A Study on Body Fat Percentage for Physical Fitness and Prevention of Obesity: A Two Compartment Model

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4 February 2023

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Abstract

The minimal amount of body fat is necessary for normal physiological functions that manages body temperature, creates energy to perform all the physical activities, and protects the organs of human body. Storage body fat consists of fat accumulation in adipose tissue. Total body fat in human body is the sum of essential fat and storage fat. At present body fat percentage is considered as one of the most accurate obesity evaluation tools. To determine body fat accurately the clinicians should use the most appropriate, accurate, and accessible strategies available in the scientific research area. Accurate measurement of body fat and lean body is essential for the nutrition assessment, and an individual's overall health and well-being. In this study some measurement processes are discussed to determine body fat percentage (BFP) properly of a person by the analysis of two compartment model: fat mass and fat free mass.

Keywords: Body fat percentage, body mass, fat mass, obesity

1. Introduction

Body composition and growth rate are key components of health sector. The body composition variables are; lean body mass, bone mass, fat mass, and body fat percentage that influence energy estimation (Jiménez, 2013). Appropriate, accurate, and accessible strategies are needed to estimate an individual's adiposity, musculature, and body habitus (Vanderwall, 2017). Usually the human body composition is analyzed with the two compartment model: i) fat compartment (density 0.9g/cc at a temperature of 36^0 Celsius), which includes the entire content of chemical fat or lipids in the body, and ii) fat-free compartment (density 1.1g/cc at a temperature of 36^0 Celsius), which includes all the rest of the body apart from fat (Brozek et al., 1963). The fat compartment consists of full fat, such as subcutaneous fat, storage fat, and essential fats, and the fat-free compartment contains not only lean body mass, such as muscle, bone, water, nerves, veins and organic structures; but also 2% to 8% lipid, based on gender (Heyward & Wagner, 2004; Can et al., 2019).

The prevalence of global overweight and obesity have increased both in developed and developing countries due to sedentary lifestyle that becomes a major health concern worldwide. Obesity is a condition of abnormal or excess fat accumulation in adipose tissue, to the extent that health may be impaired (WHO, 2005; Mohajan & Mohajan, 2023a). At present more than 1 billion (1 in 8 people) people are obese worldwide; among them 650 million are adults, 340 million are adolescents, and 39 million are children (WHO, 2011; Obesity Statistics, 2023, Mohajan, 2022). It is estimated that by 2030, globally 1 in 5 women and 1 in 7 men will have obesity (WHO, 2014; Ibrahim et al., 2021). Early evaluation of obesity and overweight status is necessary to prevent and control obesity and overweight that is associated with diseases (Barton, 2010).

For physical fitness body fat percentage (BFP) plays a crucial role in distinguishing between healthy and obese individuals in health science. BFP measures how much of the body's composition is fat (Chiplonkar et al., 2017). It is also a function of age and gender due to differences in hormones. For example, female hormone estrogen and male hormone testosterone control the sexual characteristics of males and females, respectively. Overall mortality,

cardiovascular diseases, metabolic disorder diseases, and obesity are related to BFP (Cordova et al., 2012; Bunn et al., 2019).

Physical inactivity, genetic predisposition, and dietary lifestyles are some causes of obesity and non-communicable diseases (NCDs). Accurate classification of overweight and obesity is necessary for the proper treatment in healthcare. Body Mass Index (BMI) is the most popular method, where only the weight and height of an individual are considered. But BMI alone is not an absolute indicator of obesity (Suresh & Reddy, 2017). BFP has a greater ability to differentiate between lean mass and fat mass compared to BMI. Hence, BFP helps to identify healthy and obese individuals more efficiently. Various studies support that BFP is strongly correlated with physical fitness and aerobic capacity (Shoebuddin & Daimi, 2019).

