Chapter 11

Advancing Precision in Physical Education and Sports Science:

A Review of Medical Imaging Methods for Assessing Body Composition

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ABSTRACT

This chapter provides an overview of the current state of medical imaging methods in body composition analysis. It advocates a holistic approach that combines the strengths of different approaches and addresses their limitations. We discuss the importance of using standardized protocols to improve the accuracy of body composition studies across populations and settings. By examining the capabilities

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and limitations of imaging modalities such as DEXA, MRI, CT, and ultrasound, we emphasize the need for a multidimensional approach to obtain body composition emphasis on complete understanding.

INTRODUCTION

The accurate assessment of body composition is important for enhancing health outcomes and optimizing performance and certain healthcare treatments. However, traditional methods such as weight, height, and Body Mass Index (BMI) offer a limited perspective, often failing to reflect true body composition accurately. This chapter proposes a multifaceted approach to body composition analysis, leveraging the strengths of various medical imaging methods such as Dual-Energy X-Ray Absorptiometry (DEXA), Ultrasound (US), Computed Tomography (CT) and Magnetic Resonance Imaging (MRI). We begin by describing each one of them, with their potential advantages but also outlining the limitations of conventional metrics and the necessity for adaption of advanced diagnostic imaging tools for specific goals in providing a detailed body composition analysis and their potential health outcomes. For instance, bioelectrical impedance analysis (BIA) and DEXA are acknowledged for their capabilities in distinguishing fat mass, lean body mass, and bone mineral content, despite their inherent limitations influenced by factors such as hydration status and equipment accessibility (Branco et al., 2023; Dallman et al., 2023). In this context, medical imaging techniques such as Ultrasound, DEXA, MRI, and CT scans, can have an important role because of their incomparable depth in assessing not only the overall body composition but also the detailed distribution of adipose tissue, including the clinically significant visceral fat.

Therefore, we can highlight the main points for an appropriate evaluation of the body composition:

- Quantifying the muscular gain in terms of volume and specific physical training to meet some physical objectives;
- Quantifying the muscular loss in terms of volume in elderly patients, secondary to sedentarism or health conditions (stroke, cancer, others);
- Recognizing the subcutaneous fat tissue present in some key locations and quantify it and verify the specific locations where they accumulate; and
- Verifying the visceral fat amount, to calculate metabolic health risks or potential treatment efficacy.

With these different objectives, we must keep in mind that for different purposes or quantification, there are imaging methods that could be more suitable than others, or that must be combined to give some satisfactory answer to each of these questions. Moreover, the discussion extends to the practical applications of these technologies in various settings, from clinical to athletic performance optimization, underscoring the importance of a multimodal approach for a comprehensive assessment. Ultrasound imaging, with its advantages of portability and cost-effectiveness, offers significant benefits in real-time tissue evaluation and has become increasingly crucial in assessing muscle quality and subcutaneous fat distribution (Liegnell et al., 2021). CT and MRI provide excellent anatomical detain with multiplanar cross-sectional planes. However, CT and MRI could provide similar details about visceral and subcutaneous fat quantification (Baum et al., 2016) and CT has a very limited role in the muscle anatomical and physiological evaluation (Paris, 2019).

MAIN FOCUS OF THE CHAPTER

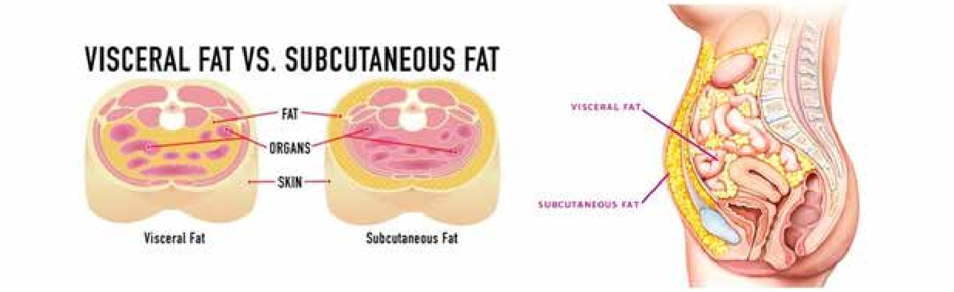
This chapter offers a comprehensive overview of the current advancements in medical imaging methods for body composition analysis. It highlights the significance of employing key medical imaging techniques to enhance the accuracy of body composition assessments across diverse populations and settings. By exploring the capabilities and limitations of modalities such as DEXA, MRI, CT, and ultrasound, the chapter underscores the importance of adopting a multidimensional approach to achieve a holistic understanding of body composition. One of the primary objectives is to optimize health and physical performance by presenting how new imaging technologies can improve body composition measurements. This discussion aligns with the global innovations in the field of physical education and health by demonstrating how these innovative imaging techniques can provide more precise and actionable data for educators, clinicians, and fitness professionals. By integrating different imaging modalities, we aim to support better clinical decision-making, enhance athletic performance, and inform tailored physical education programs. This chapter ultimately contributes to the broader conversation on advancing physical education and health practices globally through technological innovation.

THE BODY COMPOSITION ANALYSIS – BACKGROUND AND CONSIDERATIONS

Assessing body composition is crucial for optimizing health and performance (Garcia, 2019), yet obtaining accurate measurements through traditional methods presents significant challenges. Relying solely on weight, height, and BMI provides a limited view and may not accurately reflect an individual's body composition. BMI is usually used for a quick approximation of our health status. Body weight and BMI alone do not discriminate between muscle mass (which we want to maintain or increase to promote longevity) and fat mass (which we generally want to keep relatively low). Thus, when we set a goal to "lose weight," our real aim ought to be losing fat. Body composition analysis is crucial for a comprehensive health assessment and for some health treatment planning as we will see in this chapter. By understanding the specific visceral and subcutaneous fat layout of a person's body (Figure 1), healthcare providers can tailor interventions more effectively, whether they're aimed at improving athletic performance, managing weight, or treating diseases associated with body composition like obesity or sarcopenia.

It has a large impact on health and performance and is used to track changes in muscle and fat over time, providing insights into the effectiveness of training or rehabilitation programs. In aesthetic sports, weight category sports, and gravitational sports (in which body weight influences performance, e.g., ski jumping, long-distance running, etc), many athletes reduce weight rapidly or maintain an extremely low body weight or fat mass to gain a competitive advantage (Müller et al., 2016). Hence, the health of the athlete is a precondition for optimum performance (Barua, 2024; Gomez et al., 2024; Mishra et al., 2024; Morris et al., 2024). Both the protection of athletes' health and the optimization of their performance rely on the availability of accurate, precise, and valid methods for assessing body composition. MRI is usually regarded as the gold standard for clinical and research imaging of skeletal muscle, allowing researchers to accurately assess muscle mass at an individual time point and its changes over time (Frachi et al, 2017). For these reasons, these metrics fail to offer detailed insights necessary for effectively screening, monitoring, and tracking changes in body composition over time. And it may be due to the body's natural differences or the reliance on an inadequate Imaging method.

Figure 1. Cross sectional imagens depicting the subcutaneous and visceral fat distribution. In the image in left represents axial plane and the image in the right represents the sagittal plane. Source: Adapted from Fit 3D (2024).



Technologies such as BIA and DEXA can offer sophisticated means of assessing body composition that can differentiate between fat mass, lean body mass, and bone mineral content, providing a comprehensive overview of an individual's physical makeup. However, these approaches also have limitations. BIA's accuracy can be affected by hydration status, and DEXA is less accessible due to its cost and the need for specialized equipment.

Furthermore, anthropometric measurements and skinfold thickness assessments, although useful for estimating body fat percentage, do not provide specific information regarding the distribution of adipose tissue throughout the body. This is a critical gap, as the accumulation of visceral fat—fat stored around abdominal organs—is more strongly associated with metabolic risk factors than subcutaneous fat as described by Lee et al. (2020). Moreover, advanced imaging techniques, such as MRI and CT can offer precise measurements of visceral fat, but they are often impractical for routine screening due to high costs and limited availability.

Often, a multi-modal approach combining various methods may be necessary for a more accurate and comprehensive assessment of body composition. This kind of approach can help overcome the limitations of individual techniques and provide a more detailed understanding of an individual's body composition, including the specific regions most affected by excess adipose tissue. Such detailed assessments and cross-data are vital for shaping interventions and monitoring health and performance optimization program progress.

THE APPROPRIATENESS OF BMI AS A MEASURE OF OBESITY

BMI has long been used as a standard gauge for obesity, categorizing individuals based on their weight relative to their height. However, the appropriateness of BMI as an accurate measure of obesity is increasingly questioned by healthcare professionals and researchers, particularly in postmenopausal women (Banack et al., 2018). Despite its widespread use, BMI offers a simplistic overview, failing to differentiate between muscle mass and body fat or to account for variations in body composition across different demographics. BMI also does not consider fat distribution, which is a critical factor in health risk assessment. Moreover, populations such as athletes or certain ethnic groups might be misclassified by BMI due to higher muscle or bone density or differing body proportions. To address this issue, several studies have been conducted to evaluate the validity of using BMI to identify obesity in different populations. According to a study by Banack et al. (2018) involving postmenopausal women, BMI-defined obesity had a sensitivity of 32.4% for 35% body fat, 44.6% for 38% body fat, and 55.2% for 40% body fat, demonstrating that a BMI cut-point of 30 kg/m2 does not appear to be an appropriate indicator of true obesity status in postmenopausal women.

