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Assessment and Prevalence of Obesity

Application of New Methods to a Major Problem

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Overweight and obesity are major health problems worldwide. A body mass index of ≥25 has been classified as overweight and of ≥30 as obesity. However, national and epidemiologic data on overweight and obesity are not based on actual measures of body fat because of the difficulty of collecting such data from large groups and especially from the obese. There are now numerous direct and indirect methods to assess body fat. Anthropometric techniques are the most common indirect methods used in epidemiologic and clinical assessments, but these are restricted in the obese to circumferences. The other methods of assessing body fat are bioelectrical impedance, body density, total body water, and dual X-ray absorptiometry, all of which have advantages and limitations when applied to the obese. All these methods make use of statistical models in calculating body composition. There are several sources of available reference data for anthropometric measures for the US population, but no direct measures of body fat are currently available. There is a clear need for the continued development and validation of new and existing techniques to determine levels of fat.

Key Words: Obesity; body composition; anthropometry; DXA.

Introduction

Overweight and obesity are major health problems in the United States; Europe; and many developed countries in South America, Africa, and Asia *(1,2)*. Prevalence for overweight, based on the body mass index (BMI), is reported to be as high as 20–50% by the World Health Organization (WHO) for portions of the adult populations of Europe, the United States, and even among urban areas of countries such as Kuwait and India *(3)*. Variations in the prevalence of overweight and obesity among and within countries can be a function of differences in ethnicity, health and socioeconomic status, assessment methodology, and the definition of overweight and obesity. In the past, there was no universally accepted definition of obesity, but rather a collection of descriptive statements such as an "excess accumulation" or an "abnormally high percentage" of body fat *(4,5)*. Such definitions are difficult to quantify methodologically because they are subjective in their interpretation. In the United States, a BMI of 27.8 for men and 27.3 for women has been proposed as a definition for obesity based on the value at the 85th percentile for BMI data from the National Center for Health Statistics (NCHS) *(6)*. Basing a definition on a BMI value at a specific percentile level does not clarify the issue because the percentile level will vary with the distribution of BMI values in the population, and the BMI value will not correspond to a similar percentile level in a different population. In 1997, the WHO developed a classification system for overweight and obesity based on grades of BMI values related to increasing the risk of comorbidity (Table 1). A BMI of between 25 and 29 was defined as overweight and a BMI of ≥30 accepted as a definition of obesity *(3)*. The increasing risk of comorbidity with a high BMI was in reference to the relationship between a high BMI and a corresponding high level of body fat. Using this WHO definition of obesity, data from the MONICA Study indicate that 10–30% of persons of European heritage around the world are obese; these data are 15 yr old *(3)*. In fact, in some non-Western countries, overweight is now a greater health problem than undernutrition *(7)*.

The available national and epidemiologic prevalence data on overweight and obesity are not based on actual measures of body fat, because of the difficulty of collecting such data from large groups. However, the increasing prevalence of overweight and obesity among adults and children in the United States and around the world *(2,6,8)* has highlighted the need for accurate and reliable methods to assess levels of body fat. It is difficult to monitor and treat overweight and obesity without some easily acceptable assessment method or index and a reference population. This paper discusses the current status of various methods of assessing body fat as they are applicable to

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Table 1
BMI Values, Classifications of Obesity and Risk of Comorbidity from WHO

BMI range	Obesity classification	Risk of comorbidity
18.5–24.9	Normal	Average
25–29.9	Overweight	Increased
30.0–34.9	Obese class I	Moderate
35–39.9	Obese class II	Severe
≥40	Obese class III	Very severe

overweight and obese adults in clinical and epidemiologic settings.

Direct and Indirect Methods

Within the last decade of the twentieth century, the ability and availability of body composition methodology to assess body fat in large groups has improved. Although the basic theories underlying body composition methodology have not changed much since the 1960s *(9)*, there have been numerous technological improvements to these methods. A variety of methods and devices are now available to assess fat and other components of body composition, some direct and others less direct. Direct methods use electromagnetic radiation to quantify specific tissues, and chemical and molecular elements in the body and are used primarily in clinical research centers where accurate and precise measurements are essential. Methods such as neutron activation, computed tomography (CT) and magnetic resonance imaging (MRI) are examples of direct methods. Neutron activation quantifies specific elements in the body, whereas CT and MRI provide information about anatomical amounts and the distribution of muscle and adipose tissues via X-ray or magnetic imaging techniques *(10)*.

