



IMPACT OF SARCOPENIA ON SURVIVAL OUTCOMES IN MULTIPLE MYELOMA PATIENTS

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Abstract

Background: Sarcopenia, defined as progressive skeletal muscle depletion, has gained attention as a potential prognostic marker in hematological cancers. Nevertheless, its clinical relevance in multiple myeloma remains inadequately characterized, particularly regarding gender-specific variations.

Objective: This investigation sought to determine the prevalence of sarcopenia among newly diagnosed multiple myeloma patients and evaluate its relationship with progression-free survival, treatment outcomes, and gender differences.

Methods: A prospective cohort comprising 72 treatment-naïve multiple myeloma patients was recruited at Assiut University Hospital between 2021 and 2022. Computed tomography-derived skeletal muscle index at the third lumbar vertebra served as the primary sarcopenia assessment tool. Kaplan-Meier survival analysis and Cox proportional hazards modeling were employed for outcome evaluation.

Results: Sarcopenia was identified in 52.8% of enrolled subjects. Sarcopenic individuals demonstrated substantially reduced median progression-free survival compared to non-sarcopenic counterparts (9.5 versus 11.8 months; $P=0.002$). Gender-stratified analysis revealed that sarcopenia significantly compromised survival in males ($P=0.004$) while showing no statistical significance in females ($P=0.191$). Multivariate regression confirmed sarcopenia as an independent adverse prognostic determinant (hazard ratio: 2.66; 95% confidence interval: 1.37-5.14; $P=0.004$).

Conclusion: Sarcopenia constitutes a prevalent condition among multiple myeloma patients and independently predicts unfavorable progression-free survival, with pronounced effects observed in male patients. Routine sarcopenia screening may enhance risk stratification and therapeutic decision-making in this population.

Keywords: Sarcopenia; Multiple myeloma; Progression-free survival; Skeletal muscle index; Gender differences; Prognosis

Introduction

Multiple myeloma represents the second most prevalent hematological malignancy worldwide, predominantly affecting elderly populations with a median diagnostic age exceeding six decades.¹ Contemporary therapeutic advances, encompassing proteasome inhibitors, immunomodulatory agents, and autologous stem cell transplantation, have markedly extended patient longevity. However, substantial heterogeneity persists in treatment responses and disease trajectories, necessitating identification of novel prognostic biomarkers.²

Sarcopenia, originally conceptualized as age-associated skeletal muscle wasting, has evolved into a recognized clinical syndrome characterized by diminished muscle mass, strength, and functional capacity.³ The European Working Group on Sarcopenia in Older People has established standardized diagnostic criteria incorporating computed tomography-based skeletal muscle quantification at the lumbar vertebral level.⁴ Growing evidence from solid tumor investigations has established sarcopenia as a predictor of chemotherapy toxicity, diminished treatment tolerance, and abbreviated survival.⁵ Within hematological malignancies, sarcopenia research remains comparatively nascent. Preliminary investigations in lymphoma cohorts have demonstrated associations between reduced muscle mass and inferior clinical outcomes following transplantation.⁶ Multiple myeloma presents unique pathophysiological considerations, as the disease itself promotes catabolic processes through inflammatory cytokine release, osteoclast activation, and metabolic derangements.⁷ Furthermore, antimyeloma therapies frequently induce peripheral neuropathy, fatigue, and gastrointestinal disturbances that may exacerbate muscle wasting.⁸

Sex-based differences in sarcopenia manifestation warrant particular attention. Physiological distinctions in baseline muscle mass, hormonal milieu, and body composition between males and females may differentially influence sarcopenia's prognostic significance.⁹ Prior oncological studies have yielded conflicting results regarding gender-specific sarcopenia impacts, with some reporting stronger associations in male patients.¹⁰ Such heterogeneity underscores the necessity for disease-specific investigations addressing both sexes.

The present investigation was undertaken to systematically evaluate sarcopenia prevalence among Egyptian multiple myeloma patients, assess its relationship with progression-free survival and treatment response, and examine potential gender-based variations in these associations. By addressing these questions, this study aims to contribute evidence supporting sarcopenia's integration into routine clinical assessment protocols.

Patients and Methods

Study Design and Setting

This prospective cohort analysis was conducted at the Hematology Department and the Gynecology and Obstetrics Department of Assiut University Hospital, Egypt, during the period spanning 2021 to 2022. The Institutional Ethics Committee granted approval for all study procedures, and written informed consent was secured from each participant prior to enrollment. The research protocol adhered to ethical principles established in the Declaration of Helsinki.

