



Influence of Nutrition on Muscle Strength and Physical Therapy Effectiveness in Patients after Surgery

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Abstract

Background: Surgical operations, though often essential, provoke a catabolic state with substantial muscle protein breakdown, inflammation, and metabolic stress. This can lead to substantial loss of muscle mass and strength, a condition referred to as sarcopenia, which has a direct negative impact on functional recovery and on the effectiveness of post-operative physical therapy. Although physical rehabilitation is an important principle of recovery, the critical role of nutrition in modulating the response to surgical stress and in providing the necessary substrates for repair is often overlooked in clinical practice.

Aim: The current review summarizes the available evidence on how selected nutritional interventions affect muscle strength preservation and improvement of physical therapy outcomes in adult post-surgery patients.

Methods: A narrative review of literature, using PubMed, Scopus, CINAHL, and Web of Science, was performed for the period between 2013 and 2024. Search terms included the following: "post-surgical nutrition," "sarcopenia," "muscle strength," "physical therapy," "orthopedic surgery," "protein," "essential amino acids," "omega-3," "vitamin D," and "immunonutrition." The review focused on clinical trials, meta-analyses, and systematic reviews.

Results: Evidence strongly suggests that targeted nutritional support, with adequate high-quality protein intake (1.2-2.0 g/kg/day), leucine-rich essential amino acids, omega-3 fatty acids, and vitamin D, attenuates muscle catabolism and enhances anabolic signaling, while reducing inflammation, creating a more favorable metabolic environment through which the physical therapy can act. Peri-operative immunonutrition may also favorably modulate the immune response. The timing of nutrition, particularly pre-surgical (prehabilitation) and early post-surgical intake, is as critical as the composition.

Conclusion: Nutrition is not merely supportive; it constitutes the very foundation of recovery following surgery. In addition, standard rehabilitation protocols should be combined with evidence-based, individualized nutritional strategies to prevent muscle wasting, enhance the effectiveness of physical therapy, and thus improve functional outcomes and quality of life in postsurgical patients.

Keywords: post-surgical nutrition, muscle strength, physical therapy, sarcopenia, anabolic resistance.

1. Introduction

The journey of patient recovery following major surgery is a complex physiological process. While the primary goal of the operation may be to repair, remove, or replace, the biological consequences of the procedure itself present a significant challenge to regaining premorbid function. Surgery, by its very nature, is a controlled trauma that initiates a systemic stress response, characterized by hormonal alterations, increased inflammation, and a

marked catabolic state (Morton et al., 2018). This metabolic environment encourages the breakdown of skeletal muscle protein to release amino acids for gluconeogenesis and acute-phase protein synthesis, leading to a rapid and often severe loss of muscle mass and strength (Puthuchery et al., 2013; Rondanelli et al., 2016). This phenomenon, especially when exaggerated in older adults or in conditions of pre-existing sarcopenia, represents a main determinant of poor post-operative outcomes, including prolonged

functional impairment, increased dependency, higher complication rates, and delayed return to normal activities (Morley et al., 2010).

In this scenario, PT is universally recognized as a crucial intervention to regain mobility, strength, and function. Yet, the effectiveness of PT is not a given; its success is totally dependent on the body's ability to respond to the anabolic stimulus of exercise. Trying to build muscle and strength in a chronically catabolic, inflamed, substrate-depleted environment is like trying to build a house without bricks and mortar. The basic elements need to be available for the construction effort to succeed. This is where medical nutrition therapy becomes of paramount importance, shifting from a passive supportive measure to an active therapeutic intervention (Paddon-Jones et al., 2009).

This narrative review aims to summarize the current evidence that has described the critical role of nutrition in influencing muscle strength and subsequent physical therapy effectiveness in post-surgical patients. It will discuss post-surgical catabolism, review the evidence for specific macro- and micronutrients, the concept of anabolic resistance and timing of interventions, and put forward a proposed framework for incorporating nutrition into standard rehabilitation protocols. By highlighting the interplay between nutrient intake and physical rehabilitation, this review aims to promote a more integrated and physiologically based approach to post-surgical care, where dietitians, physical therapists, and surgeons work together to optimize recovery from the molecular to the functional level.

