

Nutritional pathways from treatment to management of sarcopenia in patients with gastric cancer: a narrative review

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ABSTRACT

Sarcopenia, characterized by the progressive loss of skeletal muscle mass and strength, represents a significant clinical concern among patients undergoing gastric cancer surgery. Postoperative individuals are particularly vulnerable due to gastrointestinal dysfunction, reduced nutrient intake, systemic inflammation, and treatment-induced metabolic stress. This condition is associated with higher complication rates, delayed recovery, chemotherapy intolerance, and decreased survival, underscoring the importance of early detection and effective nutritional management. This narrative review integrates and synthesizes recent evidence from clinical and experimental studies that explore the pathophysiology, diagnosis, and nutritional management of sarcopenia in gastric cancer. The review emphasizes key nutritional risk factors, assessment tools, and intervention strategies applicable to both preoperative and postoperative care. Validated methods such as SARC-F (strength, assistance with walking, rise from a chair, climb stairs, and falls), dual-energy X-ray absorptiometry, and computed tomography imaging play central roles in identifying muscle loss and functional decline. Evidence suggests that protein-enriched diets, branched-chain amino acids, omega-3 fatty acids, and micronutrients such as vitamin D and antioxidants help preserve muscle mass and improve recovery outcomes. Exercise and rehabilitation further enhance these benefits by synergistically promoting muscle protein synthesis and function. Moreover, emerging technologies—including artificial intelligence–assisted nutritional monitoring, nutrigenomics, and biomarker-based personalization—represent promising directions for individualized care. Sarcopenia in gastric cancer is a modifiable and clinically significant condition. Integrating personalized nutrition with structured rehabilitation can markedly enhance functional recovery, treatment tolerance, and quality of life. Future research should aim to develop precision-based nutritional algorithms and standardized diagnostic frameworks to optimize outcomes in this high-risk population.

Keywords: Stomach Neoplasms; Nutrition Therapy; Nutritional Support; Malnutrition; Sarcopenia; Cachexia

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Introduction

Gastric cancer remains a major global public health challenge, ranking as the fifth most prevalent malignancy and the fourth leading cause of cancer-related mortality worldwide [1]. Although incidence rates have declined in certain regions, the overall global burden is projected to increase by 62% by 2040, primarily due to population aging and lifestyle-related factors [1]. Despite advancements in surgical techniques and perioperative care that have improved survival rates, many gastric cancer survivors continue to experience persistent complications, including nutritional imbalances and progressive muscle loss.

Sarcopenia, characterized by the gradual and generalized decline of skeletal muscle mass and strength, is among the most frequently overlooked yet clinically significant complications in patients undergoing gastric cancer surgery [2]. Although sarcopenia is commonly linked to aging, it is increasingly recognized in oncology settings due to systemic inflammation, reduced physical activity, and insufficient nutritional intake. In patients with gastric cancer, the risk of sarcopenia is further aggravated by anatomical and functional alterations following gastrectomy, which may result in malabsorption, early satiety, and chronic nutritional deficiencies [3].

The reported prevalence of sarcopenia in patients with gastric cancer varies considerably, with studies indicating rates between 17% and over 40%, depending on diagnostic criteria and patient characteristics [3,4]. In this context, sarcopenia is linked to increased postoperative complications, prolonged hospitalization, reduced chemotherapy tolerance, and decreased overall survival [5]. Furthermore, it adversely affects patients' quality of life by diminishing physical function and increasing dependency.

Despite its profound clinical implications, sarcopenia frequently remains unrecognized and untreated in routine practice. This underdiagnosis partly results from the absence of standardized screening protocols and the difficulty of evaluating muscle mass and function in clinical settings. Moreover, there is a lack of comprehensive guidelines specifically addressing the nutritional management of sarcopenia in postoperative gastric cancer patients.

Nutritional intervention is fundamental to both the prevention and management of sarcopenia. Adequate protein and energy intake, along with key nutrients such as branched-chain amino acids (BCAAs), omega-3 fatty acids, and vitamin D, have been shown to support muscle mass preservation and function [6]. Early nutritional support, including preoperative optimization and postoperative enteral or parenteral nutrition, may mitigate muscle loss and improve clinical outcomes. However, the application of these interventions remains inconsistent, emphasizing the need for a systematic and structured approach to nutritional care in this population.

Given the complexity of sarcopenia in patients with gastric cancer and the multifaceted nature of its management, a multidisciplinary approach is essential. Collaboration among surgeons,

oncologists, dietitians, physiotherapists, and other healthcare professionals is vital for developing and implementing individualized care plans that address both the nutritional and functional needs of patients.

