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A Review of Scientific Methods for Measuring Body Composition: Advancements and Emerging Techniques

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Abstract: The present research paper's goal is to examine the most recent, accurate, and useful techniques for measuring human body composition. The techniques to measure Human body composition are continuously being met by emerging data results. Key efforts include the usage of imaging to help explain ectopic fat depots, quantifiable magnetic resonance for entire body water, fat and lean tissue measurement, and multi-divisional and multi-repetitive bioelectrical impedance analysis. Assessments of total body fat, fat-free mass, total body water, bone mineral content, cellular water, visceral, subcutaneous, skeletal muscle, major organs, and abnormal body fat depots are all approved using the relevant methodologies. The need for a method that generates data on biological and metabolic processes is constant. Clinicians and scientists can measure a variety of body elements and, observe changes in health and disease with implications for understanding the effectiveness of nutritional and medical disruptions, assessment, deterrence, and treatment in clinical settings. This is made possible by the wide range of measurable characteristics, analytical techniques, and designated total body composition models. The increased requirement to comprehend health risk precursors starting before conception has left a gap in the proper assessment techniques, with implementation starting during gestation, or foetal development.

Keywords: Body Composition, Anthropometry, Body Mass Index, Measurement

1. Introduction

A common health issue affecting adults, children, and the elderly is obesity (WHO, Physical Status, 1995); (Popkin & Doak, 1998). It is linked to an increased risk of cancer and renal insufficiency, as well as an increase in cardiovascular disease and related risk factors. It can also increase the risk of developing type 2 diabetes (Deitel, 2003). The evolution of obesity is accompanied by changes in body composition that have a modest but intriguing effect on insulin and metabolism. It is assumed that adipose tissue is crucial in balancing lipid and blood glucose levels by conjecturing the entire body's lipid flow (Guo, Chumlea, & Roche, 1994). The need for measuring tools and equipment for obesity research, management, and therapy emerged from the rise in obesity worldwide. (James, 2004). The evaluation of obesity and obese individuals is difficult due to the physical size restrictions placed on obesity, the body composition departure from normal weight, and complicated psychopathology (Mellits & Cheek, 1970). Numerous components of the human body are described and quantified by body composition methods (Saltzman & Mogensen, 2013).

Here, we offer the most basic approaches to assessing body composition, such as models, two-component approaches, prediction algorithms, and straightforward measures. More standardised techniques for assessment would help obesity research, allowing researchers to conduct medical and neighbourhood-based studies (Roche, Heyms & Lohman, 1996), evaluation teams to appraise intervention programmes, and health professionals to provide individual counselling. When it comes to fat composition in the four-compartment model, a certain formula is thought to be the most accurate method; it calls for the measurement of body volume using air displacement plethysmography, total body water using deuterium dilution, and bone mineral content using DXA (Silva, 2019). Standardised assessment techniques facilitate more accurate comparisons of health across groups and investigations. This is even more important since the published results are given a value that informs treatment, organisation, and policy (Chumlea, Guo, & Wholihan, 1998). A greater understanding of nutrition and growth profile evaluation in syndrome states and their therapy in populations is due to analysis of the body structure in several fields of medicine and biology. To maximise athletic performance and improve health, sports scientists need a solid grasp of nutrition, anatomy, and body composition. Studying physiology reveals the relationships between muscles, heart function, and metabolic processes, as well as how the systems in the body work when exerted physically. In the meantime, body composition analysis assists coaches and athletes in personalising food and exercise plans to reach peak physical condition and lower injury risk (Chatterjee & Sarkar, 2025). More research in these areas could enable athletes to perform at their best and preserve their health over time. The power-to-weight ratio is a key performance predictor for runners, and improving body composition is probably helpful when trying to raise this ratio. Conversely, body composition may be employed to assess if an athlete is getting enough nutrition to perform. Low energy availability can have detrimental effects on a number of health indicators, including bone density, according to studies on the female athlete triad (Loucks et al., 2011).

Changes in body composition, such as decreased body fat and increased lean mass, are frequently cited as factors that determine good performance in sports and are the focus of several therapies. Numerous body composition measuring techniques have been proposed and employed over time; each is likely to be useful in specific situations, and there is typically a trade-off between cost and practicality, precision and dependability, and both (Beestone, 2024). Up until 2020, the application of BIA and BIVA (Bioelectrical Impedance Vector Analysis) in athletes did not yield reliable results because of vague formulas and sources; although researchers and practitioners are now beginning to see things differently. Because of this, BIA, and particularly BIVA, can be used to accurately compare athletes within and between groups and to track nutritional status and seasonal variations in body composition (Campa *et al.,* 2021).

