

UNIVERSITY OF TARTU
Faculty of Medicine

Calf Circumference Adjusted for Body Composition to Assess Muscle Mass

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Abstract

Title: Calf circumference adjusted for body composition to assess muscle mass

Background: Reduced muscle mass is an important component in diagnostics of disease-related malnutrition and sarcopenia. Muscle mass can be estimated with accurate technological methods such as dual-energy x-ray absorptiometry (DEXA) or simple limb circumferences. The otherwise good correlation between calf circumference (CC) and DEXA-derived muscle mass has been found to be weaker in patients with obesity.

Aim: To investigate the effect of adiposity on the relationship between calf circumference and muscle mass, and to correct the presumed poor correlation between these parameters in patients with obesity using mid-upper arm circumference (MUAC).

Methods: 75 patients were recruited from the densitometry unit. Muscle mass was estimated with calf circumference, mid-upper arm circumference and DEXA-derived appendicular lean mass index (lean mass in limbs / height squared). Obesity status was determined by BMI and waist circumference. Patients were assessed for malnutrition with the Global leadership Initiative on Malnutrition (GLIM) criteria. Pearson or Spearman's correlation was used to assess the correlations between calf, mid-upper arm and waist circumference and appendicular lean mass index, fat mass index. Receiver operating characteristic (ROC) analysis and multiple linear regression analyses were performed in R Studio.

Results: The patients had a mean age of 64.9 (SD $\pm$ 14) years and a body mass index of 28.4 (SD $\pm$ 5.5) kg/m². Nine patients (12%) were male and 66 (88%) were female. 38.7% of the patients were obese. According to the GLIM criteria, malnutrition was identified in 6 (8.0%) patients. Due to the small sample size for the male patients, correlations, ROC curve analysis, and multiple linear regression analysis were carried out only in female patients.

Calf circumference (CC) showed a strong, positive, and significant correlation with appendicular lean mass index (ALMI) in both non-obese (BMI < 30 kg/m²; Spearman's rho = 0.61, p = 0.002) and obese (BMI $\geq$ 30 kg/m²; Spearman's rho = 0.65, p < 0.001) female subgroups. Similarly, a significant positive correlation between CC and ALMI was observed in females with normal waist circumference (Spearman's rho = 0.62, p = 0.002) and those with high waist circumference (Spearman's rho = 0.76, p < 0.001).

ROC curve analysis demonstrated high diagnostic accuracy for Calf Circumference (AUC = 0.887, 95% CI: 0.810 - 0.963) and Mid-upper Arm Circumference (AUC = 0.876, 95% CI: 0.786 - 0.967) in predicting low appendicular lean mass index (ALMI < 6.39 kg/m² (25th percentile). Multiple linear regression analysis showed that calf circumference was significantly associated with ALMI in females (overall model $p < 0.001$) after adjusting for adiposity and age, explaining 62% of ALMI variance when including fat mass index and age ($R^2 = 0.62$), and 70% when including body mass index and age ($R^2 = 0.70$).

Conclusions: Calf circumference has a strong correlation with DEXA-derived ALMI in both obese and non-obese patients undergoing DEXA scan: no need for a MUAC correction in this population. MUAC is better correlated with fat mass than lean mass and could potentially be used for correcting CC in sedentary obese patient groups. Age and BMI corrections appear to be important for determining CC thresholds for low muscle mass.

Keywords: nutrition assessment, GLIM criteria, malnutrition, sarcopenia, muscle mass, calf circumference, mid-upper arm circumference, obesity

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1. Introduction

Disease-related malnutrition and sarcopenia are major global health challenges, with high prevalence in hospitals, ICUs, oncology wards, and long-term care facilities. They are associated with increased morbidity, mortality, longer hospital stays, readmissions, functional decline, reduced quality of life, and greater healthcare costs (1,2).

Reduced muscle mass is an important criterion used in the diagnostics of both disease-related malnutrition and sarcopenia. Muscle mass can be assessed using methods with varying accuracy and accessibility – from technological “gold-standards” like dual-energy x-ray absorptiometry (DEXA) or computed tomography (CT) to simple limb circumferences (3,4).

Evaluating of muscle mass with gold-standard methods is often challenging in healthcare settings due to their high cost, lack of portability, and impracticality (4). Limb circumferences, namely calf circumference (CC) and mid-upper arm circumference (MUAC) are cost-effective, simple alternative techniques that can easily be performed to estimate muscle mass in clinical settings (5,6).

International consensus criteria for assessing disease-related malnutrition (GLIM) and sarcopenia (EWGSOP2) support the use of calf circumference for assessment of skeletal muscle mass when advanced methods are not available (7).

Calf circumference has been found to be strongly correlated with lean mass. However, this correlation tends to be weaker in patients with obesity, especially females ((8–10). Contrarily, mid-upper arm circumference (MUAC) has been found to correlate better with fat mass than lean mass. Therefore, this thesis aimed to find out whether calf circumference corrected with mid-upper arm circumference is more accurate than calf circumference alone at estimating reduced muscle mass in patients with obesity.

2. Scientific background of the research

2.1 Disease related malnutrition

Disease-related malnutrition (DRM) is a common condition associated with prolonged hospital stays, higher morbidity and mortality, and increased economic burden. The prevalence of DRM is from 20% to 50%, depending on the diagnostic criteria and patient population(1).

According to a definition provided by ESPEN, disease related malnutrition is a condition from the lack of intake or utilization of nutrients during any disease state, resulting in weight loss, loss of skeletal muscle, physical and mental dysfunctions, and worse clinical outcome(11). There are various other definitions and diagnostic methods for malnutrition.

There have been significant efforts to standardize the definitions and diagnostic criteria for malnutrition in recent years. The Global Leadership Initiative on Malnutrition (GLIM) was formed by major clinical nutrition societies to propose a global consensus for the diagnosis of malnutrition in adults in clinical settings. (11,12).

GLIM proposes a two-step approach for malnutrition assessment. Before the assessment, patients should be screened using a validated nutritional screening tool to determine if they are at risk of malnutrition. Patients identified as at risk of malnutrition will undergo detailed assessment. First step is the assessment of malnutrition. Second step is defining the severity in patients who are malnourished (12).

GLIM has five criteria which divided into two categories: the phenotypic criteria and the etiologic criteria. Phenotypic criteria are non-volitional weight loss, low body mass index (BMI) and reduced muscle mass. Etiologic criteria are reduced food intake or assimilation and inflammation. If at least one phenotypic and etiologic criterion is present, the patient will be diagnosed with disease-related malnutrition. Further step is to determine if the patient has moderate or severe malnutrition.

2.2. Sarcopenia

Sarcopenia is defined as a progressive and generalized skeletal muscle disease (muscle failure) associated with increased risk of adverse outcomes like falls, fractures, disability, and mortality by European Working Group on Sarcopenia in Older People (EWGSOP2)(13). Sarcopenia prevalence is around 10% in the general elderly population but rising sharply in clinical settings (14).

EWGSOP2 focuses on low muscle strength as a key characteristic of sarcopenia, uses detection of low muscle quantity and quality to confirm the sarcopenia diagnosis, and identifies poor physical performance as indicative of severe sarcopenia (13).

