Chapter 2

Body Composition Assessment of Obesity

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1. INTRODUCTION

Obesity is an international health problem for children, adults, and the elderly [1, 2] that can lead to the development of type 2 diabetes, enhance risk factors for cardiovascular and related diseases, and is associated with increased cancer risk and renal failure. Childhood obesity foreshadows its persistence into and through adulthood [3, 4], and obesity is becoming a common problem among the elderly [5–7]. Obesity is generally displayed as excess adipose tissue and a high body weight, but in some elderly persons and others with limited mobility it takes the form of sarcopenic obesity, in which a preferential loss of muscle tissue increases the percentage of body fat [8]. Based on the body mass index (BMI), obesity has a current prevalence of 20% to 30% for non-Hispanic white, non-Hispanic black, and Mexican-American men; 25% to 40% for non-Hispanic white and Mexican-American women; and as high as 46% to 53% for non-Hispanic black women [9]. A similar prevalence exists for portions of the adult and pediatric populations of Europe, and among urban areas of Mexico, the Middle East, India, and China [10–13]. This obesity pandemic is becoming a greater health problem than under-nutrition [14–16].

Current publications indicate that this high prevalence of obesity is a recent phenomenon [9, 17–19]. However, in the 1960s, Cheek and colleagues noted that they were spurred on in their development of new body composition techniques as a result of concern for the high prevalence of obesity among children at that time [20]. Almost 35 years later, there is still a continued need for improved body composition technology applicable to monitoring and treating obese children and adults. Numerous methods and equipment are available to assess fatness and other components of body composition [21, 22]. This chapter discusses the status of those methods applicable for assessing body fatness among obese individuals in clinical and epidemiological settings.

2. OVERVIEW OF BODY COMPOSITION METHODS

Detailed aspects of body composition methodology, underlying theories and general applications, equipment, and analytical techniques are found in several excellent texts [21–23]. Those interested in specific body composition assessment methods should first consult these references. Body composition methodology is based on assumptions regarding the density of body tissues, concentrations of water and electrolytes, and biological interrelationships between body components and body tissues and their distributions among normal weight individuals. Similar assumptions do not exist for obese persons, whose metabolic and hormonal problems together with accompanying comorbid conditions alter assumptions and interrelationships underlying the validity of body composition methods in normal weight individuals [24]. In addition, the application of body composition technology is limited among most obese adults and many older obese children because their bodies are too large for the available equipment. As a result, epidemiological and national obesity prevalence data are not completely based on actual measures of body fatness because of the difficulty of collecting such data during health surveys from sufficient numbers of obese individuals. It is also difficult to monitor and treat obesity without an easily acceptable assessment method or index and a reference population.

2.1. Anthropometry

Anthropometric measurements describe body mass, size, shape, and level of fatness. Body size changes with weight gain, which alters the associative power among anthropometric measures and indices. Standardized anthropometric techniques are necessary for comparisons between clinical and research studies, and video and text media describing these techniques are available [25–27]. Those interested in using anthropometric equipment and methods should first consult these several resources.

2.2. Weight and Stature

Weight is the obvious measure of obesity. Various scales are available for measuring weight, but these must be calibrated regularly. Persons with high body weights tend to have high amounts of body fat although this is not always true among the elderly with sarcopenic obesity, in whom stable or even low body weights occur with increased percent body fatness. Changes in weight reflect corresponding changes in body water, fat, and lean tissue. However, weight is not always the best indicator of obesity because weight is related to stature, i.e., tall people are, on average, heavier than short people. Weight also increases with age in children (because of growth) and in adults (because of fatness). To overcome this lack of specificity, weight is divided by stature squared to create the body mass index or BMI as a descriptive index of body habitus encompassing both the lean and the obese [1].

Stature is also easily measured with a variety of wall-mounted equipment that also needs to be calibrated regularly. In addition, methods are available for predicting stature when it cannot be measured for the handicapped or mobility impaired [28, 29].