A more recent study by Aizuddin et al. (2021) seems to point in the same direction. This retrospective study in Malaysia involving 136 participants found that the optimal BMI cutoff value for diagnosing obesity based on body fat percentage (BF%) was 24.8 kg/m and that the current definition of obesity based on BMI value needs to be reassessed by taking body fat percentage into account. The same study suggests that the current BMI cutoff for obesity may be inaccurate in identifying individuals with excess body fat and at risk for cardiovascular diseases. Regarding the overweight screening for children and adolescents, a diagnostic meta-analysis by Wickramasinghe et al. (2005) revealed that using self-reported BMI and obesity status presented a pooled sensitivity of 0.76 and a pooled specificity of 0.96. Hence, this study focused on Australian Sri Lankan children and found that BMI values were not sensitive enough to detect cases of childhood obesity, so preventive and corrective measures could have a serious delay.

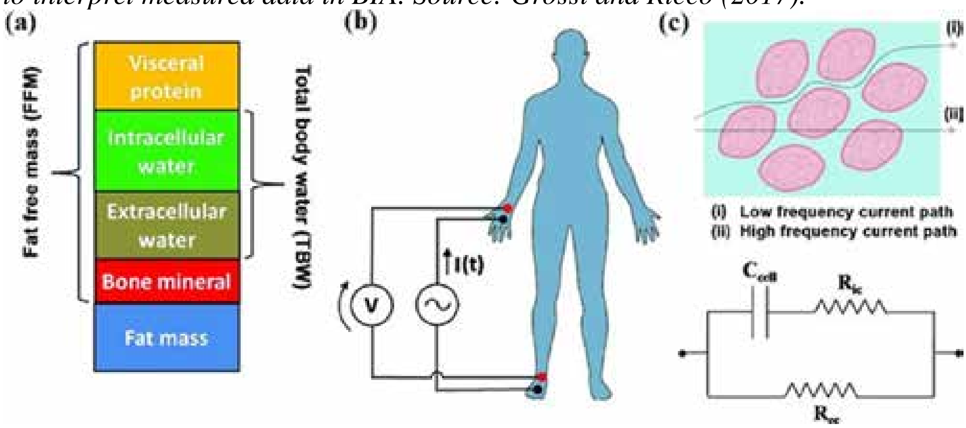
These studies, generally, point out that while BMI is widely used, it may not be the most appropriate measure of obesity, especially in specific populations such as postmenopausal women and children. Therefore, it is essential to consider alternative measures, such as an accurate mean of ascertain body fat percentage, in conjunction with BMI to provide a more comprehensive assessment of obesity.

The Role of Bioelectrical Impedance Analysis

BIA is a widely used technique that estimates total body water. From this, along with total body weight, one can typically calculate both fat and muscle mass. The Physical principle behind BIA is the electrical impedance spectroscopy (EIS), in which a sinusoidal test voltage or current is applied to the sample under test to measure its impedance over a suitable frequency range. EIS is used in a broad range of applications as a quick and easily automated technique to characterize solid, liquid, semiliquid, organic as well as inorganic materials (Grossi & Riccò, 2017).

BIA works on the principle that different tissues in the human body conduct electrical currents differently. Lean body mass, which includes muscles, blood, and organs, contains a high water and electrolyte content and conducts electricity well. Fat, on the other hand, has less water and electrolyte content and conducts electricity poorly. BIA devices send a low-level electrical current through the body, and by measuring the resistance (impedance) to this current, they can estimate various body composition parameters (Tantisattamo et al., 2022). These working principles are illustrated in Figure 2.

Figure 2. (a) The different compartments of the human body; (b) a typical four-electrode configuration for BIA measurements; (c) equivalent electrical circuit used to interpret measured data in BIA. Source: Grossi and Riccò (2017).



BIA is a reliable, non-invasive, objective, and cost-effective body composition assessment method, with high reproducibility (Branco et al., 2023) and measures several key parameters related to body composition and overall health. These measurements include (HaB, 2023):

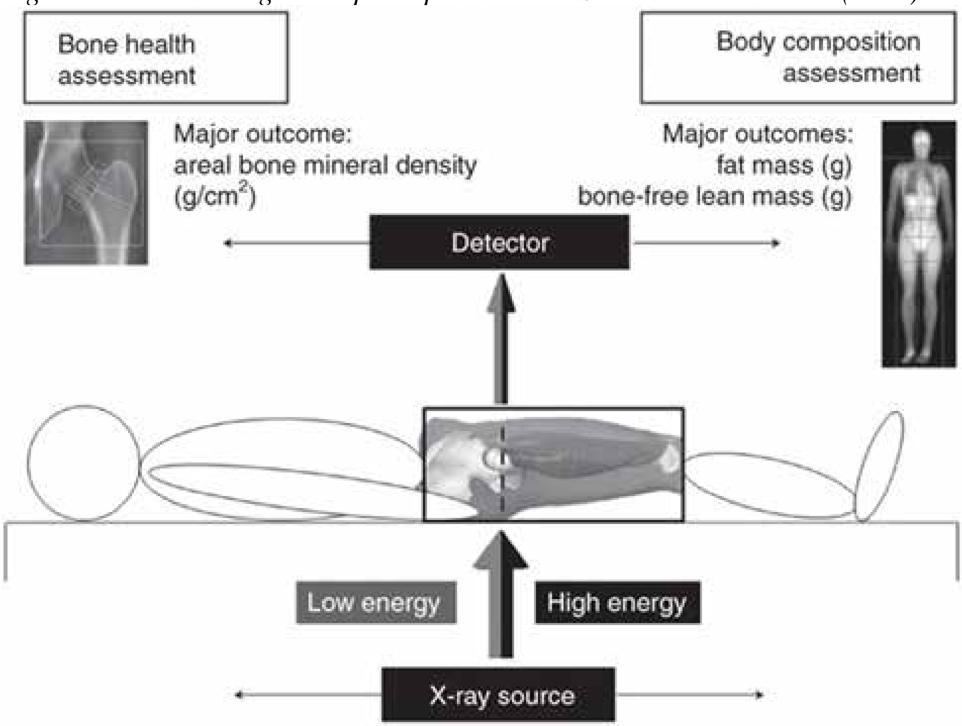
- **Body Fat Percentage**: BIA estimates the proportion of your total body weight that is composed of fat.
- **Lean Body Mass:** Provides an estimate of your lean body mass, which includes muscle, bone, blood, and organs.
- **Total Body Water**: BIA assesses your body's water content (Hydration status), which includes both intracellular and extracellular water.
- **Metabolic Rate**: Some advanced BIA devices can estimate your resting metabolic rate (RMR), which is the number of calories your body needs to maintain basic functions at rest. This information is useful for weight management and dietary planning.
- **Segmental Analysis**: Some BIA devices can provide segmental analysis, which assesses the composition of specific body segments, such as arms, legs, and the trunk helping to identify imbalances or asymmetries in muscle development.
- **Visceral Fat**: Certain BIA devices can estimate the amount of visceral fat, which is the fat stored around the internal organs in the abdominal cavity.

A review study by Sbrignadello et al. (2022) highlighted the relevance of BIA for body composition analysis in type 2 diabetes (T2DM) patients with sarcopenia or at risk of developing it. The findings suggested that BIA can be considered appropriate for body composition analysis in this population, with a wide patient cohort confirming its convenience for clinical applications. Another scoping review that included 36 studies emphasized the clinical and scientific evidence supporting the use of BIA in the oncologic context. BIA-derived measures have shown good potential and relevant clinical value in preoperative risk evaluation, in the reduction of postoperative complications and hospital stay, and as an important prognostic indicator in patients diagnosed with cancer (Branco et al., 2023). About the obesity subject, a study by Lee et al. (2020) comparing the BIA and CT on Body Composition Changes after Bariatric Surgery, showed a slight underestimation of BIA in measuring visceral fat. These results suggest that BIA can be a reliable tool for measuring body composition, especially for visceral fat, after bariatric surgery. without the need for additional CT scans that have a high dose of radiation involved. Overall, the evidence from these studies collectively supports the utility of BIA as a method for assessing body composition in various medical conditions. Next, we will talk about the imaging methods contribution on body composition.

Dual-Energy X-ray Absorptiometry in the Body Composition Analysis

DEXA is defined as a procedure that measures the amount of calcium and other minerals in a bone by passing X-rays with two different energy levels through the bones. A DEXA scan, depicted in figure 3, shows the strength and thickness of a bone and is usually done in the lower spine, hip, lower arm and heel. It is used to diagnose osteopenia or osteoporosis (a condition of lower bone density) and to evaluate the effectiveness of the treatment for this condition. More recently, DEXA scans can also measure fat and muscle composition in the total body or in specific parts of the body, such as the arms, legs, and pelvis (NCI, 2024).

Figure 3. DEXA scan general principles scheme. Source: Toombs et al. (2012).



To measure obesity signs, DEXA could give some important information such as: the percentage of body fat, visceral adipose tissue (VAT), bone mineral density, and appendicular Lean Mass Index (i.e., a measure of muscle mass). It also provides information on subcutaneous fat. However, its significance is limited due to its strong genetic determinants and minimal connection to metabolic health. In contrast, VAT shows a much stronger correlation with sophisticated biomarkers of insulin sensitivity and overall metabolic health, including indications of liver fat.

Due to its good precision, large availability, and low radiation dose, DEXA is a convenient and useful diagnostic tool for body composition assessment. The development of the field, leading to the introduction of fan-beam densitometers, has allowed for a reduction in scan time without compromising accuracy and without increasing radiation dose substantially. For these reasons, DEXA is an attractive alternative to BMI, a commonly used indicator of underweight and obese phenotypes. However, significant variations have been reported both among different DEXA and the current gold standard methods (CT and MRI) for assessing body composition, as we will develop later in this chapter. Consequently, using DEXA as a definitive standard should be approached with caution (Toombs et al., 2012).

