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Muscle-fat Phenotypes Based on Appendicular Skeletal Muscle Index and Trunk Fat Percentage: A Potentially Overlooked Body Composition Risk

Apendiküler İskelet Kası İndeksi ve Gövde Yağ Yüzdesine Dayalı Kas-yağ Fenotipleri: Gözden Kaçabilecek Bir Vücut Kompozisyonu Riski

Dilek Ün Oğuzhanasiltürk, Hatice Zehra Ferhatlar

University of Health Sciences Türkiye, Kanuni Sultan Süleyman Training and Research Hospital, Department of Physical Medicine and Rehabilitation, İstanbul, Türkiye

Abstract

Objective: Appendicular skeletal muscle index (ASMI) is widely used to evaluate skeletal muscle mass for the assessment of sarcopenia. However, normal ASMI values may not adequately reflect unfavorable body composition patterns related to fat distribution. Increased central adiposity, particularly trunk fat accumulation, may be associated with metabolic and functional risks, even in individuals with preserved muscle mass. This study aimed to investigate whether individuals with normal ASMI may still exhibit an unfavorable muscle-fat phenotype characterized by increased trunk fat percentage.

Materials and Methods: This cross-sectional study included 70 participants who underwent whole-body dual-energy X-ray absorptiometry (DXA). Appendicular lean mass, ASMI, trunk fat mass, and trunk fat percentage were assessed. ASMI status was classified according to established diagnostic criteria. Due to the absence of validated DXA-based cut-off values for trunk fat percentage, participants were categorized into low- and high-trunk-fat groups based on the cohort median. Muscle-fat phenotypes were defined using a combination of ASMI status and trunk fat percentage. Group comparisons were performed using non-parametric statistical tests.

Results: Among individuals with normal ASMI, a substantial proportion exhibited elevated trunk fat percentage. Specifically, 32 participants were classified as having normal ASMI with high trunk fat (adverse phenotype), whereas 27 participants were classified as having normal ASMI with low trunk fat (favorable phenotype). Within the normal ASMI subgroup, participants with high trunk fat had significantly higher body mass index, trunk fat mass, and trunk fat percentage. Appendicular lean mass did not differ significantly between groups, whereas ASMI values were slightly higher in the high-trunk-fat group, although they remained within the normal range.

Conclusion: Normal ASMI does not necessarily exclude an unfavorable muscle-fat phenotype characterized by increased trunk adiposity. Incorporating regional fat distribution parameters into DXA-based body composition assessments may provide a more comprehensive evaluation of sarcopenia-related risk beyond muscle mass alone.

Keywords: Sarcopenia, appendicular skeletal muscle index, trunk fat, body composition, DXA, muscle-fat phenotype

Öz

Amaç: Apendiküler iskelet kası indeksi (ASMI), sarkopeni değerlendirmesinde iskelet kası kütlesini belirlemek için yaygın olarak kullanılmaktadır. Ancak normal ASMI değerleri, yağ dağılımıyla ilişkili olumsuz vücut kompozisyonu örüntülerini yeterince yansıtmayabilir. Bu çalışmada, normal ASMI değerlerine sahip bireylerin artmış gövde yağ yüzdesi ile karakterize olumsuz bir kas-yağ fenotipi sergileyip sergilemediğinin araştırılması amaçlandı.

Gereç ve Yöntem: Bu kesitsel çalışmaya tüm vücut çift enerjili X-ışını absorbsiyometrisi (DXA) yapılan 70 katılımcı dahil edildi. Apendiküler yağsız kütle, ASMI, gövde yağ kütlesi ve gövde yağ yüzdesi değerlendirildi. ASMI durumu yerleşik tanı ölçütlerine göre sınıflandırıldı. Gövde

Corresponding Author/Sorumlu Yazar: Dilek Ün Oğuzhanasiltürk, MD, University of Health Sciences Türkiye, Kanuni Sultan Süleyman Training and Research Hospital, Department of Physical Medicine and Rehabilitation, İstanbul, Türkiye
E-mail: dilekunoguzhan@gmail.com **ORCID ID:** orcid.org/0009-0006-8911-7927
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yağ yüzdesi için doğrulanmış DXA temelli kesme değerleri bulunmadığından, katılımcılar kohort medyanına göre düşük ve yüksek gövde yağı gruplarına ayrıldı. Kas-yağ fenotipleri ASMI durumu ve gövde yağ yüzdesinin birlikte değerlendirilmesiyle tanımlandı. Gruplar parametrik olmayan istatistiksel testlerle karşılaştırıldı.