Patient Selection

Consecutive adult patients aged eighteen years or older with newly diagnosed symptomatic multiple myeloma meeting International Myeloma Working Group criteria were screened for eligibility. Inclusion required availability of baseline computed tomography imaging suitable for body composition analysis and intention to receive standard first-line antimyeloma therapy. Patients with prior malignancies, pre-existing neuromuscular disorders, or concurrent conditions substantially affecting muscle mass were excluded from participation.

Sarcopenia Assessment

Sarcopenia evaluation utilized computed tomography cross-sectional imaging at the third lumbar vertebra level, representing a validated approach for whole-body muscle mass estimation.⁴ Skeletal muscle area encompassing the psoas, paraspinal, and abdominal wall musculature was delineated using standardized Hounsfield unit thresholds ranging from -29 to +150. The skeletal muscle index was calculated by normalizing total muscle area to patient height squared (cm^2/m^2). Gender-specific sarcopenia cutoffs followed established criteria: less than $52.4 \text{ cm}^2/\text{m}^2$ for males and less than $38.5 \text{ cm}^2/\text{m}^2$ for females.

Clinical Data Collection

Baseline demographic characteristics including age, sex, and anthropometric measurements were recorded systematically. Disease-related parameters comprised International Staging System classification, cytogenetic risk stratification based on fluorescence in situ hybridization, and standard laboratory assessments including hemoglobin, serum albumin, creatinine, beta-2 microglobulin, and lactate dehydrogenase. Performance status was graded according to Eastern Cooperative Oncology Group criteria.

Treatment and Response Evaluation

All enrolled patients received proteasome inhibitor-based or immunomodulatory agent-based induction regimens per institutional protocols. Treatment response was classified according to International Myeloma Working Group uniform criteria as complete response, partial response, stable disease, or progressive disease. Adverse events were graded using Common Terminology Criteria for Adverse Events version 5.0, with grade three or higher toxicities recorded as severe events.

Outcome Definitions

The primary endpoint was progression-free survival, defined as the interval from treatment initiation to disease progression or death from any cause. Secondary endpoints included overall treatment response rate, incidence of grade three or higher adverse events, and requirement for dose modifications.

Statistical Analysis

Continuous variables were expressed as median with interquartile range, while categorical data were presented as frequencies and percentages. Between-group comparisons employed Mann-Whitney U test for continuous measures and chi-square or Fisher's exact test for categorical variables as appropriate. Survival estimates were generated using Kaplan-Meier methodology with log-rank testing for curve comparisons. Multivariable Cox proportional hazards regression identified independent predictors of progression-free survival. Statistical significance was established at a two-sided alpha level of 0.05. All analyses were performed using SPSS version 26.0 (IBM Corporation, Armonk, NY).

Results

Baseline Characteristics and Sarcopenia Prevalence

A total of 72 treatment-naïve multiple myeloma patients were enrolled during the study period. Sarcopenia was detected in 38 patients (52.8%), while 34 patients (47.2%) demonstrated preserved muscle mass. Table 1 shows demographic and clinical features stratified by sarcopenia status. The cohort comprised 43 males (59.7%) and 29 females (40.3%), with a median age of 65 years. No statistically significant differences emerged between sarcopenic and non-sarcopenic groups regarding age, sex distribution, body mass index, performance status, disease stage, cytogenetic risk profile, or laboratory parameters (all $P > 0.05$). As anticipated, skeletal muscle index differed substantially between groups (35.90 versus 42.15 cm^2/m^2 ; $P < 0.001$).

Table 1. Demographic and clinical characteristics of multiple myeloma patients stratified by sarcopenia status (N=72).

Variable	Sarcopenic (n=38)	Non-Sarcopenic (n=34)	P-value
Age (years)	65.0 (62.0-69.0)	65.0 (60.0-68.0)	0.494
Gender, n (%)			0.738
Male	22 (57.9)	21 (61.8)	
Female	16 (42.1)	13 (38.2)	
BMI (kg/m^2)	22.85 (19.40-24.70)	22.85 (21.10-25.90)	0.172
SMI (cm^2/m^2)	35.90 (30.40-39.50)	42.15 (35.20-45.00)	<0.001*
ECOG PS, n (%)			0.524
0	7 (18.4)	8 (23.5)	

1	24 (63.2)	17 (50.0)	
2	7 (18.4)	9 (26.5)	
ISS Stage, n (%)			0.868
I	5 (13.2)	6 (17.6)	
II	21 (55.3)	18 (52.9)	
III	12 (31.6)	10 (29.4)	
High-risk cytogenetics, n (%)	5 (13.2)	10 (29.4)	0.090
Hemoglobin (g/dL)	9.45 (8.20-11.10)	10.05 (8.90-11.40)	0.554
Albumin (g/dL)	3.20 (3.00-3.40)	3.25 (3.10-3.40)	0.524
Creatinine (mg/dL)	1.60 (1.30-2.00)	1.45 (1.10-1.80)	0.083
β2-microglobulin (mg/L)	5.55 (4.50-7.00)	6.45 (5.60-7.70)	0.061
LDH (U/L)	263.0 (227.0-308.0)	272.5 (223.0-311.0)	0.835

BMI: body mass index; SMI: skeletal muscle index; ECOG PS: Eastern Cooperative Oncology Group Performance Status; ISS: International Staging System; LDH: lactate dehydrogenase. Continuous data presented as median (IQR); categorical data presented as n (%). *P<0.05 considered statistically significant.