Moreover, it has been observed that weight gain among anorexics during recovery is characterized by a greater increase in fat mass than lean mass, with most of the increase in fat mass being centrally distributed (Iketani et al., 1999). Unlike anthropometric indexes, DEXA can monitor these changes in the regional distribution of fat mass and lean mass throughout the course of the illness and treatment, giving important information for a fine treatment adaptation on the patient's health status.

Further research has expanded the understanding of DEXA's role in body composition evaluation. For instance, Ofenheimer et al. (2020) provided age and gender-specific reference values for body composition parameters and VAT mass using DEXA in a European adult cohort, underscoring its utility in assessing body composition phenotypes and cardio-metabolic risk. Moreover, a study by Park et al. (2021) comparing muscle mass values assessed by two different DEXA systems in healthy Korean adults highlighted significant differences, although measurements of body composition, including muscle mass, by the two DEXA systems correlated strongly. This highlighted the necessity for accurate calibration measures to correct systematic discrepancies between different DEXA systems for precise body composition assessment.

In patients with other clinical conditions such as rheumatoid arthritis and hypogonadism, a clinical case study demonstrated DEXA's effectiveness in assessing significant changes in body composition related to disease and treatment, thus illustrating its utility in clinical practice (da Silva & Borges, 2020).

Moreover, in the sport's field, DEXA also revealed precision in measuring body composition, including fat-free soft tissue mass and bone mineral content in lean athletes confirming its suitability for sports science applications, establishing it as the "gold standard" imaging modality (Bilsborough et al., 2014). Nevertheless, a more recent review of DEXA protocols for athletes also underscored the limited literature and the absence of specific reference values for this population, highlighting the need for standardized DEXA scanning protocols and guidelines for reporting results in athletic contexts (Dallman et al., 2023). Besides, the research conducted by Bartlett et al. (2020) demonstrated the practical utility of DEXA in estimating energy balance and analysing changes in body composition in athletes across different seasonal phases. This information is particularly important for establishing training and nutritional adjustments tailored to each athlete's specific metabolic needs.

Several comparative studies have demonstrated DEXA's strong correlations with CT in measuring abdominal and thigh fat, and thigh muscle mass, particularly in premenopausal women, demonstrating its broad applicability across diverse body compositions from obesity to anorexia nervosa (Bredella et al., 2010). However, DEXA's accuracy can diminish with increasing body weight, highlighting its limitations especially in significantly obese individuals. Furthermore, a study by Maskarinec et al. (2022) compared DEXA's measurements of visceral and subcutaneous adipose tissue with MRI, revealing that while DEXA tends to overestimate subcutaneous fat in children (212 cm^2 vs. 161 cm^2 by MRI) and underestimate VAT in adults (141 cm^2 vs. 167 cm^2 by MRI), its correlations were especially stronger for subcutaneous than for visceral fat.

Overall, these studies collectively support DEXA as a valuable tool for assessing body composition and fat distribution across diverse populations. They reinforce DEXA's importance in evaluating metabolic health risks and monitoring changes due to diseases or treatments, with a potential for broader application and the necessity for standardized approaches when utilizing different DEXA systems.

Ultrasound Role in Body Composition Assessment

Ultrasound imaging is a non-invasive diagnostic technique, that utilizes high-frequency sound waves to generate detailed images of the body's internal structures. Ultrasound technology has long been revered for its diagnostic competence in the medical field, particularly in monitoring fetal development and diagnosing conditions within the abdomen. However, its application extends far beyond these traditional uses (Lobo et al., 2024). One of the less highlighted yet increasingly valuable applications of ultrasound is in the assessment of body composition. This involves measuring the distribution and volume of muscle, fat, and bone in the body, providing valuable data for health, fitness, and clinical management.

This advancement allows healthcare professionals to provide diagnostic services directly to patients, significantly minimizing the need for travel to medical facilities for examinations. This increased mobility enhances access to diagnostic services, especially in remote or underserved areas, fostering a more patient-centred approach to healthcare delivery (Lobo & Miravent, 2022). Moreover, US imaging offers enhanced accessibility due to the relatively lower cost of ultrasound devices compared to other imaging modalities. This cost-effectiveness makes ultrasound a viable option for a wide range of clinical settings, extending diagnostic capabilities to more patients and healthcare environments.

Ultrasound imaging also has the significant advantage of real-time imaging, offering immediate feedback and dynamic visualization of tissues (compression and no compression, muscle tension and no tension), as well as their interactions with various manipulations, such as probe pressure and patient movements. This real-time functionality is a distinct benefit over other imaging modalities like MRI and CT scans, which, despite their high resolution and detailed static images, cannot offer the same "live" dynamic examination.

Regarding the analysis of body composition for educational, nutritional, and healthcare purposes (Garcia et al., 2021a, 2021b), there is a wide range of articles that discuss this topic, including methods for measuring muscle thickness (MT) and calculating subcutaneous fat patterns. As mentioned earlier, calculating intra-peritoneal fat patterns with this technique is particularly challenging due to the technical and physical limitations associated with poor ultrasound propagation in fatty tissues.

As for the ultrasound application in the body composition and fat patterns, there are some examples. For instance, a study by Muller et al (2016) described a novel ultrasound technique standardized for measuring SAT (subcutaneous adipose tissue) that showed high accuracy and reliability (figure 4). In this study, three observers captured US images of uncompressed SAT in 12 athletes and applied a semiautomatic evaluation algorithm for multiple SAT measurements. They referred to nine recommended sites for SAT measurements as depicted in Figure 5.

Figure 4. Detail of a sagittal, B -mode, ultrasound image regarding the different subcutaneous layers and the corresponding detail of the subcutaneous adipose tissue thickness. Source: Müller et al. (2016).

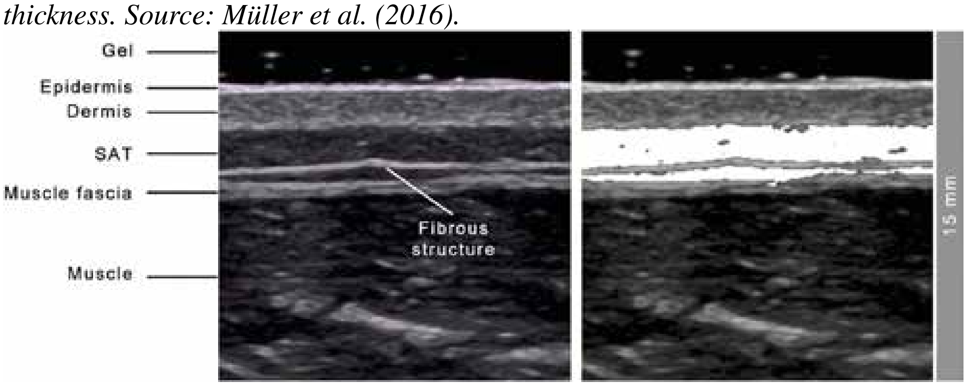
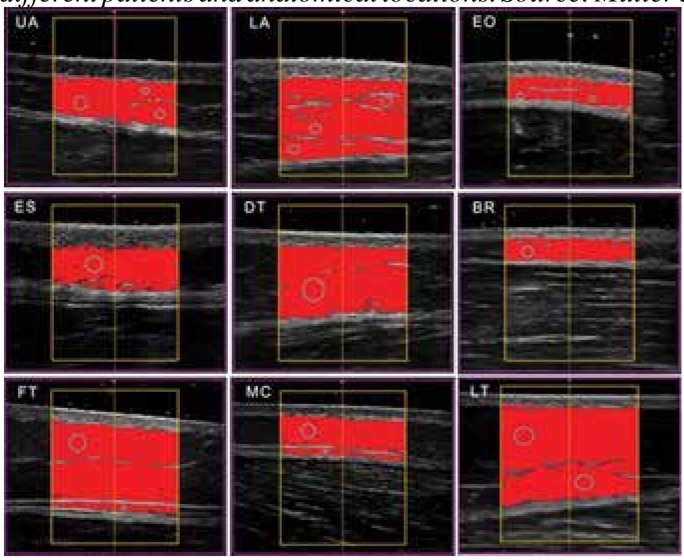


Figure 5. Detail of several sagittal B -mode ultrasound images regarding the different subcutaneous layers and the corresponding detail of the subcutaneous adipose tissue thickness in different patients and anatomical locations. Source: Müller et al. (2016).

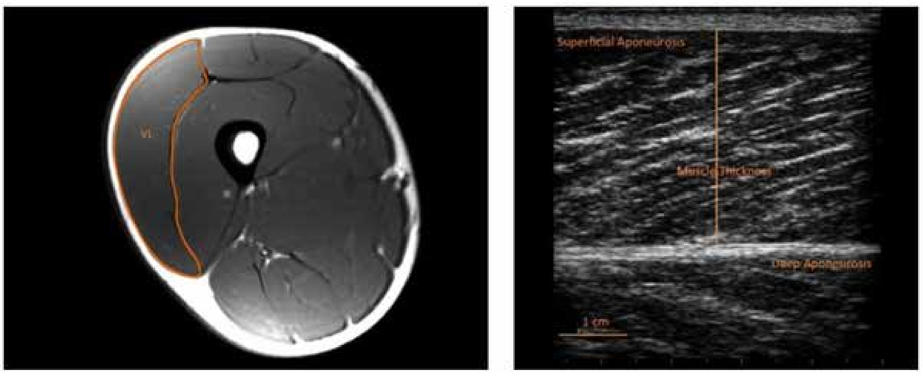


About this subject, a recent study by Van den Broeck et al. (2023), measured the inter reliability (2 examiners) between the ultrasonographic measurements of muscles such as Tibialis anterior, Gastrocnemius, Rectus femoris, Biceps Femuris, Rectus Abdominis, Erector spinae, Biceps and tríceps Brachii and forearm extensors. The measurements made were MT, Cross-sectional area, and the Echo Intensity. In this research several muscle measurements exhibit good reliability. Measuring muscle quantity with Extended Field of View (EFOV) ultrasound proved to be a reliable measurement to body composition analysis purposes.