This comprehensive narrative review aims to elucidate the nutritional pathway from treatment to the management of sarcopenia in postoperative gastric cancer patients. The objectives of this review are to: (1) examine the pathophysiological mechanisms underlying sarcopenia in the context of gastric cancer and gastrectomy; (2) discuss the assessment and diagnostic criteria for sarcopenia, emphasizing the importance of early detection; (3) review evidence-based nutritional interventions for postoperative gastric cancer patients; (4) highlight the role of exercise and rehabilitation in the management of sarcopenia; and (5) identify current gaps in practice and propose future directions for research and clinical implementation.

This review synthesizes existing research and clinical approaches to provide healthcare professionals with a comprehensive understanding of nutritional strategies for managing sarcopenia in postoperative gastric cancer patients, with the ultimate goal of enhancing recovery, patient well-being, and overall outcomes.

Methodology

This article is a narrative review that synthesizes and interprets current evidence concerning nutritional management, sarcopenia, and dietary diversity in gastric cancer. The primary aim is to provide a comprehensive overview of published research, emphasize consistent findings, and identify existing gaps in clinical and nutritional practice related to gastric cancer.

Search strategy and scope

Relevant literature was identified through a comprehensive search of biomedical and nutritional databases, including PubMed, Scopus, Web of Science, and the Cochrane Library. The search encompassed articles published between January 2010 and June 2025 and was limited to English-language studies conducted on adult human participants (≥ 18 years).

Search terms combined concepts related to both 'sarcopenia' and 'gastric cancer,' incorporating the following keywords: "sarcopenia," "muscle wasting," "skeletal muscle loss," "nutritional intervention," "protein supplementation," "oral nutritional supplements," "gastric cancer," "gastrectomy," "nutritional rehabilitation," and "dietary diversity." Reference lists of key publications and recent reviews were also examined to identify additional relevant studies.

Data extraction and analysis

As this is a narrative review, no quantitative synthesis or meta-analysis was performed. Instead, findings were synthesized qualitatively. Each eligible study was reviewed in full text, and data on study design, sample size, and principal outcomes were summarized descriptively. When appropriate, representative studies were tabulated to demonstrate the range and consistency of available evidence.

Approach to literature

This review adopts a narrative approach, synthesizing findings from recent peer-reviewed studies, clinical trials, and observational research on sarcopenia and nutritional management in gastric cancer. Emphasis was placed on studies with well-defined methodologies, clinically meaningful outcomes, and relevance to both perioperative and postoperative care.

Discussion

The findings were synthesized narratively because of methodological heterogeneity among the included studies.

Understanding the burden: pathophysiology of sarcopenia

Sarcopenia in gastric cancer results from a complex interaction of systemic inflammation, metabolic dysregulation, nutritional deficiencies, and treatment-related effects [7]. Persistent inflammation—primarily driven by tumor-derived cytokines such as interleukin-6, tumor necrosis factor- α , and interleukin-1 β —activates the ubiquitin–proteasome pathway, accelerating the breakdown of skeletal muscle proteins [8,9]. Concurrently, metabolic disturbances—particularly hypermetabolism and insulin resistance—disrupt anabolic signaling cascades, including the insulin-like growth factor 1 (IGF-1)/Akt/mTOR pathway, thereby suppressing muscle protein synthesis and promoting net muscle loss [10,11].

These inflammatory and metabolic mechanisms are further exacerbated by malnutrition, a hallmark of gastric cancer, as patients frequently experience anorexia, early satiety, nausea, and postoperative complications following gastrectomy. These manifestations cause significant reductions in dietary intake and nutrient absorption, resulting in critical deficiencies of protein, BCAAs, and micronutrients such as iron, vitamin B12, and fat-soluble vitamins [12–14]. Total or subtotal gastrectomy aggravates these deficits by impairing digestion and nutrient assimilation. Consequently, patients often develop dumping syndrome and persistent anorexia, leading to a chronic calorie-protein imbalance that accelerates skeletal muscle degradation [15].

Concurrently, a considerable proportion of patients with gastric cancer develop cancer cachexia—a multifactorial metabolic disorder characterized by involuntary weight loss, persistent systemic inflammation, and catabolic depletion of skeletal muscle tissue. This cachectic condition is driven by tumor–host metabolic interactions that shift metabolism toward catabolism, overriding normal anabolic stimuli. Within skeletal muscle cells, mitochondrial dysfunction results in excessive production of reactive oxygen species and impaired adenosine triphosphate synthesis, thereby contributing to fatigue, diminished muscle contractility, and reduced physical activity [16,17].

Moreover, gastrectomy disrupts gut-derived hormonal regulation, notably decreasing circulating levels of ghrelin and leptin, both of which are critical for appetite stimulation and muscle anabolism. Concurrent insulin resistance and reduced concentrations of IGF-1 further impair key anabolic signaling pathways, thereby hindering skeletal muscle regeneration and maintenance. When combined with underlying inflammation and nutritional compromise, these hormonal disturbances create a physiological state that markedly impairs muscle preservation. A visual overview of these interrelated mechanisms leading to muscle wasting is presented in Figure 1.