Bulgular: Normal ASMI değerlerine sahip bireylerin önemli bir kısmında gövde yağ yüzdesi yüksekti. Otuz iki katılımcı normal ASMI ve yüksek gövde yağı (olumsuz fenotip), 27 katılımcı ise normal ASMI ve düşük gövde yağı (olumlu fenotip) grubunda sınıflandırıldı. Normal ASMI alt grubunda, gövde yağı yüksek olanların vücut kitle indeksi, gövde yağ kütlesi ve gövde yağ yüzdesi anlamlı derecede daha yüksekti. Apendiküler yağsız kütle açısından anlamlı fark saptanmadı. Yüksek gövde yağı grubunda ASMI değerleri hafifçe daha yüksek olmakla birlikte normal aralıkta kaldı.

Sonuç: Normal ASMI, artmış gövde yağlanmasıyla karakterize olumsuz bir kas-yağ fenotipinin bulunmadığını garanti etmez. DXA temelli vücut kompozisyonu değerlendirmelerine bölgesel yağ dağılımı parametrelerinin eklenmesi, yalnızca kas kütlesine dayanan yaklaşımlara kıyasla sarkopeniyle ilişkili riskin daha kapsamlı değerlendirilmesini sağlayabilir.

Anahtar kelimeler: Sarkopeni, apendiküler iskelet kası indeksi, gövde yağı, vücut kompozisyonu, DXA, kas-yağ fenotipi

Introduction

Sarcopenia has traditionally been defined and operationalized based on reduced skeletal muscle mass, with the appendicular skeletal muscle index (ASMI) being one of the most commonly used quantitative indicators (1,2). Dual-energy X-ray absorptiometry (DXA)-derived ASMI is widely applied in both clinical practice and research settings and is incorporated into major consensus definitions, including the European Working Group on Sarcopenia in Older People 2 (EWGSOP2) (1). However, accumulating evidence suggests that muscle mass alone may not fully capture the complexity of body composition-related health risks (3).

Current sarcopenia definitions, largely based on appendicular skeletal muscle mass thresholds, may therefore fail to identify individuals with preserved muscle mass but adverse fat distribution. This subgroup, although falling outside the EWGSOP2 definition, may still carry biological and functional risks associated with sarcopenia-related metabolic disturbances (3,4).

In recent years, increasing attention has been directed toward the role of adiposity distribution, particularly central or trunk fat accumulation, as a critical determinant of metabolic, functional, and cardiovascular outcomes (4,5). Trunk fat is metabolically active and has been associated with insulin resistance, chronic low-grade inflammation, and impaired physical performance (4,5). Importantly, individuals with preserved or "normal" muscle mass may still harbor excess central adiposity, potentially placing them at increased risk despite apparently favorable muscle indices (3-5).

To address this limitation of muscle-centric assessments, the concept of adverse muscle-fat phenotypes, including sarcopenic obesity, has emerged (3). While this framework has improved understanding of body composition-related risk, most studies have focused on individuals with low muscle mass. In contrast, comparatively little attention has been paid to individuals who meet normal ASMI criteria but exhibit unfavorable fat distribution (3,5).

DXA offers a unique opportunity to evaluate both appendicular lean mass (ALM) and regional fat distribution within a single assessment (6,7). Despite this advantage, there is no universally accepted DXA-based cut-off value for trunk fat percentage, and trunk adiposity remains underutilized in phenotypic classifications (6,7). Consequently, potentially high-risk body composition patterns may go unrecognized in routine clinical and research settings.

Therefore, this study aimed to investigate whether individuals with normal ASMI may still exhibit an unfavorable muscle-fat phenotype, characterized by increased trunk fat percentage. We hypothesized that a substantial proportion of participants with normal ASMI would demonstrate elevated trunk fat, highlighting the limitations of relying solely on ASMI for body composition-based risk stratification.