Other study by Takai et al. (2014) showed that ultrasound MT measurements at various body sites can accurately predict whole-body fat-free mass in the elderly. This study suggests that ultrasound MT measurement is a useful tool for predicting FFM, and its accuracy is further improved by considering the product of MT and limb length. This was also noted by Li et al (2020) in a study focusing on the use of ultrasound to measure muscle mass, particularly the biceps brachii, in elderly individuals to assess sarcopenia. The same authors also concluded that ultrasound measurement of Cross-Sectional Area in the biceps brachii is a crucial indicator and a useful method for assessing sarcopenia in the elderly, confirming the effectiveness of ultrasound in such clinical settings.

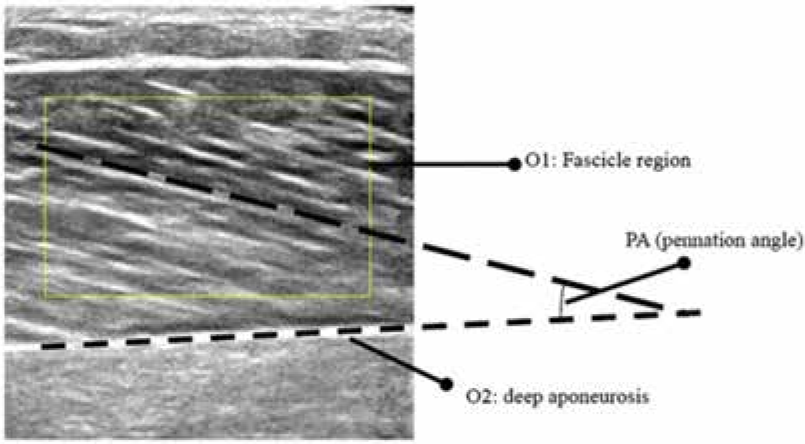
Another study by Franchi et al. (2018) explored the reliability of measuring the Vastus Lateralis muscle at 50% of femur length using ultrasound, comparing it with MRI anatomical cross-sectional area assessments (Figure 6). The study validated ultrasound as a reliable tool for monitoring local long-term hypertrophic responses to resistance training. Furthermore, Marín-Baselga et al. (2023) identified a significant correlation between ultrasound measurements and the duration of hospital stays, noting that longer stays were associated with reductions in these measurements, particularly in conditions like sarcopenia resulting from hospitalization.

Figure 6. MRI Cross sectional image of the right tight, highlighting the Vastus Lateralis section (left). In the right image Ultrasound Muscle Thickness measurements of the right Vastus Lateralis Source: Adapted from Franchi et al. (2018)



About this particular subject, Liegnell et al. (2021) made a systematic review that showed a moderate agreement of the US-based MT with the MRI muscle volume, with standard error estimates ranging from 6 to 12% for healthy adults and up to 25.6% for children with cerebral palsy. In a more specific subject regarding muscular strength calculation, ultrasound technology offered vital insights into the pennation angle of the gastrocnemius muscle. The pennation angle, which is the angle formed by the muscle fibres relative to the aponeurosis, is an important parameter related to musculoskeletal functions and plays a crucial role in the understanding of muscle architecture (Zhou et al., 2012). Studies have explored its utility in evaluating Achilles tendinitis (Phillips et al., 2022) and muscle spasticity in stroke patients (Yang et al., 2014) highlighting the ultrasound key role in this type of evaluations. This angle is directly linked to muscle force production, as higher pennation angles are associated with greater force (Lieber & Fridén, 2000). A representation of the technique of measuring the gastrocnemius pennation angle can be observed in the figure below (Zhou et al., 2012).

Figure 7. Typical ultrasound image of the medial gastrocnemius muscle and the pennation angle. Source: Zhou et al. (2012).



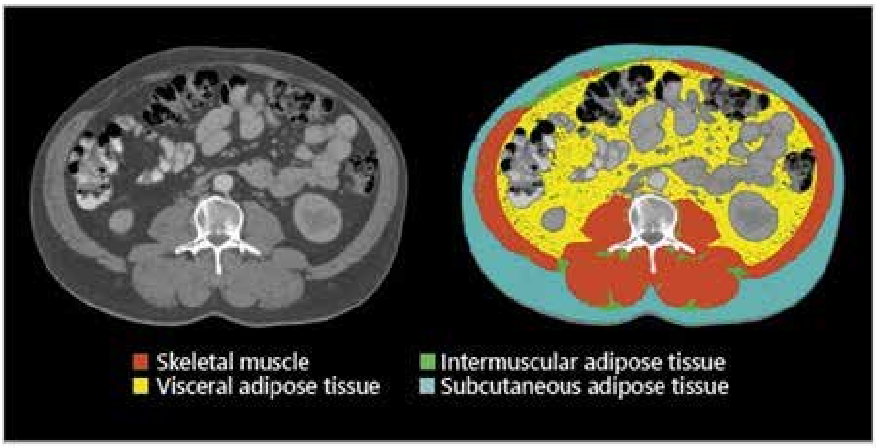
Ultrasound emerges as a decisive tool in the medical landscape, particularly in the dominion of body composition analysis and muscle architecture evaluation. Its non-invasive nature and real-time imaging capabilities make it indispensable for dynamic assessments, enabling immediate clinical decisions and interventions.

The Contribution of Computed Tomography in Body Composition Assessment

CT scanning is a sophisticated imaging technique that offers a highly detailed look inside the human body. This method uses computer-processed combinations of multiple X-ray measurements taken from different angles to produce cross-sectional (tomographic) images of specific areas of a scanned object, allowing the user to see inside the object (in 3 dimensions) without cutting it. CT is not only important for diagnostic imaging but also plays a significant role in the assessment of body composition, including the detailed analysis of muscle anatomy and different types of body fat. This precision enables the accurate measurement of muscle mass and the differentiation between visceral and subcutaneous fat. Moreover, CT may also provide important information about the changes in muscle mass and composition with aging and disease, which may, in turn, affect the muscle's function (Goodpaster et al., 2000).

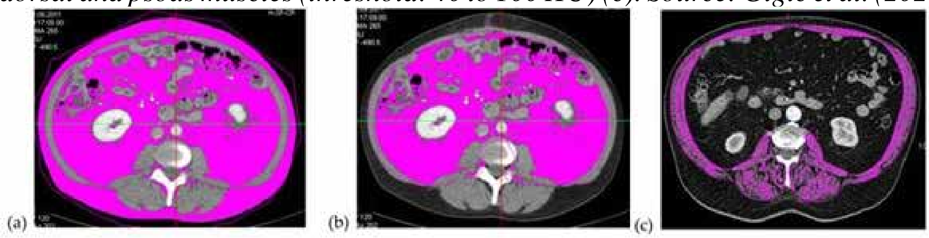
Body composition is increasingly being recognized as an important prognostic factor for health outcomes across cancer, liver cirrhosis, and critically ill patients. CT scans, provide an excellent opportunity to precisely measure the quantity and quality of skeletal muscle and adipose tissue. Currently, body composition's clinical use is mainly in retrospective studies, but applying these automated methods in prospective research could validate its importance in clinical decision-making, such as tailoring chemotherapy doses based on muscle mass to reduce toxicity risks (Paris, 2019). We can observe an example in Figure 8.

Figure 8. CT scan axial plane in grayscale in the left and in the right the same image with automated CT segmentation of the skeletal muscle, Visceral adipose tissue, intermuscular adipose tissue and subcutaneous adipose tissue. Source: (Paris, 2019).



Still about this subject, Zorps et al. (2020) developed and evaluated a software toolkit, which allowed for a fully automated body composition analysis in contrast-enhanced abdominal CT leveraging the strengths of both, quantitative information from dual-energy CT and simple detection and segmentation tasks performed by deep convolutional neuronal networks (DCNN). With this approach, this study demonstrated strong correlations with manual measurements and other body composition assessment methods. CT can also be useful to quantify Body Composition on Health-Related Quality of Life in Colorectal Cancer Patients. In a study by Gigic et al. (2020) the area-based quantification of adipose tissue compartments was performed on the L3/4 spinal level (volumetric quantification of a selected slice, divided by slice thickness) using a semiautomatic software tool as depicted in figure 9.

Figure 9. Example of a CT-scan with the area-based, densitometric quantification of adipose tissue (threshold: −190 to −30 HU) measured at spinal level L3/4: regions of interest (ROI) containing total fat area (TFA) (a) and visceral fat area (VFA) (b); and an example of the densitometric quantification of muscle area, also measured at spinal level L 3/4 with an ROI containing the muscle tissue of the abdominal, dorsal and psoas muscles (threshold: 40 to 100 HU) (c). Source: Gigic et al. (2020).



The main conclusions of this study were that patients with high amounts of visceral fat at diagnosis exhibited worse scores for social functioning and deteriorated pain after surgery, independent of treatment. Additionally, patients with higher skeletal muscle mass at diagnosis suffered more from pain one year after surgery. This last result was unexpected by the researchers but may be due to that during the first year of disease, patients experienced a rapid loss of muscle mass, (cancer-associated sarcopenia) which might occur especially in patients with more muscle mass at diagnosis. Overall, these results suggested that intervention strategies targeting visceral fat and muscle mass might improve the health-related quality of life in colorectal cancer patients during the first year after surgery (Gigic et al., 2020).

