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Sarcopenia: Definition, Radiological Diagnosis and Clinical Significance

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Sarcopenia: Definition, Radiological Diagnosis and Clinical Significance

Abstract

Sarcopenia, defined as the progressive loss of skeletal muscle mass, strength and physical performance, is an increasingly relevant clinical condition due to its strong association with heightened morbidity, disability and healthcare burden. This review summarizes the evolution of sarcopenia's definition, most recently updated by the European Working Group on Sarcopenia in Older People (EWGSOP) and emphasizes the critical role of radiological imaging in its diagnosis and monitoring. Particular attention is given to patients with osteoporotic vertebral compression fractures (OVCFs), a particularly vulnerable population in which sarcopenia is associated with poorer functional recovery, higher complication rates and increased risk of refracture following vertebral augmentation procedures such as percutaneous vertebroplasty (PVP) and kyphoplasty (PKP). A comprehensive narrative review of the literature up to June 2025 was conducted, focusing on studies, evaluating sarcopenia in OVCF patients treated with PVP or PKP, with particular attention to diagnostic imaging modalities (CT, MRI, DXA, and bioelectrical impedance analysis), anatomical landmarks (e.g., T12), muscle indices (skeletal muscle index, psoas muscle index, psoas-to-lumbar vertebral index, appendicular muscle index), and functional parameters (handgrip strength, gait speed). Radiological techniques each present specific advantages and limitations: DXA is widely available and validated but limited in assessing muscle quality; CT allows opportunistic screening and precise tissue analysis, increasingly enhanced by artificial intelligence for automated muscle segmentation and risk stratification; MRI provides high-resolution characterization of muscle composition without ionizing radiation although standardization and cost remain limiting factors; and ultrasound, while promising due to its portability and low cost, is still limited by operator dependence and lack of standardized protocols. Across studies on vertebral augmentation, sarcopenia definitions were inconsistent, limiting data comparability and clinical utility. A standardized diagnostic approach is therefore recommended, integrating low muscle mass measured by CT at the T12 level (e.g., skeletal muscle index), reduced muscle strength (e.g., handgrip), and impaired physical performance (e.g., gait speed).Sarcopenic patients undergoing PVP or PKP may benefit from multidisciplinary management strategies including nutritional support, resistance and balance training, and comorbidities, in order to reduce refracture risk and improve recovery. Establishing unified diagnostic criteria and leveraging radiological imaging and AI will be critical to improve early detection, guide treatment decisions, and improving clinical outcomes in this high-risk population. Implementing a shared and standardized assessment of sarcopenia in vertebral fracture patients holds significant potential to optimize preoperative planning, postoperative care, and long-term management.

Keywords: Sarcopenia, Radiological imaging, DXA, CT, MRI, US, Body Composition

Introduction

Sarcopenia is a progressive loss of skeletal muscle mass and strength, contributing to reduced physical performance and an increased risk of falls, fractures, disability, and mortality, particularly among older adults [1]. In 2018, the European Working Group on Sarcopenia in Older People (EWGSOP2) updated its definition, prioritizing muscle strength as the primary indicator of probable sarcopenia and recognizing skeletal muscle as a secretory organ with endocrine function. With the progressive aging of the global population, sarcopenia has emerged as a relevant clinical condition and a potential imaging biomarker for predicting clinical outcomes [2]. In this context radiological techniques, such as dual-energy X-ray absorptiometry (DXA), computed tomography (CT), and Magnetic resonance imaging (MRI) play a central role in the quantitative and qualitative assessment of muscle tissue [3,4]. However, variability in acquisition protocols, measurement techniques and diagnostic cut-offs still represents a major limitation for standardization and widespread clinical application [5]. The clinical relevance of sarcopenia is particularly evident in patients with osteoporotic vertebral compression fractures (OVCFs), in whom reduced muscle mass and quality are associated with poorer functional recovery, higher complication rates, and increased risk of refracture after vertebral augmentation procedures. In this setting, accurate and reproducible imaging-based assessment of muscle status may contribute to improved risk stratification, treatment planning, and follow-up. This narrative review aims to provide an updated overview of sarcopenia from a radiological perspective, focusing on the role of imaging modalities in its diagnosis and monitoring, as well as their clinical implications in patients undergoing vertebral augmentation procedures. Particular attention is given to current limitations, the need for standardized protocols, and the emerging role of artificial intelligence in improving the accuracy and reproducibility of sarcopenia assessment [6,7].

