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RESEARCH ARTICLE

Different Measuring Techniques for Body Fat Analysis

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ABSTRACT

Various Measuring techniques are available for determining body fat percentage, such as Underwater (Hydrostatic) weighing, Near-infrared interactance, Dual energy X-ray absorptiometry (DEXA Scan), Body average density measurement, Bioelectrical impedance analysis, Anthropometric methods such as Height and circumference methods and Skinfold methods, Ultrasound, from BMI etc. The body fat percentage is a measure of fitness level, since it is the only body measurement which directly calculates a person's relative body composition without regard to height or weight. The widely used body mass index (BMI) provides a measure that allows the comparison of the adiposity of individuals of different heights and weights. While BMI largely increases as adiposity increases, due to differences in body composition it is not necessarily an accurate indicator of body fat; for example, individuals with greater muscle mass will have higher BMIs. The thresholds between "normal" and "overweight" and between "overweight" and "obese" are sometimes disputed for this reason.

Key words: Underwater, Near-infrared interactance, DEXA, Body average density, Bioelectrical impedance, Circumference, Skinfold, Ultrasound, BMI

INTRODUCTION

Different cultures value different body compositions differently at different times, and some are related to health or different athletic performance. Levels of body fat are epidemiologically dependent on different gender and age (Cannon and Nedergaard, 2008). Different authorities have developed different recommendations for ideal body fat percentages.

The table below from the American Council on Exercise (not an official government agency) recommends the following percentages (Aarsland et al., 1997).

Description	Women	Men
Essential Fat	10-13 %	2-5 %
Athletes	14-20 %	6-13 %
Fitness	21-24 %	14-17 %
Average	25-31 %	18-24 %
Obese	32 % +	25 % +

Essential fat is the level below which physical and physiological health would be negatively affected. Controversy exists as to whether a particular body fat percentage is better for one's health; athletic performance may also be affected. The leanest athletes typically compete at levels of about 6–13% for men or 14–20% for women. Bodybuilders may compete at ranges even lower than these levels. Certified personal trainers will suggest to male bodybuilders that they aim for a body fat percentage between 2–4% by contest time. However it is unclear that such levels are ever actually attained since (a) the means to measure such levels are, as noted below, lacking in principle, and (b) 4-6% is generally considered a physiological minimum for human males (Pond, 1998).

In a severely obese person, excess adipose tissue hanging downward from the abdomen is referred to as a panniculus (or pannus). A panniculus complicates surgery of the morbidly obese. It may remain as a literal "apron of skin" if a severely obese person quickly loses large amounts of fat (a common result of gastric bypass surgery). This condition cannot be effectively corrected through diet and exercise alone, as the panniculus consists of adipocytes and other supporting cell types shrunken to their minimum volume and diameter. Reconstructive surgery is one method of treatment.

There are several more complicated procedures that more accurately determine body fat percentage. Some, referred to as multicompartment models, can include DXA measurement of bone, plus independent measures of body water (using the dilution principle with isotopically labeled water) and body volume (either by water displacement or air plethysmography). Various other components may be independently measured, such as total body potassium.

In-vivo neutron activation can quantify all the elements of the body and use mathematical relations among the measured elements in the different components of the body (fat, water, protein, etc.) to develop simultaneous equations to estimate total body composition, including body fat (Kern et al., 2001).

MATERIALS AND METHODS

A number of methods are available for determining body fat percentage, such as Underwater (Hydrostatic) weighing, Near-infrared interactance, Dual energy X-ray absorptiometry (DEXA Scan), Body average density measurement, Bioelectrical impedance analysis, Anthropometric methods - Skinfold methods, Height and circumference methods, Ultrasound and From BMI.

The body fat percentage is a measure of fitness level, since it is the only body measurement which directly calculates a person's relative body composition without regard to height or weight. The widely used body mass index (BMI) provides a measure that allows the comparison of the adiposity of individuals of different heights and weights. While BMI largely increases as adiposity increases, due to differences in body composition it is not necessarily an accurate indicator of body fat; for example, individuals with greater muscle mass will have higher BMIs. The thresholds between "normal" and "overweight" and between "overweight" and "obese" are sometimes disputed for this reason.

Underwater (Hydrostatic) weighing

Irrespective of the location from which they are obtained, the fat cells in humans are composed almost entirely of pure triglycerides with an average density of about 0.9 kilograms per liter. Most modern body composition laboratories today use the value of 1.1 kilograms per liter for the density of the "fat free mass", a theoretical tissue composed of 72% water (density = 0.993), 21% protein (density = 1.340) and 7% mineral (density = 3.000) by weight.