2. Literature Review

In any research, the literature review section is an introductory unit of research, where activities of previous researchers focus briefly (Polit & Hungler, 2013). Literature review helps the new researchers to appreciate the subject matter, and also it serves as an indicator of the subject that has been carried out before (Creswell, 2007). Mahmood Safaei and his coauthors have tried to find causes and consequences of obesity. They have also tried to mitigate threats of global obese people (Safaei et al., 2021). Tom Geeson-Brown and his coworkers have tried to determine differences in body composition between playing standard and age in male rugby union and rugby league athletes. They have stressed that practitioners should prioritize training and nutritional strategies that maximize fat-free mass development (Geeson-Brown et al., 2020).

Jennifer Bunn and her coworkers have classified adults in the USA according to cardiovascular fitness (CVF), BMI, and body fat using the National Health and Nutrition Examination Survey (NHANES) data (Bunn et al., 2019). Thant Zin and his coauthors have measured average BMI and mean BFP by body fat analyzer for obesity awareness promotion. They have stressed that further investigation about the determinants of obesity and body fat, including age, sex, race, nutrition, and changes over time, is necessary (Zin et al., 2014). Sema Can and her coauthors have examined the effects of exercise preferences on BMI, body fat according to by self-report.

In their study they have obtained that the combine exercises in both of gender, compared with only aerobic and strength have a more positive effect on body mass index and body fat (Can et al., 2019). Kathryn E. Bradbury and her coworkers have observed that in the general population, physically active people have a lower body fat percentage after taking BMI into consideration (Bradbury et al., 2017).

Shiva Shanth Reddy Ainala and his coauthors have studied how body fat can increase the risk of having serious health issues, such as high blood pressure, high cholesterol content, diabetes, cancer etc. They have obtained that the body fat percentage depends on different factors, such as age, weight, and gender (Ainala et al., 2015). Gupta Swaroopa Rani N has consulted on various measuring techniques to determine body fat percentage. She believes that BFP is a measure of fitness level, since it is the only body measurement which directly calculates an individual's relative body composition without help of height or weight (Rani, 2015). Rodrigo da Silva Guerra and his coauthors try to identify which equation, Siri or Brozek, based on the two compartment model, provides a more accurate conversion of body density in BFP in a group of older adults. In their study they observe that they found that Brozek equation may correspond to a more accurate alternative than Siri equation for the conversion of body density (BD) in BFP among older adults (Guerra et al., 2010).

Pawel Macek and his coauthors have aimed to determine optimal cut-off points for BFP, with a view of predicting the cardiovascular risk factors related to obesity. They have obtained that there are some other cardiovascular risk factors except obesity are age, gender, hypertension, dyslipidemia, diabetes mellitus, smoking, unhealthy diet, physical inactivity, and family history (Macek et al., 2020). Daniel Ter Goon and his coworkers have found that higher level of excessive BFP among school children in Central Pretoria, South Africa, also girls have significantly higher BFP compared to boys. They have also realized that racially, black children are fatter than white children (Goon et al., 2013). (Mohajan et al., 2012, 2013; Ferdous & Mohajan, 2022; Mohajan & Mohajan, 2022a-j, 2023a-w)

3. Research Methodology of the Study

The research design is the plan of the researchers to develop research area that is underpinned by philosophy (Tie et al., 2019). Methodology is the guideline to perform any kind of research in any kind of field, where scientific methods are followed precisely and efficiently (Kothari, 2008). Therefore, research methodology is a strategy for planning, arranging, designing and conducting a fruitful research confidently to obtain a successful result (Legesse, 2014). In this paper we have tried to discuss two compartment model: fat mass and fat free mass. We have started the main text with the highlight of total body fat that consists of two kinds of fats: a) essential body fat, and b) storage body fat. Then we have taken attempt to discuss obesity, afterward we have deliberated Body Fat Percentage (BFP) with various measurement methods.

