readily induced by cessation of training and in the event of prolonged bed-rest.

In clinical and public health settings, the preferential loss of lean tissue that results from tissue catabolism and gluconeogenesis in both acute and chronic infections is of particular significance. Individuals with a high fat content may lose substantial amounts of lean tissue – particularly muscle – during illness, and it is this loss of the protein-rich tissues, which are responsible for control and maintenance of organ metabolism, that is the determining factor in the individual's survival at low body weight.

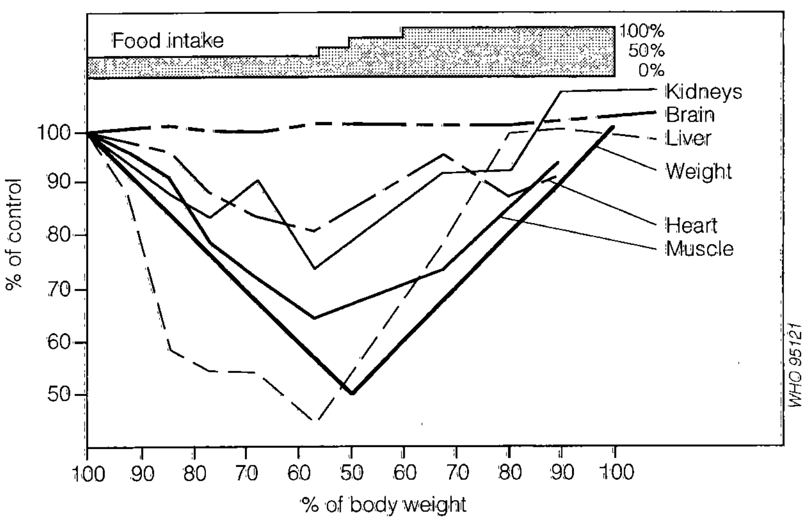
When an individual is ill, e.g. with an infection, not only does the muscle mass begin to fall but there is also a dramatic change in the fatiguability of muscle and in the maximum power that can be achieved (*47*). It is relatively simple to test muscle power and endurance by measuring the strength and sustainability of the handgrip (*47, 48*).

Starvation and semistarvation studies on humans and experimental animals have convincingly shown that most organs contribute, in variable proportion, to the loss of body weight; the brain and the spinal cord are notable exceptions (*3, 5*). Animal experiments indicate that atrophy of the organs occurs as early as that of the muscle and in parallel with loss of body weight (see Fig. 60). The organs of concentration camp prisoners and famine victims, estimated to have lost between 25% and 45% of their original weight, weighed between 52% (spleen) and 80% (heart) of normal (*5*).

The weight loss of most organs is accompanied by cytological changes, ranging from cloudy swelling and degenerative changes to mitochondrial brown atrophy. The heart is compromised and becomes susceptible to arrhythmia, anaemia develops because of reduced erythropoiesis, and the capacity of the liver to handle drugs, metabolites, hormones, or toxic substances in the diet becomes impaired. In addition, while the mucosa and other physical barriers to microbial or parasitic entry are remarkably well preserved, the immune system itself is depressed. With a defective immunological response, the stress of even a mild infection is magnified,

Figure 60
Effects of semistarvation on organ weight in the rat[a]

Note: Semistarvation was produced by lowering daily food intake by two-thirds for 6 weeks. The animals were then allowed to recover by gradually restoring food intake. Selected organ weights are plotted as a percentage of baseline weight vs. percentage of initial body weight.



[a] Reproduced from reference *3* by permission of Blackwell Scientific Publications, Inc.

and there is progressive development of widespread life-threatening conditions, such as septicaemia, parasitaemia, or miliary tuberculosis. The interaction between nutritional status and immune competence is also clearly seen in individuals infected with human immunodeficiency virus (HIV), who display marked nutritional deterioration as their disease progresses; malnutrition exacerbates the disease and is often the determinant of death when 50% of the normal lean tissue has been lost (*3, 49*).

8.5 Using anthropometry in individuals

In men and non-pregnant women, a single measurement of body weight or BMI is of limited use for assessing the individual's risk of ill-health or likely benefit from medical intervention or supplementary feeding. A better predictor of individual risk is the degree of unintentional weight loss of an adult. This risk relates to perioperative morbidity and mortality, as well as to mortality rates in population studies. More refined indices of nutritional status in weight-losing adults include the serum albumin concentration as a general index of stress or infection, and MUAC, AMC, or the creatinine-height index as a measure of muscle mass (*50, 51*). Functional tests of muscular strength (e.g. grip strength) can also be used for assessing an acute deterioration in health (*47*). Appropriate oral, enteral, or intravenous refeeding elicits an improvement in grip strength within days; circumferential measurements of the arm and the creatinine-height index, however, respond more slowly over a period of weeks (*52*).