As for more recent IA applications of Fat segmentation, Shen et al. (2023) proposed a method for the automatic outlining of subcutaneous fat, skeletal mass, and visceral fat areas on L3 cross-sectional CT images. This application obtained better segmentation results compared to U-Net, (a model previously described by Ronneberger, Fischer & Brox (2015)) representing an improvement for the attention mechanism, which was accurate in terms of Dice similarity coefficients and other assessment metrics. This proposed ensemble model of SECAUNet based on the attention mechanism accurately segmented subcutaneous fat, SM, and visceral fat on abdominal CT images. Similar results were obtained by Cao et al. (2024) about the use of a new IA method to assess body composition CT segmentation in colorectal cancer patients.

Additionally, CT can also play a decisive role in the determination of visceral obesity (VO) to predict risk of postoperative burst abdomen. A burst abdomen (BA), also known as abdominal dehiscence, is a serious surgical complication where the incision made during an abdominal surgery reopens. This reopening can involve both the skin and the deeper layers of the abdomen, including the muscle. It typically occurs within the first few weeks following surgery and can be partial or complete. A study by Mehdorn et al. (2023) revealed that Patients with BA had significantly more VO ($p < 0.001$) but less subcutaneous obesity on CT scans. This analysis gave valuable information on possible risk stratification because it shows that VO could be a major risk factor for patients to develop postoperative BA.

As CT continues to evolve, it promises to offer even greater insights into body composition and its health implications, thus solidifying its role in modern medical diagnostics and personalized medicine. Nevertheless, caution is advised in the use of this technology due to the significant radiation exposure involved. Therefore, researchers should consistently perform a risk-benefit analysis, comparing it with other imaging techniques, to ensure the safety and efficacy of its use in patients.

Magnetic Resonance Imaging Role in Body Composition Assessment

MRI is an advanced medical imaging technique increasingly utilized for the assessment of body composition. Unlike other imaging techniques, MRI does not require the use of ionizing radiation to obtain medical images of the human body. This makes MRI a safer option compared to methods such as X-rays and CT scans that rely on ionizing radiation, which can be harmful in high doses. Moreover, MRI provides detailed insights into various fat compartments, including visceral fat, subcutaneous fat, and muscle evaluation.

The fundamental physical principle behind MRI involves the excitation of hydrogen nuclei (protons), which are abundant in the body's water and fat. When a person is placed inside the MRI scanner, a strong magnetic field aligns the hydrogen protons in the body. Radiofrequency pulses are then used to temporarily disturb this alignment. As the protons return to their original state, they emit signals that are detected by the scanner. These signals are used to construct detailed images of the body's internal structures. While MRI is renowned for its detailed and precise measurement of muscles, tendons, and other body components, its use should be carefully considered due to several limitations:

- **Claustrophobia:** Many patients experience discomfort or anxiety in the enclosed MRI space. Although open MRI models are available, they are significantly more expensive and less commonly available for routine body composition studies.
- **Cost and Accessibility:** MRI is a state-of-the-art technique for evaluating human anatomy and its pathological aspects. However, it requires substantial financial investment in the equipment, the specialized room (Faraday cage), and the maintenance of the superconducting magnet with liquid helium. It

is typically reserved for advanced pathological assessments, often following initial evaluations by more accessible imaging techniques.

- **Magnetic Field Limitations:** MRI is contraindicated for individuals with certain metal implants or conditional devices, such as pacemakers or metallic foreign bodies, due to the strong magnetic field used during the examination.
- **Examination Duration:** Most MRI scans require several minutes to acquire high-quality images. Although modern MRI machines are being developed to reduce scan times, often incorporating artificial intelligence to assist, the duration remains a significant consideration.

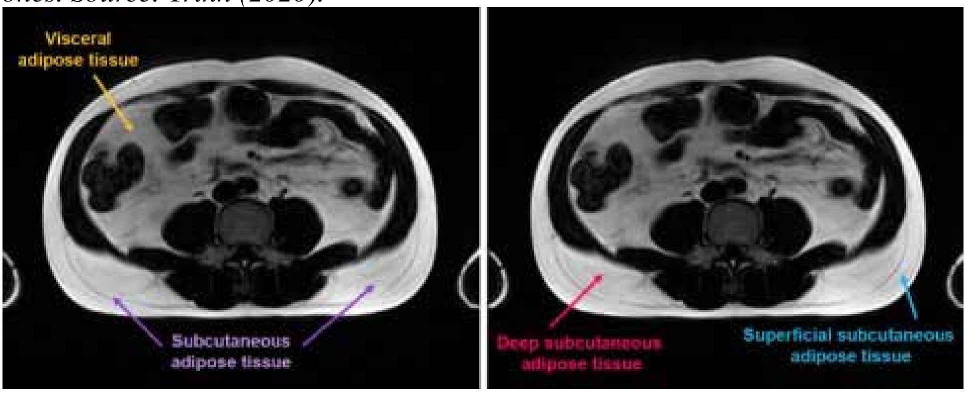
Visceral and Subcutaneous Fat Assessment

As for Visceral and Subcutaneous fat assessment, MRI has been demonstrated to accurately quantify both visceral and subcutaneous fat volumes. Studies using MRI have shown strong correlations with other imaging modalities like CT scans, with visceral fat and subcutaneous fat volumes being precisely measured even in free-breathing conditions, which is particularly beneficial for paediatric and other challenging populations (Ly et al., 2019) (Baum et al., 2016). Also, conventional breath-holding MRI can quantify visceral and subcutaneous fat volumes and hepatic proton density fat fraction (PDFF or Fatty liver) in obese children allowing to calibrate their exercise and therapeutic recovery programs. Visceral and subcutaneous fat volumes and PDFFs were strongly and positively correlated with hepatic PDFF and visceral fat PDFF explained some variation in hepatic PDFF.

MRI-based techniques, such as chemical shift-encoding and Dixon imaging, have been effectively utilized to separate and quantify water and fat, enhancing the accuracy of body composition assessments (Baum et al., 2016; West et al., 2018). According to these authors, MRI methods allowed the assessment of body fat distribution and characteristics. Nevertheless, although the promising findings based on these MRI methods, the clinical usefulness remains to be fully established.

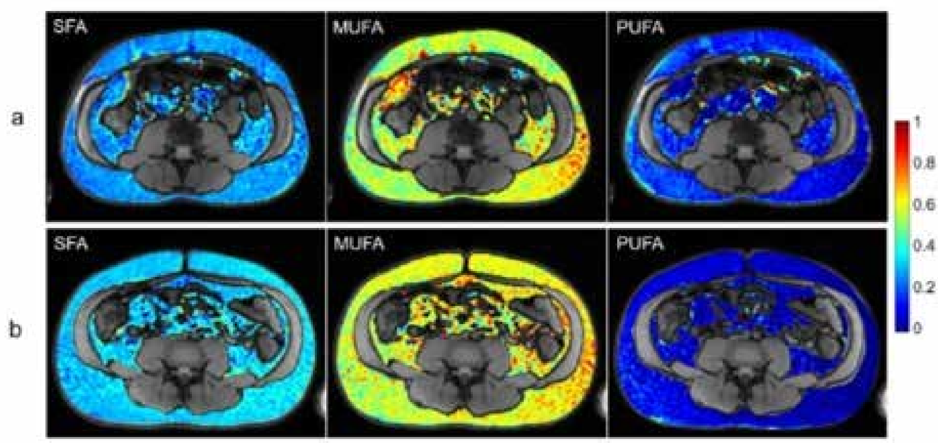
Also, Thrin (2020) investigated a T2-based fat quantification method using high-resolution MRI images (figure 10). While the method's long acquisition times may present a practical limitation, it offers the advantage of simultaneously estimating both Fat Fraction and T2-relaxation. Additionally, Trinh (2020) highlighted significant differences in subcutaneous adipose tissue distribution between Iraqi men and Swedish-born men in Sweden, although no significant differences were found in their VAT. This finding underscores the potential influence of ethnic factors on predispositions to certain clinical conditions.

Figure 10. Example of MRI axial scan plane, T2 weighted, representing the subcutaneous adipose tissue areas, the visceral adipose tissue areas and the superficial ones. Source: Trinh (2020).



Below, in figure 11, there is the representation of the MUFA (Monounsaturated fatty acid), SFA (Saturated fatty acid), and PUFA (Polyunsaturated fatty acid) distribution of MRI between the different ethnic backgrounds.

Figure 11. Example of SFA, MUFA and PUFA maps of two subjects representing a Iraqi born (a) and a Swedish born (b) men. Source: Trinh (2020).



