1 Obesity
Epidemiology: Definition and Classification of Obesity

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Introduction

The definition of obesity is a critical element in a book on the clinical aspects of obesity. Some may say that obesity is the equivalent of having “an excess of body fat.” Others will argue that it is not the total fat mass that affects obesity and related health risks, but more an “excess of fat at certain locations.” Clinicians benefit from clear definitions in protocols and clinical guidelines when identifying subjects who are candidates for treatment. Policy makers and researchers benefit from clear definitions when comparing subgroups between cities, countries or regions and when comparing obesity rates over time.

It is now clear that obesity has an important impact on the public (Fig. 1.1) [1,2]. Obesity-related healthcare costs are estimated at 1–10% of total healthcare costs, depending on obesity rates [3–6]. Obesity may have an even larger impact on indirect healthcare costs [7]. Sick leave-related productivity loss attributable to obesity has been estimated at around 10% in a Swedish study, when the obesity prevalence was less than 10% [8]. Further, obesity has a large societal impact. Obese subjects more often have social and physical disabilities and have therefore, on average, a lower quality of life [9]. Although obese subjects have a reduced life expectancy, they also have an increased number of unhealthy life-years [10].

Percentage of body fat versus location of excess fat

Since the pioneering work of Jean Vague in the 1940s it has slowly become accepted that different body morphology or types of fat distribution are independently related to the health risks associated with obesity [11]. Starting with Vague’s brachiofemoral adipomuscular ratio as an index of fat distribution (which was based on ratios of skinfolds and circumferences of the arms and thighs), more recent indices were designed specifically to predict intra-abdominal fat. The most popular among all measures is the waist/hip circumference ratio (WHR). However, the simplest of these measures is the waist circumference, which appears to predict intra-abdominal fat at least as accurately as the waist/hip ratio [12] and to predict levels of cardiovascular risk factors and disease as well as Body Mass Index (BMI) and waist/hip ratio [13]. It has also been suggested that waist circumference could replace classifications based on BMI and the waist/hip circumference ratio [14]. More complex measures, such as the sagittal abdominal diameter, the ratio of waist/thigh circumference, the ratio of waist/height or the conicity index, may perform even better than waist circumference for one or more of these purposes. However, the differences among these measures are small and the use of ratios may complicate the interpretation of associations with disease and their consequences for public health measures.

Outline of this chapter

This chapter describes the literature regarding obesity measurements and clinical definitions of obesity. Specifically, the chapter describes:

• how to measure storage of body fat. This part will describe whether and how to measure the total fat mass or fat distribution
• how to define excess body fat. Cut-off points for different measures will be presented
• measured versus reported obesity status. It will be elucidated whether obesity measures should be measured by clinicians and researchers, and whether self-reported obesity measures can be used without correction factors
• obesity in clinical practice. This section will address the measurement of obesity status as an indicator of behavior and disease,
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Obesity and disability and mortality risk. Subgroups will be specified that require increased attention to assess obesity status.

How to measure storage of body fat

Numerous techniques are available for the measurement of "stored body fat" (Table 1.1). Sophisticated, precise measurements are often time-consuming and expensive and require trained personnel, and are therefore unlikely to be adopted at a large scale in clinical or monitoring settings. Examples of reliable techniques to obtain accurate measures of total body fat are underwater weighing (densitometry), dual-energy X-ray absorptiometry (DXA), and dilution techniques. Imaging techniques such as computed tomography (CT), and magnetic resonance imaging (MRI) are less useful to measure total body fat storage, but CT and MRI are highly accurate in defining local fat storage, and thus fat distribution. Bio-impedance analysis techniques are becoming widely available commercially, but they are of moderate use in estimating total body fat and cannot be used to estimate fat distribution.

Anthropometric measures

Although percentage body fat is best measured by underwater weighing or DXA, more feasible techniques are needed in clinical and monitoring settings. Anthropometric measures are performed relatively easy and quickly, and are cheap and reliable, especially with trained personnel. One could argue whether the ideal anthropometric measure reflects total body mass or body fat distribution perfectly, but above all, the ideal anthropometric measurement should distinguish those at high risk of disability, morbidity or mortality.