The accuracy and dependability of these contemporary technologies must be assessed for widespread usage beyond research applications, considering the significance of body composition requirements in these professions for physical preparedness. Additionally, although BMI has traditionally been used to identify people who are overweight or obese, its applicability in comparison to other techniques, such as the use of body fat percentage, has been questioned (Potter *et al.,* 2024). Thus, knowing the accuracy and dependability of contemporary BIA devices benefits a wide segment of the population and, with additional research, may eventually take the role of BMI in therapeutic weight control. The article aims to examine the body composition evaluation techniques currently in use.

2. Techniques for Examining Body Composition

Body composition has been estimated using a variety of methods. The only way to accurately determine body fat would be to break down and chemically analyse bodily tissues, which is not possible with existing technologies (Chumlea, Guo, & Steinbaugh, 1994). The methods often employed to calculate body fat percentage are predicated on the correlation between BF% and other measurable variables, including skinfold thicknesses or submerged weight. These indirect approaches can be used to determine body fat percentage since the value of the measurement and body composition have a predictable connection (Kuczmarski & Chumlea, 1997). Every technique discussed in the following sections has some advantages and disadvantages. Awareness of these traits will enable you to make informed decisions about the body composition evaluation approach. In Sports Science, Assessing Physiology, Nutrition, and Body Composition explores the methodical techniques and procedures required for the accurate comprehension and enhancement of an athlete's physiological profile (Chatterjee & Sarkar, 2025). The main factors to consider when selecting a technique are relative accuracy, convenience of measurement, and cost, as outlined in a comparison for fitness experts. In other circumstances (such as for healthcare or scientific purposes), measurement precision could be more important than other factors.

3. Anthropometric Measurements

Measurements used in anthropometry are used to characterise body mass, size, form, and excess weight. Putting on weight causes changes in body size, which impacts the correlation between anthropometric indices and measurements. Video and written texts explaining standardised anthropometric procedures are available (Onis *et al.,* 2004). These approaches are required for comparisons across clinical and research investigations. Before employing anthropometric tools or techniques, interested parties should review these different resources. For discipline-specific accomplishments, the application of anthropological criteria that permit a competitor to be assigned to a certain sports discipline might be highly beneficial. According to a number of studies, anthropometric factors for people of different ages and sports activities could be divided into two categories. These are fitness-related anthropometric assessments that involve bone mineral density (BMD) and free-fat mass (FFM), as well as merely anatomical reports that include the lengths and widths of the legs and the circumferences of the chest and waist (Cangur *et al.,* 2017).

4. Stature and Weight

The most obvious indicator of obesity is weight. Several scales are suitable for monitoring weight, but these need to be calibrated regularly. People who weigh a lot often have a lot of body fat; however, this isn't necessarily the case for senior sarcopenic obesity patients, who can have constant or even low body weights along with higher percentages of body fat (Lohman, Martorell, & Roche, 1988). Weight fluctuations result from fat content, water content, and lean tissue. Both children's and adults' weights rise with age due to growth and body fat. To address this lack of specificity, the body mass index, or BMI, a descriptive indicator of body habitus that includes both lean and obese people, is computed by dividing weight by the square of height. (WHO, 1995). With a proportionate biological relationship to every component of the human body, including the head, face, trunk, limbs, and vertebral column, stature is one of the key factors for personal identification (Bashar et al., 2024). Numerous wall-mounted devices that require routine calibration might be used to measure stature without hassle. Furthermore, when a person's height cannot be assessed, there are techniques for forecasting it in the case of a handicapped or mobility-challenged person (Chumlea, Guo, & Steinbaugh, 1994).

5. Body Mass Index

The benefits of using BMI as an indicator of obesity include its wide range of global national data references, its well-established correlations with body fat percentage, illness, and mortality (WHO, 1995), and its exceptional predictive power for future threats. Significant levels of risk for adult obesity at matching high percentile levels are associated with high BMI percentile values based on ranges on the CDC BMI growth tables and changes in the values of BMI curves for children (Sun *et al.*, 2002). A guy who is 12 years old and has a BMI in the 85th percentile has a 20% chance of being 35 years old and having a BMI in the same range. The relationship between the adult obese US population as determined by BMI and mortality has changed (Flegal *et al.,* 2005). Sarcopenia in the elderly results in a rising percentage of body fat, which makes an individual with a normal BMI and weight become obese. BMI may also be used to track the effectiveness of obesity treatments; however, a change in weight of around 3.5 kg is required to create an adjustment in BMI. The measurement involves calculating the athlete's height and weight in order to calculate their BMI. The subject is positioned against the wall while the measuring device continues to pull up over the top of the subject's head. The height is indicated by the number above that, which is displayed by the measuring line (Huldani *et al.* 2019). The subjects are instructed to stand above the weighing equipment, keeping their head up and their feet in the centre of the device without obscuring the reading window, in order to measure their body weight.