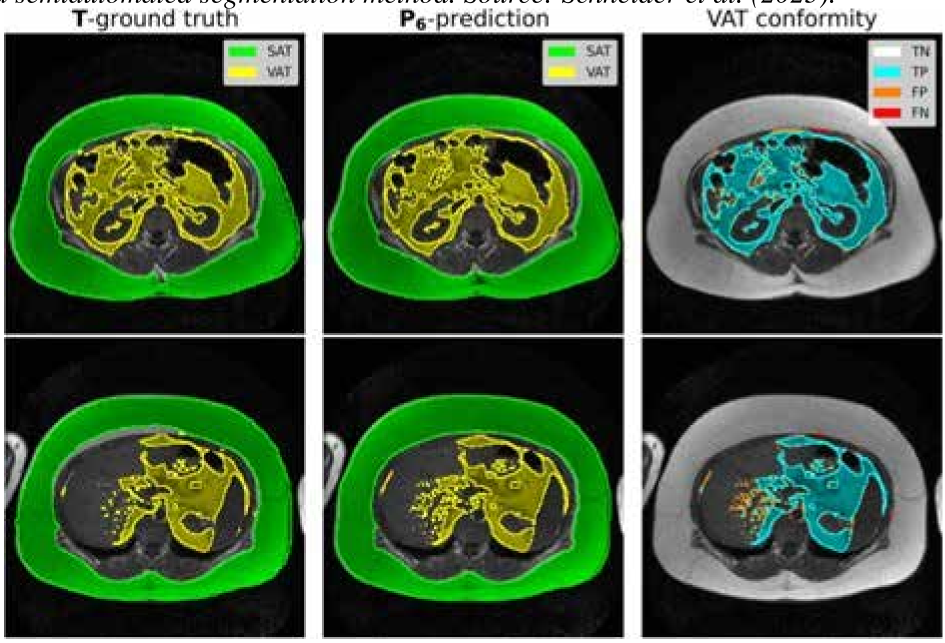
Muscle Evaluation

MRI is also capable of evaluating muscle composition, including the quantification of muscle fat infiltration (MFI) and lean muscle volumes. This is essential for assessing conditions like sarcopenia and evaluating the effectiveness of interventions such as exercise or dietary modifications (Labarthe et al., 2020). A study by West et al. (2018) tried to determine the precision of MRI based fat and muscle quantification in a group of postmenopausal women. In these 36 women, the scanned coefficient of variation was 1.1% to 1.5% for abdominal fat compartments (visceral and subcutaneous), 0.8% to 1.9% for volumes of muscle groups (thigh, lower leg, and abdomen), and 2.3% to 7.0% for individual muscle volumes (pectoralis, latissimus, and rhomboideus). This showed that advanced MRI techniques can segment individual muscle groups and provide detailed analysis, making it a powerful tool for targeted interventions and monitoring of muscle-related diseases (West et al., 2018).

Automated and AI-driven Assessments

Recent advancements have incorporated deep learning models to automate the segmentation and analysis of MRI data, improving the efficiency and consistency of body composition measurements (Zopfs et al., 2020). These models depicted in Figure 12 have demonstrated high accuracy in differentiating between various tissue types, including subcutaneous fat, visceral fat, and muscle (Schneider et al., 2023).

Figure 12. Whole-abdominal image data annotated for SAT and VAT amounts using a semiautomated segmentation method. Source: Schneider et al. (2023).



This work of Schneider et al. (2023) evaluated to what extent fully convolutional networks may serve to automatically segment and quantify abdominal adipose tissue from MRI images. Whole-abdominal image data of 331 study patients were annotated for SAT and VAT amounts using a semiautomated segmentation method. The fully convolutional networks (FCN) based methods showed excellent SAT segmentation and quantification accuracy, and the corresponding agreement for VAT was very good.

In short, this work demonstrated that deep-learning approaches for adipose tissue quantification from MRI data are also feasible for patients with obesity. The resulting accuracy was equal to or better than that of operator-driven approaches with processing requiring substantially less time and effort.

MRI proved to be a reliable and precise method for the assessment of body composition, offering detailed and accurate measurements of visceral fat, subcutaneous fat, and muscle tissues. The use of MRI in this context is enhanced by advanced imaging techniques and AI-driven analysis, providing comprehensive insights into body composition which are critical for both clinical and research applications.

IMPLICATION ON HEALTHCARE AND ATHLETIC PERFORMANCE OPTIMIZATION

Previously in the chapter we tried to describe the contribution of each of the main imaging techniques for the assessment of body composition, each with their own characteristics, strengths and weaknesses. We also had some focus on the most pertinent research that was conducted in each of the imaging modalities and some real implications on patient´s real lives. In this section, we will try to summarize the main ones and their potential implication for the healthcare profession's practice and patients' real live potential impact.

Implications on Healthcare

Disease Management and Prevention

Medical imaging techniques like DEXA, CT, and MRI provide accurate assessments of body composition, crucial for diagnosing and managing conditions such as obesity, oncologic treatments, sarcopenia, and osteoporosis. Precise measurements of bone density, muscle mass, and fat distribution help tailor treatment plans and monitor disease progression or recovery.

Personalized Treatment Plans

Understanding an individual's specific body composition allows healthcare providers to customize interventions, whether for athletic purposes, weight management, rehabilitation, or disease treatment. For instance, body composition data can guide the optimization of pharmacological dosing, dietary adjustments, and exercise regimens.

Prognostic Value

Body composition data are predictive of health outcomes in several chronic conditions, including cardiovascular disease and diabetes. High visceral fat levels, for example, are linked to increased metabolic risk, while muscle mass can predict survival and recovery rates in cancer patients.

Enhanced Patient Monitoring

Regular monitoring of body composition can significantly impact clinical outcomes by allowing for early detection of adverse changes, enabling timely interventions. This is particularly relevant in the elderly or those undergoing significant weight loss or gain, where muscle and fat changes have significant health implications.

Implications on Athletic Performance Optimization

Training and Nutrition Adjustments

For athletes, detailed insights into muscle mass and fat distribution provided by imaging methods like MRI and ultrasound can optimize training and nutritional strategies. Adjustments can be made to enhance muscle performance, recovery, focused fat loss plans, and overall athletic output based on precise body composition data.

Injury Prevention and Rehabilitation

Imaging techniques help in identifying imbalances or changes in muscle and fat that might predispose athletes to injuries. Targeted interventions can then be designed to prevent injuries or aid in rehabilitation, also, the muscle and tendons measurement and evaluation could be helpful to predict muscular gain and strength and prevent and follow up lesions.

Energy Balance Monitoring

Studies, such as those using DEXA, have linked changes in body composition to energy balance and dietary intake over athletic training cycles. This helps in planning nutritional strategies that align with training demands, ensuring that athletes maintain optimal body composition for peak performance. In short, medical imaging's role in body composition analysis offers significant benefits across healthcare management and athletic performance optimization. As these technologies evolve, their integration into routine practice will likely expand, providing deeper insights into human health and performance optimization. Below we synthesized some data regarding the role of each imaging method and their specific contribution to body composition analysis.

CONCLUSION AND FUTURE RESEARCH DIRECTIONS

This chapter tried to outline the distinctive features and contributions of leading imaging modalities, emphasizing their role in precise body composition analysis and their potential impact on treatment options, clinical outcomes, and training strategies. DEXA is noted for its precise measurement of bone mineral density and body composition, essential in managing osteoporosis and obesity. Ultrasound is recognized for its safety, portability, and cost-effectiveness, offering vital real-time data for sports science and clinical diagnostics, enabling on-the-spot treatment adjustments. CT scans provide supreme detail in tissue differentiation but require cautious use due to high radiation doses, especially in non-emergency and repeated imaging scenarios. MRI delivers high-resolution images without ionizing radiation, ideal for detailed tissue analysis and frequent monitoring, though its high costs restrict widespread use. This chapter provides examples of how various medical imaging techniques can offer precise information on SAT, VAT, and the size and fiber architecture of muscles. Such data enable the optimization of physical training programs to enhance outcomes and prevent overload injuries. Additionally, these imaging techniques can contribute valuable insights into paediatric obesity, sarcopenia in the elderly (whether due to aging or physical inactivity) and help predict responses to oncologic treatments and pain management. Furthermore, they can assist in preventing surgical complications, such as burst abdomen or follow-up musculoskeletal interventions such as in Achilles tendonitis.

Future research should address current limitations such as device standardization, cost reduction, and improved accessibility of diagnostic tools. Key areas for exploration include integrating AI and machine learning to enhance imaging accuracy and predictive modeling, combining multi-modal imaging for comprehensive body composition assessment, and developing portable, low-cost imaging technologies for broader access. Longitudinal studies could provide insights into body composition changes over time, while improving precision in visceral fat measurement remains a critical focus. Additionally, ethical considerations surrounding data privacy and AI usage must be addressed, and imaging protocols should be customized for special populations to ensure accuracy and safety.

So, in conclusion, while each imaging modality has its specific advantages and limitations, an adequate choice and the collective use of these technologies could offer a robust framework for understanding and monitoring body composition. As healthcare continues to move towards more personalized and precision-based approaches, these imaging techniques will play an increasingly vital role. Further advancements in technology and research will undoubtedly expand their capabilities and applications, reinforcing the essential role of medical imaging in modern medicine and sports science.