The EWGSOP2 recommends a pathway of Find-Assess-Confirm-Severity for use across clinical practice. First step is to find cases through screening methods like SARC-F questionnaires or clinical suspicion. Patients with probable sarcopenia should be assessed based on their muscle strength measured with handgrip strength or the chair stand test(13). This step is enough to start intervention. Next step is to confirm sarcopenia through muscle quantity or quality assessments.

2.4. The importance of muscle mass in malnutrition and sarcopenia

Reduced muscle mass is a strong independent predictor of increased mortality as it's confirmed in recent literature. This association exists in various clinical settings, including general hospital wards ((15), intensive care units (16), oncology(14), surgery(17), long-term care (14), and chronic kidney disease (18).

Reduced muscle mass is also associated with increased morbidity. Patients experience higher rates of complications, such as infections (including surgical site infections and nosocomial infections), sepsis, pneumonia, pressure ulcers, delayed wound healing, and adverse post-operative events (17) Furthermore, these conditions are associated with prolonged length of hospital stay (LOS) and higher rates of hospital readmission (19). Therefore, assessing muscle mass should not be optional in GLIM assessment. If assessment relies on only weight loss or low BMI, it is possible that many patients may be underdiagnosed.

Studies comparing GLIM to criteria without muscle mass component found that GLIM identifies a higher prevalence of malnutrition, suggesting that skipping muscle assessment

leads to underdiagnosis (20). This highlights that a comprehensive nutritional assessment, as recommended by GLIM, should include an evaluation of body composition.

2.4. Methods for Muscle Mass Assessment in Clinical Practice and Research

There are various methods to assess muscle mass, ranging from advanced imaging techniques to simpler clinical tools that are more accessible. The choice of method depends on the clinical setting, available resources and the specific patient group.

Dual-energy X-ray Absorptiometry (DEXA): A gold standard method for assessing three-compartment body composition (fat mass, lean mass, bone mineral content) (22). It is commonly used to measure appendicular lean mass (ALM) or appendicular skeletal muscle mass (ASM), which represents the muscle mass in the limbs and is considered a good proxy for total body muscle. ALM/ASM is often indexed to height squared (ASMI) (23). Both GLIM and EWGSOP2 recommend DEXA for muscle mass assessment (12).

- **Advantages:** Relatively low radiation dose, good accuracy and precision for estimating lean mass, faster and less expensive than MRI, widely used in research and available in specialized centers (e.g., osteoporosis clinics, research facilities) (13).
- **Limitations:** *High* cost equipment and lack of portability, less effective than CT/MRI for assessing muscle quality (fat infiltration) (13).

Computed Tomography (CT): A gold standard for quantifying muscle cross-sectional area (CSA). The resulting Skeletal Muscle Index is frequently used in research, particularly in oncology where abdominal/pelvic CT scans are used for disease staging or monitoring (13)

- **Advantages:** High precision and accuracy for muscle area; ability to assess muscle quality; often available as part of routine clinical care in certain specialties (e.g., oncology, surgery) (13).
- **Limitations:** Involves ionizing radiation exposure, limiting repeated measurements or use in healthy individuals for screening; relatively high cost; requires specific software and trained personnel for accurate image analysis; not portable for bedside assessment (13)

Bioelectrical Impedance Analysis (BIA): BIA estimates body composition by measuring the resistance and reactance of body tissues to a small, imperceptible electrical current (12).

Fat-Free Mass (FFM), Body Cell Mass (BCM), or Skeletal Muscle Mass (SMM) are main components of the BIA results. The phase angle (PhA), is a potential indicator of cell membrane integrity and overall nutritional/health status (2).

- Advantages: Relatively inexpensive, portable (many devices), quick and easy to perform, non-invasive (13).
- Limitations: Accuracy is highly dependent on the specific device, the prediction equations used (which should ideally be validated for the population being studied), and adherence to strict measurement protocols (e.g., regarding hydration, recent exercise, food/fluid intake). Accuracy could be lower as it is affected by hydration status (e.g., edema, critical illness) (2).

Muscle Ultrasound (US): US can measure muscle thickness and cross-sectional area of specific muscles (e.g., quadriceps rectus femoris, biceps) and potentially assess muscle quality.

- Advantages: Non-invasive, portable, free of radiation, relatively low cost compared to CT, allows for repeated measurements easily.
- Limitations: Requires specific training and standardized protocols for reliable measurements; validated cut-off points for diagnosing low muscle mass are still being established for various populations and muscles; less comprehensive than whole-body methods like DXA or BIA (24).

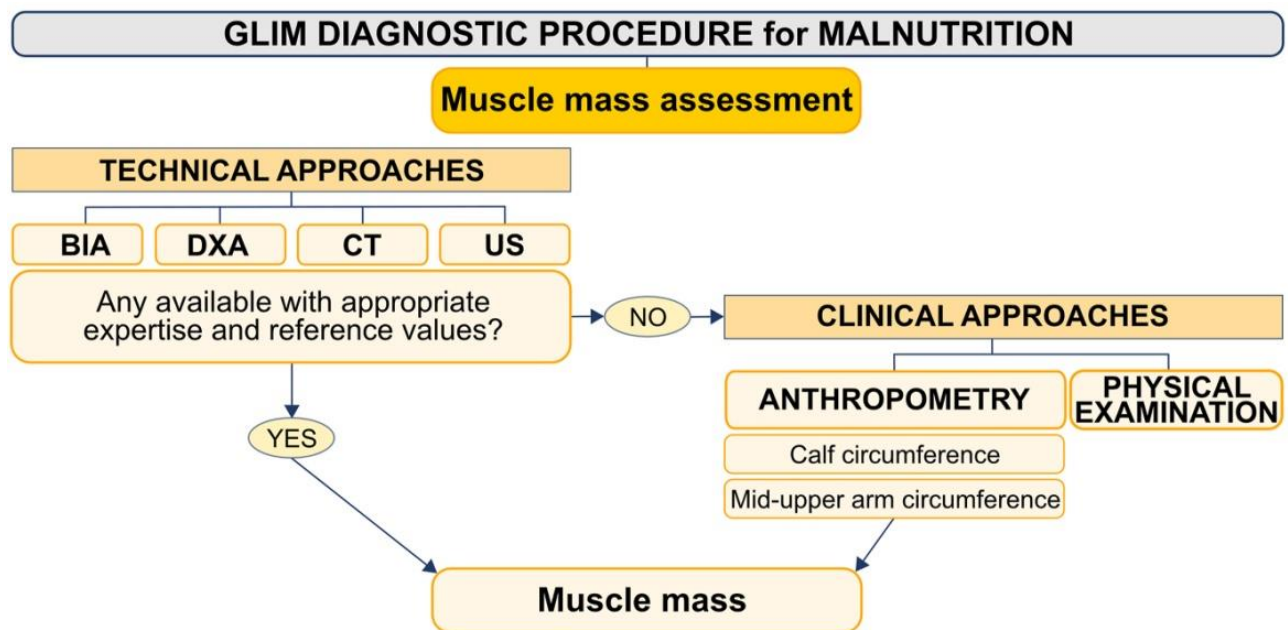


Figure. 1. GLIM approach to diagnosis of malnutrition with focus on muscle mass assessment. (25)

2.5. Calf Circumference and Mid-upper Arm Circumference as Alternative Methods

Mid-Upper Arm Circumference (MUAC): An alternative method for muscle mass assessment suggested by GLIM when other advanced methods are unavailable (12).