Indirect methods provide estimates or indices of body fat. These methods are based on assumptions regarding the density of body tissues, the concentrations of water and electrolytes in the body, and biological interrelationships among directly measured body components and body tissues and their distribution among normal individuals. The accuracy and precision of indirect methods depends on their validation against results from direct methods. Indirect methods have larger errors than direct methods and are affected by sample specificity and disease conditions. The adaptability and ease of use with large groups makes indirect methods applicable in epidemiologic studies, and in public health and obesity screening programs.

An obese person can have associated concurrent metabolic and hormonal disruptions beyond that of a normal or overweight person. These associations together with comorbid conditions can profoundly alter the relationship and assumptions underlying the validity and associations between indirect and direct methods *(11)*. Furthermore, direct and indirect body composition methods frequently have a limited application in many of the obese (and overweight) owing to the physical size of such individuals who can or need to be measured and treated. Often, obese adults cannot be measured because their bodies are too large for the machines and equipment available to assess body composition. For example, it would be quite difficult to collect MRI data from many of the obese because they are too large for the opening in the magnet. Of the direct methods, neutron activation is the easiest to use for the obese, but only a few locations in the United States have this capability. It is hoped that the technological advancements in many of the following methods we discuss will continue so that researchers can clarify their perspective on the prevalence of overweight and obesity through improved measurement capabilities.

Anthropometry

Anthropometric measurements are commonly used to describe body size, shape, and the level or degree of fat. Changes in body size and composition that occur with weight gains and losses associated with maturation, aging, and disease can alter the power and accuracy of anthropometric measurements to predict a given relationship or outcome. Anthropometric data are also frequent covariables that account for additional variance in statistical models of body composition *(12,13)*.

Weight is the most obvious measure for describing overweight and obesity. In general, most persons with high body weights tend to have high amounts of body fat. Weight has been combined with stature squared in the popular BMI as a descriptive index of overweight independent of a person's stature. The advantages of BMI are that extensive national reference data are available, it has established direct relationships with levels of body fat and with morbidity and mortality, and it is highly predictive of future risk for overweight. In adults, high levels of BMI above 25 are associated with increased morbidity and mortality *(2)*. Weight and BMI are useful in monitoring the treatment of overweight and obesity because they are both sensitive to positive progress in response to treatment. Weight is easily monitored and tracked at home. Also, a weight change of only about 3.5 kg is sufficient to produce a unit change in BMI.

The use of BMI as an index of overweight or obesity is not applicable to all persons. Its use has principally been in adults, but it is now being used in children and the elderly. The relationship between a high BMI value in childhood with corresponding morbidity has not been determined. However, high percentile levels for BMI in childhood have been linked to significant levels of risk for obesity (corresponding high percentile levels) in adulthood *(14)*. As shown in Fig. 1, a girl with a BMI at the 85^{th} percentile at age 12 has a risk (30–40%) of having a BMI at that same level at age 35 yr. For a BMI at the 95th percentile, the corresponding adult risk is between 40 and 80%. In the