2.3. Body Mass Index

The advantage of BMI as an index of obesity is the availability of extensive national reference data worldwide, its established relationships with levels of body fatness, morbidity, and mortality [1], and it is highly predictive of future risk. High BMI percentile levels based on percentiles on the CDC BMI growth charts and changes in parameters of BMI curves for children are linked to significant levels of risk for adult obesity at corresponding high percentile levels [4, 30]. A boy with a BMI at the 85th percentile at age 12 has a risk of 20% of having a BMI at that same level at 35 years of age (Figure 1). For a girl with

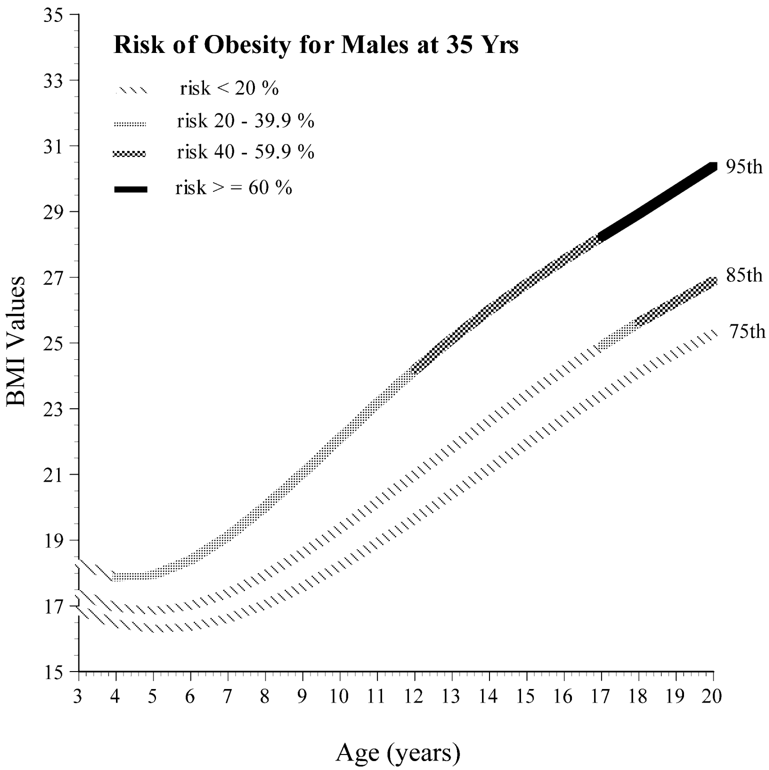

Figure 1. Risk of obesity in boys at age 35 years based on BMI percentiles in childhood [4].

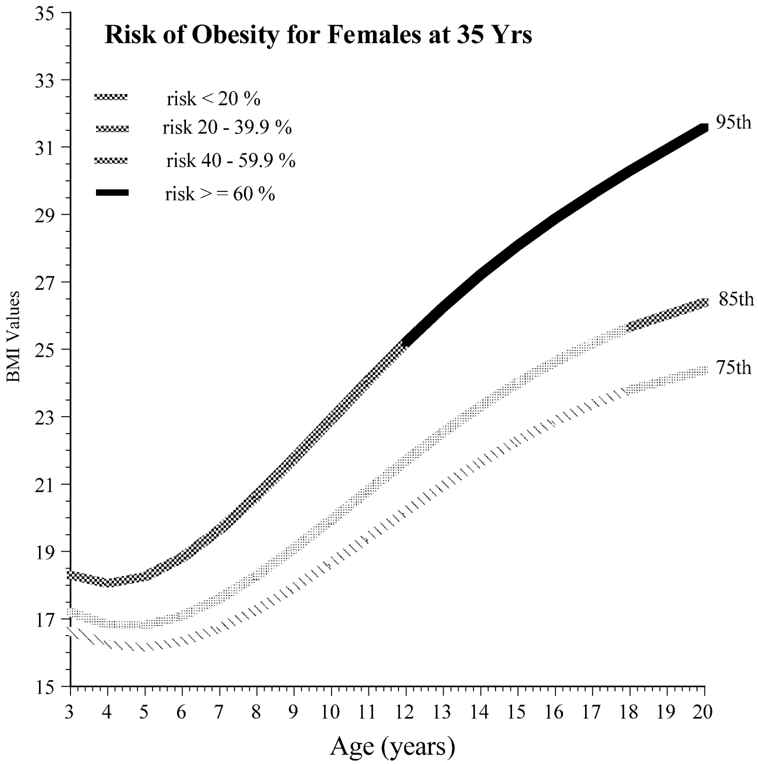

Figure 2. Risk of obesity in girls at age 35 years based on BMI percentiles in childhood [4].