Advantages: Very low cost, requires minimal equipment (measuring tape) and training, easy to perform at the bedside (26).

Limitations: Less accurate and precise than imaging or BIA; significantly influenced by subcutaneous fat and edema, potentially masking muscle loss or overestimating it. Validated, population-specific cut-offs are not always available (26).

Calf Circumference (CC): Measured at the widest point of the calf, CC is increasingly validated as a simple, very low cost, and readily available surrogate marker for skeletal muscle mass, particularly in older adults and resource-limited settings(12). It shows good correlation with DXA and CT measurements (6) and has been included into screening tools like SARC-CalF (27) Calf circumference has been shown to predict performance and survival

in older people (28). Therefore, EWGSOP2 also recommends using calf circumference as a diagnostic proxy for older adults in settings where no other advanced muscle mass diagnostic methods are available.

GLIM supports its use as an alternative method for assessing the reduced muscle mass criterion (12).

A cohort study validated the use of GLIM criteria for malnutrition diagnosis by comparing CC and MUAC measurements against the Subjective Global Assessment (SGA) in hospitalized patients. Both measures showed strong accuracy for detecting malnutrition (29).

Earlier Asian validation studies affirmed the good diagnostic performance of CC for detecting low appendicular lean mass and sarcopenia (6),(30). The Asian Working Group for Sarcopenia (AWGS) 2019 consensus recommended the addition of calf circumference in order to improve the sensitivity of sarcopenia screening (SARC-F)(21).

2.6. The problem with muscle mass assessment in patients with obesity

Assessing muscle mass in nutritional assessment for patients with obesity presents specific challenges. Studies show that a higher BMI is associated with a higher muscle mass due to the additional weight, comprising both fat and muscle (31,32).

This association can result as an overestimation of muscle mass when using mid upper-arm or calf circumference, as excess fat can hide muscle loss, potentially underdiagnosing malnutrition (33). In addition to limb circumferences, bio-electric impedance (BIA) measurements are also less reliable in this population as it overestimates the fat-free mass by BIA equations (34).

The NHANES study in the U.S. proposed BMI-specific cut-off points for calf circumference (26). Patients with obesity may have a low muscle percentage but still have a relatively high muscle amount in kg. Many individuals could still exceed reduced muscle mass cut-offs and escape malnutrition diagnosis (35).

Previous study showed that Mid-upper arm circumference (MUAC) is more representative of body fat mass than of muscle mass in patients with obesity, especially in women (10).

Therefore, MUAC may improve the accuracy of calf circumference as a muscle mass measure by adjusting for the influence of fat.

3. Aim and Hypothesis

The aim of the study was to investigate the effect of adiposity on the relationship between calf circumference and muscle mass, and to correct the presumed poor correlation between these parameters in patients with obesity.

The hypothesis of the study was that calf circumference corrected with mid-upper arm circumference is more accurate than just calf circumference at estimating reduced muscle mass in patients with obesity. In case the hypothesis proves true, corrected calf circumference measurement will have the potential to be an easy and simple approach for estimating muscle mass in patients with obesity in clinical or limited settings.

4. Methods

4.1. Overall study design

A cross-sectional observational study was designed. Inpatients or outpatients of Internal Medicine Clinic of the Tartu University Hospital who were scheduled for a DEXA scan, older than 18 years old and able to understand and sign the informed consent form were included in the study. Patients with pregnancy, lactation, acute sepsis, severe dehydration or volume overload and patients who are unable to follow study procedures were excluded. The data collection started on February 19th after receiving ethics approval, and was completed on April 2nd, 2025. Participants for this study were recruited from the Densitometry unit at Tartu University Hospital. Data collection took 20 days, averaging 4 weekdays per week. Data collection days were planned beforehand depending on the availability of the researchers and DEXA nurses. All eligible inpatients and outpatients present at the unit from morning to noon were invited to participate on each data collection day.

4.2. Approvals and trial registration

4.2.1. Approval of the Clinical Research Centre

The Clinical Research Centre of the University of Tartu supports researchers and coordinates collaboration with clinical departments. For this study, approval from the Internal Medicine Clinic of Tartu University Hospital was required. After receiving a digital signature from the Clinic confirming its participation, the Clinical Research Centre reviewed and approved the project.

4.2.2. Approval of the Ethics Committee

Ethics application form (in Estonian), patient consent forms (in Estonian and Russian), the approval of the clinical research centre and curriculum vitae of all researchers were submitted to get the approval of the University of Tartu ethics committee. The application form included the general project details, funding information, a description of the study population and research methods, ethical considerations, and a description of prior similar research. The first ethics application was submitted in December 2024, and the ethics committee's approval was received in January 2025 (ID: 396/T-16). Additional documents were submitted later if new researchers joined the team or any changes were added to the research protocol.

4.2.3. Registration of the trial protocol

The clinical trial was registered and published on the clinicaltrials.gov website (ID: NCT 06829004). Registering trials on the clinicaltrials.gov website ensures research transparency and provides a valuable resource for researchers to stay updated on studies from different institutions.

4.3. Data collection

4.3.1. Data collection team

The data collection team consisted of six people: Irem Seker (main researcher, clinical nutrition student), Grete Kurik (PhD student and junior research fellow, Merili-Mai Kivimets (clinical nutrition student), Anni Anastasia Pilvar (midwife, lecturer) and DEXA nurses Ele Klaus and Alla Olefirenko.

İrem Şeker was part of whole data collection process. She assisted the team with taking antropometric measurements from patients, recorded the data on excel during the interview, collected data from eHL and managed the database. Grete Kurik recruited other two researchers (Merili-Mai Kivimets and Anni Anastasia Pilvar). Grete Kurik, Merili-Mai Kivimets and Anni Anastasia Pilvar collected data from Estonian-speaking patients. Anni Anastasia Pilvar also collected data from Russian-speaking patients.

4.3.2. Approaching the patients

Eligible patients were approached right before their DEXA scan. Researchers informed patients about the purpose of the study, the measurements that would be taken, and how their data would be used. Each patient received an informed consent form, which the researcher explained in detail to ensure the patient fully understood its contents.

The patient got to ask questions about the study and then agreed or refused to participate. Signing the informed consent form confirmed the patient's participation. Patients also took a copy of the informed consent form. If the patient agreed to participate in the study, measurements and additional questions about their nutritional status were asked right after the DEXA scan.

4.3.3. Collecting data from the patients

The patient was asked about their reduced dietary intake, recent weight changes and nutrition-related symptoms as part of GLIM malnutrition assessment. The measurements included calf circumference (CC), mid-upper arm circumference (MUAC) and waist circumference. The height and weight were measured by DEXA nurse. CC and MUAC were measured with a non-stretchable tape measure to the nearest 0.1 cm. CC was measured from the midpoint and the widest part of the left calf with the patient seated on the chair and knees at 90° angle. The left calf was measured for all participants to ensure standardization. Mid-upper arm circumference was measured from the midpoint of the non-dominant upper arm; the patient was standing, with their arm hanging loosely. Waist circumference was measured at the midpoint between the lowest rib and the iliac crest along the mid-axillary line. Participants stood upright and the measurement was taken at the end of a normal expiration (36).