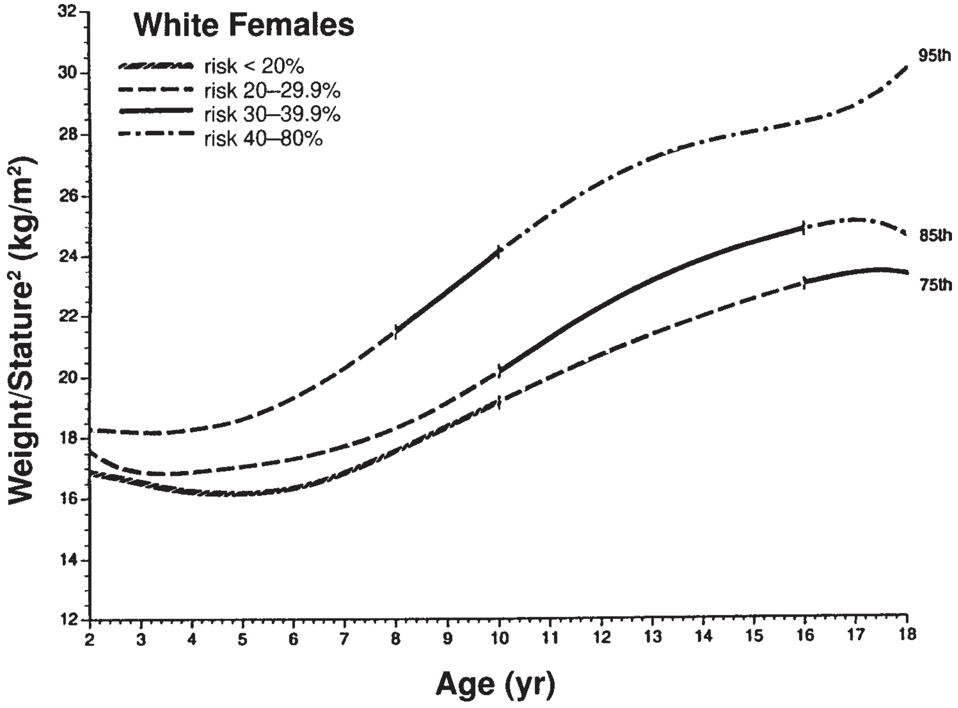

Fig. 1. Risk of overweight at age 35 based on BMI percentiles from THE NHANES II in Childhood Study *(14)*.

elderly, the loss of muscle mass known as sarcopenia can cause an elderly person of normal weight and BMI to become obese because of an increased high percentage of body fat. Obesity is not an uncommon problem among the elderly *(15,16)*.

The waist-to-hip ratio (WHR) is another popular index to describe adipose tissue distribution *(17,18)*. WHRs >0.85 are generally considered indicative of a masculine or central distribution of fat. Most men with a WHR >1.0 and women with a WHR >0.85 are at increased risk for cardiovascular disease, diabetes, and cancers *(19,20)*. Central body fat is associated with increased deposition of intraabdominal adipose tissue, although increased subcutaneous abdominal adipose tissue is involved also. The WHR is an imperfect index of intraabdominal adipose tissue, and the use of the waist or abdominal circumference alone can provide much the same information *(21,22)*. Persons in the upper percentiles for waist circumference are considered obese and at increased risk for morbidity and mortality *(5)*. Abdominal thickness is another measure that has received notoriety because of supposed relationships with levels of abdominal obesity. Conceptually, this measurement makes sense in that a large abdomen should be a thick abdomen. However, there has been a lack of consistency 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? Standardized anthropometric techniques are crucial for comparisons among both clinical and research studies, especially for assessing the body fat using reference data from the National Health and Nutrition Examination Surveys (NHANES). If a measurement is to be useful, suitable physical landmarks for the measurements need to be identified and adhered to *(23)*.

Skinfolds are the most common anthropometric method for measuring subcutaneous fat thickness, but they are not very useful in many overweight and obese adults. Most skinfold calipers have an upper measurement limit of 45–55 mm, which restricts their use to those who are "moderately" obese or thinner. The availability of skinfold calipers capable of larger measurements would not be a significant improvement because of the physical difficulty of picking up a very large skinfold on an obese adult. The majority of the available reference data is for triceps and subscapular skinfolds; however, because of the measurement limitation of skinfold calipers, we do not know the real distribution of subcutaneous fat measurements in a population because many, if not most, of the obese cannot have their skinfolds measured. There are other skinfold sites on the body, but few data are available on the relationships of subcutaneous fat at these other locations with levels of body fat. Because of their small body size, in children skinfolds can be useful in monitoring changes in subcutaneous fat, in whom the majority of fat is subcutaneous even in obese children *(24,25)*. However, the statistical relationships of skinfolds with the percentage of total body fat are often not as strong as that of BMI in both children and adults *(26)*.

Bioelectric Impedance

Bioelectric impedance (BIA) is used to estimate the amount of total body water (TBW), fat-free mass (FFM), and degree of body fat by measuring the resistance of the body to a small alternating electric current *(27,28)*. Bioelectric impedance at 50 kHz cannot reliably distinguish differences in the proportion of extracellular fluid that increases in the obese *(29)*. BIA at multiple frequencies other than 50 kHz is reported to differentiate the proportions of intra- and extracellular fluid volumes *(30,31)*. The utility and validity of estimates of body composition from single and multifrequency BIA in normal individuals are reasonably well established. If BIA is used to estimate body fat, it is important to cross-validate the developed equations using appropriate statistical techniques *(32)*. A recent National Institutes of Health consensus conference recommended the use of impedance for estimates of TBW but not in clinical conditions *(33)*. Multifrequency BIA is being collected in the current NHANES 2000 by the NCHS.