6. Abdominal Circumference

Increased levels of intra-abdominal fat are commonly linked to obesity. Adipose tissue deposited intra-abdominally is linked to a central fat pattern, but subcutaneous abdominal fat is also implicated. The hip-to-abdominal ratio—often wrongly referred to as the "waist" circumference—is one of the first markers of adipose tissue dispersion or fat structure. (Roche *et al.,* 2005). A greater than 0.85 ratio corresponds to a central body fat distribution. Most women with a ratio larger than 0.85 and most males with a ratio over 1.0 are more likely to develop cancer, diabetes, and cardiovascular disease (James, 2004; Deitel, 2003). But the abdominal circumference gives almost the same data, and this ratio is not a reliable measure of intra-abdominal adipose tissue (Salom, 1997; Crane, Sullivan, & Arterburn, 2004). Obese people are classified as having stomach sizes in the upper percentiles, which puts them at an increased risk of morbidity, such as type 2 diabetes and metabolic diseases. (Anwar, Chetty, & Valsamakis, 2004). Other body parts, including the arm and leg, may also be circumscribed (Lohman, Martorell, & Roche, 1988). Except for arm circumference, there aren't many reference numbers available. In obese people, the estimated arm fat and muscle regions are inaccurate. There is a correlation between abdominal thickness and degrees of abdominal obesity (Valsamakis *et al.,* 2004). To measure abdominal circumference, a measuring tape is used to measure the circumference of the abdomen in patients who are upright and breathing commonly. During the examination, the subject's last rib area is touched in order to establish the location of measurement for the lower portion of the rib cage. Next, between the end point of the hip bone and the final rib point, where the mid-point of measurement and the pelvic end tip are found (Huldani *et al.* 2019). Abdominal circumference measurements are obtained originating from the middle and moving horizontally and aligned to the waist and abdomen before returning to the midpoint.

7. Skinfold Measurement

Measurements of skinfolds are a popular way to find the proportion of body fat. It's crucial to use an accurate measuring procedure. It is recommended that you examine this data alongside each standard measurement location. The top measuring range of 45 to 55 mm on most skinfold callipers makes them helpful mainly for slightly thin or obese people. A few skinfold callipers have greater measuring capabilities; however, this is not a noticeable gain because it is hard to grip and grasp a large skinfold, and there is also the extra challenge of reading the numerals on the calliper, both of which lead to more inaccuracies. Some examples of field-based evaluation methods that were cross-examined against norms in young adult and athlete populations with conflicting results include skinfold measurements and bioimpedance devices. Using a double fold of grasped skin and a calliper, skinfold measurement calculates subcutaneous adiposity (also known as skinfold thickness) at specific locations throughout the body. After that, these measurements are added up and utilised in prediction formulas to determine body density and, in turn, fat mass (Kasper *et al.,* 2021). The vast majority of national statistical information currently available relates to subscapular skinfolds and the triceps; however, since the triceps are a location specific to a certain sex, changes in the triceps muscle may be reflected there rather than changes in fat mass (Flegal *et al.,* 2002). Due to their tiny stature, children's skinfolds help track changes in their level of body fat. Even in obese children, most of their fat is subcutaneous. In adults and kids, the statistical associations between skinfold and percent and total body fat are frequently less than those between skinfold and BMI (Flegal *et al.,* 2005).

8. Waist-to-Hip Ratio

This test aims to ascertain the waist-to-hip ratio because research has linked it to a higher probability of coronary heart disease (Salom, 1997). A simple calculation that divides the waist circumference by the hip circumference. Waist-to-hip ratio (WHR) is equal to Gw / Gh, where Gw is the waist circumference and Gh is the hip circumference. The most widely used methods for evaluating obesity are anthropometric metrics, particularly Body Mass Index (BMI), Waist Circumference (WC), and WHR, due to their affordability, simplicity of use, and high association with body fat percentage (PBF). The standard techniques for calculating the amount of fat that is accumulated in the abdominal area of the body are WC and WHR, two different anthropometric indicators (Paniagua *et al.,* 2008). One way to measure abdominal obesity is with WHR. Measurements of the hips offer more important details regarding the mass and shape of the gluteofemoral muscles. Because WHR also accounts for the buildup of hip fat, which may be good for health, it can be a valuable metric (Kumar *et al.,* 2012). As mentioned above, there is a correlation between WHR and cardiovascular illnesses. Vissers et al. came to the conclusion that WHR is a more reliable indicator of visceral adiposity and abdominal obesity, whereas WC is better since it is easier to evaluate in the field (Singh *et al.,* 2013).