4.4. Data Analysis

The data analysis was carried out using Microsoft Excel and R. The assistance of Gemini (2.5 pro) was used for generating the R codes for data analysis and creating tables and figures.

Associations between variables were assessed using both Pearson correlation coefficients (r) for linear relationships and Spearman rank correlation coefficients (ρ) for monotonic relationships (or when data were not normally distributed). The magnitude of the correlation, was interpreted based on the absolute value of r or ρ (37).

Table 1. Correlation Coefficient ($|r|$ or $|\rho|$) Interpretation

0.00 – 0.19	very weak / negligible
0.20 – 0.39	Weak
0.40 – 0.59	moderate
0.60 – 0.79	strong
0.80 – 1.00	very strong

A correlation was considered statistically significant if the associated p-value was less than 0.05 for both Pearson and Spearman coefficients.

4.4.1. Normality Assessment

Shapiro-Wilk normality test, histograms and Q-Q plots were used to determine the normality of the continuous variables and to permit the use of parametric statistics. Non-parametric statistical tests were used if non-normal distributions were confirmed or suspected.

4.4.2. The ability of calf circumference, mid-upper arm circumference and waist circumference to predict DEXA derived muscle mass and fat mass, stratified by gender

The correlation between anthropometric measures and DEXA-derived Appendicular Lean Mass Index (ALMI) AND Fat Mass Index (FMI), were analyzed separately for female and male groups. DEXA derived ALMI was used as the standard for muscle mass assessment, as it is one of the methods recommended by GLIM and EWGSOP2 authors. Based on normality assessments for each variable, Pearson or Spearman correlation was used.

To evaluate the diagnostic accuracy of CC and MUAC for detecting low muscle mass in female participants, Receiver Operating Characteristic (ROC) curve analysis was planned. Low muscle mass was defined using GLIM and EWGSOP2 criterion for females, based on Appendicular Lean Mass Index (ALMI) measured by DEXA, which is $< 5.5 \text{ kg/m}^2$.

Therefore, an alternative approach using a sample-specific threshold was adopted. For the ROC analysis, low muscle mass was defined as having an ALMI value below the 25th percentile (the first quartile, Q1) calculated from the ALMI distribution of all female participants in this study. This method ensured that 25% of the sample included patients with lower muscle mass, improving the reliability of the ROC analysis for this patient group.

4.4.3. Subgroup Analysis Based on Body Composition

Further analysis based on obesity status was performed, categorizing patients as non-obese ($\text{BMI} < 30 \text{ kg/m}^2$) or obese ($\text{BMI} \geq 30 \text{ kg/m}^2$) to see the effects of body composition. The analysis for correlation between circumferential circumference (CC) and appendicular lean mass index (ALMI) based on body composition was conducted only for the female group. Normality for both variables was checked within each group. As ALMI was non-normally

distributed in non-obese females (Shapiro-Wilk $p < 0.05$), Spearman's correlation was applied to both subgroups for methodological consistency and comparability.

The correlation between CC and ALMI based on central obesity required categorizing female patients by waist circumference (WC < 88 cm vs. ≥ 88 cm, reflecting WHO risk thresholds). Non-parametric testing was required for the normal WC subgroup ALMI $p < 0.05$), Spearman's rank correlation was used for both subgroups.

5. Results

5.1. Baseline characteristics of the patients

Data were collected from 75 patients, averaging 3-4 patients on each data collection day. Nine patients (12%) were male and 66 (88%) patients were female. The patients had a mean age of 64.9 (SD $\pm$ 14) years. The mean age was similar between female patients (65.0 $\pm$ 13.4 years, N=66) and male patients (64.3 $\pm$ 19.2 years, N=9). The mean body mass index (BMI) of the patients was 28.4 kg/m² (SD $\pm$ 5.5). 38.7% of the patients were obese.

According to the GLIM criteria, malnutrition was identified in 6 (8.0%) patients. When stratified by gender, 3 (4.5%) female and 3 (33.3%) male patients had malnutrition diagnosis.

The primary diagnoses were diseases of the musculoskeletal system and connective tissue, neoplasms, diseases of the respiratory system, endocrine, nutritional and metabolic diseases, diseases of the skin and subcutaneous tissue and digestive system diseases (Table 2). 9 patients out of 75 patients were inpatients.

Table 2. Patient characteristics.

N = 75¹

Age, years	64.9 $\pm$ 14.0
Gender	
Female	66 (88.0%)
Male	9 (12.0%)
BMI kg/m²	
Underweight (<18.5)	1 (1.3%)
Normal weight (18.5-24.9)	26 (34.7%)
Overweight (25-29.9)	19 (25.3%)

Table 2. Patient characteristics.**N = 75¹**

Obese (≥ 30)	29 (38.7%)
Main diagnoses	
Diseases of the musculoskeletal system and connective tissue	36 (48.0%)
Neoplasms	6 (8.0%)
Diseases of the respiratory system	4 (5.3%)
Endocrine, nutritional and metabolic diseases	4 (5.3%)
Diseases of the skin and subcutaneous tissue	3 (4.0%)
Diseases of the digestive system	3 (4.0%)
Other	19 (25.3%)

¹ Mean; n (%)

5.2. Normality Assessment

The results of Shapiro-Wilk normality test, histograms and Q-Q plots showed that the distributions of CC, MUAC, ALMI, and FMI were normal, supported by both histograms and non-significant Shapiro-Wilk tests ($p > 0.05$) in women. However, visual deviations (skewness and/or heavy tails) were noted for BMI and waist circumference in women, despite non-significant Shapiro-Wilk tests. For men, non-normal patterns such as bimodality (CC), irregular distributions (MUAC, ALMI, or significant skewness (FMI, BMI, Waist circumference) were observed despite non-significant statistical tests ($p > 0.05$). Due to these differences, analysis involving these variables was stratified by sex. Parametric tests (like t-tests or Pearson correlations) were used only within the female group.

5.3. The ability of calf circumference, mid-upper arm circumference and waist circumference to predict DEXA derived muscle mass and fat mass, stratified by gender

Low muscle mass was defined using GLIM and EWGSOP2 criterion for females, based on Appendicular Lean Mass Index (ALMI) measured by DEXA, which is $< 5.5 \text{ kg/m}^2$.

However, applying this $< 5.5 \text{ kg/m}^2$ threshold to this sample detected only three female patients (N=3 out of 66) with low muscle mass. The small number of cases in the female group were insufficient for a reliable ROC curve analysis with the standard clinical cut-off.

Therefore, for the ROC analysis, low muscle mass was defined as having an ALMI value below the 25th percentile (the first quartile, Q1) calculated from the ALMI distribution of all female participants in this study.

Calf Circumference (CC): CC showed a strong correlation with ALMI in females (Pearson's $r = 0.77$, 95% CI [0.65, 0.85], $p < 0.001$). In males, using Spearman's correlation due to non-normality, there was a strong and significant correlation with ALMI $r = 0.86$, $p = 0.003$).

FMI and CC had a strong, significant linear correlation in females (Pearson's $r = 0.69$, 95% CI [0.54, 0.80], $p < 0.001$), while the strong correlation in males was not statistically significant (Spearman's $\rho = 0.60$, $p = 0.088$).