BIA is useful in describing body composition for groups of individuals, but large errors for an individual continue to limit its clinical application. This is especially true when persons receiving treatment for obesity are monitored repeatedly. One would expect the level of fat to decrease with treatment, but the predictive errors with BIA for an individual are frequently so large that it is insensitive to small improvements in response to treatment. In only a relatively few studies has BIA been applied to overweight or obese samples *(34,35)*, so that the majority of the available BIA prediction equations are not applicable to the overweight or obese.

BIA analyzers are now commercially available to the public, and their advertisements are found on primetime television. These devices contain all the problems associated with this methodology. Most of these machines are linked with a digital weight scale that can be purchased alone at a comparatively lower price.

Body Density

Hydrodensitometry estimates body fat using measures of body weight, body volume, and residual lung volume. Body volume, or underwater weight, can be measured with increased accuracy using electronic load cells, and residual lung volume can be determined reliably with computerized spirometry. Body density has, in the past, been converted to the percentage of body weight as fat using the two-compartment models of Siri *(36)* or Brozek et al. *(37)*. More recently, however, body density is combined together with a measure of bone density from dual X-ray absorptiometry (DXA) and the volume of TBW in a multicompartment model to calculate body fat *(38)*. Despite the improved technology of measuring body density, we are still plagued with the problem of subject performance, because it is difficult for an overweight or obese person to submerge. The use of diving weight belts can reduce bouncy but not all aspects of performance. The cousin of hydrodensitometry is air displacement, which has recently become commercially available *(39,40)*; however, the devices for this method are limited to persons who are "moderately" obese at best, i.e., again, someone with a BMI >30 may be difficult to assess. At the same time, most overweight and obese persons are reluctant to put on a bathing suit and participate in body density measures, so that there are few body density measurements of these people.

Total Body Water

Conceptually, TBW is one of the easiest components of the body to measure in the overweight and obese because it does not require undressing or any real physical participation. However, there are limitations to its use when estimating body composition in the obese. The major assumption is that the estimate of FFM from TBW is based on an assumed average proportion of TBW in FFM of 73%, but this proportion ranges from 67 to 80% *(36)*. In addition, about 15–30% 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 men and higher in the obese, and can produce underestimates of FFM and overestimates of the level of fat. Variation in the distribution of TBW as a result of disease associated with obesity, such as diabetes, will affect estimates of FFM and TBF also. TBW is a potentially useful method applicable to the obese because it is not directly affected by the physical size of the person. However, several details need to be addressed if TBW is to be used in the obese. Measures of TBW (and extracellular fluid) have errors of almost a liter from the several analytical chemical methods used to quantify the concentration. The equilibration times for isotope dilution in relation to levels of body fat are not available, so that, theoretically, it might (and should) take longer for the dilution dose to equilibrate in an obese person as compared with an individual of normal weight. Also, a measure of extracellular space is necessary to correct the amount of FFM in an obese person.

Dual X-ray Absorptiometry

DXA has become the most useful (and possibly the most popular) method for quantifying fat, lean, and bone tissues. DXA machines are user friendly for the subject and the operator, but the machines require regular maintenance and calibration. The DXA method has inherent assumptions regarding levels of hydration, potassium content, and tissue density in the estimation of fat and lean tissue, and these assumptions vary by manufacturer *(41,42)*. DXA estimates of body composition are reported to be affected by differences among manufacturers in the technology, models and software employed, methodologic problems, and intra- and intermachine differences *(41,43)*. DXA values also depend on the calibration of the machine, and body fat values may change as a result of routine maintenance *(43)*. The physical limitations of body weight, length, thickness, and width also vary with each manufacturer and type of DXA machine, i.e., pencil or fan beam. For example, weight limitations are 100 and 136 kg for current Lunar and Hologic machines, respectively, and these machines are supposedly appropriate for a person of average height (178 cm) and a maximum BMI of between 31 and 43. However, both these manufacturers have a body width restriction of about 60–66 cm, and Lunar has a body thickness limit of 26 cm. These limits are a function of the available table scan area of the machines. Thus, many obese individuals with a BMI >30 are often too wide and too thick to receive a whole-body DXA scan with current machines, although some innovative adaptations such as scanning the obese twice or two hemibody scans have been proposed *(44)*. Nevertheless, DXA is a convenient method for measuring body composition in the majority of the population, and it is currently included in NHANES 2000.

Statistical Models of Body Composition

In epidemiologic and clinical studies, statistical models employing indirect methods are frequently used to predict body composition for groups or individuals because the application of sophisticated direct methods is impossible. Predicting body composition requires the use of a regression equation employing indirect measurements as predictor variables, and some direct measurement of body composition as a dependent or outcome variable. A prediction equation is used because only the predictor variables (indirect methods) can be measured. The inclusion of indirect methods as predictor variables in an equation depends on their biological and statistical relationships to the outcome variable from a direct measure. A predictor variable, or set of predictor variables, should have strong direct biological and statistical relationships to the outcome variable because the strength of the relationships affects the accuracy or precision of the prediction equation.

Several statistical methods of regression analysis are available such as forward selection and stepwise and backward elimination regression procedures. These methods should be used if there is no multicollinearity among the predictor variables. When the predictor variables are interrelated (as they frequently are), the variance of the regression coefficients will be inflated, and the precision and accuracy of the predictions reduced. In these instances, a maximum R^2 or an all-possible subsets of regression procedure is an appropriate analytical choice.

The use of regression analysis also assumes that the bivariate relationships of a response variable with predictor variables are linear. If this is not true, the derived equation will have large errors of prediction and poor performance when used. Another assumption is homogeneity—the assumption that the variance of the dependent variable is constant for all values of the predictor variables. It is assumed that the dependent variable is normally distributed in order to allow statistical inferences about the significance of the regression parameters.

In general, the larger the sample, the more precise and accurate the prediction equation. The sample size needed for an accurate equation is a function of the degree of correlation between the outcome variable and the predictor variables. The sample size required to achieve accuracy on crossvalidation depends on the number of predictor variables, the bivariate relationships among the dependent variable and the predictor variables, and the variance of the dependent variable in the cross-validation sample.

Ethnic Differences in Body Composition

Ethnic differences in body composition are affected by differences in 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 and Caucasian adults are known to differ in mean values for bone mass and density, and these differences continue into old age. African-American girls are known to become fatter at earlier ages than Caucasian girls, and they also have an earlier sexual maturation, which has been linked to an early onset of obesity *(45–47)*. At the extremes of the distributions for body fat, there are more African-American women than non-Hispanic Caucasian women. However, there are limited data for direct or indirect body composition values for large samples of African-Americans, Hispanic-Americans, or Asian-Americans, and especially for the obese among these groups *(20,48,49)*. The exception is that reasonably extensive anthropometric data are available for African-Americans, Hispanic-Americans, and non-Hispanic Caucasian Americans from the National Center for Health Statistics in the NHANES.

Available Reference Data

The principal source of reference data for overweight and obesity in the United States comes from the NCHS, Centers for Disease Control and Prevention *(6)*. Most recently, the NHANES III was conducted by NCHS from 1989 to 1994 *(50)*. This survey is the fourth in a series of national health surveys that included the National Health Examination Survey, the NHANES I and II, and Hispanic HANES. NHANES 2000 is currently in the field collecting data, and information about this survey can be found at the following web site: www.cdc.gov/nchs/nhanes.htm. These NCHS surveys are recognized for their multiple methods of data collection including interviews, physical examinations, physiologic testing, and biochemical assessments from a representative sample of the US population *(51)*. The target populations usually consist of all noninstitutionalized civilian residents of the continental United States including Alaska. During NHANES III, approx 30,000

