Review Article

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CRITICAL REVIEW OF BODY COMPOSITION MEASUREMENTS WITH RESPECT TO PHYSICAL HEALTH INDICATORS

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ABSTRACT

Body composition refers to the various elements that make up the body. It acts as a physical health indicator for cardiovascular health, musculoskeletal health, metabolic health, psychological health, physical fitness, age-related disorders, etc. Also, it helps diagnose, manage and treat them with suitable therapeutic and drug interventions. Several compartment models of the body help assess body composition for greater accuracy and ease of understanding. Assessments are done using different methods, such as body mass index, waist circumference, skinfolds, bioelectrical impedance analysis, and emerging technologies, such as artificial intelligence. Different contexts need different approaches, as these methods vary according to their specific applications. This comprehensive review focuses on prevalent diseases and their indicators. Also, comprehend their use in different circumstances. It extensively reports the pros and cons of different assessment methods, analysing multiple sources. This enables future populations and clinicians to adopt suitable, effective methods based on their requirements. Paves the way for further research and advancements in body composition and its processes.

Keywords: Body composition, Physical health indicators, Compartment models, Different methods, Prevalent diseases

INTRODUCTION

Body composition refers to the composition of the human body with different elements. It is defined as the proportion of fat body mass (FBM) and lean body mass (LBM) in the human body. FBM is the body's fat amount, whereas LBM is the body mass left after removing all fat, also called Fat-free mass (FFM)[1]. It is mainly influenced by various factors such as hereditary factors, environment, lifestyle, etc[1,2]. Gaining insight into body composition and their assessment can help individuals monitor their health status, nutritional concerns (including overweight, obesity and under nutrition), fitness, and upcoming disease risk[2]. It also influences various health indicators such as cardiovascular health, musculoskeletal health, metabolic health, physiological health, physical fitness, performance and ageing-related changes. Body composition evaluation is a routine diagnostic tool and helps physicians for early diagnosis and treatment of chronic diseases[2].

In order to assess body composition, several models were developed, including two-compartment model (2C), three-compartment model (3C), four-compartment model (4C) or multi-compartment models. This body composition assessment can be performed using multiple techniques[2]. It includes Anthropometry method like Body mass index (BMI), Waist circumference (WC), Waist to hip ratio (WHR), Skinfolds (SKF), Hydrostatic Weighing (HW); Advanced methods like Bioelectrical Impedance Analysis (BIA), Air Displacement Plethysmography (ADP), Dual-Energy X-ray Absorptiometry (DEXA), Computed Tomography (CT), Magnetic Resonance Imaging (MRI), Quantitative magnetic resonance; Emerging technologies like deep machine learning (ML), Artificial intelligence (AI), neural networks, 3-dimensional advancements (3D advancements), 3-dimensional optical imaging (3DO), etc,[1,3-6].

This work comprehensively reviews body composition and their assessment, mainly emphasising physical health indicators. This helps the overall view of different assessment criteria and directs the public and physician to the best body composition assessment, considering their pros and cons, efficiency, affordability, non-invasiveness, and accessibility to a large population.

CONCEPTUAL STUDY

Lifestyle disorders like obesity, hypertension, and diabetes are more prevalent in the current generation because of sedentary lifestyles and food habits. To manage, diagnose and treat this body composition is very much essential[3]. Body composition combines essential fat, storage fat, muscle mass, bone density, mineral content, ligaments, tendons, organs and total body water (TBW)[1]. They are divided into various models to simplify assessment methods like 2C (LBM and BFM), 3C (lean tissue mass, bone mineral content and FBM), 4C (muscle mass, TBW, bone mineral content and FBM) or multi-compartment models[3]. FBM or body fat includes essential body fat (which is necessary to maintain life and reproductive functions; Fat mass % of women > Fat mass % of men) and storage body fat (fat accumulation in adipose tissue; it also protects internal organs)[1]. FFM or LBM consist of muscle mass, bone density, bone mineral content, ligaments, tendons, organs and total body water (TBW)[1]. Commonly employed to assess body composition is the 2C model because of its simplicity and cost-effectiveness.

SIGNIFICANCE

Body composition assessment's primary benefits are understanding nutritional status and one's functional capacity [1,2,7]. These are important in describing growth and development from birth and give powerful insights into the health, origin of diseases and proper planning on nutrition, diet and therapeutics[3]. Monitoring body composition helps design personalised fitness plans, enhance athletic performance, and track progress in health. It plays a significant role in determining various health indicators such as cardiovascular health, musculoskeletal health, metabolic health, psychological health, physical fitness and age-related disorders; these are briefly discussed below.

Cardiovascular Health

Body composition affects cardiovascular health by influencing adipose tissue, lipid profiles, and fat distribution patterns. Mainly, cardiovascular health is affected by two types of abdominal fat, namely subcutaneous adipose tissue (SAT) and visceral adipose tissue (VAT). SAT is the fat beneath the skin, while VAT is the fat in the abdominal cavity, surrounding internal organs. Each has its distinct effects on cardiovascular health. Individuals with more VAT will be more vulnerable to cardio-metabolic risks, risk of insulin resistance and diabetes than SAT. Studies suggest that VAT has a positive association with systolic blood pressure (SBP), diastolic blood pressure (DBP) & mean arterial pressure (MAP) in Indian adolescents. SAT can protect against atherosclerosis in asymptomatic individuals and act as a protective metabolic reservoir. SAT, after its saturation, will be stored as VAT. Therefore, lifestyle modification strategies in clinical practice should focus on reducing VAT and maintaining a healthy balance of SAT[8].

Distribution patterns play a crucial role in determining the risk and range of cardiovascular diseases. Major fat depot areas are trunk and limb. Trunk fat mass is positively associated with SBP and DBP and is the primary factor in hypertension; however, adiposity in both upper and lower limbs negatively affects hypertension. The ratio between trunk and leg fat mass is a helpful index for predicting cardiometabolic risk [8, 9].

A lipid profile is a blood test examining various cholesterol and triglycerides in the blood. It includes very-low-density lipoprotein (VLDL), low-density lipoprotein (LDL), high-density lipoprotein (HDL), triglycerides and total cholesterol. As obesity is the major cause for cardiovascular disorders, all lipoproteins have a significant impact on obesity majorly VLDL and remnant cholesterol (formed by removing triglycerides from VLDL and intermediate-density lipoproteins). Data confirmed that VLDL, Remnant cholesterol and small LDL particles (which are more likely to accumulate in arteries) have a positive association with cardiovascular risk. Reducing VLDL particles and remnant cholesterol may help lower the cardiovascular risk in individuals with obesity, and these can be managed by perfectly using body composition indicators[10].