Materials and Methods

Study Design and Setting

This study was designed as a cross-sectional observational analysis conducted at a tertiary care university-affiliated hospital. The study was performed in accordance with the principles of the Declaration of Helsinki.

Participants

Participants were consecutively selected from individuals who underwent routine whole-body DXA assessment during the study period. No additional recruitment procedures were performed. A total of 70 participants who underwent whole-body DXA assessment were included in the analysis. Participants with complete demographic information and DXA-derived body composition data were eligible for inclusion. Exclusion criteria included conditions that could significantly affect body composition measurements, including advanced malignancy, severe systemic disease, clinically evident edema, or incomplete DXA data.

Ethical Approval

Ethical approval for this retrospective study was obtained from the Institutional Ethics Committee of University of Health Sciences Türkiye, Kanuni Sultan Süleyman Training and Research Hospital (approval date: March 11, 2026, decision no: 83). The

study was conducted in accordance with the principles of the Declaration of Helsinki. Due to the retrospective design and the use of routinely collected clinical data, the requirement for informed consent was waived in accordance with institutional regulations.

DXA Measurements

Whole-body DXA scans were performed by trained technicians using a standardized protocol. The DXA assessment provided measurements of total and regional body composition, including trunk fat mass (kg) and trunk fat percentage (%).

ALM was calculated as the sum of the lean mass of both arms and both legs.

ASMI was calculated as ALM divided by height squared (kg/m^2). All measurements were obtained using the same DXA device and software version to ensure consistency.

Definition of Muscle and Fat Parameters

ASMI status was classified according to the EWGSOP2 criteria. Participants with ASMI values above the recommended threshold for women were classified as having normal ASMI, whereas those at or below the threshold were classified as having low ASMI.

Currently, there is no universally accepted DXA-based cut-off value for trunk fat percentage. Therefore, trunk fat percentage was dichotomized at the cohort median as an exploratory approach because validated cut-off values were unavailable.

Because no validated DXA-derived trunk fat percentage threshold currently exists for defining adverse adiposity phenotypes, the cohort median was used as an exploratory stratification approach.

Muscle-fat Phenotypes

Based on the combination of ASMI status (normal vs. low) and trunk fat percentage (low vs. high), participants were categorized into four muscle-fat phenotypes:

1. Normal ASMI + low trunk fat (favorable phenotype)
2. Normal ASMI + high trunk fat (adverse phenotype)
3. Low ASMI + low trunk fat
4. Low ASMI + high trunk fat.

Statistical Analysis

Statistical analyses were performed using SPSS software (version 26.0; IBM Corp., Armonk, NY, USA). The normality of continuous variables was assessed using the Shapiro-Wilk test. Continuous variables are presented as mean ± standard deviation or median with interquartile range, as appropriate. Comparisons between groups were performed using the Mann-Whitney U test. Categorical variables were analyzed using the chi-square test. A two-sided p-value of <0.05 was considered statistically significant. Receiver operating characteristic (ROC) analysis was performed to assess the discriminatory ability of age, body mass index (BMI), and ASMI to identify the adverse muscle-fat phenotype among participants with normal ASMI.

Results

Participant Characteristics

A total of 70 participants were included in the analysis. The cohort consisted predominantly of women and exhibited a wide age range and varied body composition profiles. Baseline demographic and DXA-derived body composition characteristics of the study population are summarized in Table 1.

Distribution of Muscle-fat Phenotypes

Based on ASMI status and trunk fat percentage, participants were classified into four muscle-fat phenotypes. The distribution of phenotypes revealed that a substantial proportion of individuals with normal ASMI exhibited a high trunk fat percentage. The distribution of muscle-fat phenotypes is presented in Table 2.

Comparison within the Normal ASMI Subgroup

To further explore the clinical relevance of trunk fat distribution, participants with normal ASMI were divided into low- and high-trunk-fat groups and compared on demographic and body composition variables. The comparison of participants with normal ASMI by trunk fat percentage is shown in Table 3.

Participants with high trunk fat percentage had significantly higher BMI, trunk fat mass, and trunk fat percentage compared with those with low trunk fat percentage (all p<0.001). In contrast, age did not differ significantly between the two groups (p=0.92).