The Pathophysiology of Post-Surgical Catabolism and Muscle Wasting

Understanding nutrition in this setting requires a basic appreciation of the metabolic storm following surgery. The physiological stress response is mediated through an increase in counter-regulatory hormones, including cortisol and catecholamines, and an influx of pro-inflammatory cytokines such as TNF- α , IL-1, and IL-6. Although part of the normal healing process, this cascade has particularly deleterious consequences for muscle homeostasis.

A profound imbalance between the rates of MPS and MPB is the main driver of muscle loss. Under fasted conditions, there is a fine balance between these two processes. The stress response following surgery dramatically shifts this balance towards catabolism: MPB is greatly enhanced while the capacity of the body to stimulate MPS in response to amino acid intake becomes blunted, so-called anabolic resistance. The inflammatory cytokines, especially TNF- α , have the ability to directly activate various proteolytic pathways, such as the ubiquitin-proteasome system, which labels muscle proteins for degradation. Concomitantly, insulin resistance, another hallmark of the post-surgical state, impairs normal anabolic signaling by insulin and amino acids, thereby further exacerbating the inability to stimulate MPS.

The loss of muscle mass is not just a cosmetic concern; it directly relates to the loss of muscle strength and functional capacity. Losses of only 5-10% of total muscle mass may seriously compromise strength and immune function, whereas losses that exceed 30% are associated with marked weakness, respiratory compromise, and even mortality. For the physical therapist, this means that the patient they are working with may be fundamentally incapable of generating the force required for exercises, no matter how well-designed the regimen. The patient's physiological state is working against the therapeutic goals. Therefore, the primary objective of nutritional support in this phase is to counteract this catabolic drive, attenuate the inflammatory response, and overcome anabolic resistance to create a metabolic environment conducive to repair and adaptation.

Protein and Amino Acids: The Basic Building Blocks for Recovery

Of all nutritional factors, protein intake is the most important determinant of muscle mass preservation and depletion after surgery. The RDA for protein intake, 0.8 g/kg/day, is inadequate to meet the increased needs of the surgical patient (Conn et al., 2016). Current evidence strongly supports increasing protein intake in a range from 1.2 to 2.0 g/kg/day to optimize recovery, with higher doses frequently necessary for older adults and those who have sustained severe trauma or infections or who have pre-existing malnutrition or sarcopenia.

However, the total amount of protein is only part of the equation. Equally important is the quality and composition of the protein. The anabolic value of a protein source is determined by its digestibility and content of essential amino acids, those that cannot be synthesized *de novo* by the body and must therefore be derived from the diet. Of the EAAs, the branched-chain amino acid leucine has a uniquely potent role. Leucine is not simply a substrate for MPS but also a key signaling molecule that activates the mechanistic target of rapamycin complex 1 (mTORC1) pathway, the major regulator of cell growth and protein synthesis. In the setting of anabolic resistance following surgery, a higher leucine threshold is likely required in order to sufficiently "switch on" the mTORC1 pathway.

Consequently, strategic protein supplementation often focuses on high-quality, fast-digesting proteins rich in leucine. Whey protein is particularly effective in that regard because of its high EAA and leucine content, fast absorption kinetics, and ability to strongly stimulate MPS (Tieland et al., 2012; Mertz et al., 2021). Supplementation with whey protein is associated with better preservation of lean body mass and muscle strength compared with standard care or other protein sources in post-orthopedic and critically ill patient populations. For instance, a 2014 RCT by Deutz et al. showed that the provision of a high-protein oral nutritional supplement containing whey to elderly patients after hip fracture

surgery resulted in significant reductions in lean mass loss and shorter rehabilitation stays (Malafarina et al., 2013).

Beyond whole proteins, supplementation with specific mixtures of EAA, often supplemented with additional leucine, has shown potential, particularly in settings where total protein intake may be limited by poor appetite or gastrointestinal intolerance. These preparations offer a direct, very concentrated anabolic stimulus without the need for digestion. Research by Moro et al. (2018) demonstrated that supplementation with EAAs in older adults undergoing total knee arthroplasty was associated with better functional recovery and quadriceps strength compared to an isocaloric control.