Musculoskeletal Health

Musculoskeletal health includes the well-being of muscle, bone, joints, tendons and ligaments. It is majorly dependent on body composition. Excess VAT hurts musculoskeletal health due to chronic inflammation. The significance of this is majorly shown in Sarcopenia (age-related loss of muscle mass, strength, and function. Additionally, it is a fundamental factor in the development of disability). As muscle mass declines, fat mass tends to increase, leading to changes in body composition. This shift is linked to a higher risk of insulin resistance in older adults[11].

Bone mineral density (BMD) is one of the components of musculoskeletal health that deals with measuring the density of minerals. BMD is significantly impacted by body fat% and BMI. There was a negative correlation between body fat% and BMD, but a positive correlation between BMI and BMD. FBM tends to affect bone density negatively, whereas LBM has a positive effect. Low BMI and body weight are known risk factors for low BMD[12]. Conditions like osteoporosis, stiff joints, type 2 diabetes, obesity, heart diseases and various health conditions are marked by decreased BMD[11]. Prevalent in all populations, at all ages, significantly for postmenopausal women. As stated earlier, LBM consists of bones, organs, ligaments, and more. This reduction may result in osteological complications (osteopenia and osteoporosis) and disorders related to skeletal muscle (sarcopenia, sarcopenic obesity)[2]. Regular exercise, particularly resistance training and high-impact activities, helps build strong bones (i.e. LBM) and may lower the risk of osteoporosis[13]. Adopting healthy body composition, characterised by adequate muscle mass, low visceral fat, and balanced fat distribution, can promote musculoskeletal health by reducing the risk of osteoporosis, osteoarthritis, and sarcopenia. This can be achieved by properly utilising body composition regularly.

Metabolic Health

Metabolic health means the capacity of the body to produce, store, and efficiently utilise energy. Dysregulation of basal metabolic rate (amount of energy produced per unit time by an animal in rest) can result in metabolic diseases. They are caused by abnormal metabolic processes that can be inherited or acquired[14]. Diseases include adrenoleukodystrophy, central obesity, insulin resistance, hypertension, atherogenic dyslipidemia, etc[14,15]. If metabolic diseases are ignored for prolonged duration, they can increase the risk of developing diabetes and cardiovascular diseases (CVDs), associated with increased mortality rate[16].

Obesity is one of the metabolic diseases, and it is strongly linked to insulin sensitivity, i.e., hypertrophic adipocytes and adipose tissue stimulate the production of inflammatory cytokines that block insulin signalling and lead to low insulin sensitivity. The inefficient storage of fatty acids by hypertrophic adipocytes and adipose tissue causes a rise in circulating free fatty acids, leading to pancreatic fat accumulation, β-cell dysfunction, and low insulin sensitivity. Low insulin sensitivity, also known as insulin resistance, causes type 2 diabetes, and improving insulin sensitivity can decrease the risk of complications. Insulin resistance is crucial in developing obesity-related lipid abnormalities, characterised by increased VLDL particle production and decreased HDL particle levels. Lifestyle changes, including weight loss and low-carbohydrate diets, may be an effective way to address dyslipidemia in obese individuals[10]. Obesity is also characterised by impaired adipocyte endocrine function[17].

Cardiovascular disease (CVD) is one of the complications of metabolic diseases. Chronic inflammation is a significant CVD factor that damages the organs and tissue. Studies have identified adipocytes as a key player in the origins of low-grade chronic vascular inflammation. Orosomucoid is a protein that functions as an immunomodulatory response in inflammation, which is expressed by adipocytes. However, increased orosomucoid levels have a positive relation with cardiovascular events in middle-aged men[17]. Body composition markers help to know about the adipocytes and other factors causing metabolic disease and are addressed accordingly.

Physical Fitness and Performance

Body composition evaluation is crucial for athletes, as it provides valuable insights into their nutritional status and helps determine the effectiveness of their diet and training programs. Changing body mass or composition can be a key strategy for athletes to gain an advantage in their sport and maintain the different body mass per the specific range for various sports[18]. For instance, studies suggest that leaner body composition can benefit aerobic sports such as long-distance running, cycling, and swimming. Collectively emphasise that aerobic athletes must balance achieving a lean body composition and maintaining enough muscle mass to optimise performance, prevent injuries, and support long-term health. Anaerobic sports require rapid, explosive movements, muscle mass, and power, which are crucial for success, particularly in events like sprinting and high-intensity interval training, where every fraction of a second counts. Anaerobic performance relies heavily on muscle mass, fibre type (fast-twitch or Type II fibres), and muscle power (lower body strength). High-intensity interval training (HIIT) effectively reduces body fat, especially visceral fat, while also improving muscle function, making it a valuable training method for athletes looking to enhance both performance and body composition[19].

More muscle mass is advantageous; having the correct muscle fibres and the ability to generate power rapidly is equally crucial. Not only the quantity but also the distribution of body fat affects endurance performance. Athletes with lower central body fat perform better in endurance events. The relationship between nutrition, body composition, and athletic performance is a complex and constantly evolving field of research in sports science. Lean body mass has a significant impact on the sports athlete's performance. On the other hand, a fat body has no positive effect on endurance, strength or performance[19]. Through frequent mentoring of body composition, one can achieve physical health.

Ageing and Longevity

Ageing can be defined as the progressive accumulation of alterations that occur over time, leading to an increased risk of disease and mortality with advancing age[20]. Evaluating health risks in older adults requires a more sophisticated approach than considering body fat percentage or distribution. Aged individuals will have reduced bone and muscle mass because of increased extracellular fluid and reduced lean body mass. On the other hand, young individuals have increased lean body mass. Lean body mass significantly influences the nutritional, cognitive, physical, and nutritional, endocrine functions of aged individuals. Disorders relating to body composition indirectly relate to the above influencing factors[21].

Older citizens are often more prone to the disease "sarcopenia or Skeletal muscle atrophy". Sarcopenia has a strong link with disability and the ageing process. Obese, in tandem with sarcopenic, has more susceptibility in aged individuals. These should be identified by simultaneous assessing of fat and lean components[21]. Individuals who were overweight or obese at the age of 25 to 50 tended to have poorer physical performance and a higher risk of mobility issues in old age, highlighting the benefits of having a healthy body weight across the life course. The combination of high adiposity and low physical activity puts older adults at the highest risk for mobility limitations, and adopting a healthy lifestyle could help, but this will have a limited impact on obese older adults. Older women generally have poorer physical function compared to men. Notably, strength declines despite gains in lean mass, suggesting that the strength and composition of muscles are more significant determinants of physical function than muscle mass alone. Both lean and fat mass independently impact mortality risk. The strengths of these masses are variable as per the method used to assess, i.e., LBM measured by CT has more risk than DEXA. FBM measured by CT has less protection than FBM measured by DEXA[22].