The BMI is the measure most often used in children and adults. Numerically, waist/hip ratio is second, although it is now clear that interpreting waist circumference and hip circumference

Table 1.1 Ability of different body fat measurements to estimate body fat and body fat distribution

<table>
<thead>
<tr>
<th>Methods</th>
<th>Ability to measure total body fat</th>
<th>Ability to measure fat distribution</th>
<th>Applicability in large population studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT</td>
<td>Moderate</td>
<td>Very high</td>
<td>Low</td>
</tr>
<tr>
<td>MRI</td>
<td>High</td>
<td>Very high</td>
<td>Low</td>
</tr>
<tr>
<td>DXA</td>
<td>Very high</td>
<td>High</td>
<td>Moderate</td>
</tr>
<tr>
<td>Densitometry</td>
<td>Very high</td>
<td>Very low</td>
<td>Low</td>
</tr>
<tr>
<td>Dilution techniques</td>
<td>High</td>
<td>Very low</td>
<td>Moderate</td>
</tr>
<tr>
<td>BIA</td>
<td>Moderate</td>
<td>Very low</td>
<td>High</td>
</tr>
</tbody>
</table>

CT, computed tomography; MRI, magnetic resonance imaging; DXA, dual-energy X-ray absorptiometry; BIA, bio-electrical impedance analysis. Table adapted from Snijder et al. [89].
Body Mass Index

The BMI is calculated as body weight (kg) divided by the square of body height (m). Body weight and height are measured with the participant standing without shoes and heavy outer garments. For the height measurement, participants are asked to push heels softly to the wall or the back of the stadiometer. Because some authors subtract 1 or 1.5 kg for light clothing, the basis for the measurement and calculation should be explicit. In practice, inclusion of patients for treatment programs may differ.

Because differences in weight between individuals are only partly due to variations in body fat, many people object to the use of weight or indices based on height and weight (such as the BMI) to discriminate between overweight and normal-weight people. There are always examples which illustrate its limitations, such as identical BMIs in a young male body builder and a middle-aged obese woman. However, despite these obvious extremes, BMI correlates well with the percentage of body fat in large populations. Deurenberg established that one can quite accurately estimate the body fat percentage in adults with the following equation:

\[
\text{Body fat percent} = 1.2(BMI) + 0.23(\text{age}) - 10.8(\text{gender}) - 5.4
\]

About 80% of the variation in body fat between Dutch individuals could be explained by this formula [15]. The standard error of estimate was about 4%. In this equation the value for gender is 1 for men and 0 for women. It follows from this equation that for a given height and weight, the body fat percentage is about 10% higher in women compared to men. In addition, people get fatter when they get older even when their body weights are stable because of the loss of lean body mass with age. The good correlation between BMI and fat percentage implies that one can quite accurately estimate the body fat percentage in adults with the following equation:

The BMI is probably linearly related to increased mortality in men and women. In many studies a U- or J-shaped association between BMI and mortality was observed [16] but some recent large studies have suggested that much of the increased mortality at low BMI is due to smoking and smoking-related disease as well as other clinical disorders causing weight loss [17–20]. It is clear that the U-shaped curve disappears after exclusion of women who were ill, had unstable weights or died early. The absolute mortality rates in women who were nonsmokers and had stable weights were much lower than the mortality rates in the total group. Allison et al explained the U-shaped BMI relation by the increased mortality associated with increased fat mass and the decreased mortality associated with increased lean mass [21].

Most epidemiologic studies of anthropometric measures as risk predictors relate values of BMI to the risk of early mortality. In adults, BMI predicts increased mortality, morbidity and disability, but the relationships between BMI and morbidity and disability are stronger than the relationship between BMI and mortality [1].

Skinfolds

In 1951, Brožek and Keys used skinfold thickness to estimate body fatness [22]. Although the skinfold measures the thickness of skin and subcutaneous fat, skinfold thickness also correlates with storage of visceral fat. The subcapular, triceps, biceps, and suprailiac skinfolds are used in the Durnin and Wormersley formula [23] and Siri’s equation to calculate percentage body fat [24]. Calculators based on skinfolds for percentage body fat are found on the internet (www.bblex.de/en/calc/dw4folds.php). As suggested by Peterson, these calculations often underestimate the storage of body fat [25]. Although measurement of skinfolds may be useful in clinical studies and evaluation research, skinfold measures are not used in clinical guidelines and protocols to identify subjects with excess body fat.