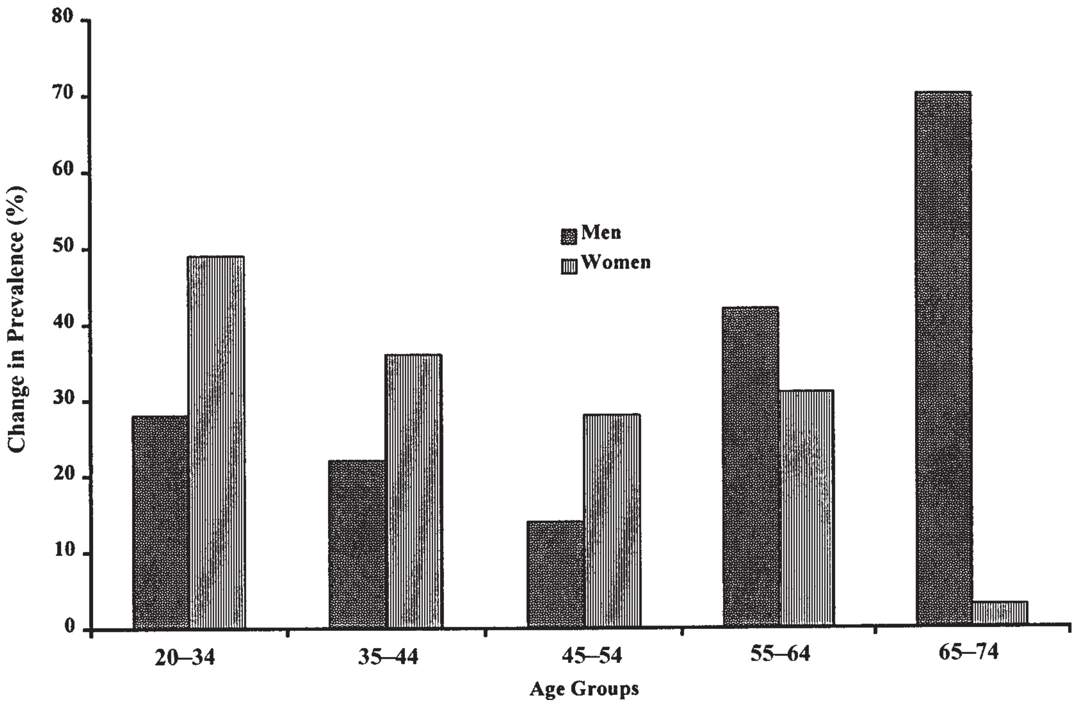

Fig. 2. Change in Prevalence of Adult Overweight from 1976 to 1991. Data from the NCHS.

individuals were examined and African- and Hispanic-Americans and children and the elderly were over-sampled. NHANES 2000 is the first survey to include DXA as a measure of body composition, other than anthropometry. NHANES III data are available on CD-ROM (www.cdc.gov/nchs/products.htm), and similar data from NHANES 2000 will be available in the near future (Kuczmarski, personal communication).

The anthropometric data included in the NHANES were selected to monitor the health and nutritional status of infants, children, adults, and the elderly. Techniques for the body measurements follow those for corresponding measurements in the *Anthropometric Standardization Reference Manual (52)* 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 these national health surveys *(53–56)*. Data from these NCHS surveys present a picture of the health status of the US population rather than a desired health goal. Regarding obesity, this is not a pretty picture. As can be seen in Table 2, the prevalence of adult obesity (i.e., a BMI ≥30) has increased considerably, but much of this increase has been in the past 10–15 yr. More dramatically is the distribution of this recent increased prevalence as seen in Fig. 2. Rather than being evenly spread across the population, the increased prevalence is higher in women than men up to about age 55, and then afterward, higher in men than women. It is hoped that the new data from subsequent NHANES will clarify some of the reasons for this unevenness.

Table 2
Secular Trend in Prevalence of Adult BMI Values ≥30 in United States Since 1960 Using Data from NCHS

	Prevalence	
Year	Men	Women
1960	10.0	15.0
1973	11.6	16.1
1978	12.0	14.8
1991	19.7	24.7

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 these health conditions is limited, in part, by our ability to assess body fat. There is no universally accepted method of measuring body fat or for quantifying overweight and obesity clearly. All the current methods are plagued with problems of nonuniversal assumptions, are limited by application of methodology, or are affected by aspects of chronic disease or subject size and performance. These issues are especially problematic for the obese. It is important to recognize the limitations of the methods used when interpreting results from any assessment of body fat. Direct body composition methods, when performed at their best, have an error of at least 2 to 3% body fat when compared with corresponding results from other methods *(28)*. With less direct methods, an error of 5% body fat is presently the best one can expect, and an error of between 5 and 10% is more realistic.

WHO *(2)* has made several recommendations concerning overweight and obesity. One of these addresses the need for the development and validation of new and existing techniques. In this paper, we have briefly reviewed many of the existing techniques and their limitations when applied to the overweight or obese. In support of this WHO recommendation, it is clear that existing techniques are not applicable to many overweight and obese in the population who are in great need of this technology. This limitation also affects our ability to determine the real prevalence of overweight and obesity because the current methods are not applicable to large epidemiologic and clinical studies. Obviously much work needs to be done.

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