Finally, cancer treatments—particularly chemotherapy and surgical resection—impose additional physiological stress. Chemotherapy-induced gastrointestinal toxicity, mucositis, and nausea reduce food intake and exacerbate inflammation, whereas surgery contributes to nutrient malabsorption and catabolic burden [18,19]. Collectively, these interconnected mechanisms accelerate progressive muscle wasting, rendering sarcopenia in gastric cancer particularly aggressive and multifactorial. This highlights the critical need for early nutritional assessment and targeted

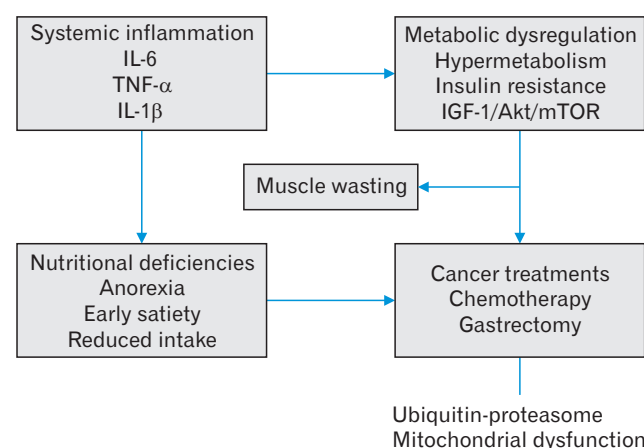


Figure 1. Pathophysiological mechanisms contributing to sarcopenia in postoperative patients with gastric cancer. The figure illustrates the interplay among systemic inflammation, metabolic dysregulation, nutritional deficiencies, and cancer treatments, which collectively lead to progressive skeletal muscle wasting. IL, interleukin; TNF, tumor necrosis factor; IGF, insulin-like growth factor; Akt, protein kinase B; mTOR, mechanistic target of rapamycin.

therapeutic interventions to mitigate muscle loss and improve clinical outcomes.

Sarcopenia's impact on recovery and prognosis

The clinical consequences of sarcopenia in patients with gastric cancer extend well beyond skeletal muscle loss, profoundly affecting postoperative outcomes, treatment tolerance, and overall prognosis. Multiple studies have identified sarcopenia as a strong, independent predictor of postoperative complications. Patients with reduced muscle mass are more prone to surgical site infections, delayed wound healing, and extended hospitalization, particularly after major procedures such as gastrectomy [20,21]. Sarcopenia also diminishes the body's capacity to tolerate chemotherapy. Reduced skeletal muscle mass alters drug pharmacokinetics, heightening the risk of dose-limiting toxicities that may result in treatment interruptions, dose reductions, or premature therapy discontinuation [22]. These consequences not only compromise oncologic control but also correlate with poorer survival outcomes. A meta-analysis by Kamran et al. [23] in 2021 demonstrated that sarcopenia was associated with a significantly higher hazard ratio for both overall and disease-specific mortality in gastrointestinal cancers. Similarly, Zhuang et al. [24] in 2016 identified preoperative sarcopenia as an independent predictor of poor long-term survival following curative gastric cancer resection, regardless of tumor stage or comorbidity burden.

Beyond clinical outcomes, sarcopenia exerts a profound impact on functional status and quality of life. Skeletal muscle depletion is associated with fatigue, loss of independence, mobility limitations, and depressive symptoms, collectively diminishing patients' ability to participate in rehabilitation and daily activities [25]. This initiates a downward cycle of deconditioning, social withdrawal, and frailty—particularly detrimental among older gastric cancer survivors. These multidimensional effects emphasize that sarcopenia is not merely a physical complication but a biopsychosocial syndrome with far-reaching implications across the cancer care continuum. Therefore, there is an urgent need to move beyond diagnosis toward targeted interventions that can slow or reverse its progression. This highlights the pivotal role of nutritional therapy, the cornerstone strategy for preserving muscle mass and improving outcomes in this high-risk population.

Diagnostic criteria for sarcopenia and early detection

Multimodal diagnostic techniques

Multiple techniques are employed to assess and screen for sarcopenia in patients with cancer, generally classified into imaging-based modalities, functional assessments, and biochemical markers. Imaging methods such as computed tomography (CT) and dual-energy X-ray absorptiometry (DXA) are regarded as the gold standards for estimating skeletal muscle mass. CT imaging at the level of the third lumbar vertebra (L3) is particularly valuable in oncology practice, as it is frequently available from routine stag-

ing scans and demonstrates a strong correlation with whole-body muscle mass [22,26].

Functional assessments—including handgrip strength, gait speed, and the short physical performance battery—offer valuable insight into muscle function and endurance. These methods are noninvasive, cost-effective, and sensitive to early muscle decline; however, they remain underutilized in oncology settings due to time constraints and workflow limitations.