8.6 Using anthropometry in populations

8.6.1 *Targeting interventions*

Low body weight or low BMI has been used for targeting supplementary feeding programmes in pregnancy. Selective benefits derive from supplementing thin women (see section 3), but as yet there are no published studies that have selected adults of low body weight or BMI within a population for interventions.

8.6.2 *Assessing response to an intervention*

Mean adult BMI and BMI distributions can be used to assess the impact of social, health, or agricultural interventions. For example, adults in a deprived area of Zimbabwe who were provided with special food allowances to counteract their perceived food insecurity had a surprisingly high mean BMI; only a negligible proportion had BMI values below 18.5 (*2*). Secular changes in the BMI distribution of Tunisian adults of low income also suggested an impact of an intervention that provided subsidized edible oils (*53*). Social and medical programmes in Nepal have also resulted in improvements in adult BMI. Studies such as these, together with demonstrable cyclic, seasonal changes in BMI (*45*), emphasize the responsiveness of this measure to general changes in the food security of a population. Whether or not arm circumference measurements prove equally useful will depend both on their reproducibility and on the general validity of their relationship to BMI (see section 8.7.2).

8.6.3 *Ascertaining determinants of malnutrition*

Deficiencies of energy, protein, and several micronutrients (e.g. zinc) can lead to a fall in body weight, which may reflect changes in lean body mass and/or fat mass. To discriminate between changes in these two components requires selective measurements of body fat (e.g. triceps skinfold thickness) or of lean body mass (e.g. AMC or creatinine-height index). In adults, the dominant cause of a reduction in body weight is a fall in food intake, caused either by the unavailability of sufficient food to meet energy needs or by anorexia.

8.6.4 *Nutritional surveillance*

Measuring the body weight of adults in developing countries has only recently been recognized as an important means of objectively assessing the degree of nutritional or other socioeconomic deprivation in a population. An unusually low range of BMI can be a useful pointer to the special needs of the population of a particular area, and a changing BMI profile may demonstrate that the population is being adversely affected by social or economic changes (e.g. during structural adjustment).

The distribution of BMI in a population can provide valuable guidance for the planning of long-term development programmes, especially in agriculture and health. Programmes that aim to improve total food supply can be directed specifically towards populations with low BMI, whereas a population with "normal" BMI may require only the limited nutritional improvements necessary to counteract anaemia and other selective nutritional deficiencies.

If a population distribution of BMI is established, further monitoring during times of threat to food availability will reveal the extent to which the population is being affected. Where body weights are near or above normal, food insecurity may result in a shift to the left in the BMI distribution and an increasing proportion of adult BMI falling to between 18.5 and 20. If the average BMI is already as low as 18.5, responsible agencies will be aware of the need for rapid intervention in the event of the food supply being threatened by war or natural disaster.

Management of existing food aid programmes in settings such as refugee camps can be facilitated by anthropometric monitoring of adults, rather than of children alone. This will provide an indication of the potential capacity of adults to contribute physically to the work of rehabilitation and development schemes. Moreover, monitoring of adults may provide a more accurate picture of the adequacy of emergency feeding programmes; the susceptibility of malnourished children in refugee camps and other deprived environments to epidemic infection may confound attempts to discriminate between adequacy of food supply and adequacy of other public health measures.