With a well engineered weighing system, body density can be determined with great accuracy by completely submerging a person in water and calculating the volume of the displaced water from the weight of the displaced water. A correction is made for the buoyancy of air in the lungs and other gases in the body spaces. If there were no error whatsoever in measuring body density, the uncertainty in fat estimation would be about ± 3.8% of the body weight, primarily because of normal variability in body constituents.

Estimation of body fat percentage from underwater weighing (or hydrostatic weighing) has long been considered to be the best method available, especially in consideration of the cost and simplicity of the equipment. Most other ways to estimate body fatness, such as by skin folds, body girths, body impedance, air displacement volume and body scanners are based on equations which predict body density. In contrast, underwater weighing gives an actual measurement of body density rather than a prediction (Siri, 1956).

Near-infrared interactance:

A beam of infra-red light is transmitted into the biceps. The light is reflected from the underlying muscle and absorbed by the fat. The method is safe, noninvasive, rapid and easy to use (Conway et al., 1984).

Dual energy X-ray absorptiometry (DEXA Scan):

Dual energy X-ray absorptiometry, or DXA (formerly DEXA), is a newer method for estimating body fat percentage, and determining body composition and bone mineral density. X-rays of two different energies are used to scan the body, one of which is absorbed more strongly by fat than the other. A computer can subtract one image from the other, and the difference indicates the amount of fat relative to other tissues at each point. A sum over the entire image enables calculation of the overall body composition. DEXA also allows for body fat distribution analysis, so you can figure out with precision how fat is distributed in various parts of your body. In the past, DEXA was only used to measure bone mineral density for ostopenia and osteoporosis in older individuals. The procedure uses a body scanner with low dose x-rays, so it's completely safe, and takes about 10-20 minutes.

Body average density measurement

Prior to the adoption of DXA, the most accurate method of estimating body fat percentage was to measure that person's average density (total mass divided by total volume) and apply a formula to convert that to body fat percentage (Sarría et al., 1998).

Since fat tissue has a lower density than muscles and bones, it is possible to estimate the fat content. This estimate is distorted by the fact that muscles and bones have different densities: for a person with a more-than-average amount of bone mass, the estimate will be too low. However, this method gives highly reproducible results for individual persons (± 1%), unlike the methods discussed below, which can have an uncertainty up to ±10%.

Bioelectrical impedance analysis

The bioelectrical impedance analysis (BIA) method is a lower-cost but less accurate way to estimate body fat percentage. The general principle behind BIA: two or more conductors are attached to a person's body and a small electric current is sent through the body. The resistance between the conductors will provide a measure of body fat between a pair of electrodes, since the resistance to electricity varies between adipose, muscular and skeletal tissue. Fat-free mass (muscle) is a good conductor as it contains a large amount of water (approximately 73%) and electrolytes, while fat is anhydrous and a poor conductor of electric current. Factors that affect the accuracy and precision of this method include instrumentation, subject factors, technician skill, and the prediction equation formulated to estimate the fat-free mass. Each (bare) foot may be placed on an electrode, with the current sent up one leg, across the abdomen and down the other leg. (For convenience, an instrument which must be stepped on will also measure weight.) Alternatively, an electrode may be held in each hand; calculation of fat percentage uses the weight, so that must be measured with scales and entered by the user. The two methods may give different percentages, without being inconsistent, as they measure fat in different parts of the body. More sophisticated instruments for domestic use are available with electrodes for both feet and for both hands.

There is little scope for technician error as such, but factors such as eating, drinking and exercising must be controlled (Williams and Wilkins, 2006) since hydration level is an important source of error in determining the flow of the electric current to estimate body fat. The instructions for use of instruments typically recommended not making measurements soon after drinking or eating or exercising, or when dehydrated. Instruments require details such as sex and age to be entered, and use formulae taking these into account; for example, men and women store fat differently around the abdomen and thigh region.

Many consumer weight scales like Tanita Body Fat Monitor Scale also come with BIA capabilities, and there are others like Omron Body Logic handheld device that require holding the BIA device in your hands. Because the BIA test is based on body water balance, your state of hydration can impact the level of accuracy. Specific equations are available for some instruments, making them more reliable (Williams and Wilkins, 2006).