Mid-upper Arm Circumference (MUAC): In females, MUAC correlated moderately with ALMI (Pearson's $r = 0.71$, 95% CI [0.56, 0.81], $p < 0.001$) and, more strongly, with FMI (Pearson's $r = 0.84$, 95% CI [0.75, 0.90], $p < 0.001$). In males, MUAC showed a significant positive correlation with ALMI (Spearman's $\rho = 0.79$, $p = 0.010$), but its correlation with FMI was not significant (Spearman's $\rho = 0.52$, $p = 0.154$).

Waist Circumference: Spearman's correlation was used in both groups based on the results of normality tests for waist circumference. In females, waist circumference showed a strong, significant correlation with ALMI ($\rho = 0.62$, $p < 0.001$) and stronger correlation with FMI ($\rho = 0.92$, $p < 0.001$). In males, the moderate correlation between waist circumference and ALMI was not significant ($\rho = 0.41$, $p = 0.273$), while the strong correlation with FMI was statistically significant ($\rho = 0.65$, $p = 0.058$).

The male sample size (N=9) was too small for a reliable Receiver Operating Characteristic (ROC) curve analysis. Since small samples can negatively affect ROC curve performance, this analysis was performed only for female participants (N=66). ROC curve analysis was performed to compare the diagnostic accuracy of Calf Circumference (CC) and Mid-upper Arm Circumference (MUAC) for detecting female patients with low muscle mass (ALMI, defined as < 25th percentile ≈ 6.39 kg/m² in this sample).

The Area Under the Curve (AUC) for CC was 0.887 (95% CI: 0.810 - 0.963), and the AUC for MUAC was 0.876 (95% CI: 0.786 - 0.967)(Figure 2, Figure 3). A formal comparison using the DeLong test indicated no statistically significant difference between the AUC values derived from CC and MUAC ($p = 0.811$).

Based on the Youden index, the optimal cut-point for CC was approximately 37.85 cm, which yielded 100% sensitivity and 75.5% specificity. The optimal cut-point for MUAC was approximately 29.25 cm, yielding 70.6% sensitivity and 89.8% specificity at this threshold.

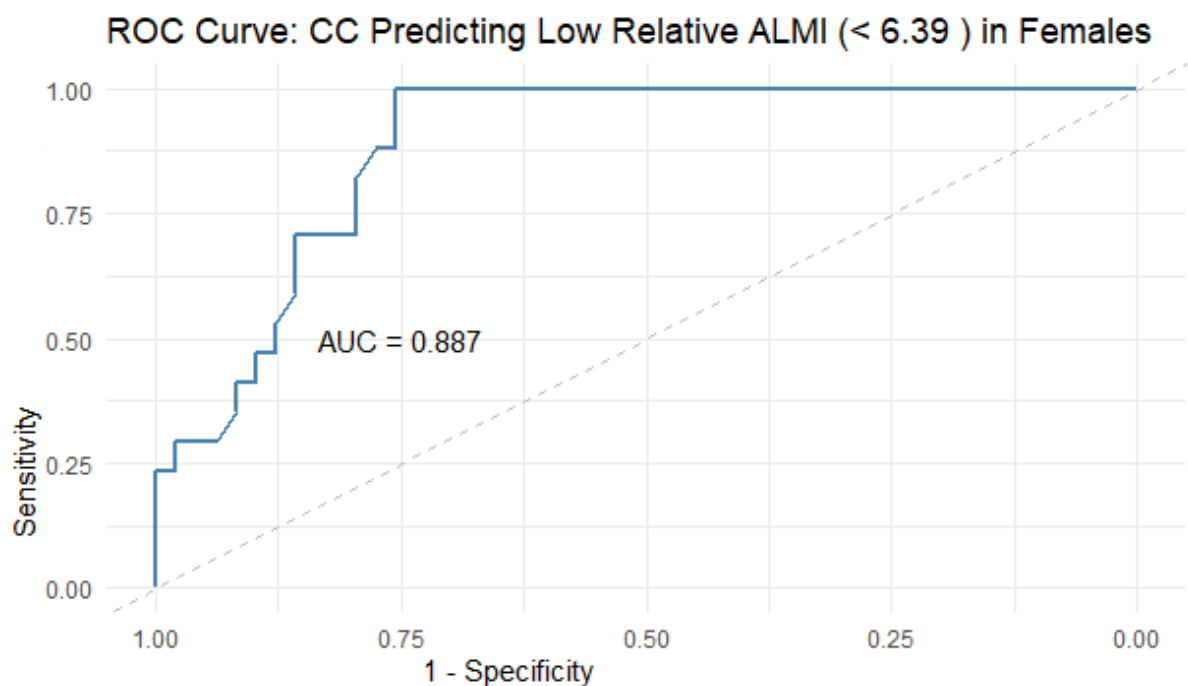


Figure 2. ROC curve of CC predicting the low appendicular lean mass index in females.

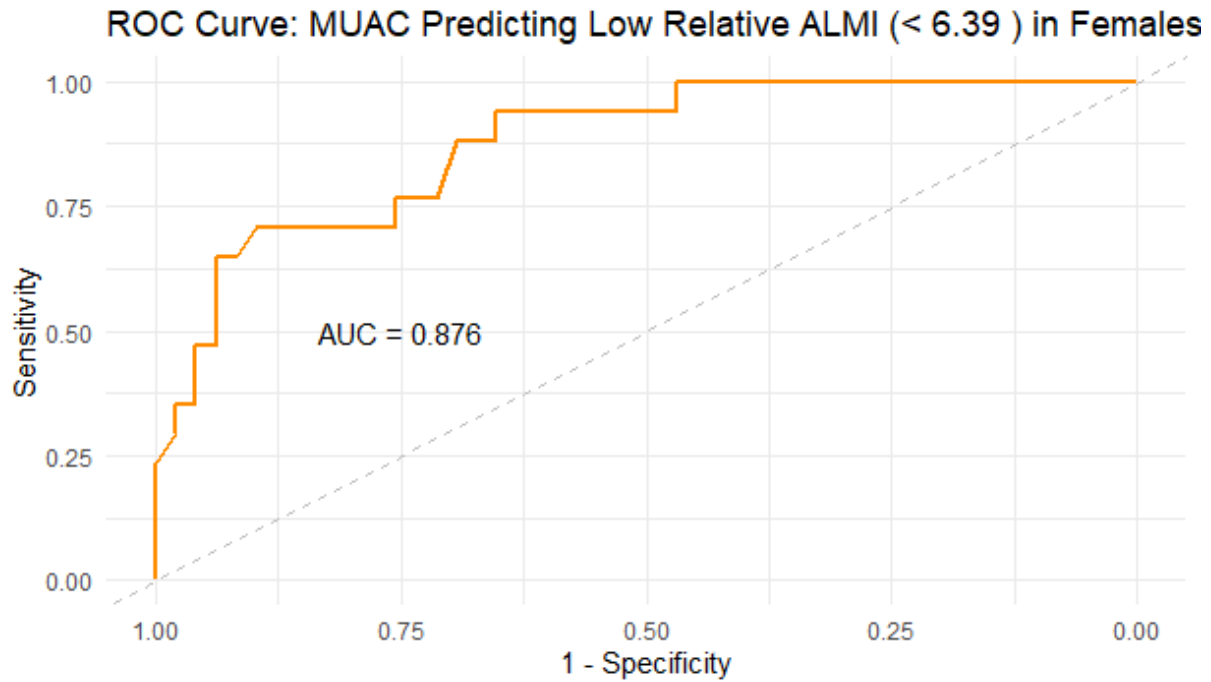


Figure 3. ROC curve of MUAC predicting the low appendicular lean mass index in females.

5.4. Subgroup Analysis Based on Body Composition

The sample size for the male group was too small to conduct reliable correlation analyses (non-obese males: N=7; obese males: N=2). Therefore, subgroup analysis based on body composition was carried out only in female group.

When categorized by BMI status (Non-obese: BMI < 30 kg/m²; Obese: BMI ≥ 30 kg/m²), calf circumference (CC) showed a strong, positive, and significant correlation with appendicular lean mass index (ALMI) in both the non-obese and obese female subgroups. In the non-obese group, Spearman's rank correlation coefficient (rho) was 0.61 (p = 0.002), while in the obese subgroup, it was 0.65 (p < 0.001).

The correlation analysis between CC and ALMI based on central obesity showed a significant positive correlation in both normal waist circumference group (Spearman's rho = 0.62, p = 0.002) and high waist circumference group (Spearman's rho = 0.76, p < 0.001). The correlation was stronger in women with high waist circumference (≥88 cm).

5.5. Calf circumference as an independent predictor of muscle mass after adjusting for adiposity in females (Multiple Regression Analysis)

Multiple regression analysis was performed to check if calf circumference (CC) is associated with muscle mass (ALMI) in females after adjusting for adiposity and age. Two models were developed: Model A including fat mass index (FMI) and age, and Model B including body mass index (BMI) and age, alongside CC.

Both models were statistically significant in predicting muscle mass (overall model $p < 0.001$). Model A (FMI model) explained 62% of the variance in ALMI ($R^2 = 0.62$, 95% CI [0.430, 0.735]; adjusted $R^2 = 0.60$). Model B (BMI model) explained 70% of the variance in ALMI ($R^2 = 0.70$, 95% CI [0.543, 0.799]; adjusted $R^2 = 0.69$).

In these models, both FMI ($p = 0.040$) and BMI ($p < 0.001$) also showed significant positive links with muscle mass when considered alongside CC and age. Age had a significant negative link with muscle mass in the model with BMI ($p = 0.020$) (Table 3).

Table 3. Multiple Regression Predicting ALMI in Females, Adjusted for Age and Adiposity.

Predictor	Model A: ALMI ~ CC + Age + FMI			Model B: ALMI ~ CC + Age + BMI		
	Beta	95% CI	p-value	Beta	95% CI	p-value
(Intercept)	1.81	0.096, 3.52	0.039	1.23	0.601, 3.25	0.051
Calf Circumference (cm)	0.132	0.085, 0.180	<0.001	0.088	0.043, 0.133	<0.001
Age (years)	-0.008	-0.021, 0.005	0.2	-0.013	-0.024, -0.002	0.020
Fat Mass Index (kg/m ²)	0.058	0.003, 0.113	0.040			
Body Mass Index (kg/m ²)				0.092	0.052, 0.131	<0.001

Abbreviation: CI = Confidence Interval

6. Discussion

This study explored whether calf circumference (CC) could be adjusted with mid-upper arm circumference (MUAC) to improve its ability to predict muscle mass in patients with obesity. DEXA-derived muscle mass (ALMI) was used as the reference standard. Only data of female patients were analysed, as the number of male participants turned out to be insufficient to conduct meaningful analysis.

6.1. Correlations between Calf Circumference and Muscle Mass Across Adiposity Levels in Females

Unlike previous that have found a weaker correlation between CC and lean mass in patients with obesity, this study showed a strong correlation between calf circumference and DEXA-derived muscle mass (ALMI) across adiposity levels (8–10). In a recent similar study conducted at Tartu University Hospital, there was no significant correlation found between CC and BIA-derived FFMI in female inpatients with obesity (10). Different reference standard muscle mass assessment methods (DEXA vs BIA) and patient characteristics (such as primary diagnoses and average age) may have contributed to this difference.

Additionally, the current sample included mostly outpatients, whereas the previous study was done in inpatients only. Outpatients with or without obesity are less likely to be bedridden and, therefore, have more muscle mass. Having more muscle mass, in turn, makes calf circumference a more accurate estimator of lean mass – this could have further contributed to our finding of strong correlation between CC and ALMI in patients with obesity.

6.2. Diagnostic Accuracy of CC for Relative Low Muscle Mass in Females

Previous studies have performed ROC curve analysis using the reduced muscle mass threshold values defined by Baumgartner and the AWGS 2019. Similarly to previous studies (38,39), we used quartiles for defining low ALMI in ROC analysis, as Baumgartner and the AWGS 2019 threshold values were too low to conduct meaningful analysis in our sample. Calf circumference demonstrated a strong ability to estimate DEXA-derived low muscle mass, with an AUC value of 0.887. This means that calf circumference remains a good alternative for estimating muscle mass when technological methods like DEXA, CT, BIA or

ultrasound are not available.

6.3. Adjusted calf circumference

Multiple regression analysis was performed to check if calf circumference (CC) is associated with muscle mass (ALMI) in females after adjusting for adiposity and age. As has been previously identified in the literature (26), our study found that calf circumference, adjusted for age and BMI, is a good predictor of ALMI. This highlights that adjusting calf circumference thresholds for age and BMI could be an important area for future research.

Despite MUAC correlating better with fat mass than fat-free mass in females, adjusting calf circumference (to estimate muscle mass) with MUAC turned out to be redundant – the correlation between calf circumference and ALMI was strong in patients both with and without obesity.

6.4. Calf circumference versus mid-upper arm circumference for estimating body composition

Calf circumference correlated more strongly with ALMI than MUAC in patients with and without obesity. MUAC, however, correlated more strongly with fat mass index (FMI; fat mass divided by height squared) than with ALMI in females. Previous studies assessing the correlation of calf circumference (CC) and mid-upper arm circumference (MUAC) with muscle mass have had similar results (40). In a study involving community-dwelling older adults, CC showed a stronger correlation with appendicular skeletal muscle mass (ASM) measured by BIA compared to MUAC (41). Another study using NHANES 1999–2006 data compared CC with ALM measured by DEXA and reported a strong correlation ($r = 0.86$ in women, $r = 0.84$ in men); however, the correlation between MUAC and muscle mass was not assessed (26).

Since MUAC tends to be better correlated to fat mass than lean mass in females, both in the literature and in our findings, using it to adjust calf circumference in obese patient groups where correction is likely to be needed (for example, sedentary or bedridden patients) could be an area of future research.

6.5. Male patients included in the study

A total of 36 patients in our sample had a primary diagnosis classified under diseases of the musculoskeletal system and connective tissue. The majority of the participants of this study were women referred for osteoporosis screening after menopause. Since similar screening is not usually performed in men, the number of male patients undergoing DEXA scans was very low. In contrast, it is possible that men are referred to DEXA only when there is a more serious underlying condition present that might cause the loss of bone density. Our findings support this assumption, as only 3 out of 66 female patients (4.5%), but 3 out of 9 male patients (33.3%) had GLIM-defined disease-related malnutrition. Future studies should include larger numbers of participants in order to carry out meaningful data analysis in males undergoing DEXA scan.

6.6. Strengths

A significant strength of this study is using DEXA to determine appendicular lean mass index (ALMI) as the reference standard for muscle mass assessment. DEXA is considered a gold-standard method for body composition assessment, providing accurate and reliable muscle mass data.

The majority of our study participants being post-menopausal females in relatively good health indicates that our sample was representative of the target population. Our study sample included a sufficient number of both obese and non-obese women, and this made comparing the accuracy of calf circumference in estimating ALMI between the two groups possible.

Despite the small sample size, a careful approach was taken to ensure the use of appropriate statistical tests. Data normality was assessed within subgroups using various tests (visual methods (histograms, Q-Q plots) and the Shapiro-Wilk test). Multiple linear regression models evaluated calf circumference (CC) as an independent predictor of appendicular lean mass index (ALMI) in females, adjusting for potential confounders (age and adiposity). This analysis clarifies the direct link between CC and muscle mass.

Calf and mid-upper circumference were measured on the same sides (mid-upper arm from non-dominant arm and calf circumference from left leg) for all participants to ensure standardization. Waist circumference was measured according to WHO guidelines ((36)

6.7. Limitations

The study sample was too small to analyse the differences between genders since there were only 9 male patients. According to the GLIM criteria, malnutrition was identified in only 6 out of 75 patients (8%). This may be explained by the fact that although many patients had muscle-related diseases, they had not been screened for malnutrition before this assessment, and there was only one underweight patient (BMI <18.5 kg/m²) and nine inpatients out of 75 patients (12%). Therefore, it wasn't statistically feasible or reliable to assess the diagnostic performance of GLIM (sensitivity, specificity, ROC curves) with calf circumference or mid-upper arm circumference.

Low muscle mass was defined using GLIM and EWGSOP2 criterion for females, based on Appendicular Lean Mass Index (ALMI) measured by DEXA, which is < 5.5 kg/m². Due to the very small number of patients (n=3) identified with low muscle mass using the standard ALMI cut-off, ROC curve analysis could not be performed with the standard clinical cut-off.

7. Conclusions

Reduced muscle mass is an important criterion in diagnostics of malnutrition and sarcopenia, and it is associated with a lower quality of life. The validation of simple and affordable measures, such as calf circumference and mid-upper arm circumference, to detect low muscle mass is important for clinical practice.

The aim of the study was to investigate the effect of adiposity on the relationship between calf circumference and muscle mass, and to correct the presumed poor correlation between these parameters in patients with obesity. However, our findings showed that correlation between calf circumference and muscle mass was strong in both obese and non-obese groups.

Calf circumference is not influenced by obesity status, whether defined by BMI or waist circumference, and shows an even stronger association with muscle mass in this patient group. This finding may contradict some existing literature, but it is significant for this population.

Our findings supports adjusting calf circumference with age and BMI. Developing age and BMI specific thresholds should be explored using large samples.

MUAC was more related to fat mass than lean mass, as in previous studies. Therefore correcting calf circumference with MUAC could be explored in obese patient groups where CC and ALMI correlation is likely to be weak (for example sedentary patients).

8. References

1. Meyer F, Valentini L. Disease-Related Malnutrition and Sarcopenia as Determinants of Clinical Outcome. *Visc Med*. 2019 Sep 2;35(5):282–91.
2. Colin-Ramírez E, Castillo-Martínez L. Editorial: Nutritional Assessment Tools for Identification and Monitoring of Malnutrition in Patients With Chronic Disease. *Front Nutr*. 2022 Mar 22;9:870514.
3. Deutz NEP, Ashurst I, Ballesteros MD, Bear DE, Cruz-Jentoft AJ, Genton L, et al. The Underappreciated Role of Low Muscle Mass in the Management of Malnutrition. *J Am Med Dir Assoc*. 2019 Jan;20(1):22–7.
4. Fayh APT, de Sousa IM, Gonzalez MC. New insights on how and where to measure muscle mass. *Curr Opin Support Palliat Care*. 2020 Dec;14(4):316–23.
5. Wu SE, Chen WL. Calf circumference refines sarcopenia in correlating with mortality risk. *Age Ageing*. 2022 Feb 2;51(2):afab239.
6. Kiss CM, Bertschi D, Beerli N, Berres M, Kressig RW, Fischer AM. Calf circumference as a surrogate indicator for detecting low muscle mass in hospitalized geriatric patients. *Aging Clin Exp Res*. 2024 Feb 7;36(1):25.
7. Barazzoni R, Jensen GL, Correia MITD, Gonzalez MC, Higashiguchi T, Shi HP, et al. Guidance for assessment of the muscle mass phenotypic criterion for the Global Leadership Initiative on Malnutrition (GLIM) diagnosis of malnutrition. *Clin Nutr Edinb Scotl*. 2022 Jun;41(6):1425–33.
8. Calf circumference positively correlates with calf muscle thickness and negatively correlates with calf subcutaneous fat thickness and percent body fat in non-obese healthy young adults. ResearchGate [Internet]. [cited 2025 May 19]; Available from: https://www.researchgate.net/publication/349952875_Calf_circumference_positively_correlates_with_calf_muscle_thickness_and_negatively_correlates_with_calf_subcutaneous_fat_thickness_and_percent_body_fat_in_non-obese_healthy_young_adults
9. Cruz RPF, Barreiro SM, Mendonça AM, Rossato LT, Nahas PC, Orsatti FL, et al. Calf circumference is similarly associated with fat mass and lean mass in postmenopausal women with high body fat percentage. *Nutrire*. 2019 Dec 18;45(1):6.
10. Kurik G, Bender EL, Lillepuu A, Lõhmus A, Ospanova G, Şeker I, et al. Poor correlation between calf circumference and muscle mass in patients with obesity. *Clin Nutr ESPEN*. 2024 Oct 1;63:1121.
11. ESPEN-Fact-Sheet-Disease-Related-Malnutrition-DRM.pdf [Internet]. [cited 2025 May 15]. Available from: <https://www.espen.org/images/files/ESPEN-Fact-Sheets/ESPEN-Fact-Sheet-Disease-Related-Malnutrition-DRM.pdf>
12. Cederholm T, Jensen GL, Correia MITD, Gonzalez MC, Fukushima R, Higashiguchi T, et al. GLIM criteria for the diagnosis of malnutrition - A consensus report from the global clinical nutrition community. *Clin Nutr Edinb Scotl*. 2019 Feb;38(1):1–9.