In the study we have tried our best to maintain the reliability and validity, and also have tried to cite references properly in the text and reference list (Das & Mohajan, 2014a,b,c; Moolio et al., 2009). To prepare this article we have dependent on the secondary data sources. We have used books of famous authors, handbooks, and theses. We have also collected valuable information from websites and internets to enrich the paper (Islam et al., 2009a,b, 2010a,b, 2011a,b,c, 2012a,b,c, Mohajan, 2011a-d, 2012a-h, 2013a-j, 2014a-g, 2015a-e, 2016a,b,c, 2017a-g, 2018a-e, 2020a-e, 2021a-e, 2022a-d, Rahman & Mohajan, 2019; Roy et al., 2021).

4. Objective of the Study

Main objective of this study is to discuss BFP and its related matters. At present obesity and obesity related non-communicable diseases (NCDs) become global health concern. Some other trivial objectives of the study are as follows:

- to familiar with the two compartment model,
- to focus on the two types of body fat, and
- to introduce the measurement methods of BFP.

5. Total Body Fat

Body fat is necessary to store lipids from which the body creates energy. It also secretes a number of important hormones, and provides the body with some cushioning as well as insulation (Kravitz & Heyward, 1992). Total body fat consists of two kinds of fats; i) essential body fat, and ii) storage body fat, and both of them are vital to good health. Accurate estimation of lean body mass and fat mass are necessary for maintaining the total health and well-being of individuals (Vanderwall, 2017; Lozano-Berges et al., 2017).

5.1 Essential Body Fat

Essential body fat (EBF) is the minimal amount of fat necessary for normal physiological function, such as regulation of body temperature, production of sexual hormones, good neurological function, vitamin absorption, healthy metabolism, balance blood sugar, oxygen absorption, etc. (Bouchard et al., 1988). It is also necessary for the regulation of glucose, cholesterol, energy release and storage to maintain life (Rani, 2015). EBF is found in the heart, brain, lungs, nerves, liver, spleen, kidneys, intestines, muscles, and bone marrow. It is not visible, as it locates deep inside the body (Ainala, 2015).

It varies from one person to the other, depending on sex and age; 2-5% in men (athletes 6-13%), and 10-13% in women (athletes 14-20%) (Bean, 2009). Below the minimum levels of essential body fat the body cannot effectively deliver macro- and micro- nutrients to organs that cause deficiencies and electrolyte imbalances. Consequently, physical and physiological health would be negatively affected (Heyward & Wagner, 2004). In this situation the risk of fracture, sarcopenia (gradual loss of muscle mass, strength and function), damage to the heart muscle, poor growth may happen, and even may cause death (Going et al., 2011). The total weight of the body except fat that is mainly made up of skeletal muscle and bone, which contains 72% water, 21% protein, and 7% mineral; by weight, is called “fat-free mass”, where density is 1.1g/cc at a temperature of 36^0 Celsius (Rani, 2015).

5.2 Storage Body Fat

Storage body fat consists of fat accumulation in adipose tissue, in the form subcutaneous fat that is found under the dermis and wrapped around vital organs, such as around the liver, pancreas, heart, intestines, and kidneys. It is a combination of brown, beige, and white fat cells. It increases or decreases depending on the weight gain or lose (Flynn et al., 2023). Too much storage fat, especially in waist area, increases risk of various non-communicable diseases. On the other hand, when storage fat becomes too little; causes various problems, such as difficulties in temperature regulation, hunger, fatigue, depression, infertility in women, etc. (Ye et al., 2022).

Abdominal fat storage patterns are generally compared to the shape of an apple, called the "*android shape*" that is more commonly found in males and post-menopausal females, and individuals experience chronic stress for generated fats (Flynn et al., 2023). Healthful ranges of storage body fat are 12 to 24% for males and 25 to 31% for females that accumulates due to excess energy. Excessive amounts of storage fat results overweight and eventually to obesity, and can have serious negative health implications, which is categorizes body fat greater than 25% in males and 32% in females (Muth, 2009). A female requires higher levels of both types of fat than a male to maintain reproductive functions. For example, due to the demands of childbearing and other hormonal functions females need more fat (Going et al., 2011).