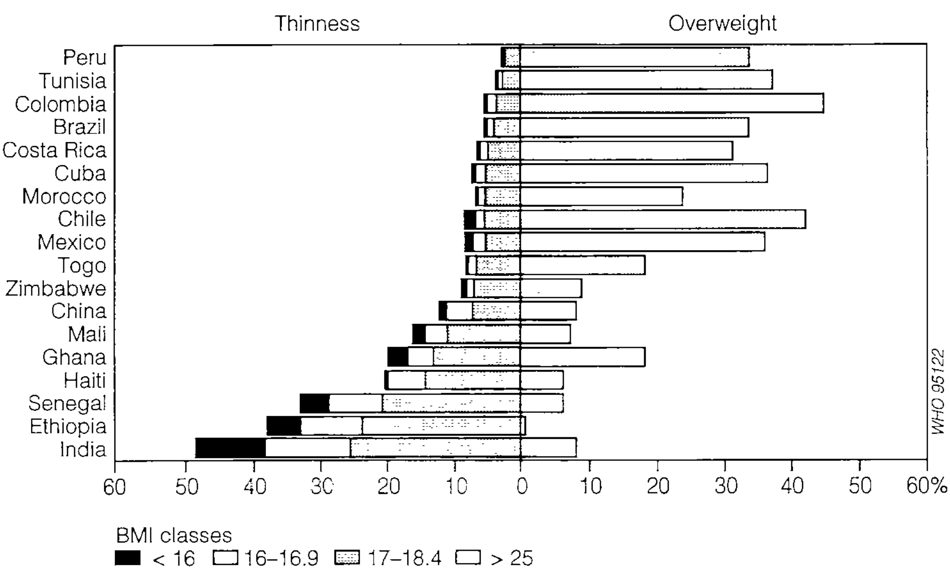
8.6.5 *Thinness as a public health problem*

It is normal for there to be a relatively small proportion of thin individuals within any population, but an excessive proportion may indicate the presence of food insecurity or the catabolic consequences of widespread infectious diseases, such as AIDS and tuberculosis. Even when the food supply is adequate or environmental stress limited, excessive thinness points to the vulnerability of certain members of the population, with marginal energy reserves, in the event of drought, seasonal food shortages, or epidemics.

The proportion of the population with low BMI that would define a public health problem is closely linked to available resources for correcting the problem, the stability of the environment, and government priorities. About 3-5% of a healthy adult population have a BMI below 18.5; the Expert Committee suggested the following classification of the public health problem of low BMI, based on BMI distribution in adult populations worldwide (see Fig. 61):

Low prevalence (warning sign, monitoring required):	5-9% of population with BMI <18.5
Medium prevalence (poor situation):	10-19% of population with BMI <18.5

Figure 61
BMI distribution of various adult populations worldwide (both sexes)



High prevalence (serious situation):	20–39% of population with BMI <18.5
Very high prevalence (critical situation):	≥40% of population with BMI <18.5

This classification is somewhat arbitrary, but reflects the distribution of BMI in many populations of developing countries and endeavours to take into consideration the societal consequences of the functional impairments commonly associated with low BMI.

8.7 Guidelines for use of anthropometric indicators

8.7.1 *Use of BMI with simple cut-off points*

For affluent societies, there are no recognized reference standards that satisfactorily define the lower limit of desirable body weight except in terms of mortality. From Fig. 61 it is evident that BMI values vary widely, depending on the populations assessed. It is also worth noting that, as the proportion of the population with low BMI decreases, there is an almost symmetrical increase in the proportion with BMI above 25. This indicates a tendency for a population-wide shift as socioeconomic conditions improve, with overweight replacing thinness. The dynamics of this shift have been only imperfectly described, but there is consistent evidence that, in the first stages of transition, the wealthier sectors of the society show an increase in the proportion of people with high BMI, which is concurrent with the continued presence of thinness among the less wealthy. The distribution changes again in the later phases of the transition, with an increase in the prevalence of high BMI among poorer people. Appropriate data for generating a reference set of weights can be obtained only if a population has a plentiful supply of food, if children's growth is unimpaired by recurrent infections, and if young adults are free of disease. By the same token, a population that tends to be overweight is unsuitable for use as a reference standard.

There is increasing evidence (*54, 55*) that dietary fat content may contribute to the propensity to gain weight in adult life, which is particularly evident in middle-age. Low levels of physical activity also appear to be a contributing factor. Thus, when a reference population is to be chosen, a group of relatively young, physically active adults should be selected for identifying the lower limits of "normality". Adults enlisted in the armed forces are medically screened and generally physically fit, and may therefore form an appropriate group. In a selected group of soldiers in the British army (*56*), mean BMI of men aged 25–40 years was 24.6; for women aged 25–35 it was 22.7. Respective values of −2 SD were 19.0 and 17.5.

Finding an appropriate society where adults in general are not inactive, not on a high-fat diet, and not subject to severe intercurrent infections or food shortages is difficult. For example, of the population of the USA, about 10% of men and 15% of women aged 25–40 had a BMI over 30 according to the NHANES surveys during the 1970s (*57*). At this age, those with a high BMI are known to be at substantial risk of premature death from chronic diseases; this population is therefore clearly unsuitable for use as a WHO reference population.

Systematic survey of the Chinese population revealed the smallest range of BMI yet identified (*53, 58*). The Chinese are active, have a dietary fat content that averages about 14% of energy intake, and do not have major epidemic infections, chronic diseases, or food shortages. In 1982, representative samples from 25 different provinces of China showed surprisingly little variation in BMI distribution. Among those aged 20–39 years, the mean and –2 SD values were 20.9 and 17.1 for men and 21.5 and 16.9 for women (see Table 44) (*58*).

Since no prospective analysis of any differential increase in risk has yet been undertaken in Chinese with a low BMI, it would seem best to rely on pragmatically derived cut-offs of BMI rather than to specify limits based on the Chinese as the reference population. A BMI below 16 is known to be associated with a markedly increased risk of ill-health, poor physical performance, lethargy, and even death, so this cut-off point has validity as an extreme limit. Moreover, BMI below 17 has been linked with a clear-cut increase in illness in adults studied in three continents, and is therefore a further reasonable value to choose as a cut-off point for moderate risk. The proposal of a single cut-off point of 18.5 for specified mild deficiency in both sexes has less experimental support, but seems a reasonable value to use pending further comprehensive studies. The choice of these three cut-off points was adopted by a working group of the International Dietary Energy Consultative Group, who were asked to propose new definitions for chronic energy deficiency in adults (*1*), and was endorsed by a more recent IDECG meeting (*59*). The Food and

Table 44
Age trend of mean body mass index in a sample of the Chinese population[a]

	Men		Women	
Age groups (years)	Mean BMI	SD	Mean BMI	SD
20–29	20.6	1.7	21.2	1.9
30–39	21.2	2.1	21.7	2.7
40–49	21.4	2.7	21.7	2.9
50–59	21.2	2.4	22.0	3.6
60–69	20.9	2.9	21.7	3.7
≥ 70	20.9	3.1	20.6	3.5

[a] Reproduced from reference *58* with the permission of the publisher.

Table 45
Sequential assessment for the epidemiological diagnosis of different grades of chronic energy deficiency (CED)[a]

1. Measure BMI	2. Measure intake or expenditure for PAL estimation *with* the predicted BMR[b]	Group	Presumptive diagnosis[c]
≥ 18.5			Normal
17.0–18.49	≥ 1.4	A	Normal
	< 1.4	B	CED grade I
16.0–16.99	≥ 1.4	C	CED grade I
	< 1.4	D	CED grade II
< 16.0			CED grade III

[a] Reproduced from reference *1* with the permission of the publisher.
[b] PAL = physical activity level, BMR = basal metabolic rate.
[c] For confirmation of the diagnosis and for use in clinical research it is necessary to measure individual BMRs in groups A–D to allow for the appreciable inter-individual variability. At a BMI above 18.5 or below 16.0, the diagnoses can be based on BMI values alone.

Agriculture Organization of the United Nations has also adopted these cut-off points and is using them in an extensive series of worldwide analyses designed to provide an estimate of the prevalence of malnutrition (*53*).

Although the original specification of chronic energy deficiency incorporated a measure of energy turnover as well as BMI, as shown in Table 45, subsequent detailed activity studies suggest that BMI values alone could be used to assess deficiency (*2*).

As mentioned in section 8.1.2 and in Annex 1, the Expert Committee described the condition of low BMI as thinness, with the following three grades:

grade 1: BMI 17.0–18.49 (mild thinness)

grade 2: BMI 16.0–16.99 (moderate thinness)

grade 3: BMI <16.0 (severe thinness)

Annexes 2 and 3 of this report provide complete and more simplified versions, respectively, of BMI tables that will facilitate the utilization of this index in the field. A nomogram is also provided in Annex 2 (Fig. A2.1).

8.7.2 *Arm and arm muscle circumference*

Body fat content can be predicted from measurement of the triceps skinfold thickness but is not particularly useful for diagnosing protein-energy malnutrition because fat is more readily expendable than fat-free mass and correlates poorly with physiological function (*60*), hospital morbidity, or mortality (*61, 62*). The principal value of the skinfold measurement is for calculating the AMC or arm muscle area (AMA), with or without a correction for the bone area.