13. Cruz-Jentoft AJ, Bahat G, Bauer J, Boirie Y, Bruyère O, Cederholm T, et al. Sarcopenia: revised European consensus on definition and diagnosis. *Age Ageing*. 2019 Jan 1;48(1):16–31.
14. Xia L, Zhao R, Wan Q, Wu Y, Zhou Y, Wang Y, et al. Sarcopenia and adverse health-related outcomes: An umbrella review of meta-analyses of observational studies. *Cancer Med*. 2020 Sep 13;9(21):7964–78.
15. Kang MC, Kim JH, Ryu SW, Moon JY, Park JH, Park JK, et al. Prevalence of Malnutrition in Hospitalized Patients: a Multicenter Cross-sectional Study. *J Korean Med Sci*. 2017 Nov 17;33(2):e10.
16. Osooli F, Abbas S, Farsaei S, Adibi P. Identifying Critically Ill Patients at Risk of Malnutrition and Underfeeding: A Prospective Study at an Academic Hospital. *Adv Pharm Bull*. 2019 Jun;9(2):314–20.
17. Durán Poveda M, Suárez-de-la-Rica A, Cancer Minchot E, Ocón Bretón J, Sánchez Pernaute A, Rodríguez Caravaca G, et al. The Prevalence and Impact of Nutritional Risk and Malnutrition in Gastrointestinal Surgical Oncology Patients: A Prospective, Observational, Multicenter, and Exploratory Study. *Nutrients*. 2023 Jul 24;15(14):3283.
18. Ribeiro HS, Neri SGR, Oliveira JS, Bennett PN, Viana JL, Lima RM. Association between sarcopenia and clinical outcomes in chronic kidney disease patients: A systematic review and meta-analysis. *Clin Nutr Edinb Scotl*. 2022 May;41(5):1131–40.
19. Cass AR, Charlton KE. Prevalence of hospital-acquired malnutrition and modifiable determinants of nutritional deterioration during inpatient admissions: A systematic review of the evidence. *J Hum Nutr Diet Off J Br Diet Assoc*. 2022 Dec;35(6):1043–58.
20. Murnane LC, Forsyth AK, Koukounaras J, Shaw K, King S, Brown WA, et al. Malnutrition defined by GLIM criteria identifies a higher incidence of malnutrition and is associated with pulmonary complications after oesophagogastric cancer surgery, compared to ICD-10-defined malnutrition. *J Surg Oncol*. 2023 Oct;128(5):769–80.
21. Li J, Jiang M, Hua X, Xu H, Wu M, Wu J, et al. Reduced muscle mass is an important part of Global Leadership Initiative on Malnutrition criteria in nutritional diagnosis of hepatocellular carcinoma. *BMC Gastroenterol*. 2024 Oct 10;24(1):358.
22. Prado CM, Purcell SA, Alish C, Pereira SL, Deutz NE, Heyland DK, et al. Implications of low muscle mass across the continuum of care: a narrative review. *Ann Med*. 2018 Dec;50(8):675–93.
23. Arnal-Gómez A, Cebrià I Iranzo MA, Tomas JM, Tortosa-Chuliá MA, Balasch-Bernat M, Sentandreu-Mañó T, et al. Using the Updated EWGSOP2 Definition in Diagnosing Sarcopenia in Spanish Older Adults: Clinical Approach. *J Clin Med*. 2021 Mar 2;10(5):1018.
24. Ozturk Y, Deniz O, Coteli S, Unsal P, Dikmeer A, Burkuk S, et al. Global Leadership Initiative on Malnutrition criteria with different muscle assessments including muscle ultrasound with hospitalized internal medicine patients. *JPEN J Parenter Enteral Nutr*. 2022 May;46(4):936–45.

25. Barazzoni R, Jensen GL, Correia MITD, Gonzalez MC, Higashiguchi T, Shi HP, et al. Guidance for assessment of the muscle mass phenotypic criterion for the Global Leadership Initiative on Malnutrition (GLIM) diagnosis of malnutrition. *Clin Nutr Edinb Scotl*. 2022 Jun;41(6):1425–33.
26. Gonzalez MC, Mehrnezhad A, Razaviarab N, Barbosa-Silva TG, Heymsfield SB. Calf circumference: cutoff values from the NHANES 1999-2006. *Am J Clin Nutr*. 2021 Jun 1;113(6):1679–87.
27. Trussardi Fayh AP, de Sousa IM. Comparison of revised EWGSOP2 criteria of sarcopenia in patients with cancer using different parameters of muscle mass. *PloS One*. 2021;16(9):e0257446.
28. Landi F, Onder G, Russo A, Liperoti R, Tosato M, Martone AM, et al. Calf circumference, frailty and physical performance among older adults living in the community. *Clin Nutr Edinb Scotl*. 2014 Jun;33(3):539–44.
29. Maffini LF, Viegas GM, Steemburgo T, Souza GC. Global Leadership Initiative on Malnutrition criteria using calf and upper arm circumference as phenotypic criteria for assessing muscle mass demonstrate satisfactory validity for diagnosing malnutrition in hospitalized patients: A prospective cohort study. *Nutr Clin Pract Off Publ Am Soc Parenter Enter Nutr*. 2024 Dec;39(6):1431–40.
30. Kim S, Kim M, Lee Y, Kim B, Yoon TY, 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*. 2018 May 14;33(20):e151.
31. Cava E, Yeat NC, Mittendorfer B. Preserving Healthy Muscle during Weight Loss. *Adv Nutr Bethesda Md*. 2017 May;8(3):511–9.
32. Tallis J, James RS, Seebacher F. The effects of obesity on skeletal muscle contractile function. *J Exp Biol*. 2018 Jul 6;221(Pt 13):jeb163840.
33. Sizoo D, de Heide LJM, Emous M, van Zutphen T, Navis G, van Beek AP. Measuring Muscle Mass and Strength in Obesity: a Review of Various Methods. *Obes Surg*. 2021 Jan;31(1):384–93.
34. Jensen B, Braun W, Geisler C, Both M, Klückmann K, Müller MJ, et al. Limitations of Fat-Free Mass for the Assessment of Muscle Mass in Obesity. *Obes Facts*. 2019;12(3):307–15.
35. Kruizenga HM, Seidell JC, de Vet HCW, Wierdsma NJ, van Bokhorst-de van der Schueren M a. E. Development and validation of a hospital screening tool for malnutrition: the short nutritional assessment questionnaire (SNAQ). *Clin Nutr Edinb Scotl*. 2005 Feb;24(1):75–82.
36. Waist circumference and waist-hip ratio: report of a WHO expert consultation [Internet]. [cited 2025 May 19]. Available from: <https://www.who.int/publications/i/item/9789241501491>

37. Papageorgiou SN. On correlation coefficients and their interpretation. *J Orthod*. 2022 Sep;49(3):359–61.
38. Fielding RA, Vellas B, Evans WJ, Bhasin S, Morley JE, Newman AB, 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*. 2011 May;12(4):249–56.
39. Newman AB, Kupelian V, Visser M, Simonsick E, Goodpaster B, Nevitt M, et al. Sarcopenia: alternative definitions and associations with lower extremity function. *J Am Geriatr Soc*. 2003 Nov;51(11):1602–9.
40. Kurik G, Bender EL, Lillepui A, Lõhmus A, Ospanova G, Şeker I, et al. Reliability of calf circumference and mid-upper arm circumference as estimates of muscle mass. *Clin Nutr ESPEN*. 2024 Oct 1;63:1106.
41. Hu FJ, Liu H, Liu XL, Jia SL, Hou LS, Xia X, et al. Mid-Upper Arm Circumference as an Alternative Screening Instrument to Appendicular Skeletal Muscle Mass Index for Diagnosing Sarcopenia. *Clin Interv Aging*. 2021 Jun 15;16:1095–104.