6. Obesity

Obesity is a multifactorial chronic disease that is developed in human body when series of excess food taking happens such a way that energy intake exceeds consumption, i.e., the excess amount of calories is taken in and less is burnt (Goettler et al., 2017; Chooi et al., 2019). The World Health Organization (WHO) defines obesity as an "*abnormal or excessive fat accumulation that may impair health*", and one of "*the fundamental cause of obesity and overweight is an energy imbalance between calories consumed and calories expended*" (WHO, 2014, 2016).

The world is facing obesity endemic due to sedentary lifestyle and consumption of high fat diet. Obesity and its related non-communicable diseases (NCDs) have increased globally as a result of

urbanization, industrialization, and mechanical changes of the society (Ellulu et al., 2014). Overweight and obesity are the fifth leading risk for global deaths. At least 2.8 million adults die each year due to obesity related diseases. Hence, obesity has become a major public health problem worldwide. Inappropriate eating habits and insufficient physical activity are main causes of the rapid increase of overweight and obesity (Babajide et al., 2020; Mohajan & Mohajan, 2023a).

Obesity affects several systems of human body, such as circulatory, digestive, musculoskeletal, respiratory, reproductive systems, and also causes emotional tension and psychological problems (Eker & Şahin, 2002). The most common two ways of measuring the level of obesity are Body Mass Index (BMI) and Body Fat Percentage (BFP). BMI is a general indicator of nutritional status, while BFP is a better predictor of visceral fat mass (Kupusinac et al., 2017).

Obesity is related to short- and long- term morbidities, such as hypertension, cardiovascular diseases, certain types of cancer, Alzheimer disease, asthma, osteoarthritis, metabolic syndrome, musculoskeletal disorders, liver steatosis, gallbladder disease, obstructive sleep apnea, hypercholesterolemia, metabolic syndrome, and type 2 diabetes (Mohajan & Mohajan, 2023a). In a severely obese person, excess adipose tissue hanging downward from the abdomen is referred to as a panniculus or pannus which seem like an "*apron of skin*" that cannot be effectively corrected through diet and exercise alone; needs a surgery to cure (Winicki et al., 2022).

7. Body Fat Percentage (BFP)

The amount of fat mass found on the body expressed as the total mass of fat divided by total body mass, and multiplied by 100, i.e.,

$$BFP = \frac{\text{Total mass of fat}}{\text{Total body mass}} \times 100 . \qquad (1)$$

Usually it is used to monitor progress during a diet or as a measure of physical fitness for certain sports, such as body building. Women have been found to have higher BFP than men (Chiplonkar et al., 2017).

Body Fat Percentage (BFP) is a measure of fitness level, since it is the only body measurement that directly calculates body composition of an individual without the use of height and weight. It varies according to sex and age (Jackson et al., 2002). The healthy range of body fat for men is typically defined as 8-19%, while the healthy range for women is 21-33% (Kupusinac et al., 2017). In males, mean BFP ranged from 23% at 16-19 years to 31% at 60-79 years. On the other hand, in females, it ranged from 32% at 8-11 years to 42% at 60-79 years (Gallagher et al., 2000). BFP score is interpreted by the American Council of Exercise and is given in Table 1 (ACE, 2010).

Description	Female%	Male%
Essential fat	10-13	2-5
Athletes	14-20	6-13
Fitness	21-24	14-17
Acceptable	25-31	18-24
Obese	≥ 32	≥ 25

Table 1: Categories of BFP. Source: (Rani, 2015).

