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FROM DUAL ENERGY X-RAY ABSORPTIOMETRY OT POSITRON EMISSION TOMOGRAPHY: DIVERSE IMAGING APPROACHES TO BODY COMPOSITION

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ABSTRACT
Accurate body composition assessment is crucial for diagnosing and managing health issues such as obesity, osteoporosis, and metabolic disorders. Diverse imaging approaches, including DXA, US, CT, MRI, and PET, each offer unique insights into body composition. By exploring these diverse imaging methods, clinicians and researchers can achieve a comprehensive understanding of body composition, leading to enhanced diagnostic accuracy and more personalized treatment strategies. Comprehensive understanding of various imaging techniques such as Dual Energy X-ray Absorptiometry (DXA), Ultrasonography (US), Computed Tomography (CT), Magnetic Resonance Imaging (MRI) and Positron Emission Tomography (PET) in body composition analysis. Body composition analysis utilizes several imaging techniques to provide a comprehensive assessment. DXA is used to measure bone mineral density and differentiate between fat and lean mass by analyzing how X-rays are absorbed at two different energy levels. US uses high-frequency sound waves to create real-time images of soft tissues, enabling the measurement of muscle thickness and fat layers. CT scans offer detailed cross-sectional images of fat and muscle distribution, while MRI produces high-resolution images of soft tissues without radiation. PET scans use radiotracers to monitor metabolic activity and detect functional changes in tissues.The exploration of diverse imaging approaches reveals the strengths and limitations of each method in body composition analysis. DXA is gaining popularity among clinicians for body composition analysis because it provides accurate measurements of lean and fat mass, similar to CT and MRI, but at a lower cost and with less invasiveness. Its widespread availability and precision in assessing both bone mineral density and soft tissue composition across the entire body or specific regions make DXA a valuable tool for managing osteoporosis and studying changes in body composition in various health conditions.

Keywords: body composition; dual energy X-ray absorptiometry; fat distribution; imaging techniques

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INTRODUCTION

Aging and obesity are two trends in developed countries that are increasing in parallel within the population. Diseases with high mortality and morbidity rates, such as cardiovascular disease, osteoporosis, and metabolic disorders, commonly occur in obese and aging individuals (Andreolli et al., 2016). Accurate body composition assessment is necessary for early diagnosis and management of these health problems. Various imaging approaches, including DXA, US, CT, MRI, and PET, each offer unique insights into body composition (BC). By exploring these diverse imaging methods, clinicians and researchers can achieve a comprehensive understanding of body composition, leading to improved diagnostic accuracy and more personalized treatment strategies. The objective of this study are comprehensive understanding of various imaging techniques such as Dual Energy X-ray Absorptiometry (DXA), Ultrasonography (US), Computed Tomography (CT), Magnetic Resonance Imaging (MRI), and Positron Emission Tomography (PET) in body composition analysis. The important with the study about; firstly, understand the strengths and limitations of each imaging technique (DXA, US, CT, MRI, PET) for measuring body composition (fat mass, lean mass, bone density). Second, Inform diagnosis, treatment, and monitoring of conditions like obesity, osteoporosis, sarcopenia, and metabolic disorders. Third, Advance understanding of body composition's role in health and disease.

METHOD

This research was a case study that describing about Body composition analysis utilizes several imaging techniques to provide a comprehensive assessment.

Procedure Details

Body composition analysis utilizes several imaging techniques to provide a comprehensive assessment, each with its own advantages and limitations (Table 1). In selecting a method, healthcare practitioners must consider cost (equipment and personnel), potential radiation exposure, time required to obtain the information, and the accuracy of the information obtained (Blue et al., 2015).

Table 1.
Several imaging methods that can be used in measuring *BC*

No	Types of Methods	Measurement	Excess	Limitations
1.	*Dual Energy X-ray Absorptiometry* (*DXA)*	• Appendicular muscle mass (APM) • Appendicular muscle mass index (ALMI)	• Most appropriate • Most accurate and reproducible • Fast • Provides information on total and regional fat percentages • Widely available • Validated limit values • Minimal irradiation • Cheap	• Not *portable* • The results vary depending on the densitometer brand. • Depends on hydration status • Two-dimensional data
2.	*Ultrasonography* (*US)*	• CSA indexed by height2 (SMI) • Muscle thickness and echogenicity	• Real-time imaging • Quick acquisition • Widely available • No radiation exposure • Cheap	• Almost unreproducible • Poor accuracy • There is no validated cutoff value for sarcopenia.
3.	*Computed Tomography scan* (*CT)*	• CSA indexed by height2 (SMI) • Attenuation value	• Quick acquisition • Widely available • Accurate and reproducible • High spatial resolution	• Time-consuming segmentation process • Irradiation that cannot be ignored • The cut-off value is still not used in clinical practice. • Expensive
4.	*Magnetic Resonance Imaging* (*MRI)*	• CSA indexed by height2 (SMI) • Fat content in DIXON • Advanced sequence experimental measurements (ADC relaxation time, FA, T2 relaxation time)	• Accurate and reproducible • No irradiation • High contrast resolution • Ability to identify muscle edema and fatty infiltration • Promising a sequel sequence	• Long acquisition time • There is no validated cutoff value for sarcopenia. • Expensive • Lower availability • Post-processing of long advanced sequences
5.	*Positron Emission Tomography scan* (*PET)*	• Fat metabolism	• Accurate • Measuring body fat compartments and metabolism including brown fat	• Expensive • Radiation

Sumber: (Andreolli et al., 2009; Chianca et al., 2021; Wang et al., 2014)

RESULT

Dual Energy X-ray Absorptiometry is the most commonly used imaging technique for estimating body composition, consisting of a whole-body scan performed with an X-ray source emitting two different energy levels (40 and 70 keV). [3] The radiation dose varies, typically around 5 μSv, making *DXA* a safe choice for body composition assessment. *DXA* allows for the simultaneous measurement *of lean mass* (*LM)*, *fat mass* (*FM)*, and *bone mineral content* (*BMC) (Albanese et al., 2003). DXA* defines *body composition* as three substances that have specific X-ray attenuation properties: bone mineral, lipids (triglycerides, membrane phospholipids, and others), and lipid-free soft tissue (Chaves et al., 2022). Fat is chemically described as lipids in the body that are soluble in organic solvents but not in water; the largest category of body fat is triglycerides found in adipocytes. Non-lipid soft tissue mass is the sum of body water, protein, glycerol, and soft tissue mineral mass. For each *pixel* in a *DXA image,* these three mass components are quantified (Figure 1) (Knapp et al., 2015).

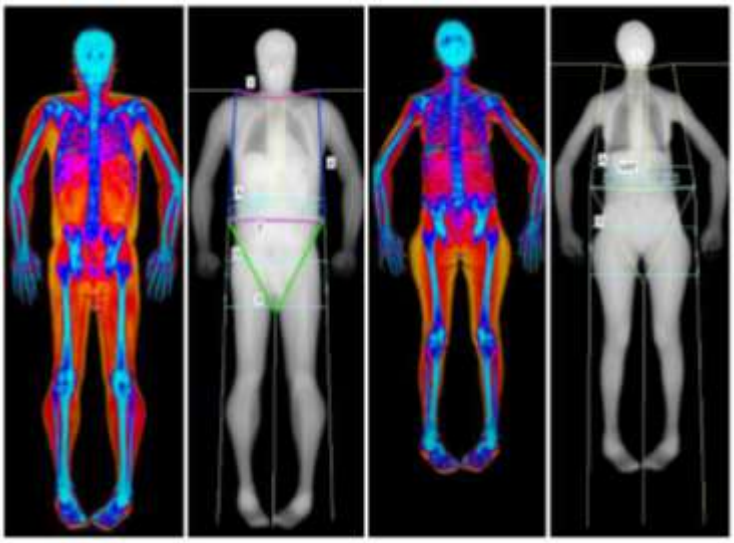

Figure 1. A visual comparison of a young man (left) with a middle-aged woman (right) clearly illustrates the differences in fat distribution (represented in yellow), with the woman exhibiting the characteristic gynoid distribution around the hips and thighs. The head line (number 1) should be placed below the jaw; the pelvic line (number 2) should be placed directly above the iliac crest; two groin lines (number 3, in green) should bisect the femoral neck on each side; the trunk line (number 4, in blue) separates the arm region from the android region of the trunk, and should pass through the gleno-humeral joint along each side of the trunk. A, android region; G, gynoid region; VAT, visceral adipose tissue (Messina et al., 2020).

Ultrasonography (*US)*

Ultrasonography is a portable, inexpensive, non-invasive imaging modality without ionizing radiation that is widely used to investigate musculoskeletal conditions. *US* has proven useful in assessing muscle quality and quantity as an accurate technique for estimating muscle properties, showing strong positive correlations with *DXA, CT,* and *MRI- based measurements (Wang et al., 2014)*. Previous studies have shown good intra- and inter-rater reliability in both elderly and younger populations. *US* also provides information on muscle echotexture depending on the degree of intramuscular fat and connective tissue infiltration (Figure 2). There are five components that can be easily measured when assessing muscle components in sarcopenia patients: muscle thickness, *pennation angle*, fascicle length, echogenicity, and *cross-sectional areas* (*CSA)* (Chianca et al., 2021).