Emerging studies have also explored the potential role of biochemical markers such as serum creatinine, C-reactive protein (CRP), myostatin, and prealbumin in detecting sarcopenia-related catabolism [27]. Nonetheless, these biomarkers currently lack adequate specificity and have yet to be incorporated into standard clinical protocols.

Summary of assessment tools in literature

As summarized in Table 1 [28-34], numerous studies have evaluated various modalities and criteria for diagnosing sarcopenia in patients with cancer, including those with gastric cancer. The literature reveals substantial methodological variability, underscoring the need for harmonized, evidence-based screening protocols.

Table 1 presents an overview of tools and techniques used to screen for and assess sarcopenia. Two studies [28,29] examined the use of the SARC-F (strength, assistance with walking, rise from a chair, climb stairs, and falls) questionnaire as a screening instrument for sarcopenia among patients with cancer. SARC-F is considered a practical tool for identifying individuals at risk of sarcopenia, particularly among older adults. Its advantages include cost-effectiveness, time efficiency, and high sensitivity [35]. SARC-F also shows a strong correlation with advanced diagnostic modalities used for detecting sarcopenia [28]. Other assessment methods include handgrip strength [30,36] and the grip-strength–lean-mass index (GSLMI) [29]. Both handgrip strength and GSLMI are simple, reliable, and cost-effective measures for evaluating sarcopenia [30,31,37]. They serve as robust predictors of overall muscle strength and physical function, both of which are critical components in the diagnosis of sarcopenia. Handgrip strength testing is noninvasive, rapid, and requires minimal equipment, making it practical for both clinical and community applications. Research indicates that low handgrip strength is associated with frailty, increased risk of falls, and adverse health outcomes in older adults [30,32]. As a central element of sarcopenia assessment guidelines, early identification of individuals at risk enables timely interventions—such as resistance exercise and nutritional support—to prevent further muscle loss. Advanced modalities that accurately assess sarcopenia include DXA and CT [33,34]. However, DXA is considered a suitable alternative to CT and magnetic resonance imaging for diagnosing radiologic sarcopenia because of its cost-effectiveness and lower radiation exposure [38]. Another technique increasingly used to detect both sarcopenia and cancer cachexia is bioelectrical impedance analysis (BIA). Guidelines from the European Working Group

Table 1. Screening and diagnostic tools for assessing sarcopenia in patients with cancer

No.	Screening or assessment tool	Study	Country	Study design	Sample size and population	Key findings and literature gap
1	SARC-F	Hess et al. [28] (2023)	USA	Prospective	Older adults (≥60 years) with cancer (n=220)	SARC-F showed limited diagnostic accuracy for low muscle mass but retained prognostic value for mortality prediction independent of CT-based measures
2	SARC-F	Ishida et al. [29] (2020)	Japan	Cross-sectional retrospective	Hospitalized older adults (≥65 years) (n=290)	A SARC-F score ≥4 effectively screened for sarcopenia; early use at admission supports timely prevention and management
3	HGS	Hadzibegovic et al. [30] (2023)	Germany	Prospective	Patients with advanced cancer (n=333)	Lower maximal HGS correlated with reduced function and higher all-cause mortality; HGS is a simple prognostic marker for functional decline
4	GSLMI	Huo et al. [31] (2025)	China	Multicenter cohort	Hospitalized adult cancer patients (n=8,831)	GSLMI showed strong diagnostic and prognostic utility for sarcopenia; it is a promising clinical index for oncology settings
5	HGS	Salama et al. [32] (2023)	Egypt	Randomized controlled trial	Adults (≥18 years) with HCV-related cirrhosis and cancer (n=64)	HGS via dynamometry is a reliable noninvasive measure for sarcopenia diagnosis and monitoring of muscle function over time
6	DXA and CT	Kim et al. [33] (2023)	Korea	Retrospective	77 men and 43 women aged ≥60 years post-gastrectomy (n=120)	Sarcopenia defined by AWGS criteria and DXA/CT indices predicted perioperative complications, particularly in men
7	CT	Lee et al. [34] (2018)	Korea	Retrospective	Patients with advanced gastric cancer receiving chemotherapy (n=140)	Baseline CT-assessed sarcopenia predicted poor prognosis and lower overall survival in advanced gastric cancer patients

SARC-F, strength, assistance with walking, rise from a chair, climb stairs, and falls; CT, computed tomography; HGS, hand grip strength; GSLMI, grip strength–lean mass index; HCV, hepatitis C virus; DXA, dual-energy X-ray absorptiometry.

on Sarcopenia in Older People (EWGSOP), the Asian Working Group for Sarcopenia (AWGS), and the International Consensus for Cancer Cachexia endorse BIA as a valid method for evaluating both sarcopenia and cachexia. By applying BIA-derived equations, several indicators of muscularity can be quantified. Among these, total skeletal muscle mass or appendicular skeletal muscle mass—adjusted for height and expressed as skeletal muscle mass index or appendicular skeletal muscle index, respectively—are the most widely accepted parameters in current consensus statements [20]. As summarized in Table 1, numerous studies have investigated different modalities and criteria for diagnosing sarcopenia in patients with cancer, including those with gastric cancer. While these investigations provide valuable insights, they also demonstrate substantial heterogeneity in diagnostic approaches, encompassing imaging modalities, functional performance measures, and biochemical indicators. This methodological inconsistency underscores the urgent need for standardized, evidence-based screening protocols that can be uniformly applied across oncology care settings.