Psychological Health

Psychological health deals with human life's mental, social, and emotional domains, and it facilitates the cognisable and sensory-motor functions. In the current scenario of lifestyle, many have psychological disorders like Attention Deficit Hyperactivity Disorder (ADHD), autism, anxiety, addiction, eating, bipolar disorder and several others. Among them, stress-related and self-esteem-motivated problems are observed in cases of unfavourable body composition. Self-esteem is the relatively stable attitude towards oneself and satisfaction with one's appearance[23]. So, due to these comparative dimensions, there may be altered psychologically developed stressful behaviour. This can lead to a diminished quality of life. People who are obese and overweight are generally subjected to discrimination, body shaming, rejection and negative stereotypes[24]. An assessment of psychological factors revealed a strong correlation between obesity and a higher prevalence of stress, anxiety, and depressive symptoms[25]. A study suggests that regular physical activity and healthy body composition can boost overall self-esteem, thereby reducing the levels of stress[26]. The reasonable way to track healthy growth is through the optimal usage of body composition markers, facilitating maintaining physical and mental health status.

Obesity and Weight Management

Obesity is defined as abnormal or excessive fat accumulation that may impair health. It is a complex trait influenced by diet, age, physical activity and genes. A chronic imbalance between energy intake and expenditure mainly causes obesity. It leads to serious health consequences such as cardiovascular disease, type 2 diabetes, musculoskeletal disorders like osteoarthritis, and some cancers (endometrial, breast and colon). Accurate body composition assessment is crucial as it can reveal potential health risks, enable categorisation into different disorders and facilitate proper, timely treatment to mitigate serious health issues. Disorders can be classified based on key body composition indicators, including the ratio of fat to lean mass, fat distribution patterns, and muscle strength levels.

Lipoprotein, specifically VLDL, triglycerides (a key component of VLDL particles), and remnant cholesterol concentration showed a stronger association with fat distribution obesity-related lipid imbalances than LDL concentration. Additionally, smaller LDL particles and HDL particles also have a significant impact on obesity. Reducing VLDL particles and remnant cholesterol may help lower the remaining cardiovascular risk in individuals with obesity. Body compositional tools help assess and modify lifestyles to be on track with lipoprotein concentration.

Techniques and Methodologies

Table 1: Body composition assessment uses LBM and FBM and their nutritional values. These can be assessed by various methods[1]

Traditional / Anthropometric methods	Advanced methods
Skinfolds (SKF)	Bioelectrical Impedance Analysis (BIA)
Hydrostatic Weighing (HW)	Air Displacement Plethysmography (ADP)
	Dual-energy X-ray Absorptiometry (DEXA)
	Computed Tomography (CT)
	Magnetic Resonance Imaging (MRI)
	Quantitative magnetic resonance - EchoMRI system

Table 2: Apart from body composition assessments, there are obesity diagnosis tools that classify obesity based on associated health risks without detailing body composition[5]

Traditional / Anthropometric methods
Body Mass Index (BMI)
Waist circumference (WC)
Waist-to-hip ratio (WHR)

Body Mass Index (BMI)

BMI is a statistical index commonly utilised as an anthropometric measure for evaluating the health risks associated with weight. It is a primary tool to estimate body fat and obesity irrespective of the sex and age of an individual. [1,3,4]

$$\text{BMI} = \frac{Weight\ (kg)}{Height\ ^2(m\ ^2)}$$

Table 3: BMI Categorization as per the WHO[27, 28]

BMI (kg/m ^{2})		Obesity class
< 18.5	Underweight	
18.5 - <25.0	Normal weight	
25.0 - <30.0	Overweight	
30.0 - 34.9	High Obesity	1
35.0 - 39.9	Very high obesity	2
≥ 40	Extreme Obesity	3

Abbreviations: WHO - World Health Organisation; BMI - Body mass index

Table 4: Categorisation based on the revised consensus guidelines for India[29]

BMI (kg/m ^{2})	
< 18.5	Underweight
18.5–22.9	Normal or Lean
23.0 –24.9	Overweight
23.0 –24.9	Obese

Abbreviations: BMI - Body mass index; kg - kilogram; m - meter

Waist Circumference (WC)

WC is an indicator of abdominal adiposity. Measured at the midpoint of the lowest rib cage and the iliac crest during end-tidal expiration using non-stretchable tape. [5]

Table 5: General WC for different gender

Gender	Increased risk (cm)	High risk (cm)
Females	≥ 80	≥ 88
Males	≥ 94	≥ 102

Abbreviations: WC - Waist Circumference; cm - centimetres

Table 6: WC Cut-off points for adult Asian Indians[30]

Waist circumference (cm)		
Gender	Action level 1 (Risk of metabolic complications increased)	Action level 2 (Risk of metabolic complications substantially increased)
Females	≥72	≥80
Males	≥78	≥90

Abbreviations: WC - Waist Circumference; cm - centimetres

Waist to Hip Ratio (WHR)

WHR also assesses abdominal adiposity, an alternate measure of lower and upper body fat distribution. WHR is calculated by dividing the waist circumference by the hip circumference (Measured at the level of the largest lateral extension of the hips in a horizontal plane). [3,5,31]

Table 7: Cut-off points of WHR[32]

WHR		
Gender	Critical limit value	Critical threshold value
Females	≥0.85 m	≥0.88 m
Males	≥0.90 m	≥1.02 m

Abbreviations: WHR - Waist to Hip Ratio; m - meters

Increased values indicate susceptibility to various obesity-related health problems and chronic cardiovascular and metabolic diseases and can cause early mortality[1].

Skinfolds (SKF)

SKF technique[1,3] is one of the methods to estimate body fat %; this can be achieved by assessing skinfold thickness at different sites(include three -triceps, chest, and subscapular skinfolds; or chest, abdomen, and thigh skinfolds; three sites for women may include triceps, abdomen, and suprailiac skinfolds; four - biceps, triceps, subscapular, suprascapular skinfolds; seven - chest, midaxillary, triceps, subscapular, abdomen, suprailiac, and thigh skinfolds sites) using callipers. There are multiple equations to estimate body fat%, and skin-fold sites, and several sites differ as per the equation; some are sex-specific, and some also include circumference measurements. This procedure is done by pulling the fold of skin and subcutaneous fat away from the muscle and calibrating using skinfold callipers; commonly used callipers are Holtain, Lange and Harpenden[3]. To calculate body fat%, FM, and FFM, the sum of SKF measurements is substituted into the corresponding equation.

$$Body\ fat\% = [\frac{4.95}{Db} - 4.50] \times 100 \text{ (or)}$$

$$Body\ fat\% = [\frac{4.570}{Db} - 4.142] \times 100$$

Db – Body density: Durnin and Womersley's equations find the body density by substituting the sum of SKF measurements. They can also use websites using formula-based calculators[39-41].

