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ORIGINAL ARTICLE

Nutritional Deficiencies as Modifiable Risk Factors for Postoperative Complications Following Abdominal Surgery

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ABSTRAKT

Postoperative complications after abdominal surgery are a major source of perioperative morbidity and mortality. Preoperative nutritional deficiencies, particularly hypoalbuminemia, vitamin D insufficiency, and iron deficiency anemia, are prevalent, underrecognized, modifiable risk factors impairing wound healing and immune defense, yet routine nutritional assessment remains inconsistent.
This narrative review synthesizes evidence on the independent and cumulative impact of preoperative hypoalbuminemia, vitamin D insufficiency, and anemia on postoperative complications after abdominal surgery, and outlines strategies for nutritional optimization.
A literature search was conducted in June 2026 using PubMed/MEDLINE, PubMed Central, and the Cochrane Library for English-language studies from January 2010 to June 2026, including randomized trials, cohort studies, systematic reviews, and meta-analyses reporting surgical outcomes in adults undergoing abdominal procedures.
Hypoalbuminemia was the most robustly supported risk factor, with pooled data showing an odds ratio of 2.37 for surgical site infection. Vitamin D insufficiency was independently associated with increased infectious complications, and preoperative anemia contributed to tissue hypoxia, impaired collagen synthesis, and immune dysfunction. Co-occurring deficiencies were associated with cumulative impairment of immune and reparative function.
Hypoalbuminemia, vitamin D insufficiency, and anemia are prevalent, mechanistically distinct, clinically significant modifiable risk factors for postoperative complications after abdominal surgery. Routine screening with validated tools and targeted laboratory evaluation is strongly supported by current evidence.

KEYWORDS

hypoalbuminemia, vitamin D deficiency, preoperative anemia, abdominal surgery, surgical site infection

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1. Introduction

Postoperative complications following abdominal surgery remain a significant clinical and public health burden worldwide. Surgical site infections represent one of the most frequent postoperative adverse events, and abdominal procedures are associated with substantial morbidity, prolonged hospitalization, reoperation risk, and increased healthcare costs [1-3]. Despite continuous improvements in surgical technique, anesthesia, and perioperative care, a considerable proportion of postoperative complications is still linked to modifiable patient-related risk factors [3,4].

Nutritional status is increasingly recognized as a clinically relevant yet underdiagnosed determinant of postoperative outcome. Malnutrition affects a substantial proportion of patients scheduled for abdominal surgery, depending on the population studied and the screening method used [5-8]. Inadequate nutritional status is associated with impaired wound healing, diminished immune response, longer hospital stay, and increased postoperative morbidity and mortality [5-9]. These observations have led to growing interest in integrating nutritional assessment into perioperative optimization pathways.

Among specific nutritional abnormalities, hypoalbuminemia, vitamin D insufficiency, and preoperative anemia appear particularly important in abdominal surgical practice. Hypoalbuminemia is a well-established predictor of surgical site infection, septic complications, and poor overall recovery following gastrointestinal procedures [1,10,11]. Vitamin D deficiency has been implicated in impaired innate immunity, delayed epithelial repair, and increased susceptibility to perioperative infection [12-15]. Preoperative anemia, frequently multifactorial in origin, contributes to tissue hypoxia, reduced collagen synthesis, poorer functional recovery, and increased transfusion requirements [16-19].

Although these deficiencies are often evaluated separately, they frequently coexist in surgical patients as a result of chronic inflammation, malignancy, malabsorption, inadequate intake, and systemic disease burden [7,8,17]. Their cumulative effect may amplify surgical risk and hinder postoperative recovery more profoundly than any single abnormality alone [7,18]. At the same time, all three deficiencies are potentially modifiable before elective surgery, which makes them attractive targets for preoperative intervention [4,9,19].