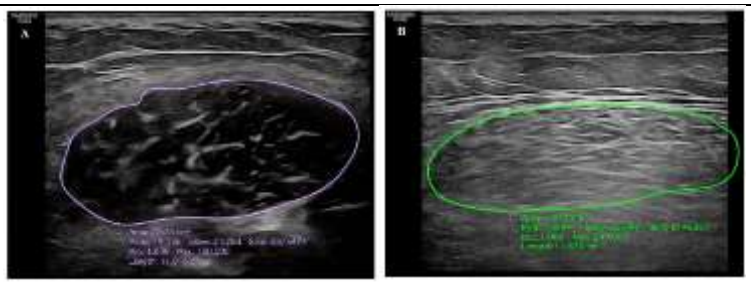

Figure 2. *Transverse* USG images of the proximal third of *the* rectus femoris in two female patients of similar age and *BMI.* A, the rectus femoris is visible in a 38-year-old female runner (*BMI* 24.2). B, the anterior rectus femoris is visible in a 42-year-old female patient who does not perform any physical exercise (*BMI* 25.1). Although there is a similarity in muscle trophism (*CSA* in patient A is 7,575 cm2, B is 7,351 cm2), there is increased echogenicity in the muscle belly seen in patient B, who has limited physical activity due to *fatty infiltration* (Chianca et al., 2021).

Computed Tomography scan* (*CT scan)

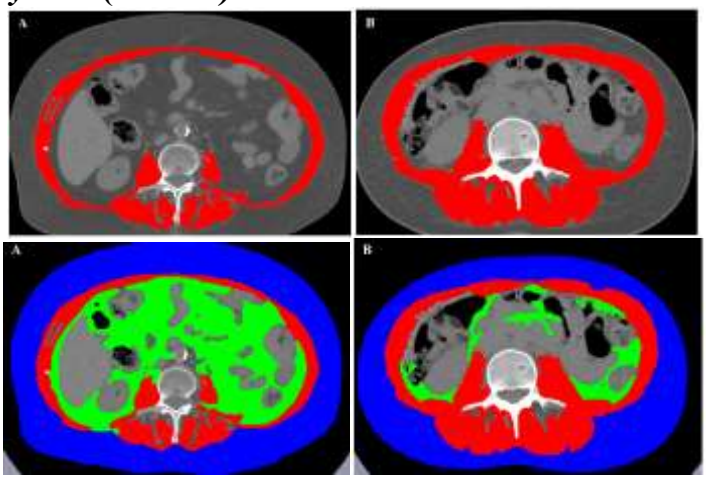

Figure 3. *CT* images of patients with sarcopenia (A) and non-sarcopenia (B). Skeletal muscle area (red) is reduced in patient A, which is especially visible in the paraspinal muscles, which appear larger and less infiltrated by intramuscular fat. *Skeletal muscle index* is measured using *CSA* and height (*CSA* /TB $^{2)}$ in patient A 38 cm ^{2} /m ^{2} and B 58 cm ^{2} /m $^{2.}$ *Body composition* on *CT* of sarcopenia (A) and non-sarcopenia (B) patients. Skeletal muscle area (red), visceral adipose tissue (green), and subcutaneous adipose tissue (blue) 3.(Chianca et al., 2021).

Magnetic Resonance Imaging* (*MRI)

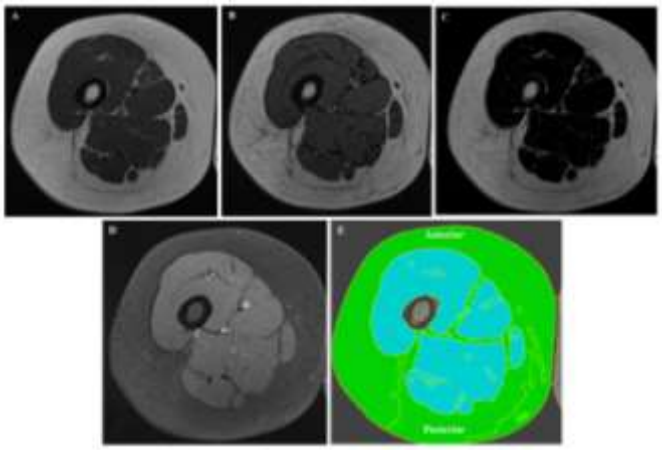

Figure 4. Dixon MRI sequence of the thigh of a 62-year-old female patient. (A) axial T1WI *in phase,* (B) *out phase,* (C) 100% *fat images,* (D) 100% *water images.* After *post-processing,* a semi-automatic segmentation was obtained (E) showing fat (green) and muscle (turquoise) separately in one slice 3.(Chianca et al., 2021).