Table 8: Fat level intervals based on gender, age group and fat%[41-44]

Fat level	Females (Body fat %)				Males (Body fat %)			
	20 - 30y	30 - 40y	40 - 50y	> 50y	20 - 30y	30 - 40y	40 - 50y	> 50y
Very low	< 17%	< 18%	< 20%	< 21%	< 9%	< 11%	< 12%	< 13%
Low	17-20%	18-21%	20-23%	21-24%	9-12%	11-13%	12-15%	13-16%
Average	21-23%	22-24%	24-27%	24-37%	13-16%	14-17%	16-20%	17-21%
Very high	24-27%	25-29%	28-31%	32-35%	17-19%	18-22%	21-25%	22-27%
Over-fat	> 28%	>30%	>32%	>36%	> 20%	> 23%	> 26%	> 28%

Abbreviations: y - years (age); < - lesser than; > - greater than; % - percentage

Hydrostatic Weighing (HW) or Hydro Densitometry [Underwater Weighing (UWW)]

HW quantifies body density (Db) and was considered the "gold standard" for evaluating FM and FFM for decades. HW is based on Archimedes' principle (which states when a body is immersed in water, it is buoyed by a counterforce equal to the weight of the displaced water). The weight of a person or an object in water is primarily less than its weight on land. HW involves measuring the volume of water displaced by the body when fully submerged, which, combined with residual lung volume measurements (amount of air remaining in the lungs after a maximal expiration), enables accurate determination of body volume (BV) and subsequent estimation of Db. A higher percentage of FFM persons will weigh more in water and consequently will have a low body fat%, because bone and muscle are denser than water, while fat is less dense than water[3]. In water, the more the FM, the lighter the body will be; subsequently, it will have high body fat%. Body density can be calculated as mass ÷ volume, and body fat% can be calculated using body composition equations[1].

Bioelectrical Impedance Analysis (BIA)

The BIA technique is used to estimate body composition by using the electrically conductive properties of the body and involves measuring the impedance to the flow of a low-electrical current (800 μA) at a fixed frequency (50 kHz). The operating principle of BIA is that electrical current flows readily through lean tissue because it consists of water and electrolytes (water and electrolytes are good conductors of electrical current). The flow of electrical current is impeded by resistance in fat tissues (fat does not have water)[3]. BIA encompasses a low-level electrical current that passes through an individual's body while resistance to the flow of the current is measured. Accordingly, individuals having lower resistance and greater reactance indicate a high proportion of FFM (i.e., low %Fat). As BIA is extremely sensitive to total body water, individuals should be assessed consistently in similar hydration states to reduce errors (e.g., fasting upon waking in the morning). BIA devices quantify impedance, based on this an estimation is made on FFM, FM, and Fat%. There are variants of BIA devices, including using single-frequency electrical and multi-frequency currents for more accuracy, segmental assessments of FM and FFM in each limb and the trunk and estimates of bone mineral content[1].

Air Displacement Plethysmography (ADP/BOD POD)

ADP and UWW operate on the same fundamental principle to measure the Db, total body fat and Lean tissues. ADP utilises the pressure-volume relationship to calculate an individual's body volume while seated within the chamber. BV is assessed as the air volume in an empty chamber minus the volume after the person sits in it. By varying the chamber's volume, the resulting change in air pressure allows for the precise calculation of the individual's volume based on the principle of air displacement. The measurement time is about 5-8 min/individual. Calculating Db using ADP has a strong resemblance with UWW. ADP method for the Indian population (more adipose for a given BMI) can accurately estimate body fat[3]. ADP uses densitometry to estimate body composition. It contains a chamber volume of 450 or 500L, and computerised sensors are used to assess BV; this is achieved by air displacement with the individual positioned within the chamber. Thoracic gas volume (i.e., the air volume in the lungs and thorax) can be quantified as an additional measure. Upon completing all requisite measurements, the BOD POD software computes approximately eight body composition parameters[1].

Computed Tomography (CT)

CT (uses ionising radiation) is an imaging technique that provides cross-sectional images of specific body regions. CT scanning gives High-resolution, three-dimensional volumetric imaging of bodily structures utilising X-ray projections from different angles of the body. Adipose tissue depots in the skeletal muscle tissue organs can be accurately determined using CT. However, body composition measurement using CT is commonly measured using a two-dimensional analysis of specific body parts, which can estimate regional body composition and is considered the most precise means of quantifying body composition at the tissue–organ level[3]. The CT system includes an X-ray tube and receiver; both rotate perpendicular to the patient. Cross-sectional images of the target area are illustrated in grayscale. The attenuation of rays reflects the composition of the tissue and varies as per the density of the tissues[1].

Magnetic Resonance Imaging (MRI)

The principle of MRI (uses radio frequency signals and magnetic resonance frequencies) is similar to the CT[1]. The body's soft tissue images can be produced by MRI, which utilises the different magnetic properties of the nuclei of elements in the cell, usually hydrogen in water and fat. This method uses magnetic resonance frequencies of protons in fat and water to separate the signals into water and fat images. Since the MRI does not use ionising radiation, it can be used for three-dimensional volumetric imaging even in neonates and infants[3]. CT and MRI enable the segmentation of specific tissues, yielding direct measurements of cross-sectional tissue area, and provide valid and in-depth body composition information[1].

Dual-energy X-ray Absorptiometry (DEXA)

Using two X-ray energies, the DEXA method measures body fat, muscle and total body bone mineral (TBBM). It is one of the most accurate techniques for quantifying body composition. The principle of DEXA is that attenuation of X-rays with high and low photon energies depends on underlying tissue properties. Precise estimates of bone mineral content and soft-tissue composition can be obtained by measuring the attenuation or weakening of X-ray beams. Using two different energy levels, images can be split into bone and soft tissue components. The procedure for DEXA measurement is for an individual to lie supine on the scanning bed, and an X-ray passes in a posterior-to-anterior direction[3]. The attenuation of an X-ray beam mainly depends on the underlying tissue's thickness, density, and chemical composition. FFM mass can be quantified through DEXA, FM, bone mineral content, and non-bone. It is also used to estimate total body composition and regional body fat[1].