Gender-Stratified Baseline Characteristics

Table 2 presents baseline characteristics according to both sarcopenia status and sex. Among male participants, sarcopenic individuals were significantly older than their non-sarcopenic counterparts (median 67.5 versus 65.0 years; P=0.041) and demonstrated lower skeletal muscle indices (38.70 versus 42.70 cm²/m²; P=0.006). In contrast, female patients exhibited no significant differences between sarcopenic and non-sarcopenic subgroups across age, anthropometric parameters, or clinical variables (all P>0.05). Disease staging, cytogenetic risk profiles, and biochemical markers remained comparable across all sex-sarcopenia subgroups.

Table 2. Demographic and clinical characteristics stratified by sarcopenia status and gender (N=72).

Variable	Male (n=43)		Female (n=29)		P1	P2
	Sarc. (n=22)	Non-S. (n=21)	Sarc. (n=22)	Non-S. (n=21)		
Age (years)	67.5 (65.0-72.0)	65.0 (61.0-68.0)	61.0 (60.0-64.0)	66.0 (59.0-68.0)	0.041*	0.454
BMI (kg/m ²)	20.85 (19.30-24.70)	23.90 (21.50-25.20)	23.35 (21.75-24.80)	21.90 (21.00-27.00)	0.058	0.861
SMI (cm ² /m ²)	38.70 (32.00-41.30)	42.70 (39.80-44.80)	32.05 (28.90-37.45)	35.80 (34.20-45.00)	0.006*	0.054
High-risk cyto., n (%)	3 (13.6)	6 (28.6)	2 (12.5)	4 (30.8)	0.229	0.227
Hemoglobin (g/dL)	9.40 (8.20-11.10)	9.60 (8.70-11.10)	9.80 (8.10-11.65)	10.70 (9.60-11.90)	0.990	0.292
Albumin (g/dL)	3.20 (3.00-3.40)	3.30 (3.10-3.40)	3.20 (2.95-3.45)	3.20 (3.00-3.40)	0.500	0.912
Creatinine (mg/dL)	1.55 (1.30-2.00)	1.40 (1.10-1.80)	1.60 (1.40-1.95)	1.50 (1.10-1.70)	0.168	0.310
β2-microglobulin (mg/L)	5.55 (4.40-6.90)	6.40 (5.60-7.50)	5.60 (4.80-7.65)	7.20 (5.60-7.70)	0.106	0.292
LDH (U/L)	274.5 (228.0-331.0)	260.0 (223.0-305.0)	249.5 (213.0-279.0)	298.0 (217.0-311.0)	0.313	0.114

Sarc.: sarcopenic; Non-S.: non-sarcopenic; P1: sarcopenic vs non-sarcopenic in males; P2: sarcopenic vs non-sarcopenic in females. *P<0.05 considered statistically significant.

Treatment Response and Clinical Outcomes

Clinical outcomes according to sarcopenia status are summarized in Table 3. Sarcopenic patients experienced significantly higher rates of disease progression events compared to non-sarcopenic individuals (73.7% versus 38.2%; P=0.002). Overall treatment response patterns differed substantially between groups (P=0.020), with sarcopenic patients demonstrating lower complete response rates (10.5% versus 26.5%) and partial response rates (10.5% versus 29.4%). Although

sarcopenic patients exhibited numerically higher incidences of grade three or greater toxicity (52.6% versus 32.4%) and dose reductions (36.8% versus 20.6%), these differences did not achieve statistical significance ($P=0.083$ and $P=0.130$, respectively).

Table 3. Clinical outcomes of multiple myeloma patients stratified by sarcopenia status (N=72).

Variable	Sarcopenic (n=38)	Non-Sarcopenic (n=34)	P-value
Progression event, n (%)	28 (73.7)	13 (38.2)	0.002*
Response, n (%)			0.020*
CR	4 (10.5)	9 (26.5)	
PR	4 (10.5)	10 (29.4)	
SD	2 (5.3)	2 (5.9)	
PD	28 (73.7)	13 (38.2)	
Grade ≥ 3 toxicity, n (%)	20 (52.6)	11 (32.4)	0.083
Dose reduction, n (%)	14 (36.8)	7 (20.6)	0.130

CR: complete response; PR: partial response; SD: stable disease; PD: progressive disease. * $P<0.05$ considered statistically significant.