Arguments against the use of skinfold measures in clinical or evaluation studies include the lack of reliability, and potential harm or inconvenience for participants. The use of skinfold measures in large population studies has shown that measuring skinfold thickness is feasible. A large subcapular skinfold predicted coronary heart disease in men independently of BMI and other cardiovascular risk factors [26]. The association between skinfolds and indicators of metabolic risk has been confirmed, but correlations of waist circumference with risk factors were either similar or stronger compared with those of the subcapular skinfold [27,28]. More research on the use of skinfold measures in clinical practice is warranted.

Waist circumference

Different scientific studies have measured the waist circumference at different sites. The original suggestions of cut-off points of 88 cm and 102 cm for women and men, respectively, were based on measurements of the waist circumference measured midway between the lower rib margin and the iliac crest with participants in standing position, without heavy outer garments and with emptied pockets, breathing out gently [14]. Without scientific rationale, other studies measured waist circumference as the minimal waist or at the umbilicus. An expert panel concluded that the location of the measurement does not affect the relationship between waist circumference and morbidity and mortality [29]. However, it is obvious that more at-risk individuals will be included for treatment when measurement is based on “maximum circumference” than when based on measurement at “umbilicus level” or “midway between iliac crest and lower rib.”

Because definitions of large waist circumference promoted by the WHO [30] and NIH [31] are based on waist circumference measured midway between iliac crest and lower rib, this
measurement seems the best option until scientific evidence proves otherwise. For research purposes it may well be valid and useful to use different sites. Enabling comparisons with other studies is a valid reason to choose one option. At the very least, authors should describe their measurement carefully and explain whether different measures could have lead to different conclusions.

The association of waist circumference with visceral fat storage is comparable to the abdominal sagittal diameter, which preceded the waist circumference as indicator of intra-abdominal fat storage. The sagittal abdominal diameter has a good correlation with insulin resistance, hypertension, type 2 diabetes mellitus, and dyslipidemia, and predicts increased mortality rates. This association appears stronger in relatively young adults [32]. A study of Dutch elderly showed no advantage of the sagittal abdominal diameter compared with other anthropometric measures as a correlate of components of the metabolic syndrome [33].

Han and Lean have explored the value of waist circumference. This measure is easy to perform, requires a tape measure only, and does not need to be calculated like the BMI [34]. Furthermore, Han et al showed that the relation between waist circumference and height was “not significant enough” to take into account body height when estimating fat storage [35]. An important advantage of waist circumference compared to BMI is that physical activity usually leads to reduction in waist circumference, whereas BMI may not decrease after physical activity, due to increased muscle mass. Interventions that do not affect BMI may prove effective when waist circumference is measured. Secular trends in waist circumference also appear stronger than the increase in BMI. High levels of waist circumference are associated with declines in quality of life and increased type 2 diabetes mellitus [9,36,37]. In longitudinal studies, waist circumference levels were clearly related to mortality [38,39].

**Hip circumference**

Hip circumference is most often recorded as the maximum circumference over the buttocks and has a strong association with leg fat mass, as well as leg lean mass. Lissner et al were among the first who showed that a small hip circumference predicted increased mortality, regardless of whether the waist circumference was taken into account [40]. This association has been replicated by more recent research [37]. A fair hypothesis is that if one has increased fat storage, the risk is lower if fat is stored in the hips and buttocks rather than the abdomen.

**Waist/hip ratio**

Waist/hip ratio is calculated as the ratio of waist to hip circumference. The different options for waist circumference (see above) will obviously lead to different values of the calculated waist/hip ratio.

Waist/hip ratio has been a popular marker for fat distribution in the last century. Some authors still present waist/hip ratio, because it may indeed be more strongly related to mortality than waist circumference. Ratios, however, are hard to interpret [41]. For example, a high waist circumference may be a consequence of a large waist circumference or a small hip circumference.

**New, promising measures**

The BOD-POD and three-dimensional imaging techniques are expensive but highly feasible measures for large groups. They are reliable and provide innovative information.