REFERENCES

Aizuddin, A. N., Chan, C. M., Anwar, A. R., Ong, Y. X., & Chin, K. Y. (2021). Performance of Body Mass Index in Identifying Obesity Defined by Body Fat Percentage and Hypertension Among Malaysian Population: A Retrospective Study. *International Journal of General Medicine*, 14, 3251–3257. DOI: 10.2147/IJGM.S316360 PMID: 34267543

Banack, H. R., Wactawski-Wende, J., Hovey, K. M., & Stokes, A. (2018). Is BMI a Valid Measure of Obesity in Postmenopausal Women? *Menopause (New York, N.Y.)*, 25(3), 307–313. DOI: 10.1097/GME.0000000000000989 PMID: 29135897

Bartlett, J. D., Hatfield, M., Parker, B. B., Roberts, L. A., Minahan, C., Morton, J. P., & Thornton, H. R. (2020). DXA-Derived Estimates of Energy Balance and Its Relationship With Changes in Body Composition Across a Season in Team Sport Athletes. *European Journal of Sport Science*, 20(7), 859–867. DOI: 10.1080/17461391.2019.1669718 PMID: 31526240

Barua, R. (2024). Unleashing Human Potential: Exploring the Advantage of Biomechanics in Sport Performance. In *Global Innovations in Physical Education and Health*. IGI Global., DOI: 10.4018/979-8-3693-3952-7.ch015

Baum, T., Cordes, C., Dieckmeyer, M., Ruschke, S., Franz, D., Hauner, H., Kirschke, J. S., & Karampinos, D. C. (2016). MR-Based Assessment of Body Fat Distribution and Characteristics. *European Journal of Radiology*, 85(8), 1512–1518. DOI: 10.1016/j.ejrad.2016.02.013 PMID: 26905521

Bilsborough, J. C., Greenway, K., Opar, D., Livingstone, S., Cordy, J., & Coutts, A. J. (2014). The Accuracy and Precision of DXA for Assessing Body Composition in Team Sport Athletes. *Journal of Sports Sciences*, 32(19), 1821–1828. DOI: 10.1080/02640414.2014.926380 PMID: 24914773

Branco, M. G., Mateus, C., Capelas, M. L., Pimenta, N., Santos, T., Mäkitie, A., Ganhão-Arranhado, S., Trabulo, C., & Ravasco, P. (2023). Bioelectrical Impedance Analysis (BIA) for the Assessment of Body Composition in Oncology: A Scoping Review. *Nutrients*, 15(22), 1–29. DOI: 10.3390/nu15224792 PMID: 38004186

Bredella, M. A., Ghomi, R. H., Thomas, B. J., Torriani, M., Brick, D. J., Gerweck, A. V., Misra, M., Klibanski, A., & Miller, K. K. (2010). Comparison of DXA and CT in the Assessment of Body Composition in Premenopausal Women With Obesity and Anorexia Nervosa. *Obesity (Silver Spring, Md.)*, 18(11), 2227–2233. DOI: 10.1038/oby.2010.5 PMID: 20111013

Cao, K., Yeung, J., Arafat, Y., Qiao, J., Gartrell, R., Master, M., Yeung, J. M. C., & Baird, P. N. (2024). Using a New Artificial Intelligence-Aided Method to Assess Body Composition CT Segmentation in Colorectal Cancer Patients. *Journal of Medical Radiation Sciences*, jmrs.798. Advance online publication. DOI: 10.1002/jmrs.798 PMID: 38777346

da Silva, M. S., & Borges, J. L. (2020). SUN-650 Body Composition Assessment in Clinical Practice: Use in Rheumatoid Arthritis and Hypogonadism. *Journal of the Endocrine Society*, 4(1, Supplement_1), 56–56. DOI: 10.1210/jendso/bvaa046.111

Dallman, J., Herda, A., Cleary, C. J., Morey, T., Diederich, A., Vopat, B. G., & Vopat, L. M. (2023). A Brief Review of the Literature for Published Dual-Energy X-Ray Absorptiometry Protocols for Athletes. *Sports Health*, 16(5), 735–743. DOI: 10.1177/19417381231208204 PMID: 37953634

Fit 3D. (2024). *Visceral Fat Measurement*. https://www.fit3d.com/blog/visceral-fat-measurement

Franchi, M. V., Longo, S., Mallinson, J., Quinlan, J. I., Taylor, T., Greenhaff, P. L., & Narici, M. V. (2018). Muscle Thickness Correlates to Muscle Cross-Sectional Area in the Assessment of Strength Training-Induced Hypertrophy. *Scandinavian Journal of Medicine & Science in Sports*, 28(3), 846–853. DOI: 10.1111/sms.12961 PMID: 28805932

Garcia, M. B. (2019). Plan-Cook-Eat: A Meal Planner App with Optimal Macronutrient Distribution of Calories Based on Personal Total Daily Energy Expenditure. *2019 IEEE 11th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management (HNICEM)*, 1-5. https://doi.org/DOI: 10.1109/HNICEM48295.2019.9073490

Garcia, M. B., Mangaba, J. B., & Tanchoco, C. C. (2021a). Acceptability, Usability, and Quality of a Personalized Daily Meal Plan Recommender System: The Case of Virtual Dietitian. *2021 IEEE 13th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management (HNICEM)*, 1-6. https://doi.org/DOI: 10.1109/HNICEM54116.2021.9732056

Garcia, M. B., Mangaba, J. B., & Tanchoco, C. C. (2021b). Virtual Dietitian: A Nutrition Knowledge-Based System Using Forward Chaining Algorithm. *2021 International Conference on Innovation and Intelligence for Informatics, Computing, and Technologies (3ICT)*, 309-314. https://doi.org/DOI: 10.1109/3ICT53449.2021.9581887

Gigic, B., Nattenmüller, J., Schneider, M., Kulu, Y., Syrjala, K. L., Böhm, J., Schrotz-King, P., Brenner, H., Colditz, G. A., Figueiredo, J. C., Grady, W. M., Li, C. I., Shibata, D., Siegel, E. M., Toriola, A. T., Kauczor, H.-U., Ulrich, A., & Ulrich, C. M. (2020). The Role of CT-Quantified Body Composition on Longitudinal Health-Related Quality of Life in Colorectal Cancer Patients: The Colocare Study. *Nutrients*, 12(5), 1–14. DOI: 10.3390/nu12051247 PMID: 32353960

Gomez, M. G. A., Petil, E. D., Bermudo, G. L., & Sampan, F. P. (2024). Role of Kinesiology in Teaching Swimming as an Intervention to Address Hyperactivity among Children with ADHD. In *Global Innovations in Physical Education and Health*. IGI Global., DOI: 10.4018/979-8-3693-3952-7.ch014

Goodpaster, B. H., Thaete, F. L., & Kelley, D. E. (2000). Composition of Skeletal Muscle Evaluated with Computed Tomography. *Annals of the New York Academy of Sciences*, 904(1), 18–24. DOI: 10.1111/j.1749-6632.2000.tb06416.x PMID: 10865705

Grossi, M., & Riccò, B. (2017). Electrical Impedance Spectroscopy (EIS) for Biological Analysis and Food Characterization: A Review. *Journal of Sensors and Sensor Systems*, 6(2), 303–325. DOI: 10.5194/jsss-6-303-2017

Iketani, T., Kiriike, N., Nagata, T., & Yamagami, S. (1999). Altered Body Fat Distribution After Recovery of Weight in Patients With Anorexia Nervosa. *International Journal of Eating Disorders*, 26(3), 275–282. https://doi.org/10.1002/(sici)1098-108x(199911)26:3<275::aid-eat4>3.0.co;2-i

Labarthe, G., Dolores, M., Verdalle-Cazes, M., Charpentier, C., Roullee, P., Dacher, J.-N., Savoye, G., & Savoye-Collet, C. (2020). Magnetic Resonance Imaging Assessment of Body Composition Parameters in Crohn's Disease. *Digestive and Liver Disease*, 52(8), 878–884. DOI: 10.1016/j.dld.2020.06.024

Lee, Y. H., Park, J., Min, S., Kang, O., Kwon, H., & Oh, S.-W. (2020). Impact of Visceral Obesity on the Risk of Incident Metabolic Syndrome in Metabolically Healthy Normal Weight and Overweight Groups: A Longitudinal Cohort Study in Korea. *Korean Journal of Family Medicine*, 41(4), 229–236. DOI: 10.4082/kjfm.18.0122 PMID: 32344994

Lieber, R. L., & Fridén, J. (2000). Functional and Clinical Significance of Skeletal Muscle Architecture. *Muscle & Nerve*, 23(11), 1647–1666. DOI: 10.1002/1097-4598(200011)23:11<1647::AID-MUS1>3.0.CO;2-M PMID: 11054744

Liegnell, R., Wessman, F., Shalabi, A., & Harringe, M. (2021). Validity of Ultrasonography-Derived Predictions for Estimating Skeletal Muscle Volume: A Systematic Literature Review. *BMC Medical Imaging*, 21(1), 1–11. DOI: 10.1186/s12880-021-00638-9 PMID: 34229618

Lobo, M. D., & Miravent, S. (2022). Challenges in Ultrasonography Education and Training: Building Bridges for the Professional Practice of Radiographer in Portugal. In Almeida, R. P. P. (Ed.), *Handbook of Research on Improving Allied Health Professions Education: Advancing Clinical Training and Interdisciplinary Translational Research* (pp. 186–203). IGI Global., DOI: 10.4018/978-1-7998-9578-7.ch012

Lobo, M. D., Miravent, S., & Almeida, R. P. P. d. (2024). Emerging Trends in Ultrasound Education and Healthcare Clinical Applications: A Rapid Review. In *Emerging Technologies for Health Literacy and Medical Practice*. IGI Global., DOI: 10.4018/979-8-3693-1214-8.ch013

Ly, K. V., Armstrong, T., Yeh, J., Ghahremani, S., Kim, G. H., Wu, H. H., & Calkins, K. L. (2019). Free-Breathing Magnetic Resonance Imaging Assessment of Body Composition in Healthy and Overweight Children. *Journal of Pediatric Gastroenterology and Nutrition*, 68(6), 782–787. DOI: 10.1097/MPG.0000000000002309 PMID: 30789865

Marín-Baselga, R., Sanz-Ortega, C., Platero-Dueñas, L., Sorriguieta-Torre, R., Palma-Milla, S., & Tung-Chen, Y. (2023). Nutritional Assessment by Ultrasound of the Rectus Femoris and Preperitoneal Adipose Tissue as Predictors of Hospitalized Patient Complications. *Revista Clínica Española*, 223(10), 640–646. DOI: 10.1016/j.rceng.2023.10.002 PMID: 37865334