Definition and Pathophysiology

Sarcopenia is a generalized and progressive muscle disorder characterized by the deterioration of skeletal muscle strength and mass, leading to frailty and an increased risk of falls, fractures, disability, and mortality. It may be classified as primary, associated with aging, or secondary, resulting from chronic diseases, malnutrition, physical inactivity, or pharmacological effects [1,8]. The prevalence of sarcopenia ranges from 1 to 29% in the general population and may reach up to 50% in institutionalized individuals. Metabolic conditions such as obesity and diabetes further accelerate muscle decline, amplifying sarcopenia’s clinical burden [9,10,11]. Diagnosis is guided by consensus definitions from expert groups including the European Working Group on Sarcopenia in Older People (EWGSOP), the European Society for Clinical Nutrition and Metabolism Special Interest Group (ESPEN-SIG), and the International Working Group on Sarcopenia (IWGS) [12,13].

According to the updated EWGSOP2 criteria, the diagnosis of sarcopenia involves a stepwise approach:

1. Probable sarcopenia is defined by reduced muscle strength, most reliably measured by handgrip strength using a handheld dynamometer [14,15].

2. Confirmed sarcopenia requires additional evidence of reduced muscle quantity or quality, typically assessed through imaging modalities such as CT, MRI, DXA, or ultrasound) [16].

3. Severe sarcopenia is characterized by impaired physical performance, such as slow gait speed [17].

Beyond its classification as a geriatric syndrome, sarcopenia is increasingly recognized as a relevant clinical risk factor for specific complications, particularly osteoporotic vertebral compression fractures (OVCFs) [3]. The close interplay between sarcopenia and osteoporosis, often referred to as osteosarcopenia, contributes to increased skeletal fragility, vertebral instability and worse clinical outcomes [8,9]. While most OVCFs are managed conservatively, a subset of patients experiences persistent pain and functional impairment [10]. Over recent decades, percutaneous vertebroplasty (PVP) and kyphoplasty (PKP) have emerged as widely used minimally invasive techniques for treating OVCFs [18,19]. These procedures, which involve injecting bone cement into the collapsed vertebra under image guidance, can provide rapid pain relief and mechanical stabilization [20,21]. However, they carry the risk of complications such as residual pain and new vertebral fractures, especially in sarcopenic patients [11,12].

To support clinical decision-making, several radiologically derived indices have been proposed for assessing skeletal muscle mass, although no universally accepted standard exists.

These include:

- **Appendicular Lean Muscle Index (ALMI)** = ASM/height^2 measured using DXA or bioelectrical impedance analysis (BIA) [22,23,24]
- **Cross-sectional area (CSA)** of skeletal muscle at the L3 level on CT or MRI [25,26]
- **Skeletal Muscle Index (SMI)** = CSA/height^2, with sex-specific thresholds [27,28]

Despite the availability of these metrics, heterogeneity in measurement techniques, imaging protocols and diagnostic thresholds remains a major limitation. This variability, together with inconsistent integration of functional parameters, complicates the identification of high-risk patients and limits the standardization of care. Therefore, harmonization of diagnostic criteria and integration of imaging findings with functional assessment are essential to improve risk stratification and clinical outcomes in this population.