The BOD-POD measures body composition through a sophisticated air displacement plethysmography technique [42]. The BOD-POD exists of two closed chambers. The participant is located in one chamber that is connected to a second chamber by a diaphragm. This diaphragm oscillates to create exactly the same volume perturbations in the two chambers. Software calculates the body's volume and density after weight has been measured [42].

Three-dimensional photography is now widely used in the fashion industry to study circumferences. Participants stand still for a few seconds and cameras take images from various positions. Software calculates circumferences of all sites requested by the researcher from these images and provides body volume estimates based on various circumferences. The combination of body volume, body mass and lung volume enables the calculation of body density and thus percentage body fat. These calculations need to be agreed upon between researchers and companies delivering the software because these techniques are relatively new in obesity research.

### How to define “excess” body fat

In adult men with an average weight the percentage body fat is in the order of 15–20%. In women this percentage is higher (about 25–30%). Based on percentage body fat, excess fat has been defined as exceeding 25% in men and 35% in women, although these definitions are not consensus based [42–45].

As stated before, accurate estimates of percentage body fat or amount of fat at certain locations are not feasible and can therefore not be used in clinical settings. Anthropometric measures provide valid alternatives for the definition of “excess fat” or "excess of fat at certain locations.” Because BMI and waist circumference are widely used and appear in guidelines for the prevention and treatment of obesity, this chapter is limited to the presentation of cut-off points for BMI and waist circumference. Furthermore, cut-off points for BMI and waist circumference have been validated in studies comparing subjects with levels below and above cut-off points with regard to disease, disability and mortality risk.

Cut-off points for measures other than BMI and waist circumference have not been studied with regard to health and mortality risk in prospective studies. Waist/hip ratio is the only exception, although cut-off points for waist/hip ratios are not consensus based. As stated before, waist/hip ratio itself is of limited use, due to difficulties in the interpretation of ratios [41] and the independent associations of waist and hip circumference with disease and mortality risk [37,40].
Table 1.2 Relative impact of overweight and obesity on coronary heart disease mortality in some recent large prospective studies in men and women

<table>
<thead>
<tr>
<th>Authors</th>
<th>Jousilahti et al. [47]</th>
<th>Willett et al. [48]*</th>
<th>Seidell et al. [20]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>Men</td>
<td>Women</td>
<td>Men</td>
</tr>
<tr>
<td>n</td>
<td>7740</td>
<td>8373</td>
<td>115,818</td>
</tr>
<tr>
<td>Follow-up (yrs)</td>
<td>15</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>Age at baseline (yrs)</td>
<td>30–59</td>
<td>30–59</td>
<td>30–55</td>
</tr>
<tr>
<td>% subjects with BMI ≥ 25 kg/m²</td>
<td>58</td>
<td>58</td>
<td>28</td>
</tr>
<tr>
<td>Relative risk BMI ≥ 25 vs &lt; 25 kg/m²</td>
<td>1.3</td>
<td>1.5</td>
<td>2.2</td>
</tr>
<tr>
<td>PAR (BMI ≥ 25 kg/m²)</td>
<td>15%</td>
<td>22%</td>
<td>25%</td>
</tr>
<tr>
<td>% subjects with BMI ≥ 30 kg/m²</td>
<td>11</td>
<td>20</td>
<td>11</td>
</tr>
<tr>
<td>Relative risk BMI ≥ 30 vs &lt; 30 kg/m²</td>
<td>1.4</td>
<td>1.3</td>
<td>2.6</td>
</tr>
<tr>
<td>PAR (BMI ≥ 30 kg/m²)</td>
<td>4%</td>
<td>6%</td>
<td>15%</td>
</tr>
</tbody>
</table>

*Fatal and nonfatal coronary heart disease combined.

PAR, population attributable risk.