Another key consideration is the distribution of protein intake throughout the day. Consuming 25-40 grams of high-quality protein in 3-4 meals seems to be more effective at maximizing the MPS response compared to consuming a large meal skewed towards one meal. This pattern presents repeated anabolic stimuli throughout the day, serving to more persistently counteract the ongoing catabolic state. The physical therapist may want to coordinate therapy sessions following a protein-containing meal strategically to leverage the subsequent rise in MPS and enhance the muscle remodeling response to exercise.

The Role of Key Micronutrients: Vitamin D and Omega-3 Fatty Acids

While protein provides the structural bricks, several micronutrients act as essential foremen and facilitators in the processes of muscle function, repair, and inflammation control. Among them, two of the most critical ones in the post-surgical context are Vitamin D and Omega-3 PUFAs.

Vitamin D is increasingly recognized as a critical pleiotropic hormone with major relevance to musculoskeletal health. The classical medical role of Vitamin D is in the maintenance of calcium homeostasis and bone mineralization, which is essential for patients undergoing orthopedic surgery. However, its non-classical roles are similarly critical for recovery. Vitamin D receptors exist on skeletal muscle cells, and adequate Vitamin D status has been linked with enhanced muscle strength, especially in proximal muscles, and lowers the risk of falls. The mechanisms include enhancing the synthesis of muscle protein, regulation of calcium flux in muscle cells for optimum contraction, and impacting morphology in type II (fast-twitch) muscle fibers, most sensitive to atrophy secondary to aging and disuse (Smith et al., 2011; Stokes et al., 2018).

Post-surgical patients are at high risk of Vitamin D deficiency due to factors like advanced age, limited sun exposure, and the systemic inflammatory response. Deficiency has been linked to poorer functional outcomes, increased complications, and longer hospital stays. Systematic reviews and meta-

analyses have concluded that Vitamin D supplementation, especially in deficient individuals, can improve muscle strength and physical performance. A 2023 meta-analysis by Laird et al. confirmed that Vitamin D supplementation reduced the risk of falls and improved lower limb strength in older adults. For post-surgical populations, supplementation to ensure sufficiency (serum 25(OH)D > 30 ng/mL) is a low-cost, high-yield intervention that supports the goals of both bone and muscle recovery, directly benefiting physical therapy efforts.

Omega-3 Fatty Acids, particularly EPA and DHA in fish oil, are powerful anti-inflammatory and pro-resolving mediators. The surgical stress response is associated with a storm of pro-inflammatory eicosanoids derived from the omega-6 fatty acid arachidonic acid. Omega-3 PUFAs compete with this pathway, resulting in less inflammatory mediators being produced, such as prostaglandin E3, and specialized pro-resolving mediators such as resolvins and protectins that actively terminate inflammation (Jeromson et al., 2015).

Beyond modulating the systemic environment, omega-3s have direct anabolic properties for skeletal muscle. They are incorporated into the phospholipid bilayer of cell membranes, increasing membrane fluidity and enhancing the sensitivity of the mTORC1 pathway to anabolic stimuli like insulin and amino acids. What this means is that, in the presence of adequate omega-3s, the muscle cell becomes more responsive to both protein ingestion and the mechanical load of exercise. RCTs have demonstrated that either pre-operative or post-operative omega-3 supplementation can attenuate the loss of lean body mass subsequent to major abdominal surgery or cancer resection (Werner et al., 2017). A seminal study by Weyland et al. (2013) showed that the pre-operative administration of EPA and DHA to patients undergoing esophageal cancer surgery resulted in better preservation of lean body mass and improved functional status. By reducing inflammation and potentiating anabolic signaling, omega-3 supplementation creates a more favorable metabolic milieu, allowing physical therapy to produce a more robust strengthening effect.