EMERGING TECHNOLOGIES

Advances in deep machine learning (ML), Artificial intelligence (AI) and neural networks

Advances in deep machine learning (ML), Artificial intelligence (AI) and neural networks have enabled automated body composition analysis. These have recently garnered increased attention in the scientific community and mainstream media. AI involves creating systems that think like humans, and ML is a method that achieves this by enabling systems to learn and adapt through data analysis. ML is a technique used to achieve AI. For instance, workflow involves AI-powered analysis of abdominal CTs, automatically measuring muscle mass, SAT, and VAT, and incorporating the data into clinical reports. This workflow is valuable because existing scans provide accurate body composition data without additional costs, enhancing patient care. This readily available data will facilitate clinicians and researchers for the rapid development of more precise predictive models and treatment algorithms. In short, technological breakthroughs in AI and ML have increased the availability of body composition data, supporting better patient care and research.

Advancement in 3D and 3-dimensional optical (3DO) imaging

Digital anthropometry has made advancements in using smartphone cameras to create 3D models; research confirms the reliability of body composition and anthropometric parameters obtained through this approach. The smartphone app required users to stand in an A-pose, rotate slowly, and capture multiple images with the phone's camera from about 1.7 meters away. Humanoid avatars were built from large datasets of images taken during a 360-degree rotation of each subject[34]. Recent studies show that 3D imaging accurately tracks body composition changes. This method involves participants wearing form-fitting attire and undergoing a 45-second scan using a 3D scanner where the platform rotated to capture their body shape, resulting in a detailed 3D mesh[1, 33].

Table 9: Pros and Cons of each Body composition method[1, 3, 35]

Methods	Pros	Cons
BMI	Easy measurement, low cost, minimal participant burden, and standardised health risk classification. Categorising weight status and monitoring changes over time.	The inability to distinguish between body fat and lean body mass (leads to incorrect classifications within athletes and some older adults) is due to the difference in their FBM and LBM. It is affected by factors like sex, ethnicity, and individual differences. Doesn't accurately reflect body fat distribution or metabolic risk. Difficulty in distinguishing between "metabolically healthy" obese and "metabolically overfat" lean individuals
WC	It can predict health risks even in individuals with normal BMI.	It is affected by the position of measurement, particularly in severely obese individuals or those with loose abdominal skin due to prior weight loss.
WHR	Significant in determining the distribution of fat.	Don't quantify LBM and FBM. Also, when body fat increases, the waist-to-hip ratio (WHR) becomes less accurate in measuring visceral fat.
SKF	Inexpensive method to estimate Body fat %	Errors can occur due to variability in technique, skill and experience of the person taking the measurements. Individual differences in fat distribution can affect accuracy. It may not precisely reflect total body fat, particularly in cases of high visceral fat and may not be suitable for individuals with obesity or loose skin.
HW	Estimate body density (Db), body volume (BV) and body fat%	Hindered by its tedious process. Need specialised equipment and trained personnel. The population finds it to be highly uncomfortable.
BIA	It offers a quick, easy, and cost-effective way to estimate fat-free mass and total body water in various populations.	It shows inaccuracies in body fat, predominantly in South Indian adults. Thus, measurements of BIA machines should be used with caution. Multi-frequency devices provide more accurate readings than single-frequency readings because of their penetrating property. Mainly dependent on regression/equation. However, these equations often lack specificity for diverse populations, potentially limiting their accuracy.
ADP	Easy to use and accurate	High cost that restricts access to only a few facilities. May overestimate body fat in lean individuals. Testing conditions, clothing, and excess hair can impact results.
CT	Can differentiate FBM and LBM	Radiation exposure - spine or pelvis expose patients to a higher dose of 6 mSv, limiting the frequency of exposure to CT scans. It requires expensive scanners, trained technicians, and specialised expertise for accurate analysis.
MRI	It is useful in infants and neonates because it does not use ionising radiation.	Limited to 1D or 2D slices. Single-slice MRI has limited accuracy in tracking visceral and subcutaneous fat changes during weight loss. It is challenging for patients due to prolonged confinement (e.g., 20–120 minutes) in a small space with loud noises, requiring them to remain still. It requires expensive scanners, trained technicians, and specialised expertise for accurate analysis.
DEXA	Accurate in estimating total body fat and differentiating between FBM and LBM. It is quick, needs little technical skill, and is commonly used for body composition analysis in various clinical settings. Exposure to very low radiation (0.001 mSv).	It assumes that fat distribution is uniform over bone and soft tissue, but actual fat patterns can differ, potentially affecting accuracy. Can't measure total body water, assuming constant hydration levels, which may lead to errors as excess water is misattributed to lean tissue. Exposure to radiation

AI, ML, neural networks	Increased accuracy, rapid results, and complex data analysis, offering personalised insights. Non-invasive.	Dependence on high-quality input data, generalised to diverse populations, lack of transparency in complex models, potential biases inherited from training data, and the need for rigorous validation and testing to ensure accuracy.
3D, 3DO imaging	3D - More convenient, quick measurements are available in various applications using smartphones[34]. 3DO - Accessible, self-operated and affordable. Highly sensitive to body composition, detects small changes during interventions, and is safe. This enables users to self-monitor on a frequent basis[33].	Dependence on high-quality input data, generalised to diverse populations, lack of transparency in complex models, potential biases inherited from training data, and the need for rigorous validation and testing to ensure accuracy.

Abbreviations: BMI - Body mass index; WC - Waist circumference; WHR - Waist to hip ratio; SKF - Skinfolds; HW - Hydrostatic Weighing; BIA - Bioelectrical Impedance Analysis; ADP - Air Displacement Plethysmography; DEXA - Dual-Energy X-ray Absorptiometry; CT - Computed Tomography; MRI - Magnetic Resonance Imaging; ML - deep machine learning; AI - Artificial intelligence; 3D - 3-dimensional; 3DO - 3-dimensional optical imaging; FBM - Fat Body Mass; LBM - Lean Body Mass; BV - Body Volume; Db - Body Density; D - dimension; % - percentage; mSv - millisievert

CRITICAL APPRAISAL OF METHODS

Critical appraisal of methods in body composition assessment involves systematically evaluating the strengths, limitations, validity, reliability, and applicability of various measurement techniques. We should consider population-specific factors such as age-related changes in fat distribution and muscle mass, sex differences in body fat percentage and distribution, and ethnicity-based variations in body shape and fat distribution.

Additionally, body composition assessment methods vary in accessibility and feasibility for different settings. Some methods, like BIA and SKF, are relatively affordable and portable, making them suitable for fieldwork, clinics, or community settings. In contrast, advanced techniques like DEXA, CT, MRI and 3D imaging require specialised equipment and expertise, making them more feasible for research institutions, hospitals, and well-equipped clinical facilities. Considering these factors is essential for selecting the most appropriate method for a particular setting or population.

BROADER APPLICATIONS IN PHYSICAL HEALTH

Preventive Health: Body composition measurements, as a preliminary component of the healthcare system, play a vital role in the early detection and management of various diseases. Non-communicable and lifestyle disorders like cardiovascular, musculoskeletal, metabolic and mental ailments deprive one's health status. As an early detector of morbid conditions, these calculators can help prevent and manage health risks.