Positron Emission Tomography scan (PET)

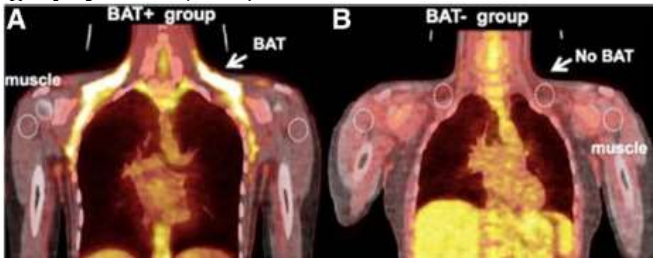

Figure 5. A. Representative images of subjects with high fluorodeoxy-d-glucose (FDG) uptake in *brown adipose tissue* (*BAT)*. B. Representative images of subjects from the *BAT*- negative group. Absence of FDG uptake in BAT sites after cold exposure (Wang et al., 2014).

DISCUSSION

Dual Energy X-ray Absorptiometry (DXA)

DXA software allows one to determine the mineral composition of bone and soft tissue in various body regions. Bone mineral composition can be determined by scanning the spine, hip, arm, or entire body (Knapp et al., 2015). Soft tissue composition can only be determined from whole-body scans, which can then be analyzed to measure *BC* in specific regions of the scan, such as the arms, legs, and trunk (Salomon-Gomez et al., 2023). The accuracy of a specific *DXA* device for assessing whole-body *BC* is generally good, with a coefficient of variation of approximately 1% for *BMC* and 2–3% for total body fat. [10] The depth of the tissue measured can vary from approximately 1 to 30 cm (Van der Sluis et al, 2002).

Ultrasonography (US)

The majority of studies have been conducted on the anterior compartment of the femur, while only a few have focused on other muscles, such as postural muscles. When measuring maximal thickness and *CSA* of a muscle, it is recommended to take the midpoint between the tendons and the midpoint between the medial and lateral borders *of the muscle belly. The pennation angle* and length of muscle fascicles should be assessed during rest and contraction, which are significantly associated with the loss of maximal force and shortening velocity of muscle fibers in patients with sarcopenia (Price & Earthman, 2018). Therefore, the tilt of muscle fascicles and their rotation within the muscle belly allow them to be oriented at a slower contraction velocity than the muscle belly, thus providing a higher force potential (Blue et al., 2015). *Ultrasound* elastography has been proposed as an investigative tool for muscle stiffness using shear wave elastography and correlated with lower stiffness values in lower and upper limb skeletal muscles in the elderly. Although *ultrasound* has shown promising results in the investigation of sarcopenia, the lack of standard cutoff values severely limits its validation for clinical practice. [1]

Computed Tomography scan (CT scan)

Computed tomography scans are increasingly used in research trials as a routine diagnostic tool for assessing muscle quantity and quality, given that decreased muscle density is associated with the degree of fatty infiltration. This imaging technique has the advantage of being used for staging and follow-up of tumors and various other disorders, allowing for prospective or retrospective assessment of sarcopenia without the need for additional scans(Chianca et al., 2021). To assess muscle mass and quality, it is possible to draw *regions of interest* (*ROIs)* that are traced to evaluate the cross- *sectional area* (*CSA)* and skeletal muscle attenuation values. A valid and accurate approach to estimating muscle and whole-body composition is to draw *ROIs* on a single axial *CT slice* to obtain *the CSA,* applying a standard threshold (-29 HU / +150 HU) to include only muscle tissue during post-segmentation processing; on the other hand, a threshold for adipose tissue (-190 HU / -30 HU) is applied to assess the amount of intermuscular fat tissue. In most studies, segmentation was performed at *L3* or *L4* and *the ROI* included the psoas muscle or all the muscles present (paraspinous, psoas, abdominal) on the same slice (Paris, 2019). *CT* slice it is also possible to calculate information regarding visceral adipose tissue and subcutaneous tissue obtaining *CT*

body composition (Figure 3). It is important to emphasize that non-contrast images should be used because muscle attenuation values increase after intravenous contrast medium injection. *CSA* is generally indexed to height (*CSA / height* $^{2)}$ to obtain a skeletal muscle index at L3 ranging from 52-55 cm2/m2 for men and from 39-41 cm2/m2 for women (Chianca et al., 2021).