Immunonutrition in the Peri-Operative Period

Immunonutrition is a specialized frontier within the area of surgical nutrition, represented by the administration of specific nutrients in pharmacologic doses to actively modulate the immune and inflammatory response to surgical trauma. Unlike standard nutritional support, the main purpose of immunonutrition is not simply providing nourishment but influencing the body's defense mechanisms directly. Such special formulas are usually enriched with key agents in various combinations, including arginine, glutamine, omega-3 fatty acids, and nucleotides. Arginine provides a substrate for nitric

oxide and thus is crucial in the function of immune cells and facilitates the wound-healing process. Glutamine is, therefore, considered a conditionally essential amino acid during severe metabolic stress and serves as the principal fuel for both the immune cells and cells populating the gut; this helps to maintain the intestinal barrier integrity, preventing bacterial translocation and associated systemic infections (Marik & Flemmer, 2012).

The clinical impact of perioperative immunonutrition has been extensively evaluated. There is a strong consensus, reinforced by multiple meta-analyses, that the administration of these formulas for approximately 5-7 days before and/or after major procedures, such as gastrointestinal, oncologic, or cardiac surgery, considerably diminishes the risk of post-operative infectious complications and shortens the overall hospital stay. Although the primary measured outcomes of these studies are infection rates, the benefits to muscle strength and the effectiveness of physical therapy are profound, though indirect. By preventing complications such as pneumonia or surgical site infections, immunonutrition prevents a secondary and potent inflammatory insult that would otherwise accelerate muscle catabolism and significantly delay mobilization. A patient without such complications is physiologically capable of engaging more fully and more early with physical therapy, thus avoiding the debilitating cycle of immobilization with progressive loss of muscle. Consequently, immunonutrition should be regarded as a strategic intervention in high-risk surgical patients, one designed to create a smoother and less complicated trajectory of recovery that then provides a stable foundation for effective rehabilitation (Wolfe, 2006).

The Critical Timing of Nutrition: Prehabilitation and the Anabolic Window

The timing of nutritional support significantly affects its efficacy, transforming the clinical paradigm from a reactive model to a proactive strategy that encompasses both the pre- and immediate post-operative phases. This proactive approach is epitomized by the concept of prehabilitation—the process of enhancing a patient's functional and metabolic reserves in anticipation of the planned surgical stress. While prehabilitation often emphasizes physical exercise, nutritional optimization is a cornerstone of this process. The objectives of nutritional prehabilitation are twofold: first, to screen for and correct pre-existing deficiencies in nutrients like protein, Vitamin D, and others contributing to sarcopenia and malnutrition; second, to initiate "anabolic priming" by increasing protein intake and potentially supplementing with anti-inflammatory nutrients like omega-3s in the weeks preceding surgery (Bauer et al., 2013; Kressel & Matsakas, 2023). This strategy aims at building lean mass and modulating the baseline inflammatory state, thereby

helping the patient to better withstand the ensuing catabolic storm.

Evidence increasingly supports the value of this integrated approach. Studies demonstrate that multimodal prehabilitation, which combines structured exercise with targeted nutrition, leads to superior postoperative functional outcomes compared to usual care (Bislev et al., 2020). For example, a 2019 randomized controlled trial by van Rooijen and colleagues showed that patients undergoing colorectal cancer surgery who received prehabilitation with whey protein and exercise saw a significantly better recovery of functional walking capacity weeks after their operation. After surgery, attention shifts to the immediate postoperative "anabolic window." During this time, the body is in a state of heightened catabolism and anabolic resistance, making early nutritional intake a critical countermeasure (Kortebein et al., 2008). The outdated practice of withholding feeding is now recognized to be harmful. Starting enteral or oral nutrition within 24 hours after surgery serves to maintain gut integrity, dampen the systemic stress response, and provide essential substrates for tissue repair. To the physical therapist, a patient who has benefited from early nutritional support is metabolically primed to participate in and derive maximum benefit from early mobilization, a salient intervention that predicts a smoother recovery and fewer complications.

Synergy with Physical Therapy: Creating the Anabolic Environment

Physical therapy and nutrition are not parallel interventions, but rather deeply synergistic. The mechanical load and muscle contractions from PT supply the necessary anabolic stimulus that sensitizes muscle tissue to the nutrients provided. In return, proper nutrition provides the substrates along with the appropriate signaling molecules necessary to realize an adaptive response from exercise (Maurel et al., 2017).

Resistance training itself, a core component of post-surgical PT, independently activates mTORC1 signaling. When combined with protein ingestion, the effects are additive or even synergistic, resulting in a greater MPS response than either stimulus alone. This is the physiological rationale for consuming protein in close temporal proximity to a bout of PT. A practical approach is to schedule a protein-rich meal or supplement, containing ~20-40g of protein, within 1-2 hours following a therapy session. This practice capitalizes on the "muscle-full" effect, wherein exercise primes the muscle to take up amino acids and utilize them for repair and growth (Børsheim et al., 2008; Moore et al., 2015).

Moreover, the anti-inflammatory effects of omega-3s and the metabolic role of Vitamin D have the potential to make a patient better able to participate in PT. Reduced systemic inflammation can decrease pain and fatigue, while improved muscle strength from Vitamin D sufficiency can increase exercise capacity

and tolerance. A positive feedback loop ensues as better nutrition leads to more effective PT, which can stimulate greater muscle adaptation, leading to improved function and strength, further allowing more challenging and beneficial PT sessions (Soeters et al., 2021).

Synthesized Recommendations and a Clinical Framework

Table 1: Evidence-Based Nutritional Recommendations for post-surgical muscle strength and the effectiveness of PT

Nutrient / Strategy	Recommendation	Mechanism of Action	Practical Considerations
Total Protein	1.2 - 2.0 g/kg/day	Provides substrate for MPS, counters catabolism.	Higher end for the elderly, critically ill, and malnourished.
Protein Type	High-quality, leucine-rich (Whey, Casein, Soy)	Maximizes MPS stimulus, overcomes anabolic resistance.	Whey protein is ideal for post-exercise due to rapid absorption.
Protein Timing/Distribution	25-40 g/meal, 3-4 meals/day; consume after PT	Creates repeated anabolic pulses, synergizes with exercise.	Coordinate supplement timing with the PT schedule.
Essential Amino Acids (EAAs)	10-15 g doses, particularly with added Leucine	Direct anabolic signaling, useful if intake is poor.	Considered as a medical food supplement under a dietitian's guidance.
Omega-3 Fatty Acids	1-2 g/day of combined EPA/DHA	Anti-inflammatory, enhances anabolic sensitivity.	Use pharmaceutical-grade fish oil; start pre-op if possible.
Vitamin D	Achieve serum level >30 ng/mL; supplement 800-2000 IU/day	Regulates MPS, improves muscle function and strength.	Mandatory to check status pre-op; supplement accordingly.
Immunonutrition	5-7 days pre-op and/or post-op for high-risk patients	Modulates immune response, reduces complications.	Standard for major GI, cancer, cardiac surgery.
Prehabilitation	Multimodal (Exercise + Nutrition) for 2-6 weeks pre-op	Builds functional and metabolic reserve.	Ideal for elective surgeries; screen for sarcopenia.

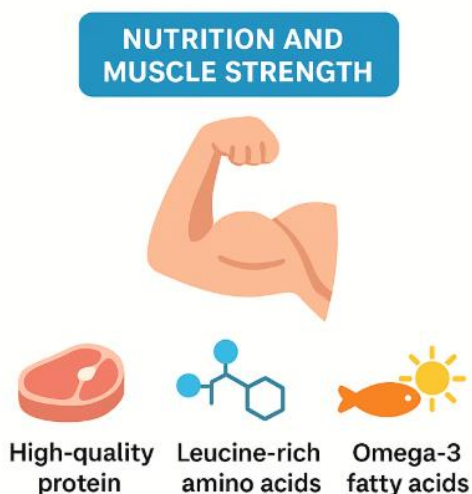


Figure 1. Key Nutritional Factors Influencing Muscle Strength After Surgery

For translating these evidence-based principles into clinical practice, a structured multidisciplinary approach is needed. Key nutritional recommendations to support muscle strength and physical therapy in post-surgical patients are synthesized in the following table (Table 1 & Figure 1).