Gender-Stratified Clinical Outcomes

Table 4 displays clinical outcomes stratified by both sarcopenia status and sex. Among males, sarcopenic patients demonstrated significantly elevated progression event rates compared to non-sarcopenic males (72.7% versus 33.3%; $P=0.010$). Female sarcopenic patients also showed higher progression rates than non-sarcopenic females (75.0% versus 46.2%), though this difference did not reach statistical significance ($P=0.111$). Treatment response distributions and toxicity profiles did not differ significantly within either sex subgroup.

Table 4. Clinical outcomes stratified by sarcopenia status and gender (N=72).

Variable	Male (n=43)		Female (n=29)		P1	P2
	Sarc. (n=22)	Non-S. (n=21)	Sarc. (n=22)	Non-S. (n=21)		
Progression event, n (%)	16 (72.7)	7 (33.3)	12 (75.0)	6 (46.2)	0.010*	0.111
Response, n (%)					0.081	0.221
CR	2 (9.1)	5 (23.8)	2 (12.5)	4 (30.8)		
PR	3 (13.6)	7 (33.3)	1 (6.3)	3 (23.1)		
SD	1 (4.5)	2 (9.5)	1 (6.3)	0 (0.0)		
PD	16 (72.7)	7 (33.3)	12 (75.0)	6 (46.2)		
Grade ≥ 3 toxicity, n (%)	12 (54.5)	7 (33.3)	8 (50.0)	4 (30.8)	0.161	0.296
Dose reduction, n (%)	10 (45.5)	5 (23.8)	4 (25.0)	2 (15.4)	0.137	0.525

Sarc.: sarcopenic; Non-S.: non-sarcopenic; P1: sarcopenic vs non-sarcopenic in males; P2: sarcopenic vs non-sarcopenic in females. * $P<0.05$ considered statistically significant.

Survival Analysis

As shown in Figure 1, Kaplan–Meier analysis revealed a significant difference in progression-free survival between sarcopenic and non-sarcopenic patients (log-rank $P=0.002$). The median PFS was markedly shorter in the sarcopenic cohort compared to the non-sarcopenic cohort (9.5 months [95% CI, 8.48–10.52] vs. 11.8 months [95% CI, 11.23–12.37]). The survival curves demonstrate an early and consistent separation between groups, indicating that sarcopenia is associated with an increased risk of disease progression and reduced PFS in multiple myeloma patients.