Rehabilitation: Body composition measurement is crucial in post-injury recovery and rehabilitation. It enables healthcare professionals to monitor changes in muscle and fat mass, tailor rehabilitation plans, optimize treatment strategies, assess nutritional needs, promote optimal recovery and functional outcomes. It is efficiently used in cases of spinal cord injury, stroke or burns. This helps healthcare providers deliver personalized care and intervention along with enhanced recovery[36-38].

Public Health: The prominent concern of public health is to provide an affordable and acceptable therapeutic effect to the concerned. Where overnutrition and undernutrition are affecting the major population. Body composition assessment enhances the diagnosis of obesity, undernutrition and malnutrition through the monitoring of responses to the treatment programs, which is highly relevant to its management[1].

Athletics and Fitness: Many sports performed by athletes are based on their body composition and the gravitational component. Moreover, many sports are weight-classified; therefore, athletes must stay within a specific body mass range. Consequently, athletes carefully adjust their training and nutritional habits depending on the demands of their sport. In this context, monitoring body composition has become crucial, and assessing it appropriately allows for an accurate evaluation.

CONCLUSION

Body composition is the combination of LBM and FBM; these are assessed by using different compartment models. This is assessed using various techniques (BMI, WC, WHR, SKF, BIA, HW, DEXA, CT, etc.). Body composition analysis helps determine key health metrics, including body fat, muscle mass, and bone density. It influences various health indicators such as cardiovascular health, musculoskeletal health, metabolic health, physiological health, physical fitness, performance and ageing-related changes. The body composition assessment method has strengths and limitations (based on accuracy, accessibility, feasibility, cost, etc.). BMI is cost-effective but fails to distinguish between FBM and LBM; fat distribution is also unknown. WC and WHR assess fat distribution, while SKF and HW weighing is cost-effective for differentiating between fat and lean mass, requiring skill and proper equipment, whereas ADP is costlier with similar requirements. Advanced methods like DEXA, MRI and CT provide precise assessments but are expensive, inaccessible to many, and carry potential radiation risks. BIA can be a cost-effective alternative to DEXA and ADP for assessing large populations' whole-body and segmental-body composition. Emerging technologies (ML, AI, advancement in 3D, 3DO) are more reliable for assessment and are more convenient. 3DO showed strong correlations with DEXA in measuring body composition changes, detecting similar significant shifts, and proving to be a valuable alternative to DEXA for tracking changes.

SKF, BIA, DEXA, and Emerging technologies (ML, AI, advancement in 3D, 3DO) can be the best tools for assessment, considering their pros and cons in every aspect. SKF, BIA because of its cost-effectiveness, accessibility to every individual and ability to differentiate FBM and FFM. DEXA for its precise measurements, but it is expensive. Emerging technologies reach every individual and help in the management of chronic diseases. This conclusion is drawn by considering economic constraints as a universal barrier. Meanwhile, BMI should be used cautiously, as relying solely on it can lead to inaccurate diagnoses and treatments, even in clinical settings.

Upcoming research on body composition measurements should focus on improving the accuracy and reliability of existing methods, developing and validating new technologies like 3D imaging and AI-driven analyses, standardising measurement protocols, and investigating applications in diverse populations. This would enhance our understanding of body composition's relationship to health outcomes, ultimately leading to better assessments and interventions.

FUTURE DIRECTIONS

Integrating body composition metrics into routine healthcare could enhance body composition analysis, allowing healthcare providers to tailor treatment plans to individual needs. It can help in early diagnosis of abnormal body composition and can prevent or manage conditions like obesity, osteoporosis, and sarcopenia. Regular assessments can help track changes in response to treatment, enabling adjustments to care plans. Reduce the risk of complications and improve patient outcomes.

Advancements in body composition assessment technologies can enhance healthcare by increasing the accessibility of body composition analysis, especially in resource-limited settings and focusing on patient-centric care with non-invasive procedures. Enhancement in monitoring by frequent measurements using portable devices. Cost-effective technologies can make body composition affordable and more feasible for routine care.

AI and machine learning revolutionise health monitoring and tracking by processing data from multiple inputs (e.g., sensors, scans), predicting health risks associated with body composition changes and providing personalised recommendations for improvement. Also, track the fitness goals and receive advice for optimal body composition.

Interdisciplinary approaches combining nutrition, exercise science, and technology can enhance body composition management with personalised exercise routines and customised dietary approaches. Utilising wearable technology and mobile apps for tracking. Providing holistic support for sustainable lifestyle changes. This integrated approach can lead to more effective weight management, enhance overall health and wellness