Maskarinec, G., Shvetsov, Y. B., Wong, M. C., Garber, A., Monroe, K., Ernst, T. M., Buchthal, S. D., Lim, U., Le Marchand, L., Heymsfield, S. B., & Shepherd, J. A. (2022). Subcutaneous and Visceral Fat Assessment by DXA and MRI in Older Adults and Children. *Obesity (Silver Spring, Md.)*, 30(4), 920–930. DOI: 10.1002/oby.23381 PMID: 35253409

Mehdorn, M., Schnarkowski, B., Moulla, Y., Pape, J., Denecke, T., Gockel, I., Kassahun, W. T., & Meyer, H.-J. (2023). Visceral Obesity Determined in Routine Preoperative CT Scans Predicts Risk of Postoperative Burst Abdomen. *Scientific Reports*, 13(1), 1–6. DOI: 10.1038/s41598-023-48714-0 PMID: 38052856

Mishra, N., Habal, B. G. M., Garcia, P. S., & Garcia, M. B. (2024). Harnessing an AI-Driven Analytics Model to Optimize Training and Treatment in Physical Education for Sports Injury Prevention. *Proceedings of the 2024 8th International Conference on Education and Multimedia Technology*, 309–315. https://doi.org/ DOI: 10.1145/3678726.3678740

Morris, G. R., Brožovský, M., Ye, J., & Wang, K. (2024). Physical Education Innovations in Transnational Higher Education Sports Training Provision in China: Challenges, Opportunities, and Best Practices. In *Global Innovations in Physical Education and Health*. IGI Global., DOI: 10.4018/979-8-3693-3952-7.ch012

Müller, W., Lohman, T. G., Stewart, A. D., Maughan, R. J., Meyer, N. L., Sardinha, L. B., Kirihennedige, N., Reguant-Closa, A., Risoul-Salas, V., Sundgot-Borgen, J., Ahammer, H., Anderhuber, F., Fürhapter-Rieger, A., Kainz, P., Materna, W., Pilsl, U., Pirstinger, W., & Ackland, T. R. (2016). Subcutaneous Fat Patterning in Athletes: Selection of Appropriate Sites and Standardisation of a Novel Ultrasound Measurement Technique: Ad Hoc Working Group on Body Composition, Health and Performance, Under the Auspices of the Ioc Medical Commission. *British Journal of Sports Medicine*, 50(1), 45–54. DOI: 10.1136/bjsports-2015-095641 PMID: 26702017

Ofenheimer, A., Breyer-Kohansal, R., Hartl, S., Burghuber, O. C., Krach, F., Schrott, A., Wouters, E. F. M., Franssen, F. M. E., & Breyer, M.-K. (2020). Reference Values of Body Composition Parameters and Visceral Adipose Tissue (VAT) by DXA in Adults Aged 18–81 Years—Results From the LEAD Cohort. *European Journal of Clinical Nutrition*, 74(8), 1181–1191. DOI: 10.1038/s41430-020-0596-5 PMID: 32123345

Paris, M. T. (2019). Body Composition Analysis of Computed Tomography Scans in Clinical Populations: The Role of Deep Learning. *Lifestyle Genomics*, 13(1), 28–31. DOI: 10.1159/000503996 PMID: 31822001

Park, S. S., Lim, S., Kim, H., & Kim, K. M. (2021). Comparison of Two DXA Systems, Hologic Horizon W and GE Lunar Prodigy, for Assessing Body Composition in Healthy Korean Adults. *Endocrinology and Metabolism (Seoul, Korea)*, 36(6), 1219–1231. DOI: 10.3803/EnM.2021.1274 PMID: 34911173

Phillips, B., Buchholtz, K., & Burgess, T. L. (2022). Gastrocnemius Muscle Architecture in Distance Runners With and Without Achilles Tendinopathy. *South African Journal of Sports Medicine*, 34(1), 1–6. DOI: 10.17159/2078-516X/2022/v34i1a12576 PMID: 36815930

Sbrignadello, S., Göbl, C., & Tura, A. (2022). Bioelectrical Impedance Analysis for the Assessment of Body Composition in Sarcopenia and Type 2 Diabetes. *Nutrients*, 14(9), 1–30. DOI: 10.3390/nu14091864 PMID: 35565832

Schneider, D., Eggebrecht, T., Linder, A., Linder, N., Schaudinn, A., Blüher, M., Denecke, T., & Busse, H. (2023). Abdominal Fat Quantification Using Convolutional Networks. *European Radiology*, 33(12), 8957–8964. DOI: 10.1007/s00330-023-09865-w PMID: 37436508

Takai, Y., Ohta, M., Akagi, R., Kato, E., Wakahara, T., Kawakami, Y., Fukunaga, T., & Kanehisa, H. (2014). Applicability of Ultrasound Muscle Thickness Measurements for Predicting Fat-Free Mass in Elderly Population. *The Journal of Nutrition, Health & Aging*, 18(6), 579–585. DOI: 10.1007/s12603-013-0419-7 PMID: 24950147

Tantisattamo, E., Sy, J., Kim, J.-C., Kopple, J. D., & Kalantar-Zadeh, K. (2022). Assessment and Risk Factors for Protein-energy Wasting and Frailty in Chronic Kidney Disease. In Kopple, J. D., Massry, S. G., Kalantar-Zadeh, K., & Fouque, D. (Eds.), *Nutritional Management of Renal Disease* (4th ed., pp. 165–189). Academic Press., DOI: 10.1016/B978-0-12-818540-7.00053-7

Toombs, R. J., Ducher, G., Shepherd, J. A., & De Souza, M. J. (2012). The Impact of Recent Technological Advances on the Trueness and Precision of DXA to Assess Body Composition. *Obesity (Silver Spring, Md.)*, 20(1), 30–39. DOI: 10.1038/oby.2011.211 PMID: 21760631

Trinh, L. (2020). *MRI-Based Methods for Quantification of Fat and Fatty Acid Composition. Validation and Applications*. Lund University. https://lup.lub.lu.se/search/files/79298727/MRI_based_FAC_quantification_Thesis_Lena_Trinh.pdf

West, J., Romu, T., Thorell, S., Lindblom, H., Berin, E., Holm, A.-C. S., Åstrand, L. L., Karlsson, A., Borga, M., Hammar, M., & Leinhard, O. D. (2018). Precision of MRI-Based Body Composition Measurements of Postmenopausal Women. *PLoS One*, 13(2), 1–16. DOI: 10.1371/journal.pone.0192495 PMID: 29415060

Wickramasinghe, V. P., Cleghorn, G. J., Edmiston, K. A., Murphy, A. J., Abbott, R. A., & Davies, P. S. W. (2005). Validity of BMI as a measure of obesity in Australian white Caucasian and Australian Sri Lankan children. *Annals of Human Biology*, 32(1), 60–71. DOI: 10.1080/03014460400027805 PMID: 15788355

Yang, Y. B., Zhang, J., Leng, Z. P., Chen, X., & Song, W. Q. (2014). Evaluation of Spasticity After Stroke by Using Ultrasound to Measure the Muscle Architecture Parameters: A Clinical Study. *International Journal of Clinical and Experimental Medicine*, 7(9), 2712–2717. https://pubmed.ncbi.nlm.nih.gov/25356129/ PMID: 25356129

Zhou, Y., Li, J.-Z., Zhou, G., & Zheng, Y.-P. (2012). Dynamic Measurement of Pennation Angle of Gastrocnemius Muscles During Contractions Based on Ultrasound Imaging. *Biomedical Engineering Online*, 11(1), 1–10. DOI: 10.1186/1475-925X-11-63 PMID: 22943184

Zopfs, D., Bousabarah, K., Lennartz, S., Santos, D. P., Schlaak, M., Theurich, S., Reimer, R. P., Maintz, D., Haneder, S., & Große Hokamp, N. (2020). Evaluating Body Composition by Combining Quantitative Spectral Detector Computed Tomography and Deep Learning-Based Image Segmentation. *European Journal of Radiology*, 130, 109153. Advance online publication. DOI: 10.1016/j.ejrad.2020.109153 PMID: 32717577

KEY TERMS AND DEFINITIONS

Bioelectrical Impedance Analysis: A method for estimating body composition, particularly body fat and muscle mass, by measuring the resistance of body tissues to electrical currents.

Dual-energy X-ray Absorptiometry: A technique used to measure bone mineral density and body composition, including fat and lean body mass.

Fat-Free Mass: The total body mass minus the fat mass, consisting of muscles, bones, water, and other tissues.

Hounsfield Units: A quantitative scale for describing radiodensity in medical CT scans, with water assigned a value of 0 and air a value of -1000.

Muscle Fat Infiltration: The presence of fat within muscle tissue, often assessed through imaging techniques, indicating changes in muscle quality and health.

Magnetic Resonance Imaging: A medical imaging technique that uses magnetic fields and radio waves to create detailed images of the organs and tissues within the body.

Superficial Adipose Tissue: Fat tissue located just beneath the skin, as opposed to visceral fat which is stored around internal organs.

Subcutaneous Obesity: Excess fat accumulation under the skin, often measured to assess overall body fat and obesity risk.

Total Fat Area: The total area covered by fat tissue in a specific region of the body, commonly measured in imaging studies.

Visceral Adipose Tissue: Fat tissue located around internal organs, associated with a higher risk of metabolic and cardiovascular diseases.

Visceral Fat Index: A measurement used to quantify the amount of visceral fat, typically calculated using imaging techniques like CT or MRI.

Visceral Obesity: Excess accumulation of visceral fat, which is associated with increased health risks, including cardiovascular disease and diabetes.