9. Bioelectric Impedance Analysers (BIAs)

It is impossible to measure biological factors or describe obesity-related biophysical models with bioelectrical impedance analysers, BIAs. The impedance index or height squared, divided by resistance (S2/R) at a frequency, typically 50 kHz, is an independent variable used in regression models to predict body composition, according to Velazquez-Alva *et al.* (2004). These equations are only used for participants whose body size and form closely resemble the target population, as bioelectrical impedance analysts use them to characterise statistical connections based on biological correlations for a particular population. The trunk region accounts for a larger portion of an obese person's body mass and body water, so their FFM has less water, and their extracellular water (ECW) to intracellular water (ICW) ratio is higher, making it challenging for BIA to predict excess fat in obese people. Significant problems with BIA accuracy and their body composition calculations affect those who are normal weight. In sports, preventive medicine, and determining adherence to military body fat guidelines, bioelectrical impedance (BIA) is a compelling technique for the practical and economical daily evaluation of body composition. The research on this topic shows how much interest there has been in electrical impedance technology during the last 20 years (Ward, 2021). While BIA's therapeutic application contains significant individual errors, it is a useful tool for identifying average body composition in groups, particularly among obese individuals insensitive to little gains in response to therapy because of its substantial prediction errors. All of the issues with this technique are present in commercial BIA analysers. There are recently available BIA prediction formulas (Sun, Chumlea, & Heymsfield, 2003). These mathematical formulas are not suggested for organisations or obese people.

10. Body Density

Body weight, body volume, and residual lung capacity are measured in hydro-densitometry to assess the body composition. Historically, the two-compartment models of Siri or Brozek and co-workers (Brozek *et al.,* 1963) were used to convert body density to the percentage of body weight as fat. However, more recently, a multi-competent structure has been used to calculate fat mass (Guo *et al.,* 1997). Body density has trouble with subject performance since it is hard, if not impossible, for an adult or child who is obese to immerse. Weighted belting reduces performance in certain areas but not in others. Adults who are at most "moderately" obese are the only ones who can use air displacement equipment (Flegal *et al.,* 2005). Since hydration makes up the biggest portion of fat free mass (FFM), it is frequently regarded as the most crucial component for a precise body composition assessment (Nickerson *et al.,* 2022). This is critical because, regardless of health state, FFM hydration may differ significantly within and between racial/ethnic groups (Tinsley *et al.,* 2020). Variations in FFM features (i.e., residual, BMC, and hydration) can be taken into account by a traditional 4-compartment (4C) model. A 4C model is frequently more precise than easily understood 2C models since it may divide FFM into distinct elements (Blue *et al.,* 2022). The necessity for body volume measurements, which historically demanded the application of hydrostatic weighing or air displacement plethysmography, makes a classic 4C model unfeasible for application in clinical settings, despite its effectiveness (Blue et al., 2018).

11. Total Body Water

Body water levels can be measured using a variety of techniques, such as bioelectrical impedance analysis (BIA), magnetic resonance imaging, and the isotope dilution technique. The level of resistance and response of bodily tissue to an undetectable low-impact alternate current as it passes through the body are measured by BIA, a non-invasive technique for measuring body water (Sun *et al.,* 2003). The deuterium dilution method is regarded as the preferred technique for measuring bodily water when there isn't a gold standard. The foundation of this approach is the idea that water is distributed throughout the body, with the exception of fat. An isotope must be ingested or administered intravenously to the body, and following an interval of equilibration, a sample of blood, urine, or saliva must be taken. The dilution method's main drawbacks are that it takes a long time and necessitates the collection of a living thing and the ingestion of an isotope (Lu *et al.,* 2023). This makes it impossible to apply this strategy consistently in regular ambulatory clinical settings, especially with small children and older adults. Although it does not need undressing or physical activity, total body water (TBW) is simple to assess, but its applicability to obese people is limited. The primary premise is that fat-free mass (FFM) is calculated from TBW using an average of 73% presumptive TBW; however, this percentage might vary from 67% to 80% (Siri, 1993). Furthermore, extracellular fluid from adipose tissue contains 15% to 30% of TBW, and this percentage rises with increased adiposity. These percentages tend to be larger in obese people and higher in women, and they lead to overestimates of obesity and underestimates of FFM. Further influencing estimations of FFM and TBF is a shift in the distribution of TBW due to obesity-related diseases such as diabetes and renal failure (Guo *et al.,* 1997). TBW is a potentially helpful strategy for obese people; however, there are certain things to take into account. A measurement of extracellular space is required to adjust the FFM in an obese individual.

12. Dual-energy X-ray Absorptiometry

The most widely used technique for measuring bone, lean, and fat tissues is dual-energy x-ray absorptiometry or DXA. Although DXA is quick and easy to use for both the participant and the operator, the equipment should be calibrated and maintained regularly. When estimating fat and lean tissue, DXA makes intrinsic assumptions about water level intake, potassium content, and tissue density; these assumptions differ depending on the manufacturer (Sun *et al.,* 2003). Changes in technology, the types of models and software used, methodological issues, and inter-machine variations impact DXA estimations of body composition (Deitel, 2003; Troiano et al., 1995). Physical restrictions include body weight, length, thickness, and width, and the kind of DXA equipment (pencil or fan beam). DXA offers paediatric software, which should be used following the manufacturer's instructions. For a large portion of the population, DXA provides a handy way to measure body composition, and the National Health and Nutrition Examination Survey (NHANES) is now using it. Measurements of intra-abdominal fat have been made using computed tomography (CT), which can handle huge body sizes but is not suitable for whole-body evaluations due to excessive radiation exposure. While magnetic resonance imaging (MRI) may be used for full-body examinations, it is often not suited for huge body sizes. Anthropometry is less accurate than CT, MRI, and DXA. Due to this, the use of prediction equations to determine fat content may be questioned; however, research indicates that the equations' estimated standard error is between 3 and 7%, and the results of body fat content calculations closely resemble those derived from the most accurate technology (Wang *et al.*; Reilly *et al.,* 2009).

13. Air-displacement plethysmography

The Bod Pod from Life Measurements Instruments, Concord, CA, is the necessary measurement equipment. The process starts with using air displacement technology to track and quantify body fat and muscle mass. By calculating body volume and body weight, the Bod Pod calculates body composition (Guo *et al.,* 1997). The participant should have slept completely for the last two hours before beginning any exercise since dehydration and elevated body temperature might hurt the outcome. Scales are used to quantify body weight. The volume of the subject's chamber is then measured while the person is inside. The subject's volume is calculated by eliminating. After calculating body weight and volume, body density can be measured and entered into an equation to determine body fat percentage. It becomes easier to calculate body volume by measuring pressure differences inside a sealed container. A speaker positioned between the front testing chamber and the back reference chamber fluctuates to produce complimentary variations in pressure in each chamber. The person being tested is oblivious to the minute variations in pressure. Excellent accuracy, user-friendliness, and quick test time. In contrast to underwater weighing, the Pod doesn't involve getting wet, making it ideal for certain demographics, including kids, the obese, the elderly, and those with disabilities. The creators' accuracy shows that the BOD POD's usual error range is 1-2%, equivalent to hydrostatic weighing (Flegal *et al.,* 2005). However, ADP is currently priced higher than DXA and necessitates the child's collaborative effort because screaming and movement of kids can affect the outcome. Based on the research experience, BODPOD is possible for kids older than three. Crucially, ADP computes body composition characteristics using given body volume based on a number of assumptions (Beijsterveldt *et al.,* 2022)

14. Conclusion

The current obesity and overweight epidemic does not seem to be going away anytime soon. Our inability to readily determine fat mass limits our capacity to diagnose, track, and treat obesity. There is no widely acknowledged way to measure body fat or accurately quantify obesity, and the methods that are currently in use are constrained by the implementation of a methodology for obese people and plagued by issues of non-universal beliefs. WHO has issued several suggestions regarding obesity. One of these talks about how new and current procedures need to be developed and validated. We have covered many current methods, with their drawbacks when used on overweight individuals. Many obese people who are in desperate need of this technology cannot benefit from the current approaches, which lends credence to the WHO suggestion. This constraint also limits our capacity to estimate the true prevalence of obesity since large epidemiological and clinical investigations cannot be conducted with current approaches. It is evident that a lot more research still has to be done.

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Author Contribution Statement

Dr. A.K. Uppal contributed to the conception of the manuscript. Abhijit Upadhayay contributed to the research and the conception of the manuscript. Both authors contributed to writing and reviewing the original draft. Dr. A.K. Uppal revised the final work. Both authors read and approved the final version of the manuscript.

Conflict of Interest

The authors declare that there was no conflict of interest.

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