However, recognizing sarcopenia is only the first step. Once diagnosed, its clinical implications in patients with gastric cancer

become immediately relevant. An expanding body of evidence identifies sarcopenia as a strong, independent predictor of adverse postoperative and oncologic outcomes, emphasizing the importance of not only identifying but also addressing it proactively. The following section examines how sarcopenia adversely affects recovery, treatment tolerance, survival, and overall patient well-being, thereby reinforcing the need for early, targeted interventions.

Need for timely recognition: assessment and diagnosis of sarcopenia

Given the multifactorial pathophysiology of sarcopenia in gastric cancer, early and accurate diagnosis is critical to preventing irreversible muscle wasting, functional decline, and unfavorable treatment outcomes. Identifying sarcopenia before it advances to severe stages allows for timely nutritional and rehabilitative interventions that can markedly improve prognosis.

To promote diagnostic consistency, several international expert groups have developed standardized consensus frameworks. The EWGSOP2 defines sarcopenia as the presence of low muscle strength as the primary criterion, supported by evidence of re-

duced muscle quantity or quality and diminished physical performance [2]. Similarly, the AWGS emphasizes population-specific cutoffs and screening algorithms tailored to Asian cohorts [39].

Nutritional interventions for sarcopenia in gastric cancer

Nutritional interventions play a pivotal role in managing sarcopenia by promoting muscle preservation, improving physical function, and enhancing overall health.

Protein and amino acid interventions

Nutritional strategies aimed at increasing protein and amino acid intake are essential for maintaining or improving skeletal

muscle mass.

As outlined in Table 2 [40-46], numerous studies have examined amino acid–based nutritional interventions in patients with gastric cancer [20,22,25]. BCAAs—valine, leucine, and isoleucine—are central to muscle metabolism and may also influence tumor biology. Emerging evidence indicates that adequate BCAA supplementation supports muscle protein synthesis and may mitigate cancer-associated muscle loss, although available data remain limited. Experimental research further suggests that disrupted BCAA metabolism may affect tumor progression and metastasis, but clinical validation in gastric cancer populations is still developing [40]. Among amino acids, arginine, leucine, and glutamine are most frequently administered in clinical practice to help preserve skeletal muscle mass and enhance postoperative

Table 2. Summary of studies evaluating protein and amino acid supplementation in patients with gastric cancer

No.	Study design	Study	Country	Sample size and population	Objective	Key finding
1	Experimental in vivo study	Aversa et al. [40] (2011)	Italy	Wistar rats, experimental (n=10) vs. control (n=10)	To evaluate the effect of HMB, a leucine metabolite, on muscle and body weight loss in cancer cachexia	HMB administration attenuated body weight and muscle loss. Phosphorylation of anabolic signaling molecules suggested improved protein anabolism in skeletal muscle
2	Prospective randomized crossover trial	Tayek et al. [41] (1986)	USA	Malnourished cancer patients (n=10) with intra-abdominal metastatic adenocarcinoma	To determine the effect of a BCAA-enriched solution on whole-body leucine kinetics and albumin synthesis	BCAA-enriched formulas improved leucine kinetics, albumin synthesis, and overall protein metabolism, suggesting enhanced nitrogen balance
3	Randomized, double-blind, parallel-group trial	Deutz et al. [42] (2011)	USA	Cancer patients with muscle wasting (n=25)	To assess the efficacy of a leucine-enriched, high-protein formulated medical food on muscle protein synthesis in cancer patients	The leucine-enriched medical food stimulated muscle protein synthesis effectively and improved anabolic response in cancer-associated muscle loss
4	Prospective, randomized, double-blind trial	Ma et al. [43] (2018)	Taiwan	Patients with gastric adenocarcinoma or GIST undergoing elective curative surgery (n=34)	To examine the impact of immune-modulating enteral nutrition (arginine, glutamine, omega-3 fatty acids) on postoperative immune function	The immune-modulating formula showed no significant immunomodulatory benefit compared to standard enteral nutrition in gastric cancer surgery patients
5	Retrospective cohort study	Kikuchi et al. [44] (2022)	Japan	40 Amino acid nutrition vs. 43 control postgastrectomy gastric cancer patients (n=83)	To evaluate the impact of amino acid nutrition on postoperative BWL and SML	Amino acid nutrition using peripheral parenteral nutrition and oral nutritional supplements effectively reduced postoperative BWL and SML during early recovery
6	Randomized controlled trial	Sun et al. [45] (2008)	Taiwan	Malnourished gastrointestinal cancer patients (n=64)	To investigate the benefits of BCAA-enriched TPN for malnourished surgical patients with gastrointestinal malignancies	BCAA-enriched TPN improved nutritional status, reduced postoperative complications, and promoted faster recovery in malnourished surgical cancer patients
7	Randomized controlled trial	Zhao et al. [46] (2013)	China	Malnourished gastric cancer patients (n=73)	To assess the long-term effects of arginine-supplemented enteral nutrition compared with standard enteral nutrition	Arginine-enriched enteral nutrition improved long-term survival and immune recovery in malnourished gastric cancer patients