Anthropometric methods

There exist various anthropometric methods for estimating body fat. The term anthropometric refers to measurements made of various parameters of the human body, such as circumferences of various body parts or thicknesses of skinfolds. Most of these methods are based on a statistical model. Some measurements are selected, and are applied to a population sample. For each individual in the sample, the method's measurements are recorded, and that individual's body density is also recorded, being determined by, for instance, under-water weighing, in combination with a multi-compartment body density model. From this data, a formula relating the body measurements to density is developed. Because most anthropometric formulas such as the Durnin-Womersley skinfold method (Durnin and Womersley, 2007), the Jackson-Pollock skinfold method, and the US Navy circumference method, actually estimate body density, not body fat percentage, the body fat percentage is obtained by applying a second formula, such as the Siri or Brozek. Consequently, the body fat percentage calculated from skin folds or other anthropometric methods carries the cumulative error from the application of two separate statistical models. These methods are therefore inferior to a direct measurement of body density and the application of just one formula to estimate body fat percentage. One way to regard these methods is that they trade accuracy for convenience, since it is much more convenient to take a few body measurements than to submerge individuals in water.

Height and circumference methods

There also exist formulas for estimating body fat percentage from an individual's weight and girth measurements. For example, the U.S. Navy circumference method compares abdomen or waist and hips measurements to neck measurement and height and other sites claim to estimate one's body fat percentage by a conversion from the body mass index. In the U.S. Navy the method is known as the "rope and choke." There is limited information, however, on the validity of the "rope and choke" method because of its universal acceptance as inaccurate and easily falsified.

The U.S. Army and U.S. Marine Corps also rely on the height and circumference method. For males, they measure the neck and waist just above the navel. Females are measured around the hips, waist, and neck. These measurements are then looked up in published tables, with the individual's height as an additional parameter. This method is used because it is a cheap and convenient way to implement a body fat test throughout an entire service. Methods using circumference have little acceptance outside the Department of Defense due to their negative reputation in comparison to other methods. The method's accuracy becomes an issue when comparing people with different body compositions, those with larger necks artificially generate lower body fat percentage calculations than those with smaller necks.

Skinfold methods

The skinfold estimation methods are based on a skinfold test, also known as a pinch test, whereby a pinch of skin is precisely measured by calipers at several standardized points on the body to determine the subcutaneous fat layer thickness (Bruner, 2001). These measurements are conver ted to an estimated body fat percentage by an equation. The accuracy of these estimates is more dependent on a person's unique body fat distribution than on the number of sites measured. As well, it is of utmost importance to test in a precise location with a fixed pressure. Although it may not give an accurate reading of real body fat percentage, it is a reliable measure of body composition change over a period of time, provided the test is carried out by the same person with the same technique.

The “skin fold” method measures your body fat percentage by pinching your fat with your fingers then measuring the thickness with a body fat caliper. The reading is given in millimeters, which you compare to a chart with age and gender to arrive at your body fat percentage. Skinfold-based body fat estimation is sensitive to the type of caliper used, and technique. This method also only measures one type of fat: subcutaneous adipose tissue (fat under the skin). Two individuals might have nearly identical measurements at all of the skin fold sites, yet differ greatly in their body fat levels due to differences in other body fat deposits such as visceral adipose tissue: fat in the abdominal cavity. Some models partially address this problem by including age as a variable in the statistics and the resulting formula. Older individuals are found to have a lower body density for the same skinfold measurement, which is assumed to signify a higher body fat percentage. However, older, highly athletic individuals might not fit this assumption, causing the formulas to underestimate their body density.

Ultrasound

Ultrasound is used extensively to measure tissue structure and has proven to be an accurate technique to measure subcutaneous fat thickness (Heymsfield et al., 2005). A-mode and B-mode ultrasound systems are now used and both rely on using tabulated values of tissue sound speed and automated signal analysis to determine fat thickness. By making thickness measurements at multiple sites on the body you can calculate the estimated body fat percentage.[12][13] Ultrasound techniques can also be used to directly measure muscle thickness and quantify intramuscular fat. Ultrasound equipment is expensive, and not cost-effective solely for body fat measurement, but where equipment is available, as in hospitals, the extra cost for the capability to measure body fat is minimal (Williams and Wilkins, 2006).

From BMI

Body fat can be estimated from body mass index (BMI), a person's weight in kilograms divided by the square of the height in meters; if weight is measured in pounds and height in inches, the result can be converted to BMI by multiplying by 703. There are a number of proposed formulae that relate body fat to BMI. These formulae are based on work by researchers published in peer-reviewed journals, but their correlation with body fat is only estimates; body fat cannot be deduced accurately from BMI. Body fat may be estimated from the body mass index by formulae derived by Deurenberg et al. (2007).

When making calculations, the relationship between densitometrically determined body fat percentage (BF %) and BMI must take age and sex into account. Internal and external cross-validation of the prediction formulas showed that they gave valid estimates of body fat in males and females at all ages. In obese subjects, however, the prediction formulas slightly overestimated the BF%. The prediction error is comparable to the prediction error obtained with other methods of estimating BF%, such as skinfold thickness measurements and bioelectrical impedance.

RESULT AND DISCUSSION

Underwater weighing

This method requires being submerged in a specialized tank of water. Because bone and muscle are more dense than water, a person with a larger percentage of fat free mass will weigh more in the water and have a lower percent body fat. Conversely, a large amount of fat mass will make the body lighter in water and have a higher percent body fat. Accuracy of the reading is contingent upon blowing all the air out of the lungs during pretest screening. The test takes about 20-30 minutes, and is available at research labs, universities, or hospitals. This technique is very accurate, considered Gold Standard but impractical**,** expensive and not repeatable (unless you liked repeatedly getting dunked in a tank)**.**

Dual energy X-ray absorptiometry (DEXA Scan)

It's based on a three-compartment model that divides the body into total body mineral, fat-free soft (lean) mass and fat tissue mass. Hydrostatic Weighing on the other hand only uses a 2 compartment model (fat free mass and fat mass). This technique is very accurate but is expensive and not repeatable.

Near-infrared interactance

This method is safe, noninvasive, rapid and easy to use.

Body average density measurement

The body fat percentage is commonly calculated from one of two formulas (ρ represents density in g/cm^3):

Brozek formula: $BF = (4.57/\rho - 4.142) \times 100$ (Brožek et al., 2006)

Siri formula : $BF=(4.95/\rho - 4.50)\times100$ (Siri,1961)

Bioelectrical impedance analysis

Bioelectric Impedence Analysis, or BIA, determines the electrical impedance, or opposition to the flow of an electric current through the body. Muscle has high water content, and is highly conductive, while fat has lower water content and is not highly conductive. Based on the strength of the impedance along with height and weight metrics, the BIA scale will estimate fat-free body mass and body fat percentage. This technique is very easy to administer, inexpensive but has questionable accuracy and variability of results dependent on hydration level.

Anthropometric methods

This technique is easy to administer and cheap but has questionable Accuracy (Body fat is not directly measured)**.** I would consider this method the least accurate because it doesn't directly measure body fat (or even attempt to). For example, I have around 6% body fat using calipers, but according to anthropometric, my body fat is around 11.5%. If you don't have a BIA scale, or calipers, it can be a decent start.

Height and circumference methods

This method uses body circumference measurements to estimate body fat percentages. The U.S. Navy method takes waist, neck, and height circumference for men and hips, neck, and height for women. Methods using circumference have little acceptance outside the Department of Defense due to their negative reputation in comparison to other methods.

The method's accuracy becomes an issue when comparing people with different body compositions, those with larger necks artificially generate lower body fat percentage calculations than those with smaller necks.

Skinfold methods

This technique is accurate, dependable (when skilled at measuring) and Repeatable. But Variability of measurement (same exact spot needs to used each time), more than one-site test requires a skilled fitness professional. For people 35+ pounds overweight, fat may not fit within caliper, so it's less accurate.

Ultrasound

Ultrasound equipment is expensive, and not cost-effective solely for body fat measurement, but where equipment is available, as in hospitals, the extra cost for the capability to measure body fat is minimal.

From BMI

The formula for children is different; the relationship between BMI and BF% in children was found to differ from that in adults due to the height-related increase in BMI in children (Deurenberg et al., 2007).

Child body fat % = (1.51 × BMI) − (0.70 × Age) − (3.6 × sex) + 1.4

Adult body fat % = (1.20 × BMI) + (0.23 × Age) − (10.8 × sex) − 5.4

Where, sex is 1 for males and 0 for females.

Other indices may be used; the body adiposity index was said by its developers to give a direct estimate of body fat percentage, but statistical studies found this not to be so.

CONCLUSION

Underwater weighing

If you are extremely curious to get the most accurate measure of your body fat percentage, or you are a bodybuilder, or fitness model tracking your progress, Hydrostatic Weighing may make sense. Otherwise, it's far too impractical.

Near-infrared interactance

This method is safe, noninvasive, rapid and easy to use.

Dual energy X-ray absorptiometry (DEXA Scan

Similar to Hydrostatic Weighing, if you are extremely curious to get the most accurate reading of your body fat percentage, or you are a bodybuilder, or fitness model tracking your progress, DEXA may make sense. Otherwise, it's far too impractical and expensive.

Body average density measurement

The body fat percentage is commonly calculated formulas .

Bioelectrical impedance analysis

If you have a high body fat percentage (calipers can't fit around your fat pinch), or you have 35+ pounds to lose, start with BIA, then move to calipers. BIA readings for those with low body fat tend to be completely inaccurate.

Anthropometric methods

This method is least accurate because it doesn't directly measure body fat (or even attempt to). For example, I have around 6% body fat using calipers, but according to anthropometric, my body fat is around 11.5%. If you don't have a BIA scale, or calipers, it can be a decent start.

Height and circumference methods

Methods using circumference have little acceptance outside the Department of Defense due to their negative reputation in comparison to other methods. The method's accuracy becomes an issue when comparing people with different body compositions, those with larger necks artificially generate lower body fat percentage calculations than those with smaller necks.

Skinfold methods

Skin Fold is hands down the most effective, accurate, practical method to measure and track your body fat percentage.

Ultrasound

Ultrasound equipment is expensive, and not cost-effective solely for body fat measurement, but where equipment is available, as in hospitals, the extra cost for the capability to measure body fat is minimal.

From BMI

The formula for children is different; the relationship between BMI and BF% in children was found to differ from that in adults due to the height-related increase in BMI in children.

REFERENCES

1. Aarsland A, Chinkes D, Wolfe RR. Hepatic and whole-body fat synthesis in humans during carbohydrate overfeeding. *Am J Clin Nutr.*, 1997;65(6):1774-82.
2. Brožek Josef, Grande Francisco, Anderson Joseph T, Keys Ancel. Densitometric Analysis of Body Composition: Revision of Some Quantitative Assumptions*". *Annals of the New York Academy of Sciences*, 2006; 110: 113–40. doi:10.1111/j.1749-6632.1963.tb17079.x. PMID 14062375.
3. Bruner Reuven (2 November 2001). "A-Z of health, fitness and nutrition". The Jerusalem Post. Retrieved 29 October 2014.
4. Cannon B and Nedergaard J. Developmental biology: Neither fat nor flesh". *Nature*,, 2008; 454 (7207): 947–948. doi:10.1038/454947a. PMID 18719573.
5. Conway, JM; Norris, KH; Bodwell, CE. A new approach for the estimation of body composition: Infrared interactance. *The Am. journal of clinical nutrition,* 1984; 40 (6): 1123–30.PMID 6507337.
6. Deurenberg Paul, Weststrate Jan A, Seidell Jaap C. Body mass index as a measure of body fatness: Age- and sex-specific prediction formulas. *British Journal of Nutrition*, 2007; 65 (2): 105–14. doi:10.1079/BJN19910073. PMID 2043597.
7. Durnin JVGA and Womersley J. Body fat assessed from total body density and its estimation from skinfold thickness: Measurements on 481 men and women aged from 16 to 72 Years". *British Journal of Nutrition*, 2007; 32 (1): 77–97. doi:10.1079/BJN19740060. PMID 4843734.
8. Heymsfield SB, Lohman TG, Wang ZM, Going SB. Human Body Composition, Champaign, IL: Human Kinetics, 2005;
9. Kern PA, Ranganathan S, Li C, Wood L, Ranganathan G. Adipose tissue tumor necrosis factor and interleukin-6 expression in human obesity and insulin, *Am J Physiol Endocrinol Metab*. 2001 May;280(5):E745-51.
10. Pineau Jean-Claude, Guihard-Costa Anne-Marie, Bocquet Michel. Validation of Ultrasound Techniques Applied to Body Fat Measurement. *Annals of Nutrition and Metabolism*, 2007; 51(5): 421–7. doi:10.1159/000111161. PMID 18025814.
11. Pond, Caroline M. The Facts of Life. Cambridge University Press. 1998; ISBN 0-521-63577-2.
12. Sarría A, García-Llop LA, Moreno LA, Fleta J, Morellón MP, Bueno M. Skinfold thickness measurements are better predictors of body fat percentage than body mass index in

malespanish children and adolescents". *European Journal of Clinical Nutrition*, 1998; 52 (8): 573 doi:10.1038/sj.ejcn.1600606.PMID 9725657.

13. Siri WE. Body composition from fluid spaces and density: analysis of methods. Donner Laboratory of Biophysics and Medical Physics, Univ. of California – Berkeley. 1956
14. Siri WE. Body composition from fluid spaces and density: Analysis of methods". In Brozek J, Henzchel A. Techniques for Measuring Body Composition. Washington: National Academy of Sciences, 1961. 224–244.
15. Utter Alan C, Hager, Marion E. Evaluation of Ultrasound in Assessing Body Composition of High School Wrestlers". *Medicine & Science in Sports & Exercise*, 2008; 40 (5): 943–9. doi:10.1249/MSS.0b013e318163f29e.PMID 18408602.
16. Williams Lippincott and Wilkins. Exercise physiology: Basis of Human Movement in Health and Disease, Second Edition, 2006;324.