8. Measuring of BFP

Many specific techniques are used for measuring BFP. Actually BFP is an anthropometric measure that is done by dual energy X-ray absorptiometry (DXA), independent measures of body water, computed tomography (CT), air displacement plethysmography (ADP) or bod pods, magnetic resonance imaging (MRI), bioelectrical impedance analysis (BIA), body fat calipers or skinfold thickness, water displacement, hydrodensitometry (underwater weighing), body volume and total body potassium, etc. (Freedman et al., 2013; Wohlfahrt-Veje et al., 2014). Some measuring techniques of BFP are as follows:

8.1 US Navy Method

The US Navy Method of BFP measurement is developed James A. Hodgdon and M. B. Beckett, in 1984, whose validity is acceptable and comparable to the gold standard. BFP formula for female is (Hodgdon & Beckett, 1984);

$$BFP_{female} = \frac{496}{1.29579 - 0.35004 \times \log_{10}(\text{waist - hip - neck}) + 0.22100 \times \log_{10} \text{height}} - 450. \quad (2)$$

BFP formula for male is (Hodgdon & Beckett, 1984);

$$BFP_{male} = \frac{496}{1.0324 - 0.19077 \times \log_{10}(\text{waist - neck}) + 0.15456 \times \log_{10} \text{height}} - 450. \quad (3)$$

8.2 Body Mass Index (BMI) Method

Belgian Flemish astronomer, mathematician, statistician, and sociologist, Lambert Adolphe Jacque Quetelet (1796-1874), has developed Body Mass Index (BMI), what he called "*social physics*" (Quetelet, 1835; Mardolkar, 2017). The Body Mass Index (BMI) is defined as the body mass divided by the square of the body height, whose unit is kg/m^2 or $lb/inch^2$; where height is measured in meters/inch, and mass in kilograms/pounds (Taylor et al., 1998). BMI scale determines whether the person falls into one of five different categories, such as in underweight, normal, overweight, obese, and severely obese (WHO, 2004, Mohajan & Mohajan, 2023b). The metric formula of BMI is as follows (WHO, 2004):

$$BMI = \frac{mass_{kg}}{height_m^2}, \quad (4)$$

where unit is kg/m^2.

If pounds and inches are used, a conversion factor of $703 \times \frac{kg/m^2}{lb/in^2}$ is applied to measure BMI. Therefore, the English formula of BMI is as follows (WHO, 2004):

$$BMI = \frac{mass_{lb}}{height_{in}^2} \times 703, \quad (5)$$

where unit is $lb/inch^2$.

Body Mass Index (BMI) typically is associated with adverse health effects at obese levels, but cannot distinguish fat, bone, and lean masses very accurately. When we want to differentiate between fat mass and fat free mass then BMI formula is not appropriate. Also BMI does not show any difference between genders, but body fat normal ranges differ for males and females (Martin, 2016). The racial analysis indicates that black children accumulated more percentage body fat (20.1%) than the whites (19.0%) (Daniels et al., 2000). Therefore, BMI cannot always properly infer the risk of chronic disease that is associated with a higher degree of body fat (Cornier et al., 2011). Hence, it may be particularly misleading in hospital patients and nutritional management system, and it is not a part of compartmental model (Bunn et al., 2019, Mohajan & Mohajan, 2023b).

In BMI method the formula of body fat percentage (BFP) is as follows (Deurenberg et al., 1991):

$$BFP = 1.2 \times BMI + 0.23 \times \text{Age} - 10.8 \times \text{Gender} - 5.4 \qquad (6)$$

where *Gender* = '1' for men and '0' for women.

From equation (6) we see that BFP of women is about 10% higher than that for men due to demands of childbearing and other hormonal functions. Therefore, for body fat measurement BMI gives no satisfactory result (Mohajan & Mohajan, 2023b).

8.3 Skinfold Method

Skinfold measurement tries to determine how much fat is in the body. This method is quick, inexpensive, and easily can perform. It estimates body composition based on skinfold thickness through the equations developed by Andrew Jackson and Michael. L. Pollock in 1985 (Jackson & Pollock, 1985). A scientific device, caliper (plicometer) is used to pinch body fat softly and measures skinfold thickness at 3 to 7 sites on the abdomen, midaxilla, triceps, pectoral area, quadriceps, subscapular area, thigh, and suprailiac area in millimeters to calculate BFP in subcutaneous adipose tissue. The four-site skinfold equations are unique for males and females and use the same variables: Sum of the four skinfolds expressed in millimeters and age in years (Vanderwall, 2017). For the accuracy of measurement skilled and expert technician, familiar and higher quality of caliper and the individual's hydration status are needed (Lohman et al., 1984).

