Research progress on evaluation methods for skeletal muscle mass assessment in sarcopenia (Review)

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Abstract. Sarcopenia, characterized by the age-related decline in muscle mass and function, especially in cancer patients, demands accurate diagnostic measures. Recent literature reflects a paradigm shift towards more accessible and diverse assessment tools. Traditional methods such as dual-energy X-ray absorptiometry and bioimpedance analysis offer precise measurements but are limited by equipment availability. By contrast, calf circumference, a simple and quick measure, has emerged as a strong predictor of overall muscle mass and health outcomes, including mortality. The Asian Working Group for Sarcopenia has refined diagnostic criteria, emphasizing the universality of calf circumference across ethnicities. Imaging modalities such as computed tomography and magnetic resonance imaging provide detailed assessments but are less accessible. Ultrasound serves as a non-invasive, portable alternative, enabling standardized muscle evaluation. Innovative self-screening tools such as the Yubi-wakka test and a simple questionnaire of sarcopenia, enhance clinical utility by identifying muscle abnormalities. The integration of these methods heralds a new era in sarcopenia diagnosis, facilitating early detection and timely intervention. The imperative for future research lies in optimizing these techniques for clinical practice and elucidating their predictive capabilities across diverse populations.

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1. Introduction

Sarcopenia is an age-related syndrome characterized by a progressive and generalized loss of skeletal muscle mass, strength and function. It is associated with various adverse clinical outcomes, including fracture, falls and mortality (1-3). Sarcopenia is particularly prevalent among elderly patients with cancer (4,5) and can occur across all types of cancer. Studies indicate that cancer patients with low skeletal muscle mass during treatment face increased risks of mortality, cancer recurrence and lower quality of life (6-8). A systematic meta-analysis of 39 studies involving 8,966 cancer patients revealed an overall pooled sarcopenia prevalence of 42% [95% confidence interval (CI) 0.36-0.48; $P<0.001$], with substantial heterogeneity across cancer subtypes (8). Consistent with these findings, a review revealed a particularly high prevalence of sarcopenia (approaching 70%) in patients with esophageal, gastrointestinal, lung, head and neck malignancies, compared with a moderate prevalence (~50%) in those with breast, renal cell and hematologic cancers (9). These tumor-specific prevalence patterns exhibited correlations with disease stage, progression kinetics and the severity of nutritional and absorptive dysfunction. Although the pathogenesis of sarcopenia is not well understood, early identification of at-risk patients and timely intervention can markedly reduce the risk of adverse clinical outcomes.

The diagnosis of sarcopenia requires assessing muscle mass, muscle strength and physical performance (10). The assessment of muscle mass is a critical component in the clinical diagnosis of sarcopenia (1,11). Currently, the measurement of the cross-sectional area (CSA) of the third lumbar vertebra (L3) using computed tomography (CT) or magnetic resonance imaging (MRI) is considered a reliable method for assessing muscle mass. However, taking into account the expense, convenience, radiation exposure and equipment availability, various alternative methods have been developed, such as calf circumference (CC), mid-upper arm circumference and surrogate vertebral measurements. The present review summarized current methods for measuring skeletal muscle mass, aiming to early identify potential sarcopenia cases and facilitate timely intervention.

2. Methodology

Literature search strategy. A systematic literature search was performed across three principal databases: PubMed/Medline (https://pubmed.ncbi.nlm.nih.gov), Web of Science (https://webofscience.clarivate.cn) and China National Knowledge Infrastructure (CNKI, https://www.cnki.net), between January 2010 and February 2024. The search strategy used Medical Subject Headings (MeSH) terminology with Boolean operators, structured as follows:

Pathology Concepts: sarcopenia OR 'skeletal muscle' OR 'muscle wasting' OR 'muscle atrophy' OR 'body composition' OR 'muscle mass' OR 'cachexia' OR 'muscle weakness'

Measuring Methods: 'calf circumference (CC)' OR 'mid-arm muscle circumference (MAMC)' OR 'Yubi-wakka test' OR 'bioimpedance analysis (BIA)' OR 'computed tomography (CT)' OR 'magnetic resonance imaging (MRI)' OR 'dual-energy X-ray absorptiometry (DXA)' OR 'ultrasound (US)'

The search syntax employed Boolean AND operators between these two conceptual groups. The study selection workflow is schematically presented in Fig. 1.

Eligibility criteria

Inclusion criteria. Eligible studies met the following criteria: Investigation of skeletal muscle mass assessment in sarcopenia populations, with particular emphasis on cancer patients or geriatric cohorts; employment of at least one validated measurement modality for muscle mass evaluation, including, but not limited to, anthropometric measurements, medical imaging techniques (CT/MRI/DXA), or BIA; and peer-reviewed original research articles published in English or Chinese.

Exclusion criteria. Studies were excluded based on the following considerations: Case reports, conference abstracts, commentaries, or non-peer-reviewed publications; articles lacking standardized diagnostic thresholds for low muscle mass determination; duplicate publications or studies with substantial cohort overlap.

Study selection and flowchart. The literature screening process followed the PRISMA guidelines (Fig. 1). Initial searches identified 5,036 records. After removing duplicates (n=1,343), 3,693 titles/abstracts were screened. Of these, 3,323 were excluded for irrelevance (non-sarcopenia or low muscle mass focus). A full-text review of 276 articles led to the exclusion of 142 studies (due to insufficient data or non-quantitative methods). Ultimately, 51 studies were included for the present review.

Data extraction. A total of two independent reviewers extracted data using a standardized form, including: Study characteristics (author, year, design); population (sample size, age, cancer type); muscle mass assessment methods and cut-off values.

3. Anthropometry

Calf circumference (CC). CC serves as a straightforward and convenient indicator for assessing muscle mass, playing a crucial role in determining sarcopenia cut-off values (12-14). The Asian Working Group for Sarcopenia (AWGS) 2019 consensus updated the diagnosis criteria for sarcopenia and recommended CC as an effective screening tool in community (15-17). Compared with commonly used methods for assessing muscle mass, CC shows a positive association with muscle mass measured by BIA and DXA, regardless of age or body fat percentage (18). Özcan *et al* (19) reported a positive association between CC and low muscle mass in patients receiving maintenance hemodialysis. Numerous studies have investigated the relationship between CC and low muscle mass, establishing frequently utilized cut-off values of <34 cm for males and <33 cm for females, as detailed in Table I.

Xu *et al* conducted two consecutive studies involving 7,311 hospitalized elderly patients aged >70 years in China, using a prospective multi-center database established by the authors. In the first study, the critical value of CC was determined using the receiver operating characteristic curve method, with in-hospital mortality as the primary outcome. This value was further validated using clinical and financial metrics. In the second study, three screening tools, NRS 2002, NA-SF and MUST, were employed for risk assessment. Malnutrition was diagnosed based on the GLIM criteria, incorporating the newly identified CC values. The optimal cut-off for CC was determined to be 29.6 cm for men and 27.5 cm for women (20).

The measurement of CC can be influenced by body type and positioning. Studies have shown that CC tends to be markedly higher in individuals with sedentary lifestyles (21). Furthermore, CC measurements vary across regions, populations and levels of physical activity intensity. These variations lead to differences in CC cut-off values for predicting low muscle mass. Therefore, it is essential to consider the effect of body type and positioning when measuring CC. Additionally, the most suitable criteria for sarcopenia screening using CC should be explored across diverse countries, regions and populations.

Mid-arm muscle circumference (MAMC). A study assessed muscle mass in aging individuals using MAMC within the community, suggesting MAMC as a valid tool for evaluating nutrition and muscle mass in elderly adults (22). Carnevale *et al* (23) compared DXA and MAMC for muscle mass assessment, showing that MAMC is a practical screening tool for elderly patients and more effective in detecting low muscle mass. Gort-van Dijk *et al* (24) conclude that MAMC

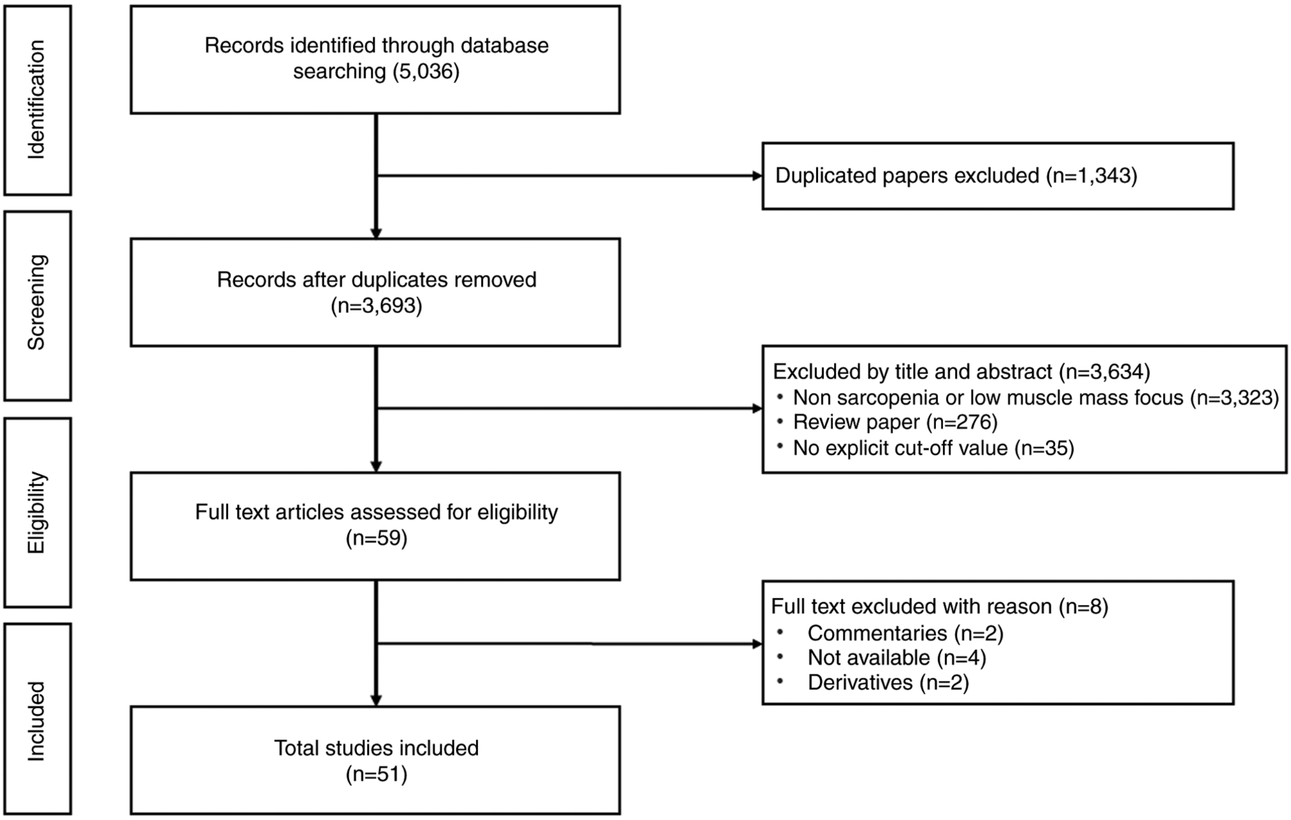

Figure 1. PRISMA flow diagram of literature search and article selection. PRISMA, preferred reporting items for systematic reviews and meta-analyses.

is more specific but less sensitive for assessing muscle mass. Despite these considerations, the convenience of MAMC makes it a recommended tool for screening decreased muscle mass in older populations (24). Notably, MAMC may be less suitable for subjects with edema (lymphedema or generalized extreme edema) or extreme obesity.

The cut-off values for determining low muscle mass using MAMC vary across studies and populations. Carnevale *et al* (23) established cut-off values of <11.0 cm for males and <10.3 cm for females in healthy young individuals. For older adults, the cut-offs were <22.3 cm for males and <18.6 cm for females. Gort-van Dijk *et al* (24) define low muscle mass as falling below the 10th percentile of MAMC cut-off values. However, there is no standardized cut-off value for MAMC to define low muscle mass. Further research is needed to establish its applicability across different age groups and to determine appropriate cut-off values.

Yubi-wakka (finger-ring) test. The finger-ring measurement (Yubi-wakka) is a self-testing tool developed by Tanaka *et al* (25) in 2018 to assess the risk of sarcopenia among community-dwelling older adults. Participants compared the circumference of their own hands with their CC. A larger CC indicated no sarcopenia risk, while equal measurements suggested potential early-stage sarcopenia. A smaller CC indicated sarcopenia risk necessitating further evaluation and intervention. Tanaka *et al* (25) verified the Yubi-wakka test in a study of 1,904 older adults (≥65 years), finding 53% in the larger CC group, 33% in the equal group and 14% in the smaller CC group. Multiple-factor analysis revealed that, compared with the larger CC group, the equal and smaller CC groups were more likely to develop sarcopenia (OR=2.4, 95% CI 1.4-4.1; OR=6.6, 95% CI 3.5-13, respectively). Lawongsa *et al* (26) replicated these findings in a study of Thai older adults, affirming the high sensitivity and specificity of the Yubi-wakka test for sarcopenia risk identification. At present, the Yubi-wakka test is primarily validated in Asian populations (27-29). Further research is needed to explore its applicability and validity across diverse ethnic groups.

4. Computed tomography (CT) and magnetic resonance imaging (MRI)

CT and MRI are widely used in clinical practice to assess muscle mass (30-32). CT can be targeted to show different body components by setting different thresholds, where the threshold for muscle tissue is -29~150 Hounsfield units (33,34). MRI relies on instrument-based marking or manual labeling of muscle tissue for accurate measurement (30). CT or MRI assessment of muscle mass usually involves measuring the skeletal muscle CSA from a single image. This value is then adjusted for height to calculate the skeletal muscle index (SMI, cm/m^2) (35). Therefore, muscle mass measurements using CT or MRI require both the selection of experienced staff to circle the muscle area and, more importantly, the selection of appropriate and typical vertebrae to measure the CSA of the muscle. In addition to measuring skeletal muscle CSA for MRI, advanced MRI sequences can also enable the estimation of body composition in combination with the assessment of muscle mass abnormalities. This combined approach enhances

Table I. Summary of research on CC cut-off values for predicting low skeletal muscle mass.

First author/s, year	Population	Country/Region	Position	Comparing	Criteria for cut-off point	Cut-off for CC (cm)	(Refs.)
Champaiboon *et al*, 2023	6,404 older adults (≥60 years)	Thailand	Sitting	BIA	AWGS	♀<33, ♂<34 BMI ≥25:♀<34, ♂<35 older-old adults ≥75 years: ♀<33, ♂<34	(13)
Fernandes *et al*, 2022	796 older adults (≥60 years)	Southeast region of Brazil	Standing	GAMs	WHO (1995) Physical Status: The Use and Interpretation of Anthropometry. WHO technical report series; 854 Geneva, Switzerland	<34.5 (mortality)	(81)
Gonzalez *et al*, 2021	3,104 participants aged 18-39 years and with normal BMI (18.5-24.9)	US population	Siting	-	1 and 2 SDs below the mean	Moderately low values ♂ ≤34, ♀ ≤33 severely low CC values: ♂≤32, ♀≤ 31 adjusted BMI: adding 4 cm (BMI <18.5) or subtracting 3,7, or 12 cm (BMI 25-29, 30-39, and ≥40, respectively)	(12)
Xu *et al*, 2020	7,311 cases of Chinese elderly hospitalized population aged >70 years	China	Supine	-	GLIM Criteria	♂≤29.6, ♂≤27.5	(20)
Kawakami *et al*, 2020	1,239 adults ≥40 years	Japan	Standing	DEXA/ BIA	AWGS	♂<35 (BIA)/36 (DXA), ♀<33 (BIA)/34 (DXA)	(18)
Kim *et al*, 2018	657 older aged (70-84 years)	Koreans	Standing	DXEA	AWGS	♂<35, ♀<33 in community-dwelling Korean elders	(64)
Pagotto *et al*, 2018	132 elderly people	Brazil	Standing	DEXA	LMM: ♂:7.26 kg/m^2, ♀5.45 kg/m^2	♂<34, ♀<33	(82)
Maeda *et al*, 2017	1,164 hospitalized, elderly adults	Japan	Supine	BIA	AWGS	♀≤ 29, ♂≤30	(83)
Barbosa-Silva *et al*, 2016	1,291 community-dwelling elderly aged 60 y or over	Brazil	Standing	DEXA	EWGSOP2	♂≤34, ♀≤33	(69)

Table I. Continued.

First author/s, year	Population	Country/Region	Position	Comparing	Criteria for cut-off point	Cut-off for CC (cm)	(Refs.)
Kawakami *et al*, 2015	40~89 y adults	Japan	Standing	DEXA	AWGS	♂<34, ♀<33	(84)

CC, calf circumference; ♀, female; ♂, male; BIA, bioelectrical impedance analysis; BMI, body mass index; GAMs, generalized additive models; AWGS, Asian Working Group for Sarcopenia; LMM, low muscle mass; DEXA, Dual Energy X-Ray Absortometry; EWGSOP2, European Working Group on Sarcopenia in Older People 2.

the diagnostic accuracy of sarcopenia in aging patients (36). Xiao *et al* (35) show that CT-based diagnosis of sarcopenia can help to predict clinical outcomes and prognosis in surgical patients and illustrate that CT is intuitive, rapid and accurate in the diagnosis of sarcopenia. Beyond CSA measurement, CT can assess muscle steatosis by measuring intermuscular adipose tissue area or identifying muscle mass loss (37). Despite their advantages in sarcopenia diagnosis, CT and MRI are not widely used for screening due to their high cost, time consumption and ionizing radiation (in the case of CT) and the need for specialized technical expertise (35,36).

The third lumbar vertebra (L3). The third lumbar vertebra (L3) is currently the most commonly used for measuring the SMI to assess whole-body muscle mass, given its strong correlation with whole-body musculature (r=0.86 ~0.94; P<0.001) (38). This method is considered the gold standard for diagnosis of low muscle mass and sarcopenia (39). Prado *et al* (40) measured the L3 SMI in patients with respiratory and gastrointestinal tumors to assess muscle mass. Martin *et al* (41) defined the cut-off value for sarcopenia as SMI <52.4 cm^2/m^2 in men and SMI <38.5 cm^2/m^2 in women. The L3 SMI cut-off values for assessing whole-body muscle mass range from 40.2-55.0 cm^2/m^2 in men and 30.0-43.23 cm^2/m^2 in women, respectively, as shown in Table II.

By analyzing the relationship between SMI and prognosis in ovarian cancer patients, Jin *et al* (42) found significant variability in the cut-off values for low muscle mass among female patients. Commonly used SMI cut-off values ranged from 38.5-41.0 cm^2/m^2, with 38.5 and 41.5 cm^2/m^2 being the most frequently applied thresholds. The authors suggested that there was a large heterogeneity in the cut-off values for low muscle mass, potentially due to variations in methodology or population characteristics. As a clinical reference standard for assessing low SMI, the use of L3 needs further refinement to establish a robust diagnostic criterion. Considering that most of the patients do not routinely undergo CT scanning of the abdomen in clinical practice, performing such examinations solely for sarcopenia diagnosis would increase radiation exposure and assessment costs. In such case, researchers have tried to measure the CSA of other non-L3 vertebrae to evaluate muscle mass (43). Thus, it may be a cost-effective alternative measurement of skeletal muscle mass in screening of sarcopenia, improving patient prognosis without increasing additional economic and radiation burdens.

The third cervical vertebra (C3). Patients with head and neck tumors have a higher risk of developing sarcopenia (44), but abdominal CT scanning is not routinely performed in this population. Thus, some researchers are exploring whether the C3 could serve as an alternative for screening low muscle mass in these patients. This approach could facilitate timely treatment, such as nutritional support or physical therapy and improve prognosis.

By measuring C3 and L3 muscle mass with CT in 51 trauma and 52 head and neck tumors patients, Swartz *et al* (44) found a strong correlation between L3 and C3 (r=0.891). The authors demonstrate that it is feasible to use the head and neck CT to evaluate muscle mass in head and neck tumors patients. This method also serves as a viable alternative to abdominal CT

Table II. Summary of research on measuring muscle mass at L3 using computerized tomography.

First author/s, year	Population	Software	Criteria for cut-off point	Cutoff for Low SMI (cm^2/m^2)	(Refs.)
Sahin *et al*, 2023	162 stomach cancer patients, aged ≥18 years, Turkey	3D Slicer (version 4.10.2) (Slicer)	-	♂52.4; ♀38.5	(85)
Sealy *et al*, 2020	213 head and neck cancer patients, the Netherlands	Slice-O-Matic V5.0 (TomoVision)	Tertiles in the cohort	♂53.4; ♀43.23	(86)
Van der Kroft *et al*, 2020	180 patients with Colorectal cancer, Germany	Slice-O-Matic V5.0 (TomoVision)	At the lowest tertile	♂46.6; ♀36.8	(87)
Li *et al*, 2019	153 gastric cancer patients, China	Slice-O-Matic V5.0 (TomoVision)	Optimum stratification	♂40.2; ♀30.0	(88)
Blauwhoff-Buskermolen *et al*, 2017	241 cancer patients, aged ≥18 years, the Netherlands	Slice-O-Matic V5.0 (TomoVision)	-	♂55.0; ♀39.0	(89)

L3, third lumbar vertebra.

for measuring L3 muscle mass. Jung *et al* (45) also advocate the use of C3 CSA measured by head and neck CT to estimate L3 muscle mass in patients with head and neck tumors and predict overall survival. Meerkerk *et al* (30) used C3 muscle mass measurements to predict frailty in patients with head and neck tumors. The authors' findings showed that low SMI and sarcopenia are associated with frailty in older patients. Additionally, a retrospective cohort study has demonstrated a correlation between C3 muscle mass and prognosis in oral cancer patients, suggesting its potential as an imaging marker for predicting outcomes (46).

However, some researchers doubt whether the CSA measured by C3 can accurately predict the CSA of L3. Yoon *et al* (34) concluded that in patients with head and neck tumors complicated with sarcopenia, the muscle mass measured by C3 did not strongly correlate with that at L3 ($r=0.381$). This discrepancy is probably due to the fact that the sternocleidomastoid muscle at C3 was excluded from the analysis due to tumor invasion, leading to variability in the results between studies. Therefore, further research is needed to explore the feasibility of using C3 as a substitute for L3 in evaluating systemic muscle mass in patients' head and neck tumors. Key questions include how to measure C3 muscle mass, which muscles should be included and correlation between C3 and L3 muscle mass as well as the determination of a cut-off value for low muscle mass based on C3.

The fourth thoracic vertebra (Th4). The Th4 is commonly used to assess muscle mass in patients undergoing chest CT scans for lung cancer and breast cancer. Gronberg *et al* (47) compared the concordance between Th4-measured SMI and L3-measured SMI and showed that there was only moderate concordance between them ($r^2=0.51$ in men and $r^2=0.28$ in women), indicating that Th4 cannot yet replace L3 to assess low muscle mass. Neefjes *et al* (48) also explored the use of Th4 for assessing low muscle mass and the findings suggested that further work is needed to validate the reliability of Th4 for this purpose. The current studies on the cut-off value of Th4 for assessing low muscle mass are summarized in Table III.

According to the current research results, the cut-off values of Th4 in evaluating low muscle mass and the muscle measurement area still are not standardized. Therefore, further research is needed for the adoption of Th4 instead of L3 to evaluate low muscle mass.

The twelfth thoracic vertebra (Th12). Chest CT scans do not cover the L3 region, as that would increase both the financial burden and radiation exposure for patients who only need a chest CT. It is worth exploring how to diagnose sarcopenia without additional CT scans. Some researchers have attempted to use Th10, Th12 and other thoracic vertebrae for muscle mass assessment.

In a study by Matsuyama *et al* (49) Th12 muscle mass was measured using chest CT in patients with progressive oral squamous cell carcinoma. This value was compared with L3 muscle mass and the results showed that SMI measured at Th12 using chest CT can be used to diagnose sarcopenia and has predictive value for postoperative outcomes in these patients. In conclusion, current evidence is insufficient to support the

Table III. Summary of research on measuring muscle mass at Th4 using computerized tomography.

First author/s, year	Population	Software	Criteria for cut-off point/muscle area	Cut-off for low SMI (cm^2/m^2)	(Refs.)
Tao *et al*, 2023	750 NSCLC patients, China	Simens syngo via VB20 (Siemens Healthineers)	X-tile software/bilateral pectoralis major, pectoralis minor muscles	♂ 18.1; ♀ 14.7	(90)
Sealy *et al*, 2020	213 head and neck cancer patients, the Netherlands	Slice-O-Matic V5.0 (TomoVision)	Tertiles in the cohort/Total muscle	♂69.45; ♀52.88	(86)
Van der Kroft *et al*, 2020	180 patients with Colorectal cancer, Germany	Slice-O-Matic V5.0 (TomoVision)	The lowest tertile/Total muscle	♂65.2; ♀51.9	(87)
Blauwhoff-Buskermolen *et al*, 2017	241 cancer patients, aged ≥18 years, the Netherlands	Slice-O-Matic V5.0 (TomoVision)	-/Total muscle	♂66.0; ♀51.9	(89)

Th4, fourth thoracic vertebra; SMI, skeletal muscle index.

use of Th10 and Th12 as alternatives to L3 for muscle mass measurement and more studies are needed.

Masticatory muscle. Masticatory muscles reflect the chewing and swallowing function of patients and are closely related to their nutritional status. Studies have shown that the mass of masticatory muscles is closely related to patients' grip strength, walking speed and physical activity (50,51). This suggests that masticatory muscles could serve as a new site for muscle mass measurement. Hwang *et al* (52) retrospectively analyzed 314 patients in emergency department and confirmed a significant association between masticatory muscle mass and systemic nutritional biomarkers. These findings suggest that masticatory muscle mass is a potential indicator of nutritional status, physical activity levels and trauma-related prognosis (53).

Chang *et al* (53) attempted to measure the muscle mass of the masticatory muscles in patients with head and neck cancers to explore its relationship with L3 muscle mass, specifically at the level of the mandibular notch. The authors found a strong correlation between masticatory muscle mass and L3 muscle mass (r=0.901). The study also suggested that C3 muscle mass measurements may be unreliable in patients with head and neck tumors involving lymphatic metastasis or severe muscle tissue invasion. Thus, measuring masticatory muscle mass might be a useful alternative. However, it should be noted that the number of studies on masticatory muscle for assessing low muscle mass is insufficient to support its validity as an alternative to L3.

Bilateral mid-thigh muscle area (TMA). TMA has also been used to assess muscle mass. It provides more accurate evaluation of overall skeletal muscle mass and is highly sensitive to changes. The 2019 European Working Group on Sarcopenia in Older People (EWGSOP) guideline highlighted that mid-thigh muscle mass correlates more strongly with whole-body muscle mass than L1-L5 measurements (10). Tsai *et al* (54) found a strong correlation between TMA and abdominal muscle area (AMA) while investigating the relationship between lower extremity muscle mass and vascular stenosis in patients with peripheral arterial disease. This suggests that TMA could be another effective method for assessing muscle mass and future research in this area is warranted.

5. Clinical ultrasound (US)

US enables evaluation of muscle echotexture by detecting variations in intramuscular fat and connective tissue composition. Recently, the Sarcopenia Group of the European Geriatric Society published a consensus protocol for the detection of sarcopenia using ultrasound, including the measurements of CSA, muscle thickness, echo intensity, muscle wing angle and muscle bundle length (55). While the quadriceps remain the most studied muscle group, uncertainty persists regarding optimal anatomical measurement sites for assessing total skeletal muscle mass. Perkisas *et al* (56) concluded that muscle mass decreases before the number of muscle fibers is lost, which could be a reliable indicator of early signs of sarcopenia in the elderly. Although human errors in the interpretation of ultrasound results, might affect the formulation of unified diagnostic criteria, ultrasound still has the potential to become a tool for early screening and clinical diagnosis of sarcopenia due to its advantages of being non-invasive, painless, non-ionizing radiation and low-cost.

6. Dual energy X-ray absorptiometry (DXA)

DXA is currently widely used in body composition measurement due to its accuracy and repeatability. DXA enables simultaneous quantification of fat mass, appendicular skeletal muscle mass (ASM), fat-free mass (FFM) and bone mineral content. Studies demonstrate strong concordance between DXA-derived non-fat/adipose tissue measurements and corresponding values obtained via CT or MRI (1,57). ASMI measured by DXA varied in different study populations, with cut-off values ranging from 5.86 kg/m^2-7.40 kg/m^2 in males and from 4.42 kg/m^2-5.67 kg/m^2 in females (58). Based on available studies, EWGSOP2 has established the cut-off value for DXA to assess low muscle mass as ASMI <7.0 kg/m^2 for males and <5.5 kg/m^2 for females (59). The AWGS has established DXA cut-off values for assessing low muscle mass as ASMI <7.0 kg/m^2 for males and <5.7 kg/m^2 for females (60).

Nevertheless, DXA is unable to assess intramuscular fat infiltration (myosteatosis), which limits muscle quality evaluation. Furthermore, DXA measurements can be inaccurate due to variations in body thickness, fluid retention conditions (e.g., renal/hepatic dysfunction) and fluctuations in hydration status.

7. Bioimpedance analysis (BIA)

BIA is widely used for body composition assessment, indirectly calculating muscle mass using specific formulas. Cheng *et al* (57) demonstrated that BIA initially overestimates muscle mass but aligns closely with DXA measurements after adjustment, making it a rapid and reliable tool for sarcopenia screening. Compared with DXA, BIA is a simple measurement method with the advantages of being non-invasive, radiation-free and fast, making it an improved better choice for muscle mass screening of sarcopenia.

Although the AWGS2019 diagnostic criteria for sarcopenia define low muscle mass as muscle mass measured by BIA <7.0 kg/m^2 for males and <5.7 kg/m^2 for females (61), there is no diagnostic criterion for low muscle mass determined by BIA in EWGSOP2. This may be due to the heterogeneity of low muscle mass cut-off values among different ethnicities. Therefore, the cut-off values for low muscle mass range from 7.4 kg/m^2-9.31 kg/m^2 for males and from 5.14 kg/m^2-7.4 kg/m^2 for females, as shown in Table IV.

The use of different evaluation instruments results in significant differences in cut-off values because different formulas are used to measure muscle mass. In the future, more studies should focus on establishing a unified and standardized instrument to explore the cut-off values for low muscle mass in different ethnicities, for the purpose of improving the sensitivity and specificity of sarcopenia screening. In general, BIA is a convenient and simple tool for measuring muscle mass and can be used in muscle mass screening for sarcopenia. However, it should be noted that muscle mass measurements by BIA are susceptible to the hydration status of patients,

Table IV. Summary of research on BIA.

First author/s, year	Population	BIA instrument	Criteria for cut-off point	Cut-off for low SMI (kg/m^2)	(Refs.)
Pineda-Zuluaga *et al*, 2023	237 people, older than 60 years, Colombia	Hydra 4200 Xitron Technologies	-2 SD of the mean value of Colombia older adults	♂8.0; ♀6.1	(91)
Bulut *et al*, 2020	1,150 participants, >60 years old, Turkey	Tanita MC-780U	-2 SD of Turkish young adults (18 ~40 years old)	♂8.33; ♀5.7	(92)
Björkman *et al*, 2019	428 healthy people, >75 years, Finland	ImpediMed SFB7	Age-specific median values	♂9.31; ♀6.9	(93)
Han *et al*, 2016	878 healthy volunteers, >65 years, China	InBody 720	-2 SD of Chinese young adults (20~40 years old)	♂7.40; ♀5.14	(94)
Bahat *et al*, 2016	301 participants, Turkey	Tanita BC 532	-2 SD of Turkish young adults (18-39 years old)	♂9.2; ♀7.4	(95)

BIA, bioimpedance analysis; SMI, skeletal muscle index.

leading to inaccurate muscle mass values. Therefore, BIA is not recommended for patients with edema.

8. Discussion

Sarcopenia, a syndrome characterized by progressive and generalized loss of skeletal muscle mass and function, has gained recognition as a critical determinant of health in older adults (62). Accurate assessment of muscle mass is crucial for the diagnosis, monitoring and management of sarcopenia, markedly influencing clinical decision-making and patient outcomes (63). Anthropometric measurements such as CC, mid-upper arm circumference and the Yubi-wakka test, offer non-invasive, rapid and cost-effective approaches for sarcopenia screening (15). These methods are particularly valuable in both in community and hospital settings, enabling widespread screening initiatives (61). However, while the Yubi-wakka test shows good applicability in Asian populations, further validation in diverse ethnic groups is needed to ensure its global applicability (64). BIA is a widely used tool for assessing body composition, including muscle mass, owing to its ease of use and non-invasive nature. However, variability in BIA devices and methodologies can affect the accuracy and reliability of measurements, highlighting the need for standardization in sarcopenia diagnosis (65,66). Cut-off values for BIA in sarcopenia screening exhibit variability, with suggested thresholds being <7.0 kg/m^2 for men and <5.5 or 5.7 kg/m^2 for women (61). The EWGSOP recommends DXA for muscle mass assessment (39), due to its precision and ability to evaluate regional lean mass. However, its high cost and limited availability may restrict its use in routine clinical practice (67). The cut-off values for DXA in sarcopenia diagnosis are <7.0 kg/m^2 for men and <5.4 kg/m^2 for women. However, these thresholds may not be universally applicable across diverse populations (68). Imaging techniques such as CT and MRI provide detailed visualization of muscle mass and quality, making them valuable tools in sarcopenia research and clinical practice (31). The use of skeletal muscle mass measured at the L3 level serves as a common reference standard. However, the lack of standardized cut-off values and variability in the selection of vertebral levels and muscles for assessment pose significant challenges (69). Future research should prioritize the establishment of standardized criteria to enable more consistent diagnosis and monitoring of sarcopenia (70-72). US is emerging as a promising tool for sarcopenia assessment, offering a non-invasive, portable and repeatable method to evaluate muscle mass and quality (25). Its potential for real-time imaging and the absence of radiation exposure represent significant advantages. However, US results are operator-dependent and further research is required to establish its reliability and validity in sarcopenia assessment (55). Despite the variety of available methods, several challenges persist, such as the lack of standardized cut-off values across methodologies, the reliance on equipment that may not be universally accessible and the dependence on techniques requiring specialized training (63). The comparative merits and drawbacks of these measurement approaches are detailed in Table V. Additionally, the heterogeneity in sarcopenia presentation across diverse populations underscores the need for more inclusive research to ensure diagnostic accuracy (73). Given the limitations of individual methods, a combined approach may offer a more comprehensive assessment of sarcopenia. Integrating anthropometric measures with BIA or imaging techniques can yield a more accurate representation of muscle mass and function (58,74). Future research should explore the integration of these methods to improve diagnostic accuracy and enhance clinical applicability. The field of sarcopenia assessment is rapidly evolving, necessitating innovative approaches that balance accuracy with practicality for widespread implementation. The development of emerging technologies, such as advanced imaging software and machine learning algorithms, holds promise for delivering more precise and accessible methods for sarcopenia diagnosis (75). Furthermore, incorporation of biomarkers and genetic factors into the assessment framework could enable a more comprehensive understanding of sarcopenia (76).

Sarcopenia is a prevalent condition among cancer patients, with significant implications for clinical outcomes. Current evidence establishes CT as the most widely adopted and clinically validated modality for body composition assessment in this population. The systematic review by McGovern *et al* (77) highlights that low SMI and skeletal muscle density, as assessed by CT, are prevalent across malignancies, independent of disease stage. However, the review underscores the lack of standardized thresholds for defining sarcopenia in oncology, with studies employing heterogeneous cut-offs. By contrast, Ubachs *et al* (78) provide compelling evidence for the prognostic value of CT-based assessments, demonstrating significant associations between both SMI [P=0.02; hazard ratio (HR): 1.17; 95% CI: 1.03-1.33] and skeletal muscle radiation attenuation (P<0.001; HR: 1.14; 95% CI: 1.08-1.20) with overall survival. The study highlights the particular clinical utility of CT in ovarian cancer, where ascites-related weight masking renders anthropometric measurements unreliable for nutritional assessment. The applicability of sarcopenia assessment varies markedly across cancer types, with methodology selection often dictated by anatomical considerations. Notably, studies in head and neck cancers predominantly employ cervical skeletal muscle index (C3 SMI) measurements, whereas investigations of gastrointestinal malignancies typically utilize lumbar skeletal muscle index (L3 SMI), reflecting site-specific clinical relevance (8). Other tools such as DXA (limited by hydration status), MRI (costly) and US (operator-dependent) are less robust for cancer-specific prognostication. Anthropometrics (such as CC) are accessible but lack precision. A meta-analysis by Zhang *et al* (8) systematically compared prognostic capabilities across skeletal muscle quantification methods, revealing that while L3 SMI remains the preferred modality for cross-cancer applications due to its standardized implementation, C3 SMI emerges as particularly predictive of mortality outcomes in head and neck malignancies; a finding that aligns with the anatomical and pathophysiological characteristics of these tumors. However, C3 SMI limited application in non-head/neck cancers restricts broader generalizability. Future research should prioritize tumor-specific diagnostic thresholds and multimodal assessment frameworks to optimize SMI assessment in cancer patients.

Normative values and cut-off criteria for muscle mass exhibit variations across ethnicities, sexes and age groups. However, a number of countries, including China, currently lack clinically

Table V. Comparative analysis of body composition assessment modalities for sarcopenia evaluation.

Methods	Strengths	Limitations
CT	• Quantitative gold standard • Widely available • Validated prognostic value	• Radiation burden • Threshold variability • Cost prohibitive for serial monitoring
MRI	• Superior soft tissue resolution • Multi-parametric tissue characterization • No ionizing radiation	• Limited availability • Lengthy acquisition • Motion artifacts
DXA	• Established reference ranges • Low radiation dose • Rapid acquisition • Widely available	• Hydration status confounding • Regional variability • Limited quality assessment
US	• Point-of-care application • Dynamic muscle evaluation • Cost-effective	• Operator expertise required • Limited reproducibility • Depth constraints
Anthropometry	• Universally accessible • Minimal training required • Low-cost screening	• Insensitive to early changes • Body habitus confounding • Qualitative only

CT, Computed tomography; MRI, magnetic resonance imaging; DXA, Dual energy X-ray absorptiometry; US, ultrasound.

validated cut-off standards and population-specific reference values derived from rigorous methodologies. To address this gap, future research is needed to determine benchmarks across diverse populations using advanced technologies, large-scale studies and high-quality methodologies. Future research should define clinically supported indices, such as FFM index in different ethnic groups, to determine sex- and age-specific normal ranges and clinically supported indices for diagnosing reduced muscle mass.

The present review presented a systematic evaluation framework that innovatively combined both conventional and emerging assessment modalities, thereby offering distinct methodological advantages compared with previous works by Muraki (methodological analysis) (79) and Li *et al* (technical imaging review) (80). The present review broadened the assessment paradigm by incorporating low-cost clinical tools including anthropometric measurements (such as CC) and validated self-assessment methods (such as the Yubi-wakka test), implemented through standardized diagnostic criteria (AWGS 2019) to enhance clinical utility across diverse settings without compromising diagnostic accuracy. Furthermore, the present review assessed multi-modal strategies, such as combining BIA with anthropometry, to improve accuracy while addressing limitations such as hydration effects or positioning errors, often overlooked in prior studies, with particular emphasis on population-specific validation for Asian cohorts to address diagnostic heterogeneity and technical rigor. Notably, the present review bridged research and practice by advocating harmonized protocols that balance gold-standard imaging (such as L3-CT) with scalable tools (such as US and CC), while also exploring emerging technologies such as machine learning for muscle segmentation. By comprehensively integrating multiple assessment approaches, our study extends the current evaluative paradigm to improve clinical utility.

9. Conclusion

While current methods provide valuable tools for both clinical practice and research, there remains a critical need for further standardization, validation and innovation. Future research should focus on the development and validation of assessment methods that are accessible, reliable and applicable across diverse populations, improving the care and outcomes for individuals affected by sarcopenia.

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Availability of data and materials

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Authors' contributions

JH and CT conceived the study and contributed to the critical revision of the manuscript. WW and ML designed the study, collected data, prepared tables, drafted the original draft and conducted the review and editing. QZ contributed to manuscript drafting, prepared the tables, and reviewed the manuscript. Data authentication is not applicable. All authors read and approved the final manuscript.

Ethics approval and consent to participate

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Competing interests

The authors declare that they have no competing interests.

References

1. Cruz-Jentoft AJ and Sayer AA: Sarcopenia. Lancet 393: 2636-2646, 2019.
2. Damluji AA, Alfaraidhy M, AlHajri N, Rohant NN, Kumar M, Al Malouf C, Bahrainy S, Ji Kwak M, Batchelor WB, Forman DE, *et al*: Sarcopenia and cardiovascular diseases. Circulation 147: 1534-1553, 2023.
3. Sayer AA and Cruz-Jentoft A: Sarcopenia definition, diagnosis and treatment: Consensus is growing. Age and ageing 51: afac220, 2022.
4. Zhang FM, Wu HF, Shi HP, Yu Z and Zhuang CL: Sarcopenia and malignancies: Epidemiology, clinical classification and implications. Ageing Res Rev 91: 102057, 2023.
5. Fang P, Zhou J, Xiao X, Yang Y, Luan S, Liang Z, Li X, Zhang H, Shang Q, Zeng X and Yuan Y: The prognostic value of sarcopenia in oesophageal cancer: A systematic review and meta-analysis. J Cachexia Sarcopenia Muscle 14: 3-16, 2023.
6. Chang KV, Chen JD, Wu WT, Huang KC, Hsu CT and Han DS: Association between loss of skeletal muscle mass and mortality and tumor recurrence in hepatocellular carcinoma: A systematic review and Meta-analysis. Liver Cancer 7: 90-103, 2018.
7. Nipp RD, Fuchs G, El-Jawahri A, Mario J, Troschel FM, Greer JA, Gallagher ER, Jackson VA, Kambadakone A, Hong TS, *et al*: Sarcopenia is associated with quality of life and depression in patients with advanced cancer. Oncologist 23: 97-104, 2018.
8. Zhang Y, Zhang J, Zhan Y, Pan Z, Liu Q and Yuan W: Sarcopenia is a prognostic factor of adverse effects and mortality in patients with tumour: A systematic review and Meta-analysis. J Cachexia Sarcopenia Muscle 15: 2295-2310, 2024.
9. Yuan S and Larsson SC: Epidemiology of sarcopenia: Prevalence, risk factors, and consequences. Metabolism 144: 155533, 2023.
10. Cruz-Jentoft AJ, Bahat G, Bauer J, Boirie Y, Bruyere O, Cederholm T, Cooper C, Landi F, Rolland Y, Sayer AA, *et al*: Sarcopenia: Revised European consensus on definition and diagnosis. Age Ageing 48: 601, 2019.
11. Dent E, Woo J, Scott D and Hoogendijk EO: Sarcopenia measurement in research and clinical practice. Eur J Intern Med 90: 1-9, 2021.
12. Gonzalez MC, Mehrnezhad A, Razaviarab N, Barbosa-Silva TG and Heymsfield SB: Calf circumference: Cutoff values from the NHANES 1999-2006. Am J Clin Nutr 113: 1679-1687, 2021.
13. Champaiboon J, Petchlorlian A, Manasvanich BA, Ubonsutvanich N, Jitpugdee W, Kittiskulnam P, Wongwatthananart S, Menorngwa Y, Pornsalnuwat S and Praditpornsilpa K: Calf circumference as a screening tool for low skeletal muscle mass: Cut-off values in independent Thai older adults. BMC Geriatr 23: 826, 2023.
14. Kiss CM, Bertschi D, Beerli N, Berres M, Kressig RW and Fischer AM: Calf circumference as a surrogate indicator for detecting low muscle mass in hospitalized geriatric patients. Aging Clin Exp Res 36: 25, 2024.
15. Chen LK, Woo J, Assantachai P, Auyeung TW, Chou MY, Iijima K, Jang HC, Kang L, Kim M, Kim S, *et al*: Asian working group for sarcopenia: 2019 consensus update on sarcopenia diagnosis and treatment. J Am Med Dir Assoc 21: 300-307.e2, 2020.
16. Oh MH, Shin HE, Kim KS, Won CW and Kim M: Combinations of sarcopenia diagnostic criteria by asian working group of sarcopenia (AWGS) 2019 guideline and incident adverse health outcomes in community-dwelling older adults. J Am Med Dir Assoc 24: 1185-1192, 2023.
17. Sri-On J, Fusakul Y, Kredarunsooksree T, Paksopis T and Ruangsiri R: The prevalence and risk factors of sarcopenia among Thai community-dwelling older adults as defined by the Asian Working Group for Sarcopenia (AWGS-2019) criteria: A cross-sectional study. BMC Geriatr 22: 786, 2022.
18. Kawakami R, Miyachi M, Sawada SS, Torii S, Midorikawa T, Tanisawa K, Ito T, Usui C, Ishii K, Suzuki K, *et al*: Cut-offs for calf circumference as a screening tool for low muscle mass: WASEDA'S Health study. Geriatr Gerontol Int 20: 943-950, 2020.
19. Özcan B, Güner M, Ceylan S, Öztürk Y, Girgin S, Okyar Baş A, Koca M, Balcı C, Doğu BB, Cankurtaran M, *et al*: Calf circumference predicts sarcopenia in maintenance hemodialysis. Nutr Clin Pract 39: 193-201, 2024.
20. Xu JY, Zhu MW, Zhang H, Li L, Tang PX, Chen W and Wei JM: A Cross-Sectional study of GLIM-defined malnutrition based on new validated calf circumference Cut-off values and different screening tools in hospitalised patients over 70 years old. J Nutr Health Aging 24: 832-838, 2020.
21. Rigby L, Frey M, Alexander KL and De Carvalho D: Monitoring calf circumference: Changes during prolonged constrained sitting. Ergonomics 65: 631-641, 2022.
22. Landi F, Russo A, Liperoti R, Pahor M, Tosato M, Capoluongo E, Bernabei R and Onder G: Midarm muscle circumference, physical performance and mortality: Results from the aging and longevity study in the Sirente geographic area (ilSIRENTE study). Clin Nutr 29: 441-447, 2010.
23. Carnevale V, Castriotta V, Piscitelli PA, Nieddu L, Mattera M, Guglielmi G and Scillitani A: Assessment of skeletal muscle mass in older people: Comparison between 2 Anthropometry-based methods and Dual-energy X-ray absorptiometry. J Am Med Dir Assoc 19: 793-796, 2018.
24. Gort-van Dijk D, Weerink LBM, Milovanovic M, Haveman JW, Hemmer PHJ, Dijkstra G, Lindeboom R and Campmans-Kuijpers MJE: Bioelectrical impedance analysis and Mid-upper arm muscle circumference can be used to detect low muscle mass in clinical practice. Nutrients 13: 2350, 2021.
25. Tanaka T, Takahashi K, Akishita M, Tsuji T and Iijima K: 'Yubi-wakka' (finger-ring) test: A practical self-screening method for sarcopenia, and a predictor of disability and mortality among Japanese community-dwelling older adults. Geriatr Gerontol Int 18: 224-232, 2018.
26. Lawongsa K, Srisuwan P, Tejavanija S and Gesakomol K: Sensitivity and specificity of Yubi-wakka (finger-ring) screening method for sarcopenia among older Thai adults. Geriatr Gerontol Int 24: 263-268, 2024.
27. Hiraoka A, Izumoto H, Ueki H, Yoshino T, Aibiki T, Okudaira T, Yamago H, Suga Y, Iwasaki R, Tomida H, *et al*: Easy surveillance of muscle volume decline in chronic liver disease patients using finger-circle (yubi-wakka) test. J Cachexia Sarcopenia Muscle 10: 347-354, 2019.
28. Hiraoka A, Nagamatsu K, Izumoto H, Yoshino T, Adachi T, Tsuruta M, Aibiki T, Okudaira T, Yamago H, Suga Y, *et al*: SARC-F combined with a simple tool for assessment of muscle abnormalities in outpatients with chronic liver disease. Hepatol Res 50: 502-511, 2020.
29. Nishikawa H, Yoh K, Enomoto H, Nishimura T, Nishiguchi S and Iijima H: Clinical impact of the finger-circle test in patients with liver diseases. Hepatol Res 51: 603-613, 2021.
30. Meerkerk CDA, Chargi N, de Jong PA, van den Bos F and de Bree R: Low skeletal muscle mass predicts frailty in elderly head and neck cancer patients. Eur Arch Otorhinolaryngol 279: 967-977, 2022.
31. Albano D, Messina C, Vitale J and Sconfienza LM: Imaging of sarcopenia: Old evidence and new insights. Eur Radiol 30: 2199-2208, 2020.
32. O'Brien ME, Zou RH, Hyre N, Leader JK, Fuhrman CR, Sciurba FC, Nouraie M and Bon J: CT pectoralis muscle area is associated with DXA lean mass and correlates with emphysema progression in a Tobacco-exposed cohort. Thorax 78: 394-401, 2023.
33. Huang W, Tan P, Zhang H, Li Z, Lin H, Wu Y, Du Q, Wu Q, Cheng J, Liang Y and Pan Y: Skeletal muscle mass measurement using Cone-beam computed tomography in patients with head and neck cancer. Front Oncol 12: 902966, 2022.
34. Yoon JK, Jang JY, An YS and Lee SJ: Skeletal muscle mass at C3 may not be a strong predictor for skeletal muscle mass at L3 in sarcopenic patients with head and neck cancer. PLoS One 16: e0254844, 2021.

35. Xiao Y, Xiao-Yue Z, Yue W, Ruo-Tao L, Xiang-Jie L, Xing-Yuan W, Qian W, Xiao-Hua Q and Zhen-Yi J: Use of computed tomography for the diagnosis of surgical sarcopenia: Review of recent research advances. Nutr Clin Pract 37: 583-593, 2022.
36. Codari M, Zanardo M, di Sabato ME, Nocerino E, Messina C, Sconfienza LM and Sardanelli F: MRI-derived biomarkers related to sarcopenia: A systematic review. J Magn Reson Imaging 51: 1117-1127, 2020.
37. Pishgar F, Shabani M, Quinaglia ACST, Bluemke DA, Budoff M, Barr RG, Allison MA, Post WS, Lima JAC and Demehri S: Quantitative analysis of adipose depots by using chest CT and associations with All-cause mortality in chronic obstructive pulmonary disease: Longitudinal analysis from MESArthritis ancillary study. Radiology 299: 703-711, 2021.
38. Mourtzakis M, Prado CM, Lieffers JR, Reiman T, McCargar LJ and Baracos VE: A practical and precise approach to quantification of body composition in cancer patients using computed tomography images acquired during routine care. Appl Physiol Nutr Metab 33: 997-1006, 2008.
39. Tagliafico AS, Bignotti B, Torri L and Rossi F: Sarcopenia: How to measure, when and why. Radiol Med 127: 228-237, 2022.
40. Prado CM, Lieffers JR, McCargar LJ, Reiman T, Sawyer MB, Martin L and Baracos VE: Prevalence and clinical implications of sarcopenic obesity in patients with solid tumours of the respiratory and gastrointestinal tracts: A population-based study. Lancet Oncol 9: 629-635, 2008.
41. Martin L, Birdsell L, Macdonald N, Reiman T, Clandinin MT, McCargar LJ, Murphy R, Ghosh S, Sawyer MB and Baracos VE: Cancer cachexia in the age of obesity: Skeletal muscle depletion is a powerful prognostic factor, independent of body mass index. J Clin Oncol 31: 1539-1547, 2013.
42. Jin Y, Ma X, Yang Z and Zhang N: Low L3 skeletal muscle index associated with the clinicopathological characteristics and prognosis of ovarian cancer: A meta-analysis. J Cachexia Sarcopenia Muscle 14: 697-705, 2023.
43. Ufuk F, Herek D and Yuksel D: Diagnosis of sarcopenia in head and neck computed tomography: Cervical muscle mass as a strong indicator of sarcopenia. Clin Exp Otorhinolaryngol 12: 317-324, 2019.
44. Swartz JE, Pothen AJ, Wegner I, Smid EJ, Swart KM, de Bree R, Leenen LP and Grolman W: Feasibility of using head and neck CT imaging to assess skeletal muscle mass in head and neck cancer patients. Oral Oncol 62: 28-33, 2016.
45. Jung AR, Roh JL, Kim JS, Choi SH, Nam SY and Kim SY: Efficacy of head and neck computed tomography for skeletal muscle mass estimation in patients with head and neck cancer. Oral Oncol 95: 95-99, 2019.
46. Lin SC, Lin YS, Kang BH, Yin CH, Chang KP, Chi CC, Lin MY, Su HH, Chang TS, She YY, *et al*: Sarcopenia results in poor survival rates in oral cavity cancer patients. Clin Otolaryngol 45: 327-333, 2020.
47. Gronberg BH, Sjoblom B, Wentzel-Larsen T, Baracos VE, Hjermstad MJ, Aass N, Bremnes RM, Fløtten Ø, Bye A and Jordhøy M: A comparison of CT based measures of skeletal muscle mass and density from the Th4 and L3 levels in patients with advanced non-small-cell lung cancer. Eur J Clin Nutr 73: 1069-1076, 2019.
48. Neefjes ECW, van den Hurk RM, Blauwhoff-Buskermolen S, van der Vorst M, Becker-Commissaris A, de van der Schueren MAE, Buffart LM and Verheul HMW: Muscle mass as a target to reduce fatigue in patients with advanced cancer. J Cachexia Sarcopenia Muscle 8: 623-629, 2017.
49. Matsuyama R, Maeda K, Yamanaka Y, Ishida Y, Kato R, Nonogaki T, Shimizu A, Ueshima J, Kazaoka Y, Hayashi T, *et al*: Assessing skeletal muscle mass based on the cross-sectional area of muscles at the 12th thoracic vertebra level on computed tomography in patients with oral squamous cell carcinoma. Oral Oncol 113: 105126, 2021.
50. Gaszynska E, Godala M, Szatko F and Gaszynski T: Masseter muscle tension, chewing ability, and selected parameters of physical fitness in elderly care home residents in Lodz, Poland. Clin Interv Aging 9: 1197-1203, 2014.
51. Yamaguchi K, Tohara H, Hara K, Nakane A, Yoshimi K, Nakagawa K and Minakuchi S: Factors associated with masseter muscle quality assessed from ultrasonography in community-dwelling elderly individuals: A cross-sectional study. Arch Gerontol Geriatr 82: 128-1232, 2019.
52. Hwang Y, Lee YH, Cho DH, Kim M, Lee DS and Cho HJ: Applicability of the masseter muscle as a nutritional biomarker. Medicine 99: e19069, 2020.
53. Chang SW, Tsai YH, Hsu CM, Huang EI, Chang GH, Tsai MS Tsai YT: Masticatory muscle index for indicating skeletal muscle mass in patients with head and neck cancer. PLoS One 16: e0251455, 2021.
54. Tsai PS, Lin DC, Jan YT, Liu YP, Wu TH and Huang SC: Lower-extremity muscle wasting in patients with peripheral arterial disease: Quantitative measurement and evaluation with CT. Eur Radiol 33: 4063-4072, 2023.
55. Perkisas S, Bastijns S, Baudry S, Bauer J, Beaudart C, Beckwee D, Cruz-Jentoft A, Gasowski J, Hobbelen H and Jager-Wittenaar H: Application of ultrasound for muscle assessment in sarcopenia: 2020 SARCUS update. Eur Geriatr Med 12: 45-59, 2021.
56. Perkisas S, Baudry S, Bauer J, Beckwee D, De Cock AM, Hobbelen H, Jager-Wittenaar H, Kasiukiewicz A, Landi F, Marco E, *et al*: Application of ultrasound for muscle assessment in sarcopenia: Towards standardized measurements. Eur Geriatr Med 9: 739-757, 2018.
57. Cheng KY, Chow SK, Hung VW, Wong CH, Wong RM, Tsang CS, Kwok T and Cheung WH: Diagnosis of sarcopenia by evaluating skeletal muscle mass by adjusted bioimpedance analysis validated with dual-energy X-ray absorptiometry. J Cachexia Sarcopenia Muscle 12: 2163-2173, 2021.
58. Walowski CO, Braun W, Maisch MJ, Jensen B, Peine S, Norman K, Müller MJ and Bosy-Westphal A: Reference values for skeletal muscle mass-current concepts and methodological considerations. Nutrients 12: 755, 2020.
59. Marini ACB, Perez DRS, Fleuri JA and Pimentel GD: SARC-F is better correlated with muscle function indicators than muscle mass in older hemodialysis patients. J Nutr Health Aging 24: 999-1002, 2020.
60. Lee YA, Kim HN and Song SW: Associations between hair mineral concentrations and skeletal muscle mass in korean adults. J Nutr Health Aging 26: 515-520, 2022.
61. Kim M and Won CW: Sarcopenia in Korean Community-dwelling adults aged 70 years and older: Application of screening and diagnostic tools from the asian working group for sarcopenia 2019 update. J Am Med Dir Assoc 21: 752-758, 2020.
62. Janssen I, Baumgartner RN, Ross R, Rosenberg IH and Roubenoff R: Skeletal muscle cutpoints associated with elevated physical disability risk in older men and women. Am J Epidemiol 159: 413-421, 2004.
63. Fielding RA, Vellas B, Evans WJ, Bhasin S, Morley JE, Newman AB, Abellan van Kan G, Andrieu S, Bauer J, Breuille D, *et al*: Sarcopenia: An undiagnosed condition in older adults. Current consensus definition: Prevalence, etiology, and consequences. International working group on sarcopenia. J Am Med Dir Assoc 12: 249-256, 2011.
64. Kim S, Kim M, Lee Y, Kim B, Yoon TY and Won CW: Calf circumference as a simple screening marker for diagnosing sarcopenia in older korean adults: The Korean frailty and aging cohort study (KFACS). J Korean Med Sci 33: e151, 2018.
65. Sergi G, De Rui M, Veronese N, Bolzetta F, Berton L, Carraro S, Bano G, Coin A, Manzato E and Perissinotto E: Assessing appendicular skeletal muscle mass with bioelectrical impedance analysis in free-living Caucasian older adults. Clin Nutr 34: 667-673, 2015.
66. Lee MM, Jebb SA, Oke J and Piernas C: Reference values for skeletal muscle mass and fat mass measured by bioelectrical impedance in 390 565 UK adults. J Cachexia Sarcopenia Muscle 11: 487-496, 2020.
67. Harvey NC, Kanis JA, Liu E, Johansson H, Lorentzon M and McCloskey E: Appendicular lean mass and fracture risk assessment: Implications for FRAX® and sarcopenia. Osteoporos Int 30: 537-539, 2019.
68. Yamada Y, Yamada M, Yoshida T, Miyachi M and Arai H: Validating muscle mass cutoffs of four international sarcopenia-working groups in Japanese people using DXA and BIA. J Cachexia Sarcopenia Muscle 12: 1000-1010, 2021.
69. Barbosa-Silva TG, Bielemann RM, Gonzalez MC and Menezes AM: Prevalence of sarcopenia among community-dwelling elderly of a medium-sized South American city: Results of the COMO VAI? study. J Cachexia Sarcopenia Muscle 7: 136-143, 2016.
70. Wang L, Zhu B, Xue C, Lin H, Zhou F and Luo Q: A prospective cohort study evaluating impact of sarcopenia on hospitalization in patients on continuous ambulatory peritoneal dialysis. Sci Rep 14: 16926, 2024.
71. Benz E, Pinel A, Guillet C, Capel F, Pereira B, De Antonio M, Pouget M, Cruz-Jentoft AJ, Eglseer D, Topinkova E, *et al*: Sarcopenia and sarcopenic obesity and mortality among older people. JAMA Netw Open 7: e243604, 2024.

72. Kirk B, Cawthon PM, Arai H, Avila-Funes JA, Barazzoni R, Bhasin S, Binder EF, Bruyere O, Cederholm T, Chen LK, *et al*: The conceptual definition of sarcopenia: Delphi consensus from the global leadership initiative in sarcopenia (GLIS). Age Ageing 53: afae052, 2024.
73. Morley JE, Abbatecola AM, Argiles JM, Baracos V, Bauer J, Bhasin S, Cederholm T, Coats AJ, Cummings SR, Evans WJ, *et al*: Sarcopenia with limited mobility: An international consensus. J Am Med Dir Assoc 12: 403-449, 2011.
74. Mizuno T, Matsui Y, Tomida M, Suzuki Y, Ishizuka S, Watanabe T, Takemura M, Nishita Y, Tange C, Shimokata H, *et al*: Relationship between quadriceps muscle computed tomography measurement and motor function, muscle mass, and sarcopenia diagnosis. Front Endocrinol (Lausanne) 14: 1259350, 2023.
75. Cruz-Jentoft AJ, Landi F, Schneider SM, Zuniga C, Arai H, Boirie Y, Chen LK, Fielding RA, Martin FC, Michel JP, *et al*: Prevalence of and interventions for sarcopenia in ageing adults: A systematic review. Report of the International Sarcopenia Initiative (EWGSOP and IWGS). Age Ageing 43: 748-759, 2014.
76. Cawthon PM, Peters KW, Shardell MD, McLean RR, Dam TT, Kenny AM, Fragala MS, Harris TB, Kiel DP, Guralnik JM, *et al*: Cutpoints for low appendicular lean mass that identify older adults with clinically significant weakness. J Gerontol A Biol Sci Med Sci 69: 567-575, 2014.
77. McGovern J, Dolan RD, Horgan PG, Laird BJ and McMillan DC: Computed tomography-defined low skeletal muscle index and density in cancer patients: Observations from a systematic review. J Cachexia Sarcopenia Muscle 12: 1408-1417, 2021.
78. Ubachs J, Ziemons J, Minis-Rutten IJG, Kruitwagen R, Kleijnen J, Lambrechts S, Olde Damink SWM, Rensen SS and Van Gorp T: Sarcopenia and ovarian cancer survival: A systematic review and meta-analysis. J Cachexia Sarcopenia Muscle 10: 1165-1174, 2019.
79. Muraki I: Muscle mass assessment in sarcopenia: A narrative review. JMA J 6: 381-386, 2023.
80. Li C, Huang Y, Wang H, Lu J and He B: Application of imaging methods and the latest progress in sarcopenia. Chin J Academic Radiol 7: 15-27, 2024.
81. Fernandes DPS, Juvanhol LL, Lozano M and Ribeiro AQ: Calf circumference is an independent predictor of mortality in older adults: An approach with generalized additive models. Nutr Clin Pract 37: 1190-1198, 2022.
82. Pagotto V, Santos KFD, Malaquias SG, Bachion MM and Silveira EA: Calf circumference: Clinical validation for evaluation of muscle mass in the elderly. Rev Bras Enferm 71: 322-328, 2018.
83. Maeda K, Koga T, Nasu T, Takaki M and Akagi J: Predictive accuracy of calf circumference measurements to detect decreased skeletal muscle mass and European society for clinical nutrition and metabolism-defined malnutrition in hospitalized older patients. Ann Nutr Metab 71: 10-15, 2017.
84. Kawakami R, Murakami H, Sanada K, Tanaka N, Sawada SS, Tabata I, Higuchi M and Miyachi M: Calf circumference as a surrogate marker of muscle mass for diagnosing sarcopenia in Japanese men and women. Geriatr Gerontol Int 15: 969-976, 2015.
85. Sahin MEH, Akbas F, Yardimci AH and Sahin E: The effect of sarcopenia and sarcopenic obesity on survival in gastric cancer. BMC Cancer 23: 911, 2023.
86. Sealy MJ, Dechaphunkul T, van der Schans CP, Krijnen WP, Roodenburg JLN, Walker J, Jager-Wittenaar H and Baracos VE: Low muscle mass is associated with early termination of chemotherapy related to toxicity in patients with head and neck cancer. Clin Nutr 39: 501-509, 2020.
87. van der Kroft G, van Dijk DPJ, Rensen SS, Van Tiel FH, de Greef B, West M, Ostridge K, Dejong CHC, Neumann UP and Olde Damink SWM: Low thoracic muscle radiation attenuation is associated with postoperative pneumonia following partial hepatectomy for colorectal metastasis. HPB (Oxford) 22: 1011-1019, 2020.
88. Li Y, Wang WB, Jiang HG, Dai J, Xia L, Chen J, Xie CH, Peng J, Liao ZK, Gao Y, *et al*: Predictive value of pancreatic dose-volume metrics on sarcopenia rate in gastric cancer patients treated with adjuvant chemoradiotherapy. Clin Nutr 38: 1713-1720, 2019.
89. Blauwhoff-Buskermolen S, Langius JAE, Becker A, Verheul HMW and de van der Schueren MAE: The influence of different muscle mass measurements on the diagnosis of cancer cachexia. J Cachexia Sarcopenia Muscle 8: 615-622, 2017.
90. Tao J, Fang J, Chen L, Liang C, Chen B, Wang Z, Wu Y and Zhang J: Increased adipose tissue is associated with improved overall survival, independent of skeletal muscle mass in non-small cell lung cancer. J Cachexia Sarcopenia Muscle 14: 2591-2601, 2023.
91. Pineda-Zuluaga MC, Gonzalez-Correa CH and Sepulveda-Gallego LE: Cut-off points for low skeletal muscle mass in older adults: Colombia versus other populations. F1000Res 11: 304, 2022.
92. Bulut EA, Soysal P, Dokuzlar O, Kocyigit SE, Aydin AE, Yavuz I and Isik AT: Validation of population-based cutoffs for low muscle mass and strength in a population of Turkish elderly adults. Aging Clin Exp Res 32: 1749-1755, 2020.
93. Bjorkman MP, Pitkala KH, Jyvakorpi S, Strandberg TE and Tilvis RS: Bioimpedance analysis and physical functioning as mortality indicators among older sarcopenic people. Exp Gerontol 122: 42-46, 2019.
94. Han DS, Chang KV, Li CM, Lin YH, Kao TW, Tsai KS, Wang TG and Yang WS: Skeletal muscle mass adjusted by height correlated better with muscular functions than that adjusted by body weight in defining sarcopenia. Sci Rep 6: 19457, 2016.
95. Bahat G, Tufan A, Tufan F, Kilic C, Akpinar TS, Kose M, Erten N, Karan MA and Cruz-Jentoft AJ: Cut-off points to identify sarcopenia according to European Working Group on Sarcopenia in Older People (EWGSOP) definition. Clin Nutr 35: 1557-1563, 2016.