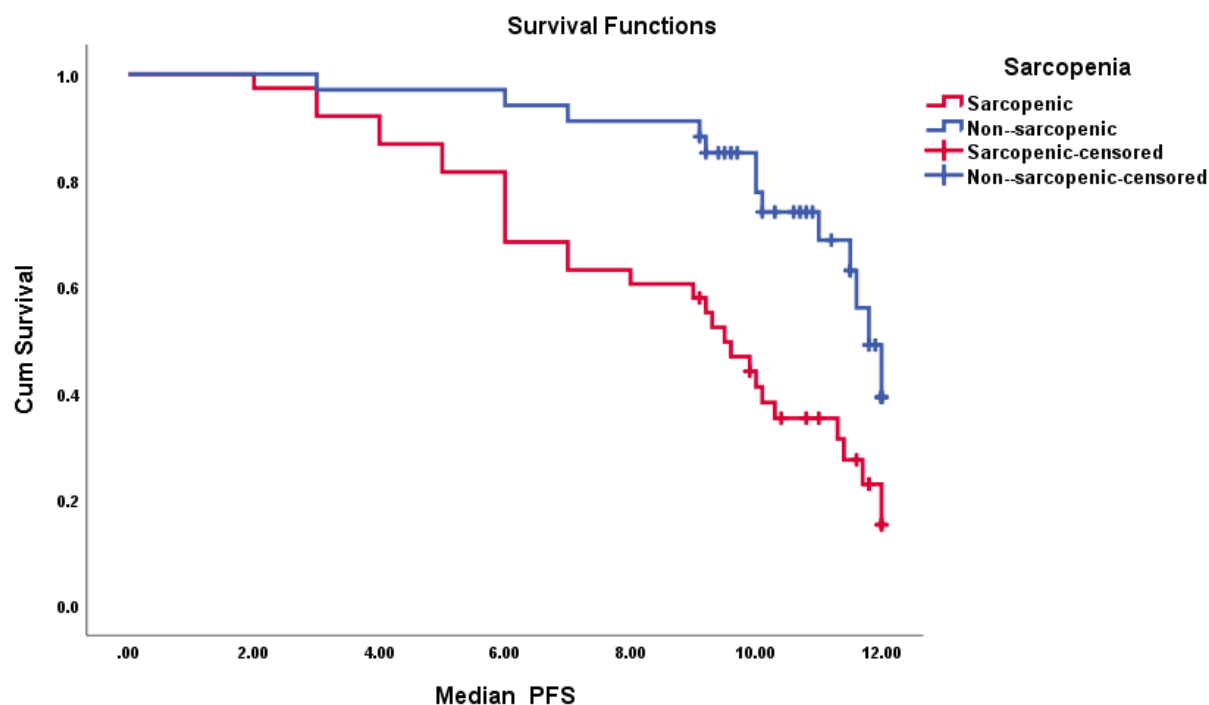


Figure 1. Kaplan–Meier curves for progression-free survival stratified by sarcopenia status in multiple myeloma patients (N=72).

As shown in Figure 2, Kaplan–Meier analysis revealed a significant difference in PFS between sarcopenic and non-sarcopenic males (median PFS: 9.6 months [95% CI, 6.88–12.32] vs. 11.8 months [95% CI, 11.06–12.54], log-rank $P=0.004$). The survival curve shows a clear separation between groups, indicating that sarcopenic males experienced earlier disease progression and shorter PFS compared to their non-sarcopenic counterparts.

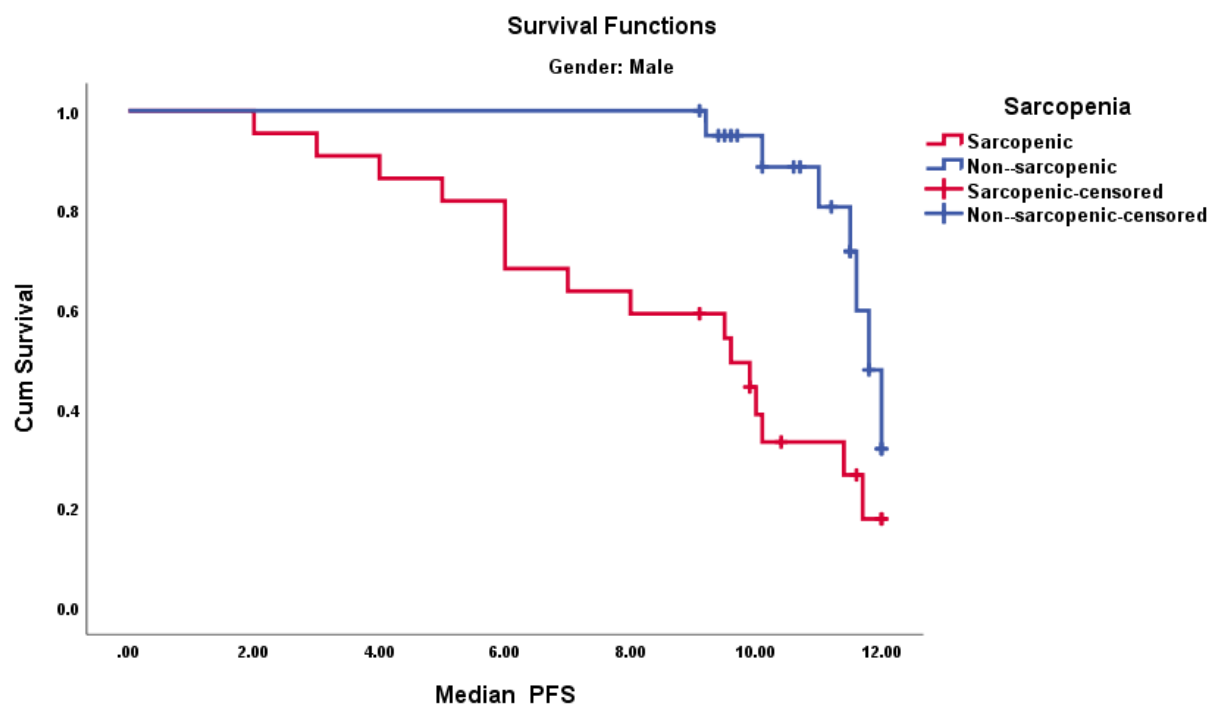


Figure 2. Kaplan–Meier curves for progression-free survival (PFS) in male multiple myeloma patients stratified by sarcopenia status (N=43).

As presented in Figure 3, no statistically significant difference in PFS was observed between sarcopenic and non-sarcopenic females (median PFS: 9.2 months [95% CI, 8.61–9.79] vs. not reached, $P=0.191$). Although sarcopenic females showed a trend toward shorter PFS, the survival curves were less distinctly separated, suggesting a weaker prognostic impact of sarcopenia in female patients.

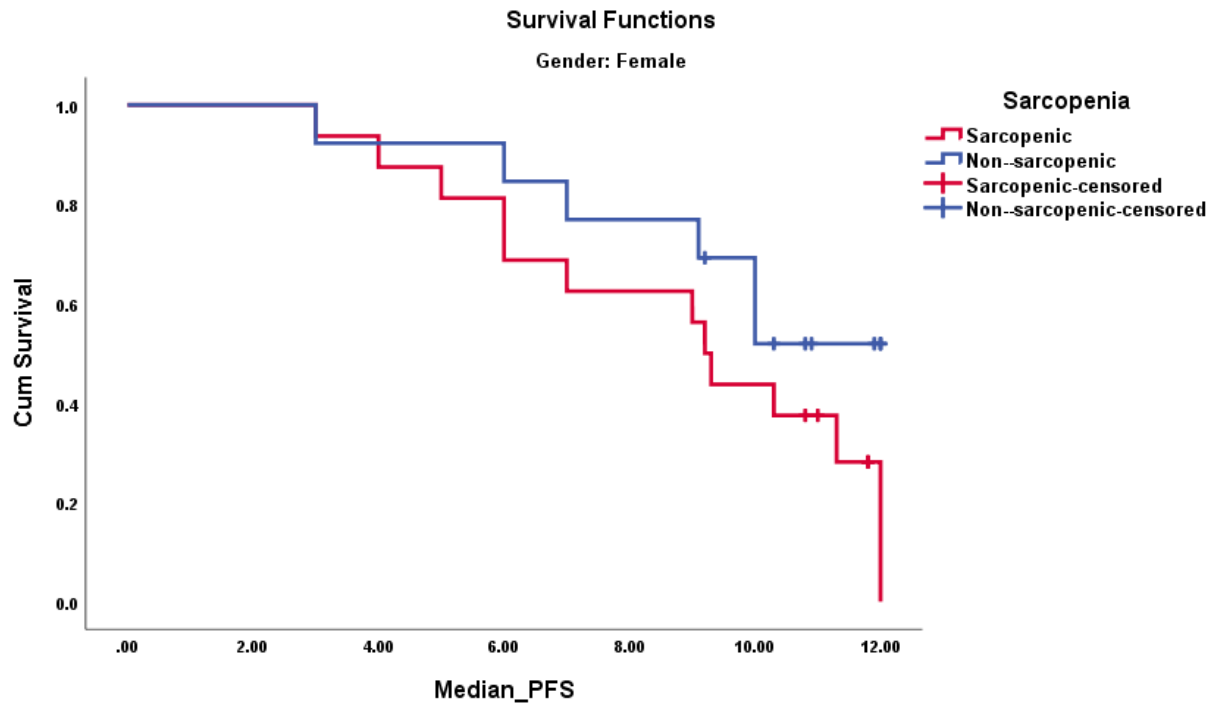


Figure 3. Kaplan–Meier curves for progression-free survival (PFS) in female multiple myeloma patients stratified by sarcopenia status (N=29).

Multivariable Analysis

Cox proportional hazards regression identified sarcopenia and skeletal muscle index as independent predictors of progression-free survival (Table 5). Sarcopenia was associated with a 2.66-fold increased hazard of disease progression or death (hazard ratio: 2.66; 95% confidence interval: 1.37–5.14; $P=0.004$). Each unit increase in skeletal muscle index conferred a 5% reduction in progression risk (hazard ratio: 0.95; 95% confidence interval: 0.91–1.00; $P=0.032$). Age, sex, and renal function did not demonstrate independent prognostic significance in the multivariable model (all $P>0.05$).

Table 5. Cox regression analysis for predictors of progression-free survival (N=72).

Variable	B	SE	HR (95% CI)	P-value
Age (years)	-0.053	0.036	0.95 (0.88-1.02)	0.141
Gender (male vs female)	-0.299	0.319	0.74 (0.40-1.38)	0.348
Sarcopenia (yes vs no)	0.977	0.337	2.66 (1.37-5.14)	0.004*
SMI (cm^2/m^2)	-0.049	0.023	0.95 (0.91-1.00)	0.032*
Creatinine (mg/dL)	0.709	0.434	2.03 (0.87-4.75)	0.102

B: regression coefficient; SE: standard error; HR: hazard ratio; CI: confidence interval; SMI: skeletal muscle index. * $P<0.05$ considered statistically significant.

Discussion

The present investigation provides compelling evidence that sarcopenia represents a prevalent and clinically meaningful prognostic factor in Egyptian multiple myeloma patients. Our findings reveal that more than half of newly diagnosed individuals harbor diminished muscle mass at presentation, and this condition independently predicts accelerated disease progression. Of particular significance, our results demonstrate notable sex-based disparities in sarcopenia's prognostic impact, with male patients exhibiting substantially greater exposure to adverse outcomes associated with muscle

wasting.

In our study, sarcopenia prevalence reached 52.8%, a figure that aligns closely with estimates from other hematological malignancy cohorts. Williams and colleagues¹¹ documented sarcopenia in 51% of multiple myeloma patients undergoing autologous transplantation using comparable CT-based methodologies. Similarly, a meta-analysis encompassing various hematological cancers reported pooled prevalence estimates ranging from 37% to 51% depending on age stratification.¹² The consistency of these findings across geographically and ethnically diverse populations underscores sarcopenia's universal relevance in this disease context.

Our results demonstrating significantly shortened progression-free survival among sarcopenic patients accord with accumulating evidence from the broader oncological literature. In our cohort, sarcopenic individuals experienced median progression-free survival of 9.5 months compared to 11.8 months in non-sarcopenic counterparts, representing a clinically meaningful difference of 2.3 months. This observation parallels findings reported by Caram and associates⁶ in lymphoma patients, where sarcopenia predicted post-transplant outcomes. The magnitude of survival detriment observed in our study, with a hazard ratio of 2.66, exceeds that reported in certain solid tumor investigations and suggests particularly pronounced prognostic implications within the myeloma disease.

In contrast to our findings, Bhamidipati and colleagues¹³ failed to identify significant survival differences between sarcopenic and non-sarcopenic multiple myeloma patients in their retrospective analysis. This discrepancy likely reflects methodological variations, as their study employed psoas muscle measurements exclusively rather than comprehensive skeletal muscle assessment. Additionally, patient selection criteria and treatment era differences may contribute to divergent conclusions. Our prospective design and standardized assessment protocols potentially captured sarcopenia's impact more accurately than retrospective approaches subject to selection bias.

Our investigation concerns the differential prognostic significance of sarcopenia between sexes. Male patients with sarcopenia demonstrated substantially worse progression-free survival compared to their non-sarcopenic counterparts, whereas female patients showed no statistically significant survival differences based on sarcopenia status. This gender disparity mirrors observations in other malignancies. Shachar and coworkers¹⁴ reported stronger sarcopenia-survival associations among men with colorectal cancer, attributing this phenomenon to fundamental differences in muscle physiology, hormonal regulation, and fat distribution patterns between sexes.

Several biological mechanisms may underlie the observed sex-based differences. Testosterone exerts potent anabolic effects on skeletal muscle, and age-related androgen decline in males may render them more susceptible to sarcopenia's deleterious consequences.¹⁵ Furthermore, estrogen appears to confer myoprotective properties through anti-inflammatory and antioxidant actions.¹⁶ Our observation that sarcopenic males were significantly older than non-sarcopenic males, whereas no such age difference existed among females, supports the hypothesis that accelerated muscle loss in aging men drives the observed prognostic disparity.

The relationship between sarcopenia and treatment response observed in our study warrants careful consideration. Sarcopenic patients achieved lower complete and partial response rates while experiencing more frequent disease progression. Similar patterns have been documented in solid tumor investigations, where reduced muscle mass correlated with diminished chemotherapy efficacy.¹⁷ Proposed explanations include altered drug pharmacokinetics in sarcopenic individuals, as lean body mass influences distribution volumes for hydrophilic chemotherapeutic agents.¹⁸ Consequently, standard weight-based dosing may produce relatively higher drug concentrations in sarcopenic patients, potentially increasing toxicity while paradoxically reducing efficacy through treatment interruptions.

Although our results revealed results toward increased severe toxicity and dose reductions among sarcopenic patients, these differences did not achieve statistical significance. This finding diverges somewhat from prior reports linking sarcopenia with heightened chemotherapy toxicity in various cancers.⁵

In our results, the independent prognostic value of skeletal muscle index as a continuous variable in our multivariable analysis reinforces sarcopenia's biological significance beyond arbitrary diagnostic

thresholds. Each unit increase in skeletal muscle index conferred measurable survival benefit, suggesting that muscle preservation efforts might improve outcomes even in patients not meeting formal sarcopenia criteria. This dose-response relationship aligns with observations by Prado and colleagues¹⁹ demonstrating incremental survival improvements with increasing muscle mass across the entire distribution spectrum.

Our study carries several clinical implications. Routine sarcopenia screening using CT imaging, already performed for disease staging in multiple myeloma, could enhance risk stratification without additional resource expenditure. Identified sarcopenic patients might benefit from nutritional optimization, exercise interventions, and closer monitoring during treatment.²⁰ Gender-specific risk assessment protocols recognizing male patients' heightened vulnerability to sarcopenia-related adverse outcomes may further refine prognostication and therapeutic decision-making.

Conclusion

Sarcopenia constitutes a prevalent condition affecting more than half of Egyptian multiple myeloma patients at diagnosis and independently predicts progression-free survival. The prognostic impact demonstrates prominent sex-based variation, with male patients experiencing substantially greater survival detriment associated with muscle depletion. Integration of CT-based sarcopenia assessment into routine clinical practice may enhance risk stratification and guide modified management approaches.

REFERENCES

1. Palumbo A, Anderson K. Multiple myeloma. *N Engl J Med*. 2011;364(11):1046-60.
2. Kumar SK, Rajkumar V, Kyle RA, et al. Multiple myeloma. *Nat Rev Dis Primers*. 2017; 3:17046.
3. Cruz-Jentoft AJ, Baeyens JP, Bauer JM, et al. Sarcopenia: European consensus on definition and diagnosis. *Age Ageing*. 2010;39(4):412-23.
4. Cruz-Jentoft AJ, Bahat G, Bauer J, et al. Sarcopenia: revised European consensus on definition and diagnosis. *Age Ageing*. 2019;48(1):16-31.
5. Prado CM, Lieffers JR, McCargar LJ, et al. Prevalence and clinical implications of sarcopenic obesity in patients with solid tumours of the respiratory and gastrointestinal tracts: a population-based study. *Lancet Oncol*. 2008;9(7):629-35.
6. Caram MV, Bellile EL, Englesbe MJ, et al. Sarcopenia is associated with autologous transplant-related outcomes in patients with lymphoma. *Leuk Lymphoma*. 2015;56(10):2855-62.
7. Terpos E, Ntanasis-Stathopoulos I, Gavriatopoulou M, Dimopoulos MA. Pathogenesis of bone disease in multiple myeloma: from bench to bedside. *Blood Cancer J*. 2018;8(1):7.
8. Richardson PG, Delforge M, Beksac M, et al. Management of treatment-emergent peripheral neuropathy in multiple myeloma. *Leukemia*. 2012;26(4):595-608.
9. Janssen I, Heymsfield SB, Wang ZM, Ross R. Skeletal muscle mass and distribution in 468 men and women aged 18-88 yr. *J Appl Physiol*. 2000;89(1):81-8.
10. Shachar SS, Williams GR, Muss HB, Nishijima TF. Prognostic value of sarcopenia in adults with solid tumours: A meta-analysis and systematic review. *Eur J Cancer*. 2016; 57:58-67.
11. Williams A, Baruah D, Patel JJ, et al. Prevalence and significance of sarcopenia in multiple myeloma patients undergoing autologous hematopoietic cell transplantation. *Bone Marrow Transplant*. 2021;56(1):225-31.
12. Surov A, Wienke A. Sarcopenia predicts overall survival in patients with malignant hematological diseases: a meta-analysis. *Clin Nutr*. 2020;39(9):2926-33.
13. Bhamidipati PK, Carson KR, Wildes TM. Psoas cross-sectional area as radiographic measure of sarcopenia does not predict overall survival in multiple myeloma. *Blood*. 2013;122(21):5326.
14. Shachar SS, Deal AM, Weinberg M, et al. Skeletal muscle measures as predictors of toxicity, hospitalization, and survival in patients with metastatic breast cancer receiving taxane-based chemotherapy. *Clin Cancer Res*. 2017;23(3):658-65.
15. Bhasin S, Storer TW, Berman N, et al. The effects of supraphysiologic doses of testosterone on muscle size and strength in normal men. *N Engl J Med*. 1996;335(1):1-7.

16. Tiidus PM. Estrogen and gender effects on muscle damage, inflammation, and oxidative stress. *Can J Appl Physiol.* 2000;25(4):274-87.
17. Miyamoto Y, Baba Y, Sakamoto Y, et al. Sarcopenia is a negative prognostic factor after curative resection of colorectal cancer. *Ann Surg Oncol.* 2015;22(8):2663-8.
18. Prado CM, Baracos VE, McCargar LJ, et al. Body composition as an independent determinant of 5-fluorouracil-based chemotherapy toxicity. *Clin Cancer Res.* 2007;13(11):3264-8.
19. Prado CM, Lieffers JR, Bowthorpe L, et al. Sarcopenia and physical function in overweight patients with advanced cancer. *Can J Diet Pract Res.* 2013;74(2):69-74.
20. Bauer J, Capra S. Nutrition intervention improves outcomes in patients with cancer cachexia receiving chemotherapy--a pilot study. *Support Care Cancer.* 2005;13(4):270-4.