Radiological Assessment of Sarcopenia

Dual energy X-ray absorptiometry (DXA) is one of the most widely recommended and commonly used imaging modality for the assessment of body composition, including lean mass, fat distribution, and bone mineral density. One of its key applications in sarcopenia diagnosis is the calculation of the appendicular lean muscle index (ALMI), defined as appendicular skeletal muscle mass (ASM), the sum of lean muscle mass in the upper and lower limbs, divided by height squared (ASM/height²). According to the EWGSOP2 consensus commonly used ALMI cut-off values are approximately 7.0 kg/m² for men and 6,0 kg/m² for women (figure 1). Although variations exist depending on the population studied and the reference standards adopted [23,24]. DXA offers several advantages: it is non-invasive, involves minimal radiation exposure (around 0.001 mSv), is relatively low-cost, and widely available in clinical practice [22,29]. Additionally, validated cut-offs support its utility in clinical and research settings. However, DXA has important limitations. It provides a two-dimensional assessment and cannot accurately evaluate trunk musculature or intra-abdominal fat due to its inability to differentiate between visceral and subcutaneous fat. More importantly, it does not allow assessment of muscle quality, particularly fat infiltration (myosteatosis) which has been shown to have independent prognostic significance and is better evaluated with CT and MRI. In addition, DXA measurements may be affected by fluid imbalance, such as edema, as the techinque cannot reliably differentiate between lean tissue and extracellular water [3,30]. Other limitations include potential positioning errors, inter-operator variability, and the lack of universally accepted population-specific reference values. Despite these limitations, DXA remains a valuable diagnostic tool in the assessment of sarcopenia, and is particularly useful for confirming reduced muscle mass in patients with suspected sarcopenia, especially when integrated with functional parameters such as muscle strength and physical performances [31].

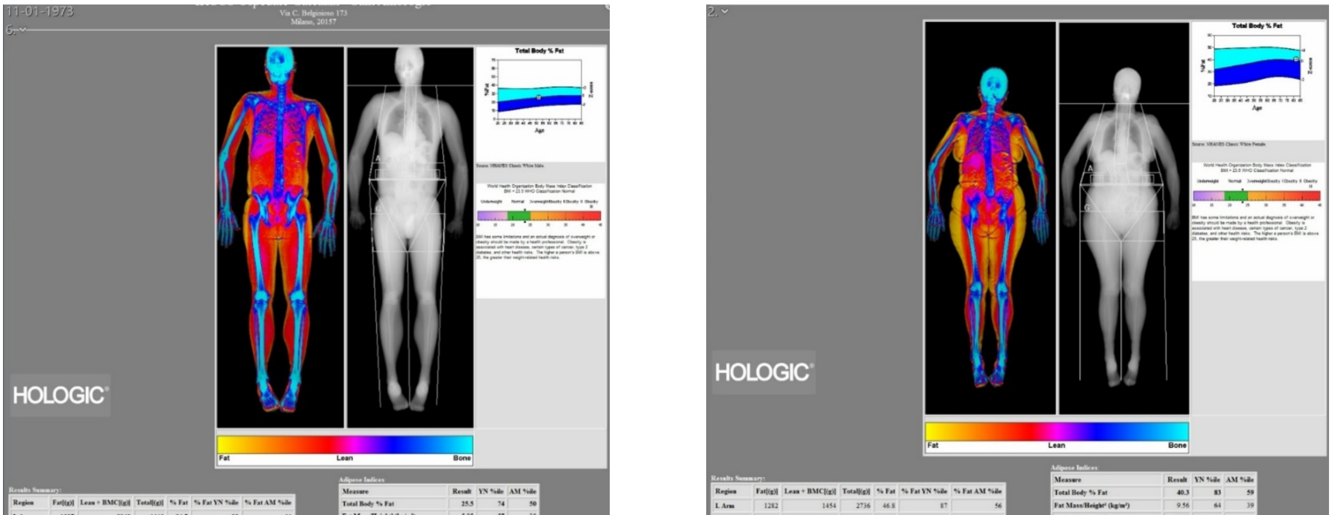

Figure 1 Dual-energy X-ray absorptiometry (DXA) body composition scan of a male and a female patient. Image A shows a 52-year-old man with out sarcopenia, with a value of Append. Lean/Height2 (ALMI index, see the red circle) of 7.54 kg/m2 (normal values > 7.0 kg/m2 for men according to EWGSOP2). Conversely, image B shows a 82-year-old woman with a DXA-based diagnosis of sarcopenia and a very low value of Append. Lean/Height2 (red circle, ALMI index) of 5.57 kg/m2 (normal values > 6.0 kg/m2 for women according to EWGSOP2

Computed tomography (CT) represents a highly reliable and widely used imaging modality for body composition analysis, enabling both quantitative and qualitative assessment of skeletal muscle. In addition to measuring muscle mass, CT allows evaluation of intramuscular adipose tissue (IMAT), a key marker of muscle quality, through attenuation values expressed in Housfield units (HU). High-resolution cross-sectional imaging enables accurate quantification of skeletal muscle area, most commonly at the third (L3) or fourth (L4) lumbar vertebral levels, where motion artifacts are minimal and is considered a reproducible anatomical landmark with strong correlation to whole-body muscle mass [32]. In this setting, muscle quantity is typically assessed by measuring the cross-sectional area (CSA, cm^2) and normalizing it by height squared to obtain the skeletal muscle index (SMI, cm^2/m^2) [26]. However, reported SMI cut-off values vary widely across studies (e.g., 36.0–42.6 cm^2/m^2 in men and 29.0–30.6 cm^2/m^2 in women), reflecting differences in population characteristics and methodological approaches [28,33]. Beyond muscle quantity, CT provides unique insight into muscle quality through attenuation measurements. Reduced muscle attenuation, typically defined by lower HU values (e.g., <30 HU), reflects increased fat infiltration (myosteatosis), which has been shown to be an independent predictor of adverse clinical outcomes, including postoperative complications, prolonged hospitalization, and mortality. Importantly, muscle attenuation may provide prognostic information beyond that obtained from SMI alone, highlighting the need to consider both quantitative and qualitative parameters in sarcopenia assessment. CT is frequently performed in routine clinical practice, particularly in oncology and perioperative settings, enabling opportunistic screening for sarcopenia without additional radiation exposure [34]. In the context of vertebral compression fractures (VCFs), CT plays a dual role by supporting procedural planning for percutaneous vertebroplasty (PVP) or kyphoplasty (PKP) and allowing retrospective evaluation of paraspinal and abdominal musculature [35,36]. Despite these advantages, CT-based sarcopenia assessment presents several limitations. Muscle attenuation values can be influenced by contrast enhancement, potentially altering HU measurements, and therefore non-contrast scans are generally preferred for accurate evaluation. In addition, technical factors such as slice thickness, reconstruction algorithms (kernels), and scanner variability may affect quantitative measurements, limiting reproducibility across institutions. While automated segmentation tools are increasingly available, manual segmentation remains widely used, being time-consuming and subject to inter-observer variability [37,38]. Overall, CT is a powerful tool for the assessment of both muscle quantity and quality and is often considered a reference technique for evaluating myosteatosis (figure 2). However, the lack of standardized acquisition protocols, anatomical landmarks, and validated cut-off values continues to limit its widespread integration into routine clinical practice [39,40].

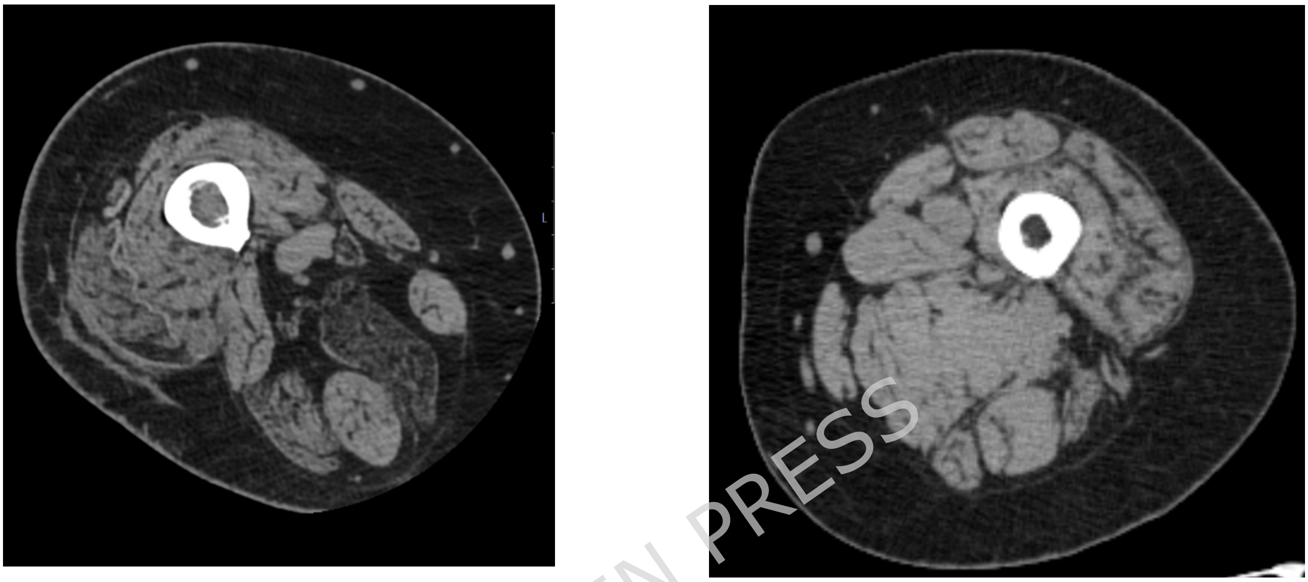

Figure 2 Computed tomography images illustrating a typical sarcopenic (image A) and non-sarcopenic (image B) patient.

Magnetic resonance imaging (MRI) provides excellent soft-tissue contrast and high accuracy in measuring skeletal muscle cross-sectional area (CSA) across different anatomical regions, showing strong correlation with CT-derived measurements [7,41,42]. A major advantage of MRI is the absence of ionizing radiation, making it particularly suitable for longitudinal assessments and follow-up studies.

Beyond the evaluation of muscle quantity, MRI allows detailed characterization of muscle quality, including the detection of intramuscular fat infiltration, edema, and fibrous replacement. Advanced quantitative techniques, such as Dixon-based sequences, enable reliable estimation of proton density fat fraction (PDFF), providing a reproducible biomarker of myosteatosis (figure 3). In particular, multi-echo Dixon techniques allow accurate separation of fat and water signals, generating “fat-only” and “water-only” images and improving the quantification of muscle composition [43].

Additional advanced approaches, including diffusion tensor imaging (DTI) and T2 mapping, offer further insights into muscle microstructure and tissue integrity, although their clinical application remains largely limited to research settings.

Despite these advantages, MRI has several limitations. High cost, longer acquisition times, and limited availability restrict its widespread use in routine clinical practice. Moreover, the lack of standardized acquisition protocols, variability between scanners, and absence of universally accepted diagnostic cut-offs for sarcopenia reduce reproducibility and comparability across studies.

Overall, MRI represents a powerful tool for comprehensive evaluation of both muscle quantity and quality, particularly through quantitative fat fraction analysis. However, further standardization and validation are required before its routine implementation in clinical sarcopenia assessment. [7,44].

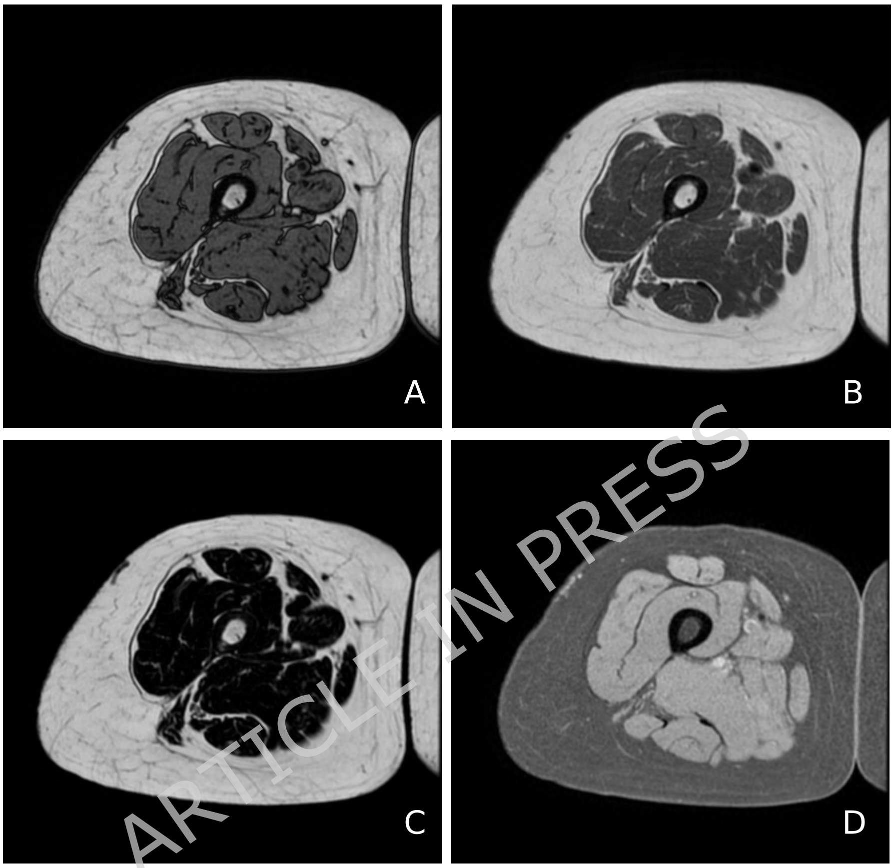

Figure 3. Dixon magnetic resonance imaging of the right thigh in an 82-year-old woman. Axial images include out-of-phase T1-weighted (A), in-phase T1-weighted (B), fat-only (C), and water-only (D) reconstructions. Dixon sequences enable accurate separation of fat and water signals, allowing quantitative assessment of intramuscular fat infiltration (myosteatosis) and muscle composition.

Ultrasound (US) is a practical, widely accessible, and radiation-free imaging modality that offers several advantages, including portability, ease of use, repeatability, and low cost. These features make US particularly suitable for bedside evaluation, outpatient settings, and longitudinal follow-up, especially in frail, elderly, or hospitalized patients. US enables the assessment of both muscle quantity and quality through multiple parameters, including muscle thickness (MT), cross-sectional area (CSA), echo intensity (EI), pennation angle (PA), and fascicle length (FL). In particular, measurements of the anterior thigh musculature—such as the rectus femoris and vastus intermedius—have shown good correlation with CT-, MRI-, and DXA-derived muscle metrics (figure 4) [45,46].

Echo intensity, reflecting intramuscular fat and fibrous infiltration, has emerged as a potential surrogate marker of muscle quality. In recent years, efforts have been made to standardize US assessment of sarcopenia, notably through the SARCUS (SARCopenia through UltraSound) working group, which has proposed methodological recommendations to improve reproducibility and clinical applicability. Despite its potential, ultrasound has several important limitations. The lack of standardized acquisition protocols, normative reference values, and validated diagnostic cut-offs limits its widespread clinical adoption. In addition, US is highly operator-dependent, and inter- and intra-observer variability may affect measurement reliability. Therefore, while US represents a promising, cost-effective tool for muscle assessment, further validation and standardization are required before it can be fully integrated into routine sarcopenia diagnostic algorithms [47].

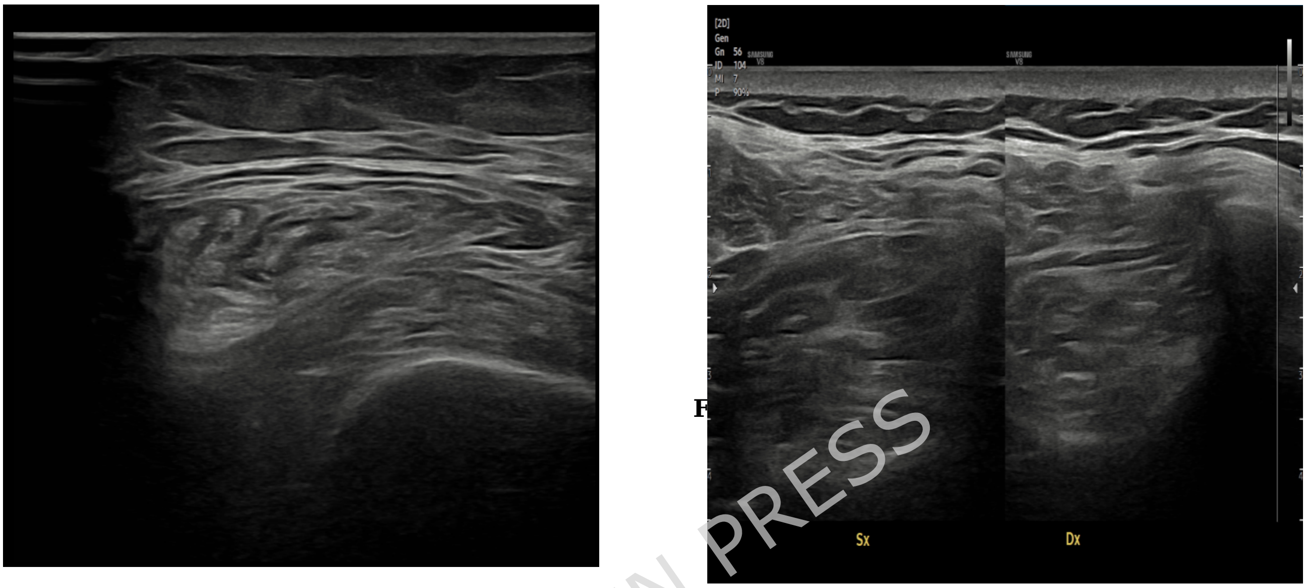

Figure 4 Ultrasound transverse images of typical sarcopenic patient**.**

The main advantages, limitations and measurable parameters are summarized in table 1.

	Advantages	**Limitations**	**Measurements**
DXA	Accurate, Low radiation and costs Reproducible Accepted cut-offs	Varies by densitometer brand. Affected by hydration status Provides 2D data only	Appendicular Lean Mass Index (ALMI)

		Cannot assess intramuscular fat	
CT	Fast and widely available High spatial resolution Accurate for muscle and fat quantification Gold standard for muscle quality Retrospective analysis possible	Radiation exposure Expensive Time-consuming segmentation Cut-offs not standardized Limited to abdominal scans	Cross-sectional Area (CSA) Skeletal Muscle Index (SMI)
MRI	No radiation High contrast resolution Excellent soft tissue contrast Differentiates fat/water	Expensive Long acquisition and post-processing Limited availability No validated cut-offs Mostly research use Sensitive to artifacts Complex interpretation	Cross-sectional Area (CSA) index by height^2 (SMI) Fat content with Dixon Advances sequences: ADC, FA, T2 relaxation time
US	Portable real time imaging Low cost No radiation Dynamic assessment Muscle stiffness (elastography) Microvascular changes (CEUS)	Lack of standardization Limited predictive value	Cross-sectional Area (CSA) Muscle thickness Echogenicity Pennation angle Fascicle length

Table 1 Advantages and disadvantages of the main tools for the assessment of body composition and mass/fat assessment.

Clinical Relevance of Radiological Sarcopenia Assessment

Prognostic Value

Imaging-assessed sarcopenia has emerged as a strong negative prognostic factor across multiple several clinical settings, especially in oncology. Numerous studies have demonstrated that reduced muscle mass and impaired muscle quality, as assessed by CT or MRI, are associated with poorer outcomes in malignancies such as esophageal, non-small cell lung, urothelial, and head and neck cancers. In these patients, sarcopenia has been shown to influencing negatively response to chemoradiation and postoperative recovery. Sarcopenia's relevance extends to trauma and chronic conditions, making early identification crucial to improving outcomes and reducing healthcare expenditures [7,48].

Association with other conditions

Sarcopenia is associated with an increased risks of falls, fractures, cardiovascular and respiratory diseases, cognitive impairment, and adverse outcomes in conditions such as inflammatory bowel disease, rheumatologic disorders, chronic liver disease, and prosthetic joint infections. It also significantly impacts tolerance to treatments, including chemotherapy and major surgery, further emphasizing its systemic clinical relevance [49,50].

Opportunistic screening

A major advantage of radiological assessment is the feasibility of opportunistic screening for sarcopenia. As skeletal muscle is routinely included in CT and MRI examinartions,, radiologists can assess muscle mass and quality without additional radiation exposure or scan time. This approach is particularly relevant in oncology, trauma and spine imaging, where the cross-sectional imaging is frequently obtained. The integration of artificial intelligence (AI)-based tools for automated muscle segmentation and quantification further enhances the feasibility of opportunistic screening and supports the incorporation of sarcopenia metrics into standard radiological reports, thereby improving multidisciplinary clinical decision-making,[7,51].

Challenges and Future Directions

Despite growing evidence supporting its clinical relevance, several challenges limit the widespread implementation of radiological sarcopenia assessment. These include the lack of consensus on diagnostic definitions, standardized imaging protocols, and universally validated cut-off thresholds. In addition, each imaging modality presents specific technical limitations: DXA provides limited information on trunk muscle and muscle quality; CT involves ionizing radiation; MRI is constrained by high cost, limited availability, and lack of standardization; and ultrasound is affected by operator dependency and variable reproducibility [13,52].
Emerging imaging techniques such as radiofrequency echographic multi-spectrometry (REMS) may further enhance the assessment of bone quality and fracture risk without ionizing radiation. By analyzing raw ultrasound radiofrequency signals, REMS provides both quantitative and qualitative information on bone status and may represent a valuable complementary tool in the integrated evaluation of patients with osteosarcopenia, particularly in fragile populations requiring repeated assessments. [53].

Future directions should prioritize:

• Standardization of imaging acquisition and diagnostic criteria
• Artificial Intelligence for automated segmentation and reporting
• Radiomics to extract predictive imaging features
• Advanced MRI methods (e.g., DTI, MRS) for microstructural analysis
• Opportunistic Imaging using existing scans to reduce cost and burden
• Emerging technologies like dual-energy and photon-counting CT

Conclusion

Sarcopenia is a progressive muscle disorder with serious health and economic consequences, especially in aging populations and patients with chronic or complex conditions. Radiological imaging plays a central role in its assessment, offering objective, reproducible and quantifiable insights into muscle composition and quality. Techniques such as DXA, CT, MRI, and US each offer complementary advantages, with increasing integration in clinical practice. Overcoming current limitations through standardization, technological integration, and further research will strengthen radiology’s role in early detection, risk stratification, monitoring, and treatment planning. Ultimately, improved radiological assessment of sarcopenia may support personalized management strategies, enhance clinical outcomes, and more efficient healthcare resource use.

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