Cut-offs for BMI

Until recently, anthropometry-based definitions of excess fat were most often based on BMI. Moderate overweight has long been classified as BMI between 25 and 29.9 kg/m² and obesity as BMI ≥ 30 kg/m² [30]. These cut-points apply to both men and women and to all adult age groups, and are based on the associations between BMI and mortality risk. Mortality risk is generally lowest in individuals with a BMI between 18.5 and 25 kg/m² [46]. Obesity based on BMI is related to diabetes mellitus and coronary heart disease in men and women. In addition, increasing degrees of overweight are associated with an increased incidence of osteoarthritis of knees and hips, gallbladder disease, sleep apnea and certain types of cancer (breast and endometrial cancer in women, colon cancer in men). In Tables 1.2 and 1.3 the relative impact of overweight (BMI ≥ 25 kg/m²) and obesity (BMI ≥ 30 kg/m²) is calculated for coronary heart disease [20,47,48] and diabetes mellitus [49,50]. In these studies performed in Finland, the United States and The Netherlands it can be shown that BMI in the range of 25–30 kg/m² is responsible for the major part of the impact of overweight on coronary heart disease mortality. If no one in these populations had a BMI greater than 25 kg/m², 15–30% of all deaths of coronary heart disease could theoretically have been prevented. It is difficult to see the impact of the increased prevalence of obesity on coronary heart disease (CHD) mortality because CHD mortality rates have been steadily decreasing in most rich countries since the 1970s due to improved diagnosis and treatment of CHD and its risk factors.

The impact of obesity on diabetes mellitus is much greater than for coronary heart disease (see Table 1.3). If these figures are correct then about 64% of male and 77% of female cases of type 2 diabetes mellitus could theoretically have been prevented if no person in these cohorts had a BMI over 25 kg/m². It is clear that the epidemic of obesity is closely followed by an epidemic of type 2 diabetes mellitus [51].

Recent literature has suggested that BMI 25–29.9 kg/m² was not associated with increased mortality risk [52]. However, there were methodologic explanations for not finding those relations, including inappropriate control for smoking and reverse causation [53,54]. More importantly, regardless of the mortality effects, BMI levels of ≥ 25 and ≥ 30 kg/m² are even more strongly related to morbidity and disability risks (Fig. 1.2). Thus, BMI 25–29.9 kg/m² does imply increased risk for individuals and public health and even exceeds costs of BMI ≥ 30 kg/m², at least in The Netherlands, due to high prevalence rates of BMI between 25 and 29.9 kg/m² [55]. When morbidity, disability and mortality are combined in analyses, both subjects with BMI 25–29.9 kg/m² and subjects with BMI ≥ 30 kg/m² have more unhealthy life-years than subjects with BMI 18.5–24.9 kg/m² [10].

Cut-offs for waist circumference

Lean et al defined action levels for waist circumference, based on a sample of 904 men and 1014 women participating in the Scottish MONICA sample. Waist circumference levels of 80 cm in women and 94 cm in men (action level 1) were associated with BMI of 25 kg/m². Waist circumference levels of 88 cm in women and 102 cm in men were in concordance with BMI ≥ 30 kg/m² [14]. These cut-off points are known as “action level 2” and identify subjects at increased risk for morbidity, disability, and mortality. No suggestions for other action levels are known, and although debated [56], waist circumference levels of 102 cm

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for men and 88 cm for women have now reached the current WHO reports [30] and NIH guidelines [31] as indicators of increased health and mortality risk.

Waist circumference provides additional information on health and mortality risk independent of BMI. The NIH uses a combination of BMI and waist circumference to indicate individuals’ health risk (Table 1.4) [31]. Note that large waist circumference is depicted as >102 and >88 cm for men and women, respectively, whereas Lean defined action level 2 as ≥102 and ≥88 cm, respectively [14]. Surgeons tend to use the terminology of super-obesity and super-super obesity for BMI levels of ≥50 and ≥60 kg/m², respectively.

Although the distribution of WHR categories is continuous, only dichotomous classifications have been proposed. No consensus has been reached regarding alternative cut-off points [56]. There are no commonly accepted cut-off points for high or low hip circumference or skinfolds.

The literature describes different categories of subjects with a different body composition or different body morphology, in which different levels of fat storage have a different link to risk of morbidity or premature risk. Conclusions that these relationships differ are often based on epidemiologic studies of subjects in whom BMI and not body fat has been measured. It could thus be questioned whether cut-off points that are presented here can be used in all individuals.