a BMI at the 95th percentile, the corresponding adult risk is greater than 60% (Figure 2). The relationship of obesity as indexed by BMI with mortality has been revised for the US adult population [19]. In the elderly, sarcopenia causes a person of normal weight and BMI to become obese owing to an increased high percentage of body fat. BMI is also useful in monitoring the treatment of obesity, but a weight change of about 3.5 kg is needed to produce a unit change in BMI.

2.4. Abdominal Circumference

Obesity is frequently associated with increased amounts of intraabdominal fat. A central fat pattern is associated with the deposition of intraabdominal adipose tissue, but subcutaneous abdominal adipose tissue is involved also. The ratio of abdominal circumference (sometime incorrectly referred to as "waist" circumference) to the hip circumference is an early index describing adipose tissue distribution or fat patterning [31, 32]. Ratios greater than 0.85 represent a masculine or central distribution of fat. Most men with a ratio greater than 1.0 and women with a ratio greater than 0.85 are at increased risk

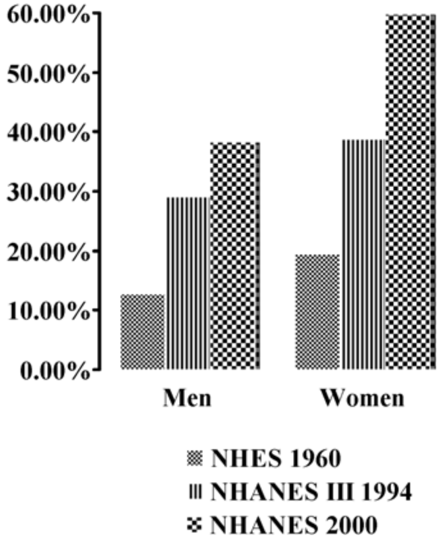

Figure 3. Change in prevalence of adult from 1960 to 2000. (Data from the National Center for Health Statistics.)

for cardiovascular disease, diabetes, and cancers [33, 34]. However, this ratio is an imperfect indicator of intraabdominal adipose tissue and the use of the abdominal circumference alone provides much the same information [35, 36]. Persons in the upper percentiles for abdominal circumference are considered obese and at increased risk for morbidity, specifically type 2 diabetes and the metabolic syndrome, and mortality [37, 38]. The increased prevalence in abdominal circumference in the general population can be seen in Figure 3 [39]. Circumferences of other body segments such as the arm and leg are possible [25] but there are little available reference data except for arm circumference. The calculation of fat and muscle areas of the arm is not accurate or valid in the obese.

Abdominal thickness is associated with levels of abdominal obesity because a large abdomen should be a thick abdomen [12]. However, there is some inconsistency in standardizing this measurement; should it be taken standing or recumbent, from the small of the back, or from the top of a table when recumbent? There are little available reference data.

2.5. Skinfolds

Skinfolds measure subcutaneous fat thickness, but they are not very useful for the obese. Most skinfold calipers have an upper measurement limit of 45 to 55 mm, which restricts their use to the “moderately” obese or thinner. A few skinfold calipers take larger measurements, but this is not a significant improvement because of the difficulty of grasping and holding a large skinfold, plus the additional problem of reading the caliper dials, all of which create additional errors. The majority of the available national reference data is for triceps and subscapular skinfolds, but the triceps is a sex-specific site and can reflect changes in the underlying triceps muscle rather than an actual change in body fatness. Skinfolds are useful in monitoring changes in fatness in children because of their small body size, and the majority of fat is subcutaneous even in obese children [40, 41]. The statistical relationships of skinfolds with percent and total body fat are often not as strong as that of BMI in both children and adults [42]. Also, we do not know the real upper distribution of subcutaneous fat measurements because most obese children and adults have not had their skinfolds measured.