HMB, β -hydroxy- β -methylbutyrate; BCAA, branched-chain amino acid; GIST, gastrointestinal stromal tumor; BWL, body weight loss; SML, skeletal muscle loss; TPN, total parenteral nutrition.

nutritional recovery, though findings across studies remain variable [20-25]. While several small randomized controlled trials, summarized in Table 2, demonstrate potential benefits of BCAA supplementation, large-scale, high-quality trials are required to establish definitive efficacy.

High-calorie diet intervention

A high-calorie dietary intervention for sarcopenia in patients with gastric cancer aims to provide adequate energy and protein to counteract muscle wasting and improve overall nutritional status. Patients with gastric cancer frequently experience weight loss and muscle depletion as a result of reduced oral intake, malabsorption, and elevated metabolic demands [47]. Insufficient caloric intake can lead to a negative energy balance, which has been linked to approximately a 20% reduction in muscle protein synthesis rates and increased catabolism of both skeletal muscle and adipose tissue [48,49]. To mitigate these effects, nutritional guidelines recommend an energy intake of 30 to 35 kcal/kg/d combined with 1.2 to 1.5 g of protein/kg/d. Priority should be given to high-quality protein sources such as lean meats, fish, dairy products, eggs, and plant-based proteins to support muscle preservation and recovery [50]. Incorporating healthy fats from sources such as olive oil, nuts, and avocados increases caloric density without excessive food volume—an advantage for patients experiencing early satiety. Additionally, offering small, frequent meals rich in nutrients, including fortified shakes and oral nutritional supplements, can further enhance overall energy intake [51].

Omega-3 intervention

Omega-3 fatty acid supplementation represents a promising approach for managing sarcopenia in patients with gastric cancer, as it may help counteract inflammation-induced muscle loss and promote muscle protein synthesis. Omega-3 fatty acids—particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA)—have been shown to reduce muscle catabolism and enhance anabolic signaling, suggesting an important role in preserving lean body mass [46]. Patients with gastric cancer frequently experience chronic inflammation and metabolic disturbances that contribute to sarcopenia, and omega-3 supplementation appears to attenuate these effects [47,52]. Several studies further indicate that omega-3 fatty acids improve insulin sensitivity, decrease systemic inflammation, and enhance mitochondrial function, thereby supporting muscle metabolism and physical performance [48,49]. When combined with adequate protein intake and regular physical activity, omega-3 supplementation may help maintain skeletal muscle and improve nutritional outcomes in gastric cancer. Consuming at least two servings of fatty fish per week—such as salmon, mackerel, herring, tuna, or their oils—can serve as an effective dietary source of omega-3 fatty acids.

Micronutrients

Micronutrient supplementation plays a vital role in managing

sarcopenia among patients with gastric cancer. Because gastric cancer and its treatments—such as gastrectomy and chemotherapy—can result in malabsorption, reduced dietary intake, and systemic inflammation, adequate micronutrient support is essential for maintaining muscle mass and function.

Vitamin D

Vitamin D is a secosteroid hormone critical for skeletal integrity and a range of biological processes [50,53]. Several studies indicate that serum vitamin D concentration may serve as an independent prognostic marker in patients with gastric cancer, as deficiency has been associated with poorer clinical outcomes [51]. Bone mineral density tends to decline markedly following gastrectomy, and vitamin D deficiency—together with secondary hyperparathyroidism—has been proposed as a major mechanism underlying this deterioration. Therefore, patients undergoing gastric resection should receive long-term nutritional and bone health monitoring as part of postoperative management [54]. Evidence from both interventional and mechanistic studies demonstrates that vitamin D supplementation can enhance muscle strength, possibly by stimulating protein synthesis through activation of the mammalian target of rapamycin complex 1 signaling pathway and promoting skeletal muscle hypertrophy. Moreover, the biologically active form of vitamin D, 1,25(OH)₂D, may further support skeletal muscle function by improving mitochondrial efficiency and cellular energy metabolism [55,56].