Table 1.4 Classification of overweight and obesity by cut-points of the BMI and the waist circumference, and related health risks (type 2 diabetes mellitus and cardiovascular diseases) [31]

<table>
<thead>
<tr>
<th>BMI</th>
<th>Normal waist circumference</th>
<th>Large waist circumference (&gt;102 cm men, &gt;88 cm women)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underweight</td>
<td>&lt;18.5</td>
<td>–</td>
</tr>
<tr>
<td>Normal weight</td>
<td>18.5–24.9</td>
<td>–</td>
</tr>
<tr>
<td>Overweight</td>
<td>25–29.9</td>
<td>Increased</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Obesity I</td>
<td>30–34.9</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Very high</td>
</tr>
<tr>
<td>Obesity II</td>
<td>35–39.9</td>
<td>Very high</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Very high</td>
</tr>
<tr>
<td>Extreme obesity</td>
<td>≥40</td>
<td>Extremely high</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Extremely high</td>
</tr>
</tbody>
</table>

*Increased waist circumference can also be a marker for increased risk even in persons of normal weight.

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Measured versus self-reported obesity status

When identifying subjects who are candidates for treatment or prevention, measured rather than self-reported body weight should be used. When selection is based on self-reports a substantial proportion of subjects will be missed for appropriate treatment. Obese adults tend to under-report their body weight. This is understandable if patients do not routinely weigh themselves because body weight increases by 300–500 grams per year [57].

Four reviews have compared measured and reported body weight and height among adults [58–61], of which the review by Gorber et al. [60] was the most recent and most comprehensive. All concluded that there is a tendency to over-report body height and under-report body weight.

Large-scale studies that utilize BMI levels are often based on self-reported body weight and height. This could lead to under-estimates of obesity prevalence rates, because adults also tend to under-report their body weight, especially the obese, and subjects tend to over-report body height. The significance of under-reporting has been questioned, and some authors argue that mean levels of BMI may be estimated relatively well by use of self-reported data.

Measured body weight and height are generally most valuable when monitoring body weight and obesity prevalence rates, but there are alternatives. Measuring body weight and height consumes more time and money than self-reported height and
weight. Reporting body weight and height is less time consuming. Therefore, people are more likely to participate.

Size of under-reporting

Gorber et al. [60] identified 28 studies that provided mean differences between both measured and reported body height. Mean difference between self-reported and measured body height varied between $-1.3$ cm (underestimation) to $5.0$ cm (overestimation) among men and between $-1.7$ cm to $5.0$ cm among women. One study on both men and women exceeded the $5.0$ cm difference. Hill and Roberts found a mean difference of $7.5$ cm between measured and reported body height [62].

A total of 14 studies were found by Gorber et al. that presented difference in mean body weight when based on measured and reported body weight, and 24 studies provided these data for either men or women. Body weight was overestimated in all but two studies on both men and women; one was a sample of anorectics. All but three studies of women showed body weight was underestimated (range: $0.1$ – $6.5$ kg). The largest mean underestimation occurred in a study of women with BMIs between $35$ and $40$ kg/m$^2$. One study of women did not find a difference, and one of the two studies showing an overestimation was a study of women with BMI $<20$ kg/m$^2$. Twenty-four of 27 studies of men showed that body weight was underestimated (range: $0.1$ – $3.2$ kg).

Underestimation of BMI was calculated from those studies that included both reported and measured weight and height. In studies that combined men and women, underestimates ranged from $0.2$ to $2.3$ kg/m$^2$. Fourteen of 16 studies of men showed underestimates of BMI, ranging from $-0.3$ to $-1.1$ kg/m$^2$. Fifteen of 16 studies of women showed underestimates of BMI ranging from $-0.1$ to $-2.4$ kg/m$^2$. The largest underestimates occurred among women with BMI $>40$ kg/m$^2$. One study of the general Scottish population aged 25–64 years showed an overestimation by $0.2$ kg/m$^2$ with standard deviations of $1.4$ and $1.3$ kg/m$^2$ in men and women, respectively [63]. In the Spanish general population aged 15 years and over, BMI was overestimated by $0.5$ and $0.9$ kg/m$^2$ among men and women, respectively [64].