2.6. Bioelectric Impedance Analysis

Bioelectrical impedance analyzers (BIAs) do not measure any biological quantity or describe any biophysical model related to obesity. The impedance index, stature squared divided by resistance (S^2/R) at a frequency, most often 50 kHz, is an independent variable in regression equations to predict body composition [43–45]. Bioelectrical impedance analyzers use such equations to describe statistical associations based on biological relationships for a specific population, and as such the equations are useful only for subjects that closely match the reference population in body size and shape. BIA has been applied to overweight or obese samples [46, 47] in a few studies; thus the available BIA prediction equations are not applicable to overweight or obese children or adults. The ability of BIA to predict fatness in the obese is difficult because they have a greater proportion of body mass and body water accounted for by the trunk, the hydration of fat-free mass (FFM) is lower in the obese, and the ratio of extracellular water (ECW) to intracellular water (ICW) is increased in the obese.

BIA validity and its estimates of body composition are significant issues for normal weight individuals. BIA is useful in describing mean body composition for groups of individuals, but large errors for an individual limit its clinical application, especially among the obese. The large predictive errors with BIA render it insensitive to small improvements in response to treatment. Commercial BIA analyzers contain all of the problems associated with this methodology.

Recent BIA prediction equations have been published [48] along with body composition mean estimates for non-Hispanic whites, non-Hispanic blacks, and Mexican-American males and females from 12 to 90 years of age [49]. These equations are not recommended for obese individuals or groups.

2.7. Body Density

Hydrodensitometry estimates body composition using measures of body weight, body volume, and residual lung volume. Historically, body density was converted to the percentage of body weight as fat using the two-compartment models of Siri [50] or Brozek and co-workers [51], but more recently, a multicompartment model is used to calculate body fatness [52]. Body density is plagued with the problem of subject performance because it is difficult if not impossible for an obese adult or child to submerge. Weight belts reduce bouncy, but not all aspects of performance. Air displacement devices [53–55] are limited to adults who are "moderately" obese at best. Regardless, most overweight and obese persons are reluctant to put on a bathing suit and participate in body density measurements.

2.8. Total Body Water

Total body water (TBW) is easy to measure because it does not require undressing or any real physical participation, but this method is limited in the obese. The major assumption is that FFM is estimated from TBW based on an assumed average proportion of TBW in FFM of 73%, but this proportion ranges from 67% to 80% [49, 50]. In addition, about 15% to 30% of TBW is present in adipose tissue as extracellular fluid, and this proportion increases with the degree of adiposity. These proportions tend to be higher in women than in men, higher in the obese, and produce underestimates of FFM and overestimates of fatness. Variation in the distribution of TBW as a result of disease associated with obesity, such as diabetes and renal failure, affects estimates of FFM and TBF further.

TBW is a potentially useful method applicable to the obese but there are details that need to be considered. The several analytical chemical methods used to quantify the concentration of TBW (and extracellular fluid) have errors of almost a liter. Equilibration times for isotope dilution in relation to levels of body fatness are unknown, because, theoretically, it might (and should) take longer for the dilution dose to equilibrate in an obese person as compared with a normal weight individual. Also, a measure of extracellular space is necessary to correct the amount of FFM in an obese person. Such data could also be very useful in the treatment of end-stage renal disease.

2.9. Dual-energy x-ray Absorptiometry

Dual energy x-ray absorptiometry (DXA) is the most popular method for quantifying fat, lean, and bone tissues. DXA is fast and user friendly for the subject and the operator, but the machines require regular maintenance and calibration. DXA has inherent assumptions regarding levels of hydration, potassium content, or tissue density in the estimation of fat and lean tissue, and these assumptions vary by manufacturer [56, 57]. DXA estimates of body composition are also affected by differences among manufacturers in the technology, models and software employed, methodological problems, and intra- and intermachine differences [56, 58]. There are physical limitations of body weight, length, thickness and width, and the type of DXA machine, i.e., pencil or fan beam. Most obese adults and many children are often too wide, too thick, and too heavy to receive a whole-body DXA scan although some innovative adaptations have been reported [59]. Pediatric software is available for DXA and should be used according to the manufacturer's recommendations. DXA is a convenient method for measuring body composition in much of the population, and it is currently included in the ongoing National Health and Nutrition Examination Survey (NHANES).

The other imaging systems, such as computed tomography (CT) and magnetic resonance imaging (MRI) are not practical for obese individuals. CT is able to accommodate large body sizes but has high radiation exposures and as such is inappropriate for whole-body assessments, but it has been used to measure intraabdominal fat. MRI is not able to accommodate large body sizes in many instances but can be used for whole body assessments. Both these methods require additional time and software to provide whole-body quantities of fat and lean tissue.

3. ETHNIC DIFFERENCES IN BODY COMPOSITION

Ethnic differences in body composition and obesity are affected by differences in and associations with socioeconomic status, diet, utilization of health care, and levels of genetic admixture. These associations and effects in some ethnic groups may not be clear because the health status of minority groups is frequently affected by socioeconomic factors. African-American girls are fatter at earlier ages than white girls; they also have an earlier sexual maturation that has been linked to an early onset of obesity [60–64]. At the extremes of body fatness, there are more African-American women than non-Hispanic white women. There are limited body composition data for large samples of African, Hispanic, or Asian Americans and especially for the obese among these groups [34, 65–67]. The exception is that reasonably extensive anthropometric data are available for African, Hispanic and non-Hispanic white Americans from the National Center for Health Statistics in the NHANES.

4. AVAILABLE REFERENCE DATA

The principal source of national reference data for obesity in the United States comes from the National Center for Health Statistics, Centers for Disease Control and Prevention in the form of the NHANES (http://www.cdc.gov/

nchs/nhanes.htm). The target populations for these surveys consist of all non-institutionalized civilian residents of the continental United States including Alaska, and data from these NCHS surveys presents a picture of the health status of the US population rather than a desired health goal. The current NHANES is the first national survey to include DXA measures of body composition.

The anthropometric data in the NHANES were selected to monitor the health and nutritional status of infants, children, adults, and the elderly. These body measurements follow techniques for corresponding measurements in the *Anthropometric Standardization Reference Manual* [25] and are similar across other NCHS surveys. Mean values and distribution statistics for stature; weight; and selected body circumferences, breadths, and skinfold thicknesses of children and adults are available from all these national health surveys.

5. RECOMMENDATIONS

A body composition assessment in an obese child or adult depends on several conditions. For most children until they are postpuberty, DXA is the method of choice. This provides an estimate of the amount of fat, lean, and bony tissues, all of which should be monitored along with any change in weight during treatment. For older obese children and adults, the easiest measure to monitor is body weight. This can be combined with a measure of abdominal circumference and BMI to track progress. As fat tissue is reduced and weight is lost, it is important that there is not a greater loss of lean tissue, which can have significant health risks. Other body composition methods that would only be useful in adults as a measure of lean tissue are possibly from DXA or TBW. For overweight and moderately obese individuals, with a managed regimen of diet and exercise, weight will be lost, but some will experience a weight gain as lean tissue is added [68].

Of all the methods available to monitor obesity, BMI is currently the easiest and most informative index. Numerous sets of reference data are available and it is possible to determine, monitor, and track a change in BMI percentiles for children and adults. This, along with changes in weight, will provide a good, clinical estimate of the amount of change that is occurring with treatment for an obese individual.

6. CONCLUSION

It does not appear that the present epidemic of overweight and obesity will attenuate in the near future. Our ability to diagnosis, monitor, and treat obesity is limited, in part, by our limited ability to assess body fatness easily. There is no universally accepted method of measuring body fatness or for quantifying obesity clearly, and current methods are hampered with problems of nonuniversal assumptions, and limited by application of methodology for obese individuals.

The WHO [10] has made several recommendations concerning obesity. One of these addresses the need for the development and validation of new and existing techniques. In this chapter, we have briefly reviewed many of the existing techniques and their limitations when applied to obese persons. In support of this WHO recommendation, it is clear that existing techniques are not applicable to many obese who are in great need of this technology. This limitation also affects our ability to determine the real prevalence of obesity because the current methods are not applicable to large epidemiological and clinical studies. Obviously much work is yet to be done.

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