Calcium

Gastric acid plays a vital role in promoting the dissolution and ionization of calcium salts, many of which are otherwise poorly soluble. Conditions that reduce gastric acid secretion—such as gastrectomy, long-term proton pump inhibitor use, and chronic atrophic autoimmune gastritis—have been shown to impair calcium solubility, thereby decreasing intestinal absorption efficiency [57]. After gastrectomy, patients face an increased risk of osteoporosis and fractures, primarily due to calcium malabsorption, weight loss, and changes in body composition, including reductions in skeletal muscle mass [58].

In a study by Can et al. [59] in 2017, individuals with sarcopenia demonstrated significantly lower levels of several biochemical markers, including hemoglobin, albumin, total protein, calcium, triglycerides, uric acid, and adiponectin. These findings highlight that ensuring adequate calcium intake, tailored to individual physiological requirements, may constitute an important component of sarcopenia management in patients with gastric cancer.

Iron

Iron deficiency anemia is highly prevalent among patients with gastric cancer, particularly during chemotherapy. In a study by Tang et al. [60], 79% of patients developed iron deficiency anemia during adjuvant therapy. Although both iron deficiency and iron overload contribute to disease-related complications, the connec-

tion between iron homeostasis and skeletal muscle disorders remains insufficiently characterized. Emerging evidence indicates an inverse relationship between serum iron levels and muscle mass in adults, suggesting that disturbances in iron balance may adversely affect muscle health [61,62]. Given this association, continued investigation of iron status may be beneficial for preventing and managing muscle wasting in oncology populations.

The European Society for Medical Oncology Clinical Practice Guidelines provide a detailed framework for evaluating and managing anemia, including cases occurring in individuals with myelodysplastic syndromes. These guidelines recommend evidence-based strategies for addressing chemotherapy-induced anemia, including the use of erythropoiesis-stimulating agents, intravenous or oral iron supplementation, red blood cell transfusions, and appropriate combination therapies [63].

Vitamin E

Vitamin E is a lipid-soluble micronutrient recognized for its potent antioxidant capacity and its regulatory role in intracellular signaling pathways [64]. Acting as an efficient peroxyl radical scavenger, vitamin E prevents lipid peroxidation chain reactions within cell membranes and plasma lipoproteins. In addition to its antioxidant effects, vitamin E functions as a bioactive signaling molecule that modulates several cellular processes [65].

Vitamin E deficiency may develop as early as 6 months after gastrectomy in patients with gastric cancer, likely as a result of impaired intestinal absorption [66]. Several studies have reported an association between serum vitamin E concentration and sarcopenia, with lower levels correlating with reduced grip and knee extensor strength. These findings suggest a potential protective role of vitamin E in maintaining muscle function. Its antioxidative activity may protect muscle tissue from oxidative damage related to aging and cancer therapy. Moreover, a diet rich in vitamin E may contribute to the restoration of impaired muscle tissue and help sustain muscular performance [64-66].

Vitamin C

Vitamin C plays a pivotal role in cellular antioxidant defense, particularly by regenerating vitamin E within cell membranes and neutralizing vitamin E radicals, thereby making it the most prominent water-soluble antioxidant [67]. Vitamin C deficiency is frequently observed in individuals with advanced-stage cancer. Key determinants of plasma vitamin C concentration include dietary intake and the presence of systemic inflammation. Low plasma levels have been associated with decreased survival rates in this patient population [68].

A cross-sectional study conducted by Welch et al. [69] in 2020 in women aged 18 to 79 years demonstrated a positive correlation between vitamin C status and both skeletal muscle mass and muscle power in community-dwelling adults. These findings underscore the importance of vitamin C in the prevention and management of sarcopenia and frailty across the adult lifespan.

Similarly, a study conducted in Spain among older adults reported a significant inverse association between dietary vitamin C intake and the onset of frailty [70].

However, not all outcomes of antioxidant supplementation are beneficial. In a randomized controlled trial involving 34 elderly men who received either high-dose antioxidant supplementation (vitamins C and E) or placebo, those receiving antioxidants exhibited smaller gains in total lean body mass. This suggests that excessive supplementation may impair muscle hypertrophy by attenuating the oxidative signaling necessary for muscle adaptation [71]. This observation emphasizes the limitations and potential risks associated with non-specific nutritional supplementation.

Such evidence supports the emerging paradigm of precision nutrition—an approach in which dietary strategies are personalized according to an individual's clinical condition, metabolic characteristics, physical activity level, and genetic profile. Advancements in nutrigenomics, biomarker-guided personalization, and artificial intelligence (AI)-assisted decision algorithms are becoming increasingly vital for optimizing outcomes and minimizing unintended consequences in the nutritional management of sarcopenia.