Operationalizing these recommendations requires a clinical framework. This starts with a systematic screening for nutritional risk and sarcopenia at the time of hospital admission or even as early as the preoperative clinic (Van Wissen et al., 2016). Tools such as the Malnutrition Universal Screening Tool (MUST) or the Short Nutritional Assessment Questionnaire (SNAQ) can identify at-risk patients in a matter of minutes. For sarcopenia, handgrip strength, calf circumference, or even the SARC-F questionnaire are practical assessments (Yoshimura et al., 2018).

After screening, a nutrition prescription should be formulated, preferably by a registered dietitian, and included in the patient's total care plan. The prescription should outline the objectives for energy, protein, and essential micronutrients. Lastly, interprofessional collaboration is not optional. Surgeons, hospitalists, nurses, physical therapists, and dietitians need to communicate and work in concert to ensure that nutritional intake is emphasized, tracked, and aligned with the rehabilitation timeline (Chen et

al., 2022). Table 2 & Figure 2 are one possible example of how this coordination can be achieved.

Table 2: Nutrition Integration into Post-Surgical Rehabilitation Framework

Phase of Care	Key Nutritional Actions	Role of Physical Therapy	Interprofessional Coordination
Pre-Operative (Prehab)	- Screen for malnutrition/sarcopenia. - Correct micronutrient deficits. - Implement high-protein diet $\pm$ immunonutrition.	- Conduct baseline functional assessment. - Implement a strengthening exercise program.	- Surgeon refers to the prehab program. - Dietitian and PT co-manage prehab plan.
Immediate Post-Op (0-72 hrs)	- Initiate early oral/enteral feeding. - Provide protein-rich supplements. - Continue immunonutrition if indicated.	- Initiate early mobilization (e.g., sit on the edge of the bed, stand, transfer). - Breathing exercises.	- Nurses ensure nutritional intake is not delayed. - PT informs the team of the patient's tolerance and energy levels.
In-Patient Rehabilitation	- Achieve full protein & energy targets. - Provide oral nutritional supplements between meals. - Ensure Vitamin D & Omega-3 supplementation.	- Progress mobility and resistance exercises. - Focus on functional tasks.	- Schedule PT sessions after meals/supplements. - Daily huddles to discuss patient progress and intake.
Post-Discharge / Outpatient	- Continue high-protein diet and supplementation. - Monitor weight and intake.	- Progress home/exercise program. - Focus on returning to normal activities.	- Outpatient PT reinforces nutritional messaging. - Follow up with the dietitian as needed.



Figure 2. The Role of Nutrition in Enhancing Physical Therapy Effectiveness Post-Surgery Conclusion and Future Directions

The evidence is unequivocal: nutrition is a powerful, non-negotiable determinant of recovery after surgery. It directly influences the foundational element of functional recovery-skeletal muscle strength, modulating the catabolic response to trauma, providing the substrates for repair, and creating a metabolic environment where physical therapy can exert its maximal effect. In this respect, the synergistic relationship between nutrient intake and mechanical load means that neither intervention is fully effective

in isolation. Excellent physical therapy provided to a malnourished, catabolic patient represents an exercise in futility, just as high-quality nutrition provided to a completely immobile patient will not fully prevent muscle atrophy.

This review has emphasized the pivotal roles of adequate high-quality protein, leucine, omega-3 fatty acids, and vitamin D, underscoring the importance of timing, from prehabilitation to the immediate postoperative period. Integration of these evidence-based nutritional strategies into standard surgical and rehabilitative care pathways is no longer an optional "add-on" but a basic standard of care necessary to optimize patient outcomes. Future studies need to focus on the refinement of these recommendations for specific surgical populations, defining optimal dosing and timing protocols, and the study of the effects of other nutrients such as creatine and HMB (β -hydroxy β -methylbutyrate). In addition, implementation science must be engaged to overcome systems barriers to incorporating nutrition care into the busy clinical workflow. Ultimately, true adoption of a multidisciplinary model in which nutritional status is considered a vital sign and nutritional therapy is prescribed with the same intentionality as physical therapy will be where better, faster, and resilient recoveries are realized for our post-surgical patients.

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