Frisancho (*57*) developed a series of standards for mid-upper arm circumference and arm muscle area from a multi-stage, stratified survey (1971–1980) of nearly 44 000 children and adults in the USA. He also devloped the Frame Index 2, calculated as [elbow breadth (mm)/stature (cm)] × 100, which allows the individual to be assigned to one of three frame size categories – small, medium, or large. In adult men, a sharp rise in both MUAC and AMA from 18 to 30 years of age was noted; these measurements declined progressively after the age of 40. Women, however, showed a slow, steady rise in MUAC and AMA throughout adult life. The changes in arm circumference and calculated muscle area paralleled weight gains, and were seen in adults of all three frame sizes. The pattern of changes in arm measurements is consistent with those of muscle and other lean tissues, contributing the expected 38% to weight change in adult life (*63*). Given the recognized high BMI values even of young adults in the USA, it seems unwise to use these data as a reference.

Even for other populations for which relevant medical or other health information exists, few data are as yet available that relate to measurements of MUAC and AMA. In the absence of defined cut-offs for these measurements based on health criteria, an alternative method for developing cut-off points is to relate arm measurements to the BMI of individuals in different populations and then choose circumferential values that are equivalent to the existing BMI cut-off. These circumferential measurements may then be considered as practical alternatives to BMI measurements in field studies where there are instrumental or organizational limitations. In due course, it may also become possible to assess the benefits of combining arm measurements with BMI to provide a more specific index of nutritional status (*64*).

The relationship between MUAC and BMI for groups of adults from eight developing countries, for athletes, and for hospital patients in the USA is illustrated in Figs 62 and 63. The athletes comprised 137 track and field athletes and 63 wrestlers and weightlifters who participated in the 1964 Olympic Games and the 1958 Commonwealth Games (*65*). The hospital patients were receiving aggressive nutritional support for severe protein-energy malnutrition complicating critical illness (Bistrian BR, personal communication). The figures show very close agreement between anthropometric measurements in all communities, with a robust and linear correlation (except for male patients) between MUAC and BMI. Clinical patients present a different pattern, with a lower increase in MUAC for each BMI increment. The eight developing communities show slopes and intercepts reasonably similar to each other but different from those of the athletes and clinical patients. Data for these eight communities were combined to produce an overall regression line, and

Table 46
Classification of BMI classes by mid-upper arm circumference for men in seven developing countries[a]

MUAC (cm)	BMI classes < 16 n (%)	16–16.99 n (%)	17–18.49 n (%)	≥ 18.5 n (%)	Row total
< 22.4	141 (88)	64 (43)	70 (21)	41 (2)	316
22.4–23.1	8 (5)	28 (19)	44 (13)	52 (3)	132
23.2–24.3	8 (5)	28 (19)	76 (23)	161 (9)	273
> 24.3	3 (2)	29 (19)	139 (42)	1513 (86)	1684
Column total (%)	160 (100)	149 (100)	329 (100)	1767 (100)	2405

[a] China, India, Mali, Papua New Guinea, Senegal, Somalia, Zimbabwe.

Table 47
Classification of BMI classes by mid-upper arm circumference for women in eight developing countries[a]

MUAC (cm)	BMI classes < 16 n (%)	16–16.99 n (%)	17–18.49 n (%)	≥ 18.5 n (%)	Row total
< 21.4	110 (75)	61 (38)	54 (13)	37 (2)	262
21.4–22.1	23 (15)	31 (19)	74 (18)	71 (3)	199
22.2–23.2	10 (7)	43 (27)	118 (29)	188 (8)	359
> 23.2	3 (2)	26 (16)	156 (39)	2060 (87)	2245
Column total (%)	146 (100)	161 (100)	402 (100)	2356 (100)	3065

[a] China, Ethiopia, India, Mali, Papua New Guinea, Senegal, Somalia, Zimbabwe.

the MUAC equivalents of the three BMI cut-offs were derived from this line. The MUAC cut-off values that correspond to the BMI cut-off points are given in Tables 46 and 47. It is apparent that MUAC is a reasonable predictor of BMI for the lowest and highest BMI categories, with over 70% correctly classified; prediction of BMI categories of 16.0–16.99 and 17.0–18.49 from arm measurement, however, is relatively poor.

At cut-offs of 24 cm in men and 23 cm in women, the sensitivity of MUAC for BMI <18.5 was 73% and 74% respectively; corresponding figures for specificity were 86% and 87%, and for positive predictive value 65% and 64%.