Four-site skinfold equation for males is given by (Jackson & Pollock, 1985),

$$BFP_{male} = \left(0.29288 \times \text{sum of skinfolds in mm}\right) - \left(0.0005 \times \text{square of the sum of skinfolds in mm}^2\right) + \left(0.15845 \times \text{age in year}\right) - 5.76377 \ . \quad (7)$$

Four-site skinfold equation for females is given by (Jackson & Pollock, 1985),

$$BFP_{female} = \left(0.292669 \times \text{sum of skinfolds in mm}\right) - \left(0.00043 \times \text{square of the sum of skinfolds in mm}^2\right) + \left(0.02963 \times \text{age in year}\right) + 1.4072 \ , \quad (8)$$

where the skinfold four sites (measured in millimeter) are abdominal, triceps, thigh, and suprailiac.

8.4 Hydrodensitometry Method

Hydrodensitometry is considered as the gold standard for measuring volume. Body volume originally was measured by hydrodensitometry. The density of a matter is defined as the mass divided by its volume, i.e.,

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \ . \quad (9)$$

In human body the density of fat mass is fairly constant, but the density of fat-free mass depends on its composition, such as bone vs. tissue. Fat-free resources are denser than water, but fat is less dense than water. Therefore, a person with a greater fat-free mass may have a greater density than a person with a greater fat mass (Wells & Fewtrell, 2006).

The densitometry acts on the basis of fact that there are specific densities for fat mass and fat-free mass (Vanderwall, 2017). Since fat tissue has a lower density than muscles and bones, it is possible to estimate the fat content in the body. The BFP is calculated from the density using either the Brozek or Siri estimation equation has established by American psychology educator, scientist Josef Brozek (1913-2004) and American biophysicist, mountaineer and environmentalist William E. Siri (1919-2004). The two compartment model, Brozek and Siri equations are given as;

Brozek equation is (Brozek et al., 1963);

$$BFP_{Brozek} = \left(\frac{4.570}{\rho} - 4.142\right) \times 100 \, , \quad (10)$$

where ρ represents the density in g/cc.

Siri equation is (Siri, 1961);

$$BFP_{Siri} = \left(\frac{4.950}{\rho} - 4.500 \right) \times 100, \tag{11}$$

where ρ represents the density in g/cc. Underwater weighing requires weighing individuals on dry land, and then immersing them completely in water and weighing them again underwater. The individual must be weighed underwater for 3 to 5 times to find a reliable average (Wells & Fewtrell, 2006). The equipment can be used from a stainless steel tub to a cot mounted to an underwater scale. During weighing the tub water can be in no movement. Air remaining in an individual's lungs is not completely expelled, but tries to reduce as much as possible (Guerra et al., 2010).

Hydrodensitometry measurement technique is inappropriate or uncomfortable for specific individuals, such as for children and individuals with anxiety, panic, or posttraumatic stress disorders due to the nature of the measurement method (Vanderwall, 2017).

9. Conclusions

In this study we have examined the effectiveness of anthropometric based two compartmental formulas for predicting body fat percentage (BFP). In this study we have also observed that the BMI-BFP relationship differs significantly between male and female. So that BMI cut-off values may not be adequate to identify obesity in healthcare. We have seen that BMI has limited ability to discriminate between fat and lean mass, and also BFP provides body composition better than BMI. It is very important to have a healthy amount of body fat to regulate human body to function properly. It is an established fact that physical activity and exercise are parts of a healthy lifestyle that are essential for the healthy growth and proper functionality of the muscular system and bone; which are also reduce the risk of obesity, stress and anxiety. Also appropriate eating habits can help in this regard.

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