Clinical gaps, limitations, and future directions

Despite the availability of validated diagnostic tools, sarcopenia remains substantially underdiagnosed in cancer care, particularly within surgical oncology settings. Routine preoperative assessments rarely incorporate evaluations of muscle quality or function, and nutritional screening is often delayed until significant weight loss becomes clinically apparent. In a study by Barreto et al. [72], fewer than 30% of gastric cancer patients undergoing curative surgery received preoperative sarcopenia screening, despite the high prevalence of the condition in this population.

Barriers contributing to underdiagnosis include: (1) lack of awareness among surgeons and oncologists; (2) absence of standardized institutional protocols; (3) restricted access to functional assessment tools; and (4) competing clinical priorities within acute care environments.

Consequently, many patients enter the postoperative period in a nutritionally depleted state, diminishing their capacity to tolerate chemotherapy, recover from surgery, and regain functional independence.

As the clinical burden of sarcopenia in gastric cancer becomes increasingly recognized, existing limitations in conventional nutritional care underscore the need for integrating personalized and precision-based strategies. Traditional one-size-fits-all interventions often fail to address interindividual differences in metabolism, genetics, and treatment response. In this context, emerging technologies such as AI-assisted nutritional modeling are gaining momentum. These systems can process complex datasets—integrating dietary intake, body composition parameters, laboratory data, and clinical outcomes—to produce individual-

ized nutrition plans that dynamically adjust to patient-specific needs [73]. For example, AI-based platforms have demonstrated the ability to predict calorie-protein adequacy and identify patients at elevated risk of postoperative muscle loss using preoperative CT imaging and serum biomarkers [74].

Another promising frontier is nutrigenomics, which explores the complex interactions between diet and gene expression. By identifying genetic polymorphisms in key genes involved in muscle protein synthesis (e.g., *FTO*, *PPARGC1A*), clinicians may soon be able to tailor nutritional strategies—such as optimizing protein dosage, leucine responsiveness, and antioxidant support—based on a patient's individual genetic profile [72]. Concurrently, advances in biomarker-based response prediction are facilitating the early identification of individuals who are less likely to respond to standard nutritional support. For example, elevated levels of CRP and myostatin have been proposed as predictors of anabolic resistance and poor nutritional responsiveness in patients with cancer-associated sarcopenia [75,76].

Moreover, digital health innovations are transforming the landscape of patient monitoring. Wearable technologies and mobile health applications now enable real-time assessment of muscle mass, physical activity, and dietary intake, thereby improving adherence and allowing for timely intervention. Devices such as bioimpedance-integrated patches and mobile-based dietary tracking systems, when synchronized with cloud-based clinical dashboards, provide seamless continuity of care—particularly valuable in outpatient and post-discharge settings [77].

Collectively, these advancements signify a paradigm shift from reactive to proactive nutritional management. They empower clinicians to identify high-risk patients before overt sarcopenia develops and to modify interventions dynamically. As precision oncology continues to advance, precision nutrition will become a central pillar in optimizing outcomes for patients with gastric cancer, bridging the gap between molecular biology, data science, and clinical nutrition.

Conclusion

Sarcopenia, defined by the progressive decline in skeletal muscle mass and function, is a prevalent and serious complication among patients with gastric cancer, exerting a substantial impact on treatment tolerance, surgical recovery, and overall prognosis. This condition develops through the combined effects of cancer-related metabolic alterations, chronic inflammation, and nutritional deficiencies arising from reduced intake and impaired absorption, particularly following gastrectomy. Effective nutritional intervention plays a central role in sarcopenia management. High-protein diets providing 1.2 to 1.5 g/kg/d of protein and essential amino acids especially leucine and BCAAs—are fundamental for stimulating muscle protein synthesis. Adequate energy intake (25–30 kcal/kg/d) and balanced macronutrient dis-

tribution are also critical to preventing further muscle depletion. Omega-3 fatty acids, particularly EPA and DHA, demonstrate potential in reducing inflammation and muscle degradation, while vitamin D, calcium, iron, and antioxidants such as vitamins C and E contribute to improved muscle strength and function. Oral nutritional supplements and enteral nutrition remain beneficial for malnourished patients or those with insufficient oral intake, ensuring optimal nutritional support during postoperative recovery. In addition to dietary measures, resistance training and regular physical activity synergize with nutritional therapy to preserve muscle mass, whereas emerging pharmacological approaches—such as anabolic agents and myostatin inhibitors—show promise in enhancing muscle anabolism. A multidisciplinary strategy that integrates nutritional care, exercise rehabilitation, and medical management is essential for optimal sarcopenia prevention and treatment. Given its profound influence on patient outcomes, future research should focus on developing personalized nutritional protocols and establishing standardized, evidence-based guidelines for the management of sarcopenia in gastric cancer.

Article Information

Conflict of interest

No potential conflict of interest relevant to this article was reported.

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Data availability

Data of this research are available from the corresponding author upon reasonable request.

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