Importantly, ALM did not differ between groups (p=0.41), indicating that muscle mass was largely preserved regardless of trunk fat status. ASMI values were slightly higher in individuals with a high trunk fat percentage (p=0.033), although all values remained within the normal ASMI range.

Table 1. Baseline characteristics of the study population (n=70)

Variable	Mean ± SD	Median	IQR
Age (years)	57.2±10.6	58.0	49.0-66.0
BMI (kg/m^2)	30.1±5.2	29.8	26.4-33.7
Trunk fat mass (kg)	16.2±5.1	15.8	12.6-19.4
Trunk fat percentage (%)	39.6±6.8	40.1	35.2-44.3
Appendicular lean mass, ALM (kg)	18.7±3.1	18.4	16.6-20.7
Appendicular skeletal muscle index, ASMI (kg/m^2)	6.2±0.7	6.1	5.7-6.6

BMI: Body mass index, ALM: Appendicular lean mass, ASMI: Appendicular skeletal muscle index, IQR: Interquartile range, SD: Standard deviation

These findings suggest that individuals with normal ASMI may still exhibit markedly different body composition profiles, particularly with respect to central adiposity.
The ROC analysis results are presented in Table 4.

Discussion

The present study investigated whether individuals with a normal ASMI may nonetheless exhibit unfavorable body composition patterns characterized by increased trunk fat. The principal finding of this DXA-based analysis is that a substantial proportion of individuals with normal ASMI exhibited high trunk fat percentage, representing a potentially overlooked adverse muscle-fat phenotype that is not captured by current sarcopenia definitions. To our knowledge, this is one of the few studies to focus specifically on individuals with normal ASMI and to identify a masked risk phenotype based on regional adiposity.
Traditionally, sarcopenia has been defined primarily based on reduced skeletal muscle mass, with ASMI serving as one of the most widely used indicators (1,2). However, recent consensus statements emphasize that sarcopenia should not be evaluated solely based on muscle mass but rather as a multidimensional condition incorporating muscle quality, function, and adiposity (3,4). Our findings further support this evolving perspective, suggesting that individuals with preserved muscle mass may still demonstrate metabolically unfavorable fat distribution patterns, particularly increased central adiposity. These findings challenge the current muscle mass-based paradigm used in sarcopenia assessment.
A key finding of this study is that within the normal ASMI subgroup, individuals with higher trunk fat exhibit significantly worse anthropometric and adiposity-related parameters, despite similar appendicular lean mass. This observation supports the presence of a masked risk phenotype, in which conventional muscle mass indices may provide a false sense of metabolic or functional adequacy. This concept parallels the well-described phenomenon of normal weight obesity, where individuals with apparently normal body composition indices may still carry increased cardiometabolic risk due to excess fat accumulation (5).
Central adiposity, particularly trunk fat accumulation, is metabolically active and has been associated with insulin resistance, chronic low-grade inflammation, reduced physical performance, and increased cardiovascular risk (6,7). Moreover, previous studies have demonstrated that DXA-derived trunk fat is closely associated with visceral adiposity and cardiometabolic risk, supporting its clinical relevance as a surrogate marker of central fat distribution (8,9). Therefore, the coexistence of normal muscle mass and elevated trunk fat may represent an intermediate risk state, potentially preceding overt sarcopenic obesity or metabolic impairment.
Importantly, the ROC analysis in the present study demonstrated that BMI had moderate discriminatory ability to identify individuals with the adverse muscle-fat phenotype, whereas ASMI had poor discriminatory ability. This finding further underscores the limitation of relying solely on muscle mass-based indices for risk stratification. Although BMI is a crude measure, its relatively better performance in this context suggests that adiposity-related parameters remain clinically relevant and should not be overlooked when evaluating body composition. Notably, patients currently considered low-risk based on ASMI alone may in fact represent a metabolically vulnerable group.
From a clinical perspective, this phenotype may also be associated with early functional decline and increased vulnerability to frailty, even in the absence of reduced muscle mass (10,11). Therefore, individuals with normal ASMI but increased trunk fat should not be considered low-risk, and a more comprehensive assessment of body composition may be warranted.
From a practical standpoint, these findings support the integration of regional fat distribution parameters, particularly trunk fat percentage, into routine DXA interpretation. Given that DXA is already widely used in clinical practice, incorporating such parameters would not require additional cost or patient burden,