Under-reports of mean body weight and BMI may be regarded as relatively small, and about $97\%$ of men and $95\%$ of women report a body weight within $10\%$ of their measured body weight. About $80\%$ of men and $77\%$ of women reported a body weight within $5\%$ of their measured body weight [61]. Mean body height was $0.5$ cm and $0.6$ cm higher, and mean BMI was $0.4$ kg/m$^2$ and $0.6$ kg/m$^2$ lower among men and women respectively, when based on self-reported data [61]. Prevalence rates of overweight and obesity, however, were significantly lower when based on reported rather than measured body weight and height (Fig. 1.3) [61]. The prevalence of obesity was $3.0\%$ and $3.3\%$ lower among men and women, respectively, when based on self-reported data. As a percentage of the measured prevalence, obesity was underestimated by $26.1\%$ among men and by $30.0\%$ among women, when based on reported data.

The variance in difference between measured and reported obesity prevalence rates varies between studies, from $0.0\%$ to $49.6\%$ as a percentage of the true obesity prevalence rate (Fig. 1.4) [62–71]. In one study, where underestimation of obesity was nearly absent, the questionnaire to report body weight was sent out 2 weeks before the clinic appointment date [63]. There was no relationship between the reported obesity prevalence rate and the size of underestimation.

A few studies have presented linear regression equations to estimate “true” obesity prevalence rates from reported body weight and height [63,68,72–75]. Some of these estimates appeared valid within the sample from which the linear regression equation was formulated [63,68,73]. One study (NHANES II) developed linear regression equations from half of the sample to test the validity of the equations in the other half of the sample,
and concluded that self-reported BMI is difficult or impossible to correct by the use of such equations [23]. Furthermore, when different correction equations are applied to a single database, a large variety of estimations for percentage of obesity is found [61].

Frequent weighing, at least once per month, reportedly leads to more accurate reporting of body weight [69]. Although self-reported body weight and height may not be valid alternatives for measuring body weight and height, it seems advisable to ask subjects to weigh themselves before they report their body weight and height in an interview or questionnaire. Spencer et al. hypothesized that an alternative may be to measure a few subjects per quantile of the BMI distribution [68].

Reporting body weight and body height is not a valid alternative for measuring body weight and height when estimating the obesity prevalence in a population or an individual’s obesity status. Adjusting prevalence rates that are based on reported body weight and height does not lead to valid estimates. In addition, formulas used to calculate prevalence rates from reported data do not lead to valid estimates. Measuring body weight and height is costly and time consuming, but valuable efforts for monitoring and evaluating prevention and treatment studies do require direct measurements of body weight and height. As the most important determinant of under-reporting body weight is true body weight, we propose that monitoring efforts should include measured values of body weight and height once in every 3–5 years.

**Obesity in clinical practice**

Clinicians have two good reasons for discussing overweight or obesity with their patients. First, as described, obesity is not only a major risk factor but also a precursor for chronic diseases, disabilities, and premature mortality. Recent guidelines for the treatment of obesity suggest that body weight be measured and discussed only when co-morbidities are present. Second, obesity is the result of an overconsumption of energy, reduced activity or excess inactivity. Overweight alone is not the only reason for discussing nutrition and physical activity patterns, but body weight status provides an opportunity to discuss determinants of obesity.

**Determinants of obesity**

Diminished physical activity, high-calorie diets and inadequate adjustments of energy intakes to the diminished energy requirements are likely to be major determinants of weight changes. Prentice and Jebb [76] have proposed that, on a population level, limited physical activity may be more important than energy or fat consumption in explaining the time-trends of obesity in the UK. Their analyses were based on aspects of physical activity (such as number of hours spent watching television) and household consumption survey data. Although such data may be suggestive, they may also be biased. For example, under-reporting of fat consumption increases with the degree of overweight [77]. Changes in smoking behavior may also contribute to changes in body weight on a population level. Data from the United States showed that although smoking cessation could explain some of the increase in the prevalence of overweight, smoking cessation alone could not account for the major portion of the increase [78]. Other studies have also shown that the increase in obesity prevalence may be independent of smoking status [79,80].

Very little is known about the factors that may explain the large differences between populations in the distributions of BMI. Obviously, overweight in individuals in any population is the result of a long-term positive energy balance. The conclusion that overweight is attributable to physical inactivity or ingestion of large quantities of food is an oversimplification. Several epidemiologic studies have shown that the following factors are associated with overweight in the population.