From a regression of BMI versus MUAC, it was estimated that the average MUAC is about 24 cm in people with BMI <18.5. It is likely that, at a BMI of less than 18.5, individuals with MUAC greater than 24 cm – a group that probably includes a larger proportion of "thin but healthy people" – will fare better than those with a smaller MUAC.

Unlike the US data, no relationship between MUAC and adult age was found in the communities studied, nor was any relationship seen between MUAC and height.

Limited analysis of the relationship between AMA and BMI in these population groups showed no better correlation than that between BMI and MUAC. Although discrimination between changes in lean and fat tissue may be helpful in assessing an individual's nutritional state, the data suggest that MUAC alone may be as helpful a measure as AMA for general population studies. However, AMC is of greater significance in dealing with individuals in clinical studies, because its reduction is directly related to the severity of disease. Muscle is known to be lost preferentially in infection as amino acids are transferred to visceral

Figure 62

Relationship between mid-upper arm circumference and body mass index in seven groups of adult men from developing countries, one group of athletes, and one group of clinical patients

Note: The overall regression line includes only those from developing countries.

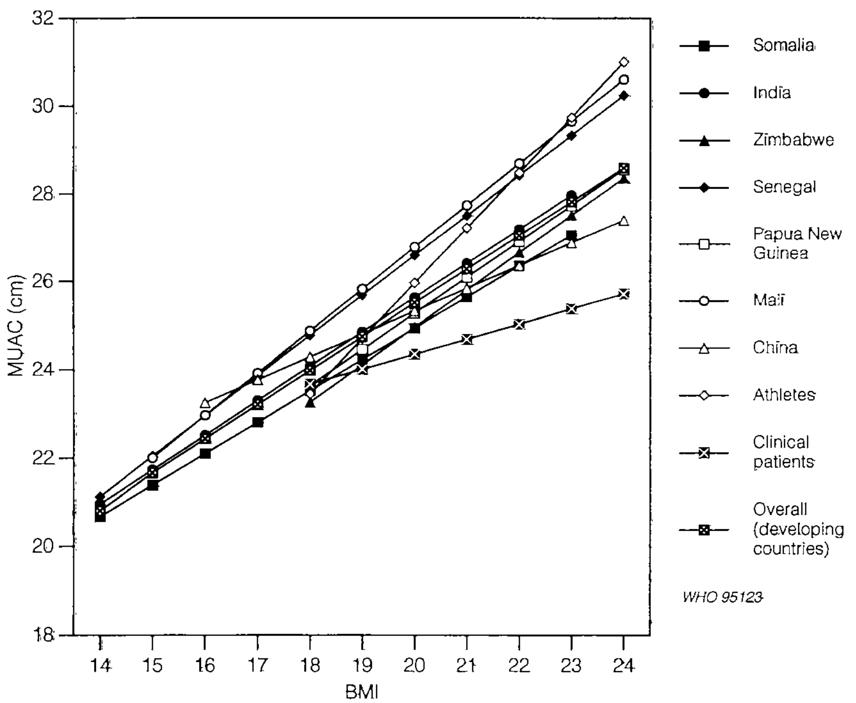
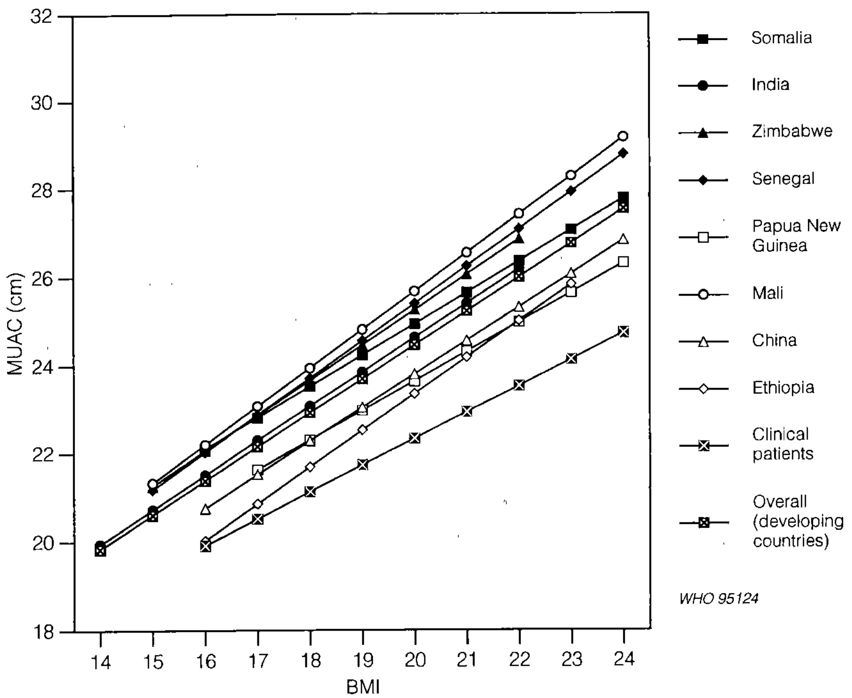