Table 2. Distribution of muscle-fat phenotypes

Muscle-fat phenotype	n (%)
Normal ASMI + low trunk fat (favorable phenotype)	27 (38.6%)
Normal ASMI + high trunk fat (adverse phenotype)	32 (45.7%)
Low ASMI + low trunk fat	8 (11.4%)
Low ASMI + high trunk fat	3 (4.3%)

ASMI: Appendicular skeletal muscle index

Table 3. Comparison of participants with normal ASMI according to trunk fat percentage

Variable	Low trunk fat (n=27) Median (IQR)	High trunk fat (n=32) Median (IQR)	p-value
Age (years)	57.0 (49.0-66.0)	58.0 (50.0-65.0)	0.92
BMI (kg/m^2)	26.8 (24.9-28.7)	32.4 (30.1-35.2)	<0.001
Trunk fat mass (kg)	12.4 (10.8-13.9)	19.2 (17.1-22.4)	<0.001
Trunk fat percentage (%)	33.8 (31.4-36.2)	45.1 (42.3-48.6)	<0.001
Appendicular lean mass, ALM (kg)	18.2 (16.5-20.1)	18.6 (16.9-21.0)	0.41
ASMI (kg/m^2)	5.9 (5.6-6.2)	6.3 (5.9-6.7)	0.033

Statistical analysis: Mann-Whitney U test. Significance: p<0.05. BMI: Body mass index, ALM: Appendicular lean mass, ASMI: Appendicular skeletal muscle index, IQR: Interquartile range

Table 4. ROC analysis of predictors of adverse muscle-fat phenotype in individuals with normal ASMI

Predictor	AUC
BMI	0.72
Age	0.52
ASMI	0.55

ROC: Receiver operating characteristic, AUC: Area under the curve, BMI: Body mass index, ASMI: Appendicular skeletal muscle index
ROC analysis showed that BMI had moderate discriminatory ability for identifying individuals with the adverse muscle-fat phenotype (AUC =0.72). In contrast, age and ASMI demonstrated poor discrimination, with AUC values close to 0.50

yet may substantially improve risk identification. Clinicians should therefore be cautious when interpreting normal ASMI values in isolation, as they may mask unfavorable body composition profiles.

Study Limitations

The present study has several limitations. First, the cross-sectional design precludes causal inference regarding the relationship between trunk fat and clinical outcomes. Second, the relatively small sample size may limit generalizability. Third, because there are no universally accepted DXA-based cut-off values for trunk fat percentage, classification of trunk fat groups was based on the cohort median, which may reduce external validity. In addition, muscle strength and physical performance measurements were not available in this retrospective dataset. Therefore, the relationship between the identified muscle-fat phenotypes and functional outcomes could not be evaluated directly.

Future studies with larger populations, standardized cut-off values, and longitudinal follow-up are needed to better define the clinical implications of this phenotype.

Conclusion

The present study demonstrates that normal ASMI does not necessarily indicate a favorable body composition profile. A substantial proportion of individuals with normal ASMI may still exhibit an adverse muscle-fat phenotype characterized by increased trunk adiposity. These findings highlight the limitations of muscle mass-based definitions of sarcopenia and suggest that incorporating regional fat distribution parameters into DXA-based assessments may improve identification of individuals at risk beyond traditional criteria. Reliance on ASMI alone may lead to systematic under-recognition of individuals at increased metabolic and functional risk.

Ethics

Ethics Committee Approval: Ethical approval for this retrospective study was obtained from the Institutional Ethics Committee of University of Health Sciences Türkiye, Kanuni Sultan Süleyman Training and Research Hospital (approval date: March 11, 2026, decision no: 83).

Informed Consent: Due to the retrospective design and the use of routinely collected clinical data, the requirement for informed consent was waived in accordance with institutional regulations.

Footnotes

Authorship Contributions

Concept: D.Ü.O., Design: D.Ü.O., Data Collection or Processing: D.Ü.O., H.Z.F., Analysis or Interpretation: D.Ü.O., H.Z.F., Literature Search: D.Ü.O., Writing: D.Ü.O., H.Z.F.

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