**Demographic factors**

- **Age:** obesity increases with age at least up until age 50–60 years in men and women. Figure 1.5 shows the relation between age and prevalence of obesity in The Netherlands [81].
- **Gender:** the prevalence of obesity is generally higher in women compared to men especially when older than 50 years of age.
• **Ethnicity:** large variations between ethnic groups are often not explained by socio-economic status measured by level of education and or income.

**Sociocultural factors**
- **Educational level and income:** in many industrialized countries there is a higher prevalence in those with lower education and/or income. Figure 1.6 illustrates the inverse association between the level of education and the prevalence of obesity in adults in The Netherlands.
- **Marital status:** obesity usually increases after marriage.

**Biologic factors**
It has been claimed that BMI increases with increasing number of children but recent evidence suggests that this contribution is, on average, likely to be small, less than 1 kg per pregnancy. Many study designs confound the changes in weight with aging with changes in weight with parity [82].

Obesity rates are increased in certain categories which deserve increased attention, as well as the absolute risks of morbidity, disability and mortality. Important subcategories that need further attention are men/women, elderly populations, children, and disabled persons.

**Men/women**
Usually, the same cut-off points are applied to men and women and to different age groups. This is done because the relationships between BMI and mortality are similar (i.e. the relative mortality associated with obesity is similar in men and women). In most age groups the absolute mortality among women is much lower. The same relative risk and lower absolute risk associated with overweight and obesity among women compared to men implies that women tolerate body fat better than men. Excess body fat in women is usually distributed as subcutaneous fat and mainly peripherally (thighs, buttocks, breasts) whereas in men there is a relative excess of body fat stored as visceral and subcutaneous abdominal fat.

**Elderly**
Body Mass Index levels are associated with increased mortality risk in the elderly, although relative risks decline with aging [10,83] and the optimal BMI with lowest mortality risk seems to increase with age [84]. The reasons why older people seem to tolerate excess body fat better than younger people are manifold and range from selective survival to decreased lipolysis of adipose tissue in older people.

Although BMI is still the most often used estimate of total body fat storage in older adults, there are limitations to its use as a single estimate for body fat. Body composition is changing in the elderly, muscle mass is decreasing, fat mass is increasing and becoming more centralized to the abdominal region. Health behaviors in the elderly differ from younger populations; undernutrition is more common and physical activity levels decline. Some have suggested the use of height measured at a younger age to calculate BMI in older adults, but this does not solve the problem of changing body composition and sarcopenia – losing muscle mass.

Waist circumference at age 55 has shown a fair association with risk factors for cardiovascular diseases and type 2 diabetes mellitus in both men and women. In never-smoking men, a large waist circumference identified more men with an increased risk of mortality than did high BMI. Changes in waist and hip circumference were better anthropometric predictors of changes in body fat storage over a 10-year period compared with changes in skinfold thickness [85]. High BMI in persons aged 70–79 years, however, had a stronger association with total body fat than did waist circumference.

**Disabled persons**
Disabled persons have an increased risk of developing obesity [86]. Some categories of physical disabilities prevent patients standing for measurement of body weight, waist and hip circumference or skinfold thickness. It is still unclear whether and which correction factors can be used for body height measures that are taken in standing and sitting or lying position. Suggestions have been made, however, to use knee height as proxy for body height in children and adults [87]. It should be noted that these studies have been performed in nondisabled persons and thus may not
be necessarily valid for specific disability categories. Upper arm length, tibial length, and knee height have been suggested as proxies for body height in children with disorders such as cerebral palsy [88].

**Conclusion**

All European ministers of public health have now committed themselves to appropriate monitoring of overweight and obesity levels in children and adults. These efforts will lead to a further understanding of the increase in obesity and of measurement issues of obesity. Validation studies based on large-scale studies using innovative measures such as BOD-POD and threedimensional imaging will lead to a further understanding of the value of definitions for the identification of individuals with "excess body fat" or at "increased risk." Research is especially needed in the elderly.

Clinicians can play an important role in the identification of individuals with overweight or obesity. Although their role will be further specified in the near future, measuring obesity status is already part of standard procedures when co-morbidities are presented or when patients have questions regarding their weight, nutrition or physical activities.

**References**

Chapter 1 Epidemiology: Definition and Classification of Obesity