Magnetic Resonance Imaging* (*MRI)

MRI allows for the assessment of muscle composition using several semiquantitative or quantitative sequences without the need for ionizing radiation (Figure 4). Although *MRI* can be used to measure skeletal muscle *CSA, advanced sequences MRI* allows for combined body composition estimation and evaluation of muscle quality abnormalities, such as muscle disorders, edema, fatty infiltration (myosteatosis), or fibrosis (myofibrosis). ^{Three} sequences that can be used include: T2 *mapping* has been proposed as an imaging marker for fatty changes in skeletal muscle tissue because it allows objective, comparable, and precise assessment of small changes in muscle fiber composition. Multiecho sequences are used to generate T2 *maps,* by acquiring multiple echoes from the same image with *pixel* -by- *pixel adjustment* of the T2 relaxation curve. Measurement of T2 relaxation time can be used to identify pathological increases in T2 values of fattyly infiltrated muscles in patients with sarcopenia due to microstructural changes.

- *MR Spectroscopy* is a non-invasive functional imaging technique that provides information about biochemical processes within the body.
- The Dixon sequence overcomes the limitations of *MR spectroscopy applications* due to the inhomogeneity of fatty muscle infiltration, thus allowing a precise quantitative assessment of sarcopenia. From a technical point of view, a two- or multipoint Dixon sequence offers the possibility of obtaining two separate " *fat-only* " and " *water-only* " images, by acquiring two or more echoes at different echo times. The first acquisition is performed at an echo time when the fat and water protons are in phase, while the second acquisition is then performed at an echo time when the protons are out of phase. Furthermore, another advantage is the possibility of combining Dixon with different sequence types, both *gradient* and *spin echo,* and with different weightings (T1-w, T2-w, or PD-w). Studies have shown that Dixon exhibits high accuracy in the detection and quantification of fat replacement in muscle in patients with dystrophy or diabetes mellitus. However, this sequence requires a long acquisition time and is sensitive to metal artifacts in cases of prosthesis use.
- *Diffusion Tensor Imaging* (*DTI)* is *an advanced MRI technique* traditionally used to track fiber pathways in the central nervous system, offering the possibility of detecting and quantifying fatty tissue replacement in muscle fibers. Fractional anisotropy is a parameter, ranging between 0 and 1, used to measure the directional orientation of water molecules as an indirect indicator of fiber microstructural changes.

Although *MRI* is a promising technique, with the advantages of no radiation exposure and excellent accuracy in measuring quantitative and qualitative parameters of skeletal muscle, *MRI* is still limited to the research stage and is rarely applied in clinical practice due to its high cost, long acquisition time, and lack of cut-off values and standard protocols (Murata et al., 2022).

Positron Emission Tomography scan* (*PET)

Although *CT* and *MRI* are highly informative in quantifying fat within organs, their analysis is largely limited to fat volume. These techniques have reinforced the importance of anatomical, regional, and fat heterogeneity. However, it remains unclear why certain fat sites are more harmful than others. In vivo imaging techniques that can provide specific metabolic information on specific fat storage sites could significantly enhance our understanding of human adipose tissue (Messina et al., 2020). Positron emission tomography (*PET)* detects the emission of γ-rays from molecules labeled with a positron-emitting tracer. An image is then constructed to reveal a dimensional representation of the tracer's activity at a specific location of interest. A widely used tracer is the glucose analog, 2-fluorodeoxy-D-glucose (2FDG). The concentration of this tracer reflects tissue glucose uptake, serving as a surrogate for tissue metabolic activity. *PET* may be useful in fat phenotyping and has been used to track increased metabolic activity *in brown adipose tissue* (Figure 5) (Wang et al., 2014).

CONCLUSION

An exploration of various imaging approaches reveals the strengths and limitations of each method in body composition analysis. DXA is gaining popularity among clinicians for body composition analysis because it provides accurate measurements of fat and lean mass, similar to CT and MRI, but at a lower cost and less invasive. Its widespread availability and precision in assessing both bone mineral density and soft tissue composition throughout the body or specific areas make DXA a valuable tool for managing osteoporosis and studying changes in body composition in both health and disease.

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