The impact of nutritional deficiencies on surgical outcomes has gained increasing attention in the context of Enhanced Recovery After Surgery (ERAS) protocols, which have systematically identified preoperative patient optimization as a key determinant of postoperative recovery [4,9]. While ERAS guidelines have standardized many aspects of perioperative care, the implementation of nutritional screening and correction remains heterogeneous across surgical centers. Surveys of clinical practice suggest that formal nutritional assessment is conducted routinely in fewer than half of elective surgical admissions, despite clear evidence that malnutrition is associated with a two- to threefold increase in postoperative complication rates [7,8].

Surgical site infection rates after major abdominal procedures range from approximately 5% to 30%, depending on the procedure type, contamination class, and patient comorbidity profile [1,3]. Beyond SSI, nutritional deficiencies have been implicated in anastomotic insufficiency, prolonged ileus, impaired fascial healing, respiratory complications, and extended intensive care requirements. The economic consequences are substantial: malnourished surgical patients incur significantly higher inpatient costs and are more likely to require readmission, reoperation, and long-term rehabilitation [5,7].

Against this background, there is growing recognition that the preoperative period represents a critical and underutilized window for nutritional intervention. Unlike fixed risk factors such as age, comorbidity burden, or malignant diagnosis, nutritional deficiencies are potentially reversible within a clinically meaningful time frame. This principle of modifiability justifies the investment of clinical resources in systematic screening and targeted treatment [4,9].

Research Objective. The objective of this narrative review is to synthesize current evidence on the impact of hypoalbuminemia/protein malnutrition, vitamin D insufficiency, and preoperative anemia on postoperative complications following abdominal surgery and to outline clinically relevant strategies for preoperative nutritional optimization.

Research Problems.

- What is the association between preoperative hypoalbuminemia and postoperative complications after abdominal surgery?
- Does vitamin D insufficiency increase the risk of infectious and wound-related complications in surgical patients?
- To what extent does preoperative anemia affect postoperative morbidity, transfusion requirements, and recovery?
- Can targeted preoperative correction of these de-

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ficiencies reduce complication rates?

Research Hypotheses.

- Preoperative hypoalbuminemia, vitamin D insufficiency, and anemia each independently increase the risk of postoperative complications following abdominal surgery.
- Coexistence of multiple nutritional deficiencies is associated with a cumulative adverse effect on surgical outcomes.
- Early recognition and correction of nutritional deficiencies may reduce preventable postoperative morbidity.

2. Research materials and methods

2.1. Participants.

This narrative review considered studies involving adult patients aged 18 years or older undergoing elective or urgent abdominal surgery, including colorectal surgery, small bowel surgery, pancreatic surgery, hepatobiliary procedures, appendectomy, cholecystectomy, and

2.2. Procedure

A comprehensive search of PubMed/MEDLINE, PubMed Central, and the Cochrane Library was conducted in June 2026. Search terms combined concepts related to abdominal surgery and nutritional deficiencies, including vitamin D deficiency, 25-hydroxyvitamin D, hypoalbuminemia, serum albumin, preoperative anemia, iron deficiency anemia, malnutrition, nutritional risk, and postoperative complications. Additional searches were performed for perioperative nutritional treatment and nutritional screening tools.

Inclusion criteria were original research articles, systematic reviews, meta-analyses, and randomized controlled trials; English-language publications; publication dates from January 2010 to June 2026; and studies reporting postoperative outcomes such as surgical site infection, anastomotic leak, wound complications, mortality, length of stay, or transfusion requirement. Exclusion criteria included case reports, conference abstracts, editorials, narrative commentaries without primary data, and studies lacking extractable outcome data.

2.3. Data collection and analysis / Statistical analysis.

2.3.1. Statistical Software.

Because this manuscript is a narrative review, no original statistical software was used for primary data analysis. Quantitative findings were extracted directly from eligible studies, including odds ratios, relative risks, confidence intervals, and p values where available.

2.3.2. Statistical Methods.

Results from included studies were synthesized qualitatively and grouped by type of nutritional deficiency. Greater interpretative weight was assigned to systematic reviews, meta-analyses, randomized controlled trials, and prospective cohort studies. Observational retrospective studies were used to complement the evidence base where higher-level evidence was limited.

3. Research results

3.1. Hypoalbuminemia and protein malnutrition as risk factors for postoperative complications

Serum albumin remains one of the most widely used biochemical indicators of nutritional and inflammatory status in the preoperative setting. Hypoalbuminemia has consistently been associated with a higher risk of postoperative complications across gastrointestinal and abdominal procedures [1,10,11]. A recent systematic review and meta-analysis demonstrated that preoperative hypoalbuminemia significantly increases the risk of surgical site infection after abdominal surgery, with a pooled odds ratio of 2.37 [10]. Earlier multicenter cohort data similarly showed markedly increased rates of superficial and deep surgical site infection in patients with low albumin levels before gastrointestinal surgery [1].

The clinical impact of hypoalbuminemia extends beyond wound infection. Low albumin levels have also been associated with intra-abdominal septic complications, impaired anastomotic healing, and

more severe postoperative morbidity in bowel surgery and pancreatic procedures [11]. Recent literature emphasizes that malnourished perioperative patients, particularly older adults, are at elevated risk of wound complications and slower postoperative recovery, with hypoalbuminemia being one of the most relevant nutritional warning signs in surgical practice [4,20,21].

Hypoalbuminemia is also an independent predictor of anastomotic leakage following digestive tract surgery. A 2025 systematic review and meta-analysis of 33 studies including over 31,000 patients demonstrated that lower preoperative albumin levels were associated with a 2.67-fold greater risk of anastomotic leakage, with an optimal risk stratification threshold identified at 3.75 g/dL [26]. This finding has particularly important clinical implications for colorectal and upper gastrointestinal surgeons, given that anastomotic leak is one of the most feared postoperative complications, carrying a mortality risk of 10-30% and frequently necessitating reoperation, stoma formation, and prolonged intensive care admission [26,27]. In patients undergoing rectal cancer resection, a group at especially high anastomotic risk due to pelvic anatomy and the effects of neoadjuvant radiotherapy on tissue perfusion, hypoalbuminemia may compound an already elevated baseline leak risk.

Recent literature has further demonstrated that serial perioperative albumin monitoring can serve as an early warning indicator of anastomotic complications. In a prospective series of 200 colorectal cancer patients, postoperative serum albumin levels on days 1 and 3 after surgery were significantly lower in patients who subsequently developed anastomotic leakage than in those who did not, with a multivariate OR of 7.53 for low perioperative albumin as a predictor of leak [27]. This suggests that albumin monitoring should not be limited to the preoperative assessment but should extend into the early postoperative period as a surveillance tool, enabling timely clinical escalation in patients with unexplained hypoalbuminemia after bowel surgery.

3.1.1. Mechanisms linking hypoalbuminemia to impaired healing and infection

The mechanistic relationship between hypoalbuminemia and postoperative morbidity is multifactorial. Albumin reflects not only protein reserve but also the intensity of systemic inflammation, capillary leakage, and metabolic stress [6,11,23]. From the standpoint of wound biology, protein depletion impairs fibroblast proliferation, decreases collagen deposition, delays granulation tissue formation, and weakens the tensile strength of healing tissue [6,11]. Hypoalbuminemia reduces oncotic pressure, promoting interstitial edema at the wound edge and anastomotic site, which compromises microcirculatory perfusion and increases susceptibility to bacterial translocation [6,11,23]. Additionally, protein deficiency has been associated with reduced lymphocyte proliferation, diminished complement activity, and impaired phagocytic function, collectively reducing the host's ability to mount an effective perioperative immune response [6,11].

In addition to protein status, vitamin D levels represent another common and clinically relevant deficiency in abdominal surgical candidates. The prevalence of vitamin D insufficiency in patients scheduled for abdominal surgery reflects broader epidemiological patterns in hospitalized populations. Chronic gastrointestinal disease, malabsorption syndromes, reduced outdoor activity, obesity, and dark skin pigmentation independently reduce circulