Protein Intake and Skeletal Muscle Mass as Determinants of Sarcopenia Risk in Type 2 Diabetes Mellitus

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Abstract. Sarcopenia represents progressive decline in muscle mass and function that significantly elevates morbidity risk in elderly populations. The risk of sarcopenia may increase in individuals with type 2 diabetes mellitus (T2DM), primarily due to insulin resistance and poor glycemic control. The skeletal muscle mass serves as a fundamental predictor for sarcopenia development and is strongly linked to protein intake. However, comprehensive investigations examining the relationship between protein intake, skeletal muscle mass, and sarcopenia risk among T2DM patients remain limited in Indonesian populations. This study aimed to evaluate the association between protein intake and skeletal muscle mass with sarcopenia risk in individuals diagnosed with T2DM residing in Malang City. A cross-sectional analytical study was conducted involving 46 respondents selected through purposive and simple random sampling. Protein intake was assessed using the SQ-FFQ, while muscle mass was measured using BIA body composition analysis. Sarcopenia screening utilized the SARC-CalF instrument and skeletal muscle index calculation followed established protocols. Statistical analysis incorporated Spearman correlation coefficients to examine variable relationships. Participant characteristics demonstrated protein intake among respondents was 78,96 (66,42%) and the Skeletal Muscle Index (SMI) was 6,45±1,1 kg/m². Correlation analysis revealed a significant negative association between protein intake and sarcopenia risk ($p=0.035$, $r=-0.311$). Furthermore, skeletal muscle index exhibited a statistically significant correlation with sarcopenia risk ($p=0.002$, $r=-0.450$). Significant associations exist between protein intake and muscle mass with sarcopenia risk among type 2 diabetes mellitus patients in Malang City, suggesting the potential value of nutritional interventions in sarcopenia prevention.

Keywords: Protein Intake, Skeletal Muscle Index, Sarcopenia, Type 2 Diabetes Mellitus.

1 Introduction

Diabetes is a chronic metabolic condition characterized by persistent hyperglycemia resulting from impaired insulin secretion, reduced insulin sensitivity, or a combination of both mechanisms [1], [2]. The global prevalence of T2DM in 2024 is estimated to reach 11.1% with 588.7 million sufferers aged 20–79 years. This number is projected

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to rise to 852.5 million (13%) by 2050 [3]. According to IDF (2025), diabetes cases in Indonesia are ranked fifth in the world for the age range of 20-79 years and seventh for the age group of 65-99 years. At the regional level, Malang City reports 20,771 individuals living with diabetes [4].

Based on the Indonesian Health Survey [3], 8.7% of older adults with diabetes experience dependency in activities of daily living. T2DM is a lifelong condition that remains incurable but manageable through appropriate treatment and lifestyle modification [5] When this condition is uncontrolled, T2DM can cause serious impacts on the cardiovascular system, blood vessels, eyes, kidneys, and nervous system [2]. Damage to nerve cells that innervate skeletal muscle can interfere with muscle contractility to the point of causing atrophy and decreased muscle mass and strength [6].

Sarcopenia is a progressive condition characterized by the generalized loss of skeletal muscle mass, muscle quality, and strength associated with aging and chronic disease [7]. Its development is influenced by multiple factors, including age, physical activity, dietary intake, nutritional status, and comorbid conditions [8]. Chronic diseases such as T2DM may accelerate the onset and progression of sarcopenia [9]. Globally, the prevalence of sarcopenia among individuals aged ≥60 years reaches 10%, with even higher rates observed among patients with T2DM [10]. Research on sarcopenia among patients with T2DM in Indonesia remains limited. Therefore, further studies are needed to determine the relationship between protein intake, muscle mass and sarcopenia risk among patients with T2DM in Malang City.

2 Methods

This study employed an analytical observational study with a cross-sectional design conducted at the Kendalkerep Primary Health Center, Malang City, Indonesia, from June to December 2025. The study site was selected using purposive sampling, whereas participants were recruited through simple random sampling. The minimum sample size was calculated using the Lemeshow formula with a standard alpha value of 1.96, a standard beta value of 0.84, and a minimum correlation coefficient of 0.41 based on the findings of Moyama et al. (2025), resulting in a total sample of 46 participants [11]. The inclusion criteria comprised men and women aged 45 years or older diagnosed with type 2 diabetes mellitus (T2DM), who were able to communicate effectively and voluntarily agreed to participate in the study. The exclusion criteria included: (a) a history of limb amputation; (b) inability to stand independently; and (c) a history of stroke, chronic kidney disease (CKD), liver disease, chronic obstructive pulmonary disease (COPD), tuberculosis (TBC), or human immunodeficiency virus/acquired immunodeficiency syndrome (HIV/AIDS). All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and national research committee (ethical approval has been obtained from the Ethics Commission of the Faculty of Health Science, Brawijaya University with No. 192/UN10.F17.10.4/TU/2025).

Participant characteristics were collected through interviews using a structured questionnaire. Protein intake was assessed using a Semi-Quantitative Food Frequency Questionnaire (SQ-FFQ) covering the previous month and analyzed using NutriSurvey 2004 to determine the percentage of protein adequacy by comparing the average daily protein intake with the individual protein requirement of 1.2 g/kg body weight/day. Muscle mass was measured using Bioelectrical Impedance Analysis (BIA) (Omron HBF-375), and the Skeletal Muscle Index (SMI) was subsequently calculated by dividing total skeletal muscle mass (skeletal whole body) by height squared (kg/m^2). Sarcopenia risk was assessed using the SARC-CalF questionnaire, which consists of five components: Strength, Assistance in walking, Rise from a chair, Climb stairs, Falls, and calf circumference measurement.

Data was analyzed using SPSS version 22.0. Descriptive statistics were used to summarize participant characteristics and study variables. The associations between protein intake, muscle mass, and sarcopenia risk were evaluated using Spearman's rank correlation test, with statistical significance set at $p < 0.05$.

3 Results

3.1 Characteristics of Study Subjects

The study sample consisted of 46 respondents diagnosed with type 2 diabetes mellitus (T2DM) who agreed and signed the informed consent form, recruited from Puskesmas Kendalkerep (16 males and 30 females, age 60,89±7,4 years). The characteristics of respondents are shown in Table 1.

Table 1. Characteristics of study subjects.

Respondent Characteristics	Frequency	Persentase (%)
Gender		
Male	16	34,8
Female	30	65,2
Age Distribution		
Pre-elderly (≥ 45 years)	20	43,5
Elderly (≥ 60 years)	26	56,5
Marital Status		
Married	37	80,4
Widow/Widower	9	19,6
Education Level		
Low education level (< senior high school)	34	73,9
Higher education level (> senior high school)	12	26,1
Occupation		
Trader	4	8,7
Labor	1	2,2
Housewife	16	34,7

Unemployed	5	10,9
Self-employed	1	2,2
Others	19	41,3
BMI		
Underweight	1	2,2
Normal	6	13,0
Overweight	5	0,9
Pre-obese	24	52,1
Obese Type 1	9	19,6
Obese Type 2	1	2,2

Table 1 presents the demographic and clinical characteristics of the participants. Of the 46 respondents, the majority were female (65.2%), while males accounted for 34.8%. More than half of the respondents were elderly (≥60 years) (56.5%), whereas 43.5% were pre-elderly (45–59 years). Most respondents were married (80.4%), had a low educational level (73.9%), and worked as housewives (34.7%) or had other occupations (41.3%). Based on body mass index (BMI), the largest proportion of respondents was classified as pre-obese (52.1%), followed by obese type 1 (19.6%), normal weight (13.0%), overweight (10.9%), underweight (2.2%), and obese type 2 (2.2%).

3.2 Protein Intake Adequacy

Table 2. Distribution of protein intake adequacy categories.

Protein Intake Adequacy Categories	Gender				Total	
	Male		Female			
	n	%	n	%	n	%
Very Inadequate (<80%)	7	15.2	17	37.0	24	52.2
Inadequate (80–99%)	2	4.3	5	10.9	7	15.2
Normal (100–120%)	3	6.5	1	2.2	4	8.7
Excessive (>120%)	4	8,7	7	15.2	11	23.9
Total	16	34.8	30	65.2	46	100

Table 2 presents the protein intake adequacy of participants with type 2 diabetes mellitus (T2DM). Most participants were classified as having very inadequate protein intake adequacy (<80%). These findings indicate that more than half of the participants did not meet their daily protein requirements, whereas only a small proportion achieved the recommended protein intake.

3.3 Skeletal Muscle Index

Table 3 presents the mean Skeletal Muscle Index (SMI) of the participants was 6.45 ± 1.10 kg/m^2, indicating that, overall, the participants had relatively low skeletal muscle mass.

Table 3. Distribution of skeletal muscle index (SMI) categories.

SMI Categories	Frequency	Persentase (%)
Male		
Low (<7.0 kg/m²).	5	31.2
Normal (≥7.0 kg/m²).	11	68.8
Female		
Low (<5.4 kg/m²).	7	23.3
Normal (≥5.4 kg/m²).	23	76.7

3.4 Sarcopenia Risk

Table 4 showed that a relatively small proportion of participants were at risk of sarcopenia, with the prevalence being higher among elderly (≥60 years) than among pre-elderly (45–59 years).

Table 4. Distribution of sarcopenia risk categories.

Protein Intake Adequacy Categories	Gender				Total	
	Male		Female			
	n	%	n	%	n	%
Pre-elderly (≥ 45 years)	19	41.3	1	2.2	20	43.5
Eldelry (≥ 60 years)	21	45.6	5	10.9	26	56.5
Total	40	87.0	6	13.0	46	100

3.5 Relation between Nutrition Intake and Skeletal Muscle Index with Sarcopenia Risk

Table 5. Relationship between nutrition intake and skeletal muscle mass with sarcopenia risk.

Variables	Mean±SD	p	r
Protein daily intake	23,81±3,49	0.006	-0.399**
Protein daily adequacy	94.2±65,43	0.035	-0.311*
Skeletal Muscle Mass	16.18±3.95	0.018	-0.348*
Skeletal Muscle Index	6.5±1.10	0.002	-0.450**

*Correlation is significant at the 0.05 level (2-tailed)
**Correlation is significant at the 0.01 level (2-tailed)

Table 5 shows the associations between protein intake, skeletal muscle mass, and sarcopenia risk among participants with type 2 diabetes mellitus (T2DM). The mean daily protein intake was 23.81 ± 3.49 g, with a mean protein adequacy of 94.2 ± 65.43%. The mean skeletal muscle mass and skeletal muscle index (SMI) were 16.18 ± 3.95 kg and 6.50 ± 1.10 kg/m², respectively. Spearman correlation analysis demonstrated significant negative correlations between daily protein intake ($p = 0.006$, $r = -0.399$), protein adequacy ($p = 0.035$, $r = -0.311$), skeletal muscle mass ($p = 0.018$, $r = -0.348$), and SMI ($p = 0.002$, $r = -0.450$) with sarcopenia risk.

4 Discussion

4.1 Characteristics of Study Subjects

The proportion of respondents with type 2 diabetes mellitus (T2DM) was higher among females compared to males. The Perkumpulan Endokrinologi Indonesia (PERKENI) in 2021 reported that the prevalence of T2DM in females is higher than in males because physiologically females have higher BMI compared to males. Based on the results of this study, demonstrated that overweight was more prevalent among female respondents, with 27 individuals (58.7%), compared to 12 male respondents (26.08%). Most of the respondents (56.5%) were classified as elderly. According to Delfina (2021) [1], the risk of glucose intolerance increases in the age group ≥ 45 years. This condition is associated with age-related declines in cellular and tissue function [2]. Most respondents were married. Partner participation has a positive influence on the implementation of a healthy diet, increased self-efficacy, improved psychological well-being, increased perception of support and behavioral changes that contribute to the control of blood glucose levels [3]. Regarding educational level, most respondents (73.9%; n = 34) had a low level of education (not completing senior high school or up to senior high school), while 26.1% (n = 12) had higher education levels (diploma, bachelor's degree, or postgraduate education). Low levels of education result in low health literacy so that a person tends to have difficulty understanding diet, drug dosage, and blood glucose checks [4]. Most of the respondents have jobs as housewives followed by retirees and are not working. Person with a sedentary job (such as a housewife, administrative worker, or retiree) has a higher risk of developing DMT2 [5]. Work with low physical activity or high stress levels can worsen blood glucose regulation [4]. Half of the participants were classified as pre-obese based on their body mass index (BMI). Individuals with a BMI ≥25 kg/m² had an eightfold higher risk of developing type 2 diabetes mellitus (T2DM) [6]. Obese individuals exhibited higher blood glucose levels and a higher prevalence of T2DM (93.8%) [7]. Furthermore, there is a significant association between BMI and random blood glucose levels ($p < 0.001$; OR = 2.21), indicating that obesity is associated with poorer glycemic control among patients with T2DM [8].

4.2 Protein Intake Adequacy

Most participants were older adults (≥60 years), an age group that commonly experiences physiological changes such as impaired swallowing, reduced taste and smell sensitivity, decreased appetite, digestive dysfunction, and anabolic resistance, all of which may reduce the body's ability to utilize dietary protein for muscle protein synthesis [9], [10] . Older adults are also less responsive to the anabolic effects of low-dose protein intake than younger individuals, increasing their susceptibility to inadequate protein intake [11].

In the present study, inadequate protein intake was more common among women than men. This finding may be explained by sex differences in body composition and protein metabolism, as men generally have greater lean body mass and higher protein requirements [12]. In addition, dietary patterns differ between sexes, with men tending to consume more meat and women consuming more vegetables, which may contribute to lower protein intake among women [13].

Low educational attainment and occupational status may also have contributed to inadequate protein intake. Lower educational level has been associated with poorer nutrition literacy and limited knowledge regarding protein requirements in individuals with T2DM [14]. Furthermore, limited income and sedentary or unemployed status may reduce access to nutritious foods and result in poorer dietary quality, with carbohydrate-rich foods often being preferred over protein-rich foods [4], [15], [16], [17]. Family support, particularly spousal involvement, has also been shown to facilitate healthier dietary behaviors among individuals with diabetes [18].

4.3 Sarcopenia Risk

In the present study, the proportion of participants at risk of sarcopenia was relatively low, although the prevalence was higher among older adults (≥60 years) than pre-older adults. This finding is consistent with previous studies reporting that the prevalence of sarcopenia increases with advancing age and is higher among individuals with T2DM than in the general older population [19], [20]. Aging is the primary intrinsic risk factor for sarcopenia because it is associated with progressive declines in muscle mass and function, neuromuscular impairment, hormonal changes, mitochondrial dysfunction, and chronic inflammation [21], [22]. Furthermore, older adults with T2DM have an approximately threefold higher risk of developing sarcopenia than those without T2DM due to insulin resistance and chronic inflammation, which impair glucose uptake and muscle protein synthesis. Conversely, sarcopenia may further exacerbate diabetes by reducing skeletal muscle glucose utilization [22], [23].

4.4 Relation between Nutrition Intake and Skeletal Muscle Index with Sarcopenia Risk

Based on the results of statistical analysis in assessing the protein intake among elderly with T2DM and analyzing the relationship between protein intake and skeletal muscle mass and the risk of sarcopenia. The results showed that majority of respondents had very inadequate protein intake (<80%) or below the recommendation (1,2–1,5 g/kgBW/day) which increase the risk of sarcopenia [22]. This study was supported by [24] through a meta-analysis of the elderly population of Korea found that protein intake <0.8 g/kgBW/day increased the risk of sarcopenia by 1.79 times compared to an intake of ≥1.2 g/kgBW/day. Age-related conditions such as decreased appetite, reduced taste sensitivity, impaired digestive function, and anabolic resistance further reduce the body's ability to effectively respond to and utilize protein intake for optimal muscle

protein synthesis [10]. This study demonstrated a statistically significant association between protein intake and sarcopenia risk, although the strength of the relationship was weak. This shows that in addition to protein intake, there are other factors that can affect the risk of sarcopenia such as physical activity, insulin resistance, chronic inflammation and a decrease in anabolic hormones in DMT2 sufferers.
Based on Table 5, the skeletal muscle index (SMI) of respondents was 6.45 ± 1.1 kg/m^2. SMI is one of the main predictors of the risk of sarcopenia, especially in individuals with T2DM. It has been developed as a more sensitive diagnostic tool to detect decreased muscle mass in such populations [25]. This study showed a statistically significant association between SMI and sarcopenia risk with a moderate correlation strength. This is supported by a review study by [26] showing that individuals with T2DM experience an accelerated decline in skeletal muscle mass compared to non-diabetic individuals. This suggests that a low SMI is related to poor glycemic control. This suggests that although muscle mass plays an important role in the assessment of sarcopenia, muscle mass is not the only factor that affects it. Sarcopenia is a condition that is influenced by various factors, not only muscle mass. The Asian Working Group for Sarcopenia (AWGS) states that the criteria for measuring sarcopenia can be done through muscle mass, muscle strength, and physical performance [27]. Sarcopenia is a multifactorial condition influenced by age, sex, physical activity, and chronic diseases such as type 2 diabetes mellitus (T2DM) [28]. According to [28], age is the primary intrinsic risk factor for the development of sarcopenia. This is further supported by the study conducted by [29], which reported that individuals aged 60–70 years' experience a decline in muscle mass and function ranging from 5% to 13%, with the decline increasing to 11%–50% among individuals aged over 80 years. In addition, long-term T2DM can reduce the muscle's ability to utilize glucose and impair protein synthesis through insulin resistance mechanisms. Insulin resistance is a major pathophysiological factor in DMT2 and has a significant role in the development of sarcopenia [30]. Prolonged exposure to hyperglycemia may lead to the accumulation of advanced glycation end products (AGEs) in muscle tissue, accelerating cellular aging and reducing tissue elasticity which can worsen the condition of sarcopenia [31]. This study is the first study to show the relationship between protein intake and skeletal muscle mass in the elderly in Indonesia and DMT2 in a community setting. Therefore, further studies are warranted to address the limitations of the present study, including the potential recall bias associated with the use of the Semi-Quantitative Food Frequency Questionnaire (SQ-FFQ), the absence of data on daily protein intake distribution, and the inability to differentiate between animal- and plant-based protein sources, which may have influenced the associations between protein intake, skeletal muscle mass, and sarcopenia risk.

4.5 Skeletal Muscle Index

In the present study, 31.2% of male participants and 23.3% of female participants had low skeletal muscle index (SMI). This finding may be attributed to aging, as most participants were older adults, a condition associated with progressive loss of muscle mass, hormonal decline, anabolic resistance, and impaired muscle protein synthesis [2], [21],

[32], [33]. In addition, most participants had lived with T2DM for ≥5 years, and a significant negative correlation was observed between diabetes duration and SMI ($p = 0.032$; $r = -0.317$), suggesting that prolonged insulin resistance contributes to muscle loss through impaired protein synthesis, chronic inflammation, oxidative stress, hyperglycemia, and the accumulation of advanced glycation end products (AGEs) [22]. Other factors, including the use of oral antidiabetic drugs, low levels of physical activity, and poor glycemic control, may also have contributed to reduced muscle mass [34], [35], [36]. Although smoking has been reported to accelerate muscle loss through oxidative stress and impaired protein synthesis [37], no similar pattern was observed in this study, likely due to the small number of participants with a history of smoking.

5 Conclusion

Daily protein intake among individuals with T2DM in Malang was classified as severely inadequate. This condition indicates that most respondents had not met the recommended daily protein requirements. Meanwhile, skeletal muscle mass among individuals with T2DM also requires attention to prevent the development of sarcopenia. Further analysis showed a significant association between protein intake, skeletal muscle mass, and the risk of sarcopenia among patients with type 2 diabetes mellitus in Malang. These findings indicate that adequate protein intake and muscle mass condition are important factors that play a role in determining the risk of sarcopenia in DMT2 patients. So appropriate nutritional interventions need to be part of comprehensive diabetes management.

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References

1. S. Delfina, I. C. Maharani, S. Habsah, and Ayatillahi, "Literature Review: Analisis Determinan Faktor Risiko Kejadian Diabetes Mellitus Tipe 2 pada Usia Produktif," *Jurnal Kesehatan Tambusai*, vol. 2, 2021.
2. S. Meng *et al.*, "The prevalence of sarcopenia and risk factors in the older adult in China: a systematic review and meta-analysis," *Front. Public Health*, vol. 12, 2024, doi: 10.3389/fpubh.2024.1415398.
3. W. Pratiwi, E. Harfiani, and Y. H. Hadiwiardjo, "Faktor-Faktor Yang Berhubungan Dengan Kepatuhan Dalam Menjalani Pengobatan Pada Penderita Hipertensi Di Klinik Pratama GKI Jabar Jakarta Pusat," in *Seminar Nasional Riset Kedokteran*, 2020, pp. 27–40.
4. F. Hill-Briggs *et al.*, "Social determinants of health and diabetes: A scientific review," *Diabetes Care*, vol. 44, pp. 258–279, 2021, doi: 10.2337/dci20-0053.

5. M. T. Hamilton, D. G. Hamilton, and T. W. Zderic, "Sedentary behavior as a mediator of type 2 diabetes," in *Diabetes and Physical Activity*, S. Karger AG, 2014, pp. 11–26. doi: 10.1159/000357332.
6. Y. Imansary, M. Yunus, and R. Gayatri, "The Correlation Between Physical Activity, Body Mass Index (BMI), and Abdominal Circumference with Type 2 Diabetes Mellitus (DM) Cases at Public," in *Advances in Health Sciences Research*, 2021.
7. R. U. R. Samapati, R. M. Putri, and H. M. Devi, "Perbedaan Kadar Gula Darah Berdasarkan Jenis Kelamin dan Status Gizi (IMT) Lansia Penderita Diabetes Melitus Tipe 2," *Jurnal Akademika Baiturrahim Jambi*, vol. 12, p. 417, 2023, doi: 10.36565/jab.v12i2.699.
8. B. S. Arsana, M. Bagiansah, S. I. Zoraya, and M. B. Azhar, "Association of Body Mass Index, Age, and Sex with Blood Glucose Levels in Type 2 Diabetes Mellitus Patients," *Jurnal Biologi Tropis*, vol. 24, pp. 567–574, 2024, doi: 10.29303/jbt.v24i1b.8255.
9. R. Smith *et al.*, "Older adults' acceptability of and preferences for food-based protein fortification in the UK, France and Norway," *Appetite*, vol. 197, 2024, doi: 10.1016/j.appet.2024.107319.
10. J. I. Baum and R. R. Wolfe, "The link between dietary protein intake, skeletal muscle function and health in older adults," *Healthcare*, vol. 3, pp. 529–543, 2015, doi: 10.3390/healthcare3030529.
11. C. Nowson and S. O'Connell, "Protein requirements and recommendations for older people: A review," 2015, doi: 10.3390/nu7085311.
12. A. Feraco *et al.*, "Gender differences in dietary patterns and physical activity: an insight with principal component analysis (PCA)," *J. Transl. Med.*, vol. 22, 2024, doi: 10.1186/s12967-024-05965-3.
13. H. Kujawska-Danecka *et al.*, "Socioeconomic and Health-Related Determinants of Eating Habits in Polish Caucasian Older Population—The Nationwide PolSenior2 Study Results," *Nutrients*, vol. 17, 2025, doi: 10.3390/nu17101640.
14. F. Retiati, N. Andarwulan, N. S. Palupi, F. Ernawati, R. Kazimierczak, and D. Średnicka-Tober, "Contribution of Food, Energy, Macronutrients and Fiber Consumption Patterns to Obesity and Other Non-Communicable Disease Risks in the Indonesian Population," *Nutrients*, vol. 17, 2025, doi: 10.3390/nu17091459.
15. T. P. Minari *et al.*, "The Impact of a Nutritional Intervention on Glycemic Control and Cardiovascular Risk Markers in Type 2 Diabetes," *Nutrients*, vol. 16, 2024, doi: 10.3390/nu16091378.
16. J. Lin, M. Hu, X. Gu, T. Zhang, H. Ma, and F. Li, "Effects of cigarette smoking associated with sarcopenia in persons 60 years and older: a cross-sectional study in Zhejiang province," *BMC Geriatr.*, vol. 24, 2024, doi: 10.1186/s12877-024-04993-4.
17. M. Han, K. Woo, and K. Kim, "Association of Protein Intake with Sarcopenia and Related Indicators Among Korean Older Adults: A Systematic Review and Meta-Analysis," 2024, doi: 10.3390/nu16244350.
18. I. N. Pratiwi, Nursalam, I. Y. Widyawati, and V. Ramoo, "Spousal Involvement in Collaborative Management and Glycemic Behavior Change among Patients with Diabetes Mellitus: A Systematic Review," *SAGE Open Nurs.*, vol. 10, 2024, doi: 10.1177/23779608241245196.
19. L. K. Chen *et al.*, "Sarcopenia in Asia: Consensus report of the Asian working group for sarcopenia," 2014, doi: 10.1016/j.jamda.2013.11.025.
20. S. Yuan and S. C. Larsson, "Epidemiology of sarcopenia: Prevalence, risk factors, and consequences," 2023, doi: 10.1016/j.metabol.2023.155533.
21. Y. Hou *et al.*, "Pathogenesis and comprehensive treatment strategies of sarcopenia in elderly patients with type 2 diabetes mellitus," 2023, doi: 10.3389/fendo.2023.1263650.

22. I. G. P. S. Aryana, *Sarkopenia pada Lansia: Problem Diagnosis dan Tatalaksana*. Baswara Press, 2021. doi: 10.53638/9786239795580.
23. B. Alabadi, M. Civera, A. De la Rosa, S. Martinez-Hervas, M. C. Gomez-Cabrera, and J. T. Real, "Low Muscle Mass Is Associated with Poorer Glycemic Control and Higher Oxidative Stress in Older Patients with Type 2 Diabetes," *Nutrients*, vol. 15, 2023, doi: 10.3390/nu15143167.
24. C. Y. Chiu *et al.*, "Advanced glycation end-products induce skeletal muscle atrophy and dysfunction in diabetic mice via a RAGE-mediated, AMPK-down-regulated, Akt pathway," *Journal of Pathology*, vol. 238, pp. 470–482, 2016, doi: 10.1002/path.4674.
25. J. E. Park, S. Lee, and K. Kim, "The effect of combining nutrient intake and physical activity levels on central obesity, sarcopenia, and sarcopenic obesity: a population-based cross-sectional study in South Korea," *BMC Geriatr.*, vol. 23, no. 1, Dec. 2023, doi: 10.1186/s12877-023-03748-x.
26. J. M. Lopez-Pedrosa *et al.*, "The Vicious Cycle of Type 2 Diabetes Mellitus and Skeletal Muscle Atrophy: Clinical, Biochemical, and Nutritional Bases," Jan. 01, 2024, *Multidisciplinary Digital Publishing Institute (MDPI)*. doi: 10.3390/nu16010172.
27. L. K. Chen *et al.*, "Sarcopenia in Asia: Consensus report of the Asian working group for sarcopenia," 2014, *Elsevier Inc.* doi: 10.1016/j.jamda.2013.11.025.
28. I. G. P. S. Aryana, *Sarkopenia pada Lansia: Problem Diagnosis dan Tatalaksana*. Baswara Press, 2021. doi: 10.53638/9786239795580.
29. B. Alabadi, M. Civera, A. De la Rosa, S. Martinez-Hervas, M. C. Gomez-Cabrera, and J. T. Real, "Low Muscle Mass Is Associated with Poorer Glycemic Control and Higher Oxidative Stress in Older Patients with Type 2 Diabetes," *Nutrients*, vol. 15, no. 14, Jul. 2023, doi: 10.3390/nu15143167.
30. Y. Hou *et al.*, "Pathogenesis and comprehensive treatment strategies of sarcopenia in elderly patients with type 2 diabetes mellitus," 2023, *Frontiers Media SA*. doi: 10.3389/fendo.2023.1263650.
31. C. Y. Chiu *et al.*, "Advanced glycation end-products induce skeletal muscle atrophy and dysfunction in diabetic mice via a RAGE-mediated, AMPK-down-regulated, Akt pathway," *Journal of Pathology*, vol. 238, no. 3, pp. 470–482, Feb. 2016, doi: 10.1002/path.4674.
32. S. Moyama *et al.*, "Dietary Protein Intake Is a Determining Factor for Skeletal Muscle Mass in Japanese Older People with Type 2 Diabetes: A Cross-Sectional Study," *Nutrients*, vol. 17, 2025, doi: 10.3390/nu17040731.
33. C. S. Deane, J. Cox, and P. J. Atherton, "Critical variables regulating age-related anabolic responses to protein nutrition in skeletal muscle," 2024, doi: 10.3389/fnut.2024.1419229.
34. A. J. Cruz-Jentoft *et al.*, "Sarcopenia: Revised European consensus on definition and diagnosis," 2019, doi: 10.1093/ageing/afy169.
35. J. E. Park, S. Lee, and K. Kim, "The effect of combining nutrient intake and physical activity levels on central obesity, sarcopenia, and sarcopenic obesity: a population-based cross-sectional study in South Korea," *BMC Geriatr.*, vol. 23, 2023, doi: 10.1186/s12877-023-03748-x.
36. M. Kim and T. Kobori, "Association of a Combination of Sarcopenia and Type 2 Diabetes with Blood Parameters, Nutrient Intake, and Physical Activity: A Nationwide Population-Based Study," *Nutrients*, vol. 15, 2023, doi: 10.3390/nu15234955.
37. J. M. Lopez-Pedrosa *et al.*, "The Vicious Cycle of Type 2 Diabetes Mellitus and Skeletal Muscle Atrophy: Clinical, Biochemical, and Nutritional Bases," 2024, doi: 10.3390/nu16010172.