Figure 63

Relationship between mid-upper arm circumference and body mass index in eight groups of adult women from developing countries, and one group of clinical patients

Note: The overall regression line includes only those from developing countries.



organs to produce acute-phase proteins and to support other functions, such as immune activity. The decline in measured muscle mass can therefore be rapid and profound, and Heymsfield et al. have shown that, if AMA is reduced to 10 cm^2, death invariably occurs in both men and women (*66*).

In a clinical setting, AMC below the 5th US percentile established by Frisancho (*57*) (which is approximately 80% of the standard) indicates adult malnutrition (*67*). The AMC correlates with both serum albumin and percentage weight loss (*68, 69*); AMA is considered by some to better reflect the volume associated with the mass of skeletal muscle (*3*), but it relies essentially on the same measurement as AMC. A triceps skinfold thickness of 1-2 mm, a total body fat of 1-3 kg, or a bone-corrected AMA of 9-10 cm^2 are all pointers to imminent death from inanition (*3*).

8.7.3 *Populations for which the guidelines may not be appropriate*

Male soldiers in the British army show a clear tendency for some weight gain between the ages of 18 and 25 years (*56*), and this may reflect the final stages of maturation. In enlisted women, however, this weight gain does not occur until about 30 years of age; they are probably unusually active and may also consciously control any weight gain. The NHANES data from the USA (*57*) and other population-representative data on BMI from China (*58*), Cuba (*70*), India (*71*), and Viet Nam (*72*) show that men between the ages of 18 and 25 years have a mean BMI 0.2–1.6 lower than that of men aged 26 to 40 years; at -2 SD, however, the difference is only 0.2–0.7 units. In women aged 18–25 years, the difference in mean BMI from those aged 26–40 years is more variable (0–1.8). Given the difficulty of establishing appropriate limits of BMI in young adults aged 18 to 25 years, particular care is needed to avoid the misclassification of a large proportion of people in this age group as mildly or moderately thin.

Rather than a reduction in the cut-off for grade 1 thinness from 18.5 to 18.0, it is recommended that this age group be examined separately from older cohorts in population studies and results subjected to prudent interpretation. This approach may need revision in the light of further evidence, with the cut-off point being set at a different level.

8.8 Recommendations

8.8.1 *For practical implementation*

For Member States

The new information relating low adult weights to impaired physical capacity, productivity, and health demonstrates the importance of any government's being aware of the range of BMI values within its country. It is therefore recommended that, as part of general surveillance, adult weight and height are routinely measured in health, nutrition, and general community development programmes.

For WHO

WHO should ensure that, in accordance with the recommendation of the FAO/WHO International Conference on Nutrition (Rome, December 1992) to incorporate nutritional objectives in all development programmes, adult anthropometry be included with other measures in such programmes.

8.8.2 *For future research*

Further research is needed in the following areas:

1. To establish more conclusively the validity of BMI cut-off points, by examining the various functional outcomes of low BMI. More precisely, there is a need to document the nature of the relationship between low BMI and immunocompetence as a modulator of susceptibility to infectious diseases and of their severity. Such studies will need to control for confounding factors, notably concomitant micronutrient deficiencies.

2. To assess the value of arm circumference measurement, used alone or in conjunction with BMI, as an indicator of nutritional status and food sufficiency in a community. Such assessment should also address the issue of precision.
3. To evaluate BMI cut-off points for ages 18 to 25 years, for which lower cut-offs may be deemed appropriate.
4. To improve understanding of the effects of low BMI on the composition of lean body mass, e.g. whether the integrity of the mass and composition of lean tissues inevitably compromised by low BMI.
5. To test the usefulness of adult BMI in different settings, especially in populations in which morphotype differs significantly from the norm.
6. To test the usefulness of adult BMI in conjunction with child anthropometry to discriminate between general issues of public health and household food security.

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