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REFERENCES

1. Holmes CJ, Racette SB. The Utility of Body Composition Assessment in Nutrition and Clinical Practice: An Overview of Current Methodology. Nutrients. 2021 Jul 22 [cited 2025 April 02];13(8):2493. Available form: https://pubmed.ncbi.nlm.nih.gov/34444653/
2. Bazzocchi A, Gazzotti S, Santarpia L, Madeddu C, Petroni ML, Aparisi Gómez MP. Editorial: Importance of body composition analysis in clinical nutrition. Front Nutr. 2023 Jan 12 [cited 2025 April 02];9:1080636. Available form: https://pmc.ncbi.nlm.nih.gov/articles/PMC9878674/
3. Kuriyan R. Body composition techniques. Indian J Med Res. 2018 Nov [cited 2025 April 02];148(5):648-658. Available form: https://pubmed.ncbi.nlm.nih.gov/30666990/
4. Dobrowolski P, Prejbisz A, Kuryłowicz A, Baska A, Burchardt P, Chlebus K, Dzida G, Jankowski P, Jaroszewicz J, Jaworski P, Kamiński K, Kapłon-Cieślicka A, Klocek M, Kukla M, Mamcarz A, Mastalerz-Migas A, Narkiewicz K, Ostrowska L, Śliż D, Tarnowski W, Wolf J, Wyleżoł M, Zdrojewski T, Banach M, Januszewicz A, Bogdański P. Metabolic syndrome - a new definition and management guidelines: A joint position paper by the Polish Society of Hypertension, Polish Society for the Treatment of Obesity, Polish Lipid Association, Polish Association for Study of Liver, Polish Society of Family Medicine, Polish Society of Lifestyle Medicine, Division of Prevention and Epidemiology Polish Cardiac Society, "Club 30" Polish Cardiac Society, and Division of Metabolic and Bariatric Surgery Society of Polish Surgeons. Arch Med Sci. 2022 Aug 30 [cited 2025 April 04];18(5):1133-1156. Available form: https://pmc.ncbi.nlm.nih.gov/articles/PMC9479724/
5. Mallik R, Carpenter J, Zalin A. Assessment of obesity. Clin Med (Lond). 2023 Jul [cited 2025 April 04];23(4):299-303. Available form: https://pubmed.ncbi.nlm.nih.gov/37524433/
6. Wang B, Torriani M. Artificial Intelligence in the Evaluation of Body Composition. Semin Musculoskelet Radiol. 2020 Feb [cited 2025 April 03];24(1):30-37. Available form: https://pubmed.ncbi.nlm.nih.gov/31991450/
7. Thibault R, Genton L, Pichard C. Body composition: why, when and for who? Clin Nutr. 2012 Aug [cited 2025 April 04];31(4):435-47. Available form: https://pubmed.ncbi.nlm.nih.gov/22296871/
8. Emamat H, Jamshidi A, Farhadi A, Ghalandari H, Ghasemi M, Tangestani H. The association between the visceral to subcutaneous abdominal fat ratio and the risk of cardiovascular diseases: a systematic review. BMC Public Health. 2024 Jul 9 [cited 2025 April 05];24(1):1827. Available form: https://pubmed.ncbi.nlm.nih.gov/38982435/
9. Zhao S, Tang J, Zhao Y, Xu C, Xu Y, Yu S, Zhang Y. The impact of body composition and fat distribution on blood pressure in young and middle-aged adults. Front Nutr. 2022 Sep 2 [cited 2025 April 08];9:979042. Available form: https://pubmed.ncbi.nlm.nih.gov/36118739/
10. Wei D, Marrachelli VG, Melgarejo JD, Liao CT, Janssens S, Verhamme P, Vanassche T, Van Aelst L, Monleon D, Redón J, Zhang ZY. Lipoprotein profiles of fat distribution and its association with insulin sensitivity. Front Endocrinol (Lausanne). 2022 Oct 25 [cited 2025 April 05];13:978745. Available form: https://pubmed.ncbi.nlm.nih.gov/36387872/
11. Volpi E, Nazemi R, Fujita S. Muscle tissue changes with aging. Curr Opin Clin Nutr Metab Care. 2004 Jul [cited 2025 April 05];7(4):405-10. Available form: https://pubmed.ncbi.nlm.nih.gov/15192443/
12. Nahar VK, Nelson KM, Ford MA, Sharma M, Bass MA, Haskins MA, Garner JC. Predictors of Bone Mineral Density among Asian Indians in Northern Mississippi: A Pilot Study. J Res Health Sci. 2016 fall [cited 2025 April 08];16(4):228-232. Available form: https://pubmed.ncbi.nlm.nih.gov/28087857/
13. NIH Consensus Development Panel on Osteoporosis Prevention, Diagnosis, and Therapy. Osteoporosis prevention, diagnosis, and therapy. JAMA. 2001 Feb 14 [cited 2025 April 08];285(6):785-95. Available form: https://pubmed.ncbi.nlm.nih.gov/11176917/
14. National Center for Biotechnology Information (US). Genes and Disease [Internet]. Bethesda (MD): National Center for Biotechnology Information (US); 1998-. Nutritional and Metabolic Diseases. [cited 2025 April 05]. Available from: https://www.ncbi.nlm.nih.gov/books/NBK22259/
15. Swarup S, Ahmed I, Grigorova Y, et al. Metabolic Syndrome. [Updated 2024 Mar 7]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2025 Jan [cited 2025 April 08]. Available from: https://www.ncbi.nlm.nih.gov/books/NBK459248/
16. Fahed G, Aoun L, Bou Zerdan M, Allam S, Bou Zerdan M, Bouferraa Y, Assi HI. Metabolic Syndrome: Updates on Pathophysiology and Management in 2021. Int J Mol Sci. 2022 Jan 12 [cited 2025 April 08];23(2):786. Available form: https://pubmed.ncbi.nlm.nih.gov/35054972/

17. Pettersson-Pablo P, Nilsson TK, Breimer LH, Hurtig-Wennlöf A. Body fat percentage is more strongly associated with biomarkers of low-grade inflammation than traditional cardiometabolic risk factors in healthy young adults - the Lifestyle, Biomarkers, and Atherosclerosis study. Scand J Clin Lab Invest. 2019 May [cited 2025 April 08];79(3):182-187. Available form: https://pubmed.ncbi.nlm.nih.gov/30767573/
18. Campa F, Toselli S, Mazzilli M, Gobbo LA, Coratella G. Assessment of Body Composition in Athletes: A Narrative Review of Available Methods with Special Reference to Quantitative and Qualitative Bioimpedance Analysis. Nutrients. 2021 May 12 [cited 2025 April 08];13(5):1620. Available form: https://pubmed.ncbi.nlm.nih.gov/34065984/
19. Martín-Rodríguez A, Belinchón-deMiguel P, Rubio-Zarapuz A, Tornero-Aguilera JF, Martínez-Guardado I, Villanueva-Tobaldo CV, Clemente-Suárez VJ. Advances in Understanding the Interplay between Dietary Practices, Body Composition, and Sports Performance in Athletes. Nutrients. 2024 Feb 19 [cited 2025 April 08];16(4):571. Available form: https://pubmed.ncbi.nlm.nih.gov/38398895/
20. Harman D. The aging process. Proc Natl Acad Sci U S A. 1981 Nov [cited 2025 April 10];78(11):7124-8. Available form: https://pubmed.ncbi.nlm.nih.gov/6947277/
21. Baumgartner RN. Body composition in healthy aging. Ann N Y Acad Sci. 2000 May [cited 2025 April 02];904:437-48. Available form: https://pubmed.ncbi.nlm.nih.gov/10865787/
22. Newman AB, Visser M, Kritchevsky SB, Simonsick E, Cawthon PM, Harris TB. The Health, Aging, and Body Composition (Health ABC) Study-Ground-Breaking Science for 25 Years and Counting. J Gerontol A Biol Sci Med Sci. 2023 Oct 28 [cited 2025 April 10];78(11):2024-2034. Available form: https://pubmed.ncbi.nlm.nih.gov/37431156/
23. Kernis MH. Goldman. BM (2006). Assessing stability of self-esteem and contingent self-esteem. Self-esteem: Issues and answers [cited 2025 April 10]:77-85. Available form: https://www.researchgate.net/publication/255711833_Assessing_stability_of_self-esteem_and_contingent_self-esteem
24. Wardle J, Cooke L. The impact of obesity on psychological well-being. Best Pract Res Clin Endocrinol Metab. 2005 Sep [cited 2025 April 10];19(3):421-40. Available form: https://pubmed.ncbi.nlm.nih.gov/16150384/
25. Jaison K I, Asharaf H, Thimothy G, George S, Jose J, Paily R, et al. Psychological impact of obesity: A comprehensive analysis of health-related quality of life and weight-related symptoms. Obesity Medicine [Internet]. 2024 Jan 1 [cited 2025 April 10];45(45):100530. Available from: https://www.sciencedirect.com/science/article/abs/pii/S2451847623000544#:~:text=Psychological%20factors%2C%20including%20stress%20and
26. Krupa-Kotara K, Markowski J, Gdańska A, Grajek M, Działach E, Szlachta G, Rozmiarek M. Global Self-Esteem, Body Composition, and Physical Activity in Polish University Students. Nutrients. 2023 Sep 8 [cited 2025 April 10];15(18): Available form: https://pubmed.ncbi.nlm.nih.gov/37764691/
27. Salmón-Gómez L, Catalán V, Frühbeck G, Gómez-Ambrosi J. Relevance of body composition in phenotyping the obesities. Rev Endocr Metab Disord. 2023 Oct [cited 2025 April 11];24(5):809-823. Available form: https://pubmed.ncbi.nlm.nih.gov/36928809/
28. Purnell JQ. In: Feingold KR, Ahmed SF, Anawalt B, et al., editors. Endotext Definitions, Classification, and Epidemiology of Obesity. 2023 May 4 [cited 2025 April 02]. Available from: https://www.ncbi.nlm.nih.gov/books/NBK279167/
29. Aziz N, Kallur SD, Nirmalan PK. Implications of the revised consensus body mass indices for asian indians on clinical obstetric practice. J Clin Diagn Res. 2014 May [cited 2025 April 11];8(5):OC01-3. Available form: https://pubmed.ncbi.nlm.nih.gov/24995216/
30. Obesity: preventing and managing the global epidemic. Report of a WHO consultation. World Health Organ Tech Rep Ser. 2000 [cited 2025 April 14];894:i-xii, 1-253. Available form: https://pubmed.ncbi.nlm.nih.gov/11234459/
31. Jaeschke L, Steinbrecher A, Pischon T. Measurement of waist and hip circumference with a body surface scanner: feasibility, validity, reliability, and correlations with markers of the metabolic syndrome. PLoS One. 2015 Mar 6 [cited 2025 April 14];10(3):e0119430. Available form: https://pubmed.ncbi.nlm.nih.gov/25749283/
32. Bramhankar M, Pandey M, Rana GS, Rai B, Mishra NL, Shukla A. An assessment of anthropometric indices and its association with NCDs among the older adults of India: evidence from LASI Wave-1. BMC Public Health. 2021 Jul 9 [cited 2025 April 14];21(1):1357. Available form: https://pubmed.ncbi.nlm.nih.gov/34238276/
33. Wong MC, Bennett JP, Leong LT, Tian IY, Liu YE, Kelly NN, McCarthy C, Wong JMW, Ebbeling CB, Ludwig DS, Irving BA, Scott MC, Stampley J, Davis B, Johannsen N, Matthews R, Vincellette C, Garber AK, Maskarinec G, Weiss E, Rood J, Varanoske AN, Pasiakos SM, Heymsfield SB, Shepherd JA. Monitoring body composition change for intervention studies with advancing 3D optical imaging technology in comparison to dual-energy X-ray absorptiometry. Am J Clin Nutr. 2023 Apr [cited 2025 April 08];117(4):802-813. Available form: https://pmc.ncbi.nlm.nih.gov/articles/PMC11184470/
34. Tinsley GM, Rodriguez C, Florez CM, Siedler MR, Tinoco E, McCarthy C, Heymsfield SB. Smartphone three-dimensional imaging for body composition assessment using non-rigid avatar reconstruction. Front Med (Lausanne). 2024 Oct 7 [cited 2025 April 04];11:1485450. Available form: https://pubmed.ncbi.nlm.nih.gov/39434777/
35. Bosy-Westphal A, Müller MJ. Diagnosis of obesity based on body composition-associated health risks-Time for a change in paradigm. Obes Rev. 2021 Mar [cited 2025 April 08];22 Suppl 2:e13190. Available form: https://pubmed.ncbi.nlm.nih.gov/33480098/
36. Branski LK, Norbury WB, Herndon DN, Chinkes DL, Cochran A, Suman O, Benjamin D, Jeschke MG. Measurement of body composition in burned children: is there a gold standard? JPEN J Parenter Enteral Nutr. 2010 Jan-Feb [cited 2025 April 08];34(1):55-63. Available form: https://pubmed.ncbi.nlm.nih.gov/19884353/
37. van der Scheer JW, Totosy de Zepetnek JO, Blauwet C, Brooke-Wavell K, Graham-Paulson T, Leonard AN, Webborn N, Goosey-Tolfrey VL. Assessment of body composition in spinal cord injury: A scoping review. PLoS One. 2021 May 7 [cited 2025 April 14];16(5). Available form: https://pubmed.ncbi.nlm.nih.gov/33961647/
38. Irisawa H, Mizushima T. Correlation of Body Composition and Nutritional Status with Functional Recovery in Stroke Rehabilitation Patients. Nutrients. 2020 Jun 29 [cited 2025 April 14];12(7). Available form: https://pmc.ncbi.nlm.nih.gov/articles/PMC7400130/
39. Shenoy S, Tyagi BS, Sandhu JS. Concurrent validity of the non-exercise based VO2max prediction equation using percentage body fat as a variable in Asian Indian adults. Sports Med Arthrosc Rehabil Ther Technol. 2012 Sep 21 [cited 2025 April 14];4(1):34. Available form: https://pubmed.ncbi.nlm.nih.gov/22998672/
40. Linear Software. Body Tracker [Internet]. Linear-software.com. 2019 [cited 2025 April 02]. Available from: http://www.linear-software.com/online.html

41. Durnin JV, 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. Br J Nutr. 1974 Jul [cited 2025 April 02];32(1):77-97. Available form: https://pubmed.ncbi.nlm.nih.gov/4843734/
42. Siri WE. Body composition from fluid spaces and density: analysis of methods. 1961. Nutrition. 1993 Sep-Oct;9(5):480-91 [cited 2025 April 02]; discussion 480, 492. Available form: https://pubmed.ncbi.nlm.nih.gov/8286893/
43. Peterson MJ, Czerwinski SA, Siervogel RM. Development and validation of skinfold-thickness prediction equations with a 4-compartment model. Am J Clin Nutr. 2003 May [cited 2025 April 14];77(5):1186-91. Available form: https://pubmed.ncbi.nlm.nih.gov/12716670/
44. Viorel Ciorniciuc. Body Fat 4 Site Skinfold Measurement Calculator 2016 [cited 2025 April 02]. Available from: https://www.thecalculator.co/health/Body-Fat-4-Site-Skinfold-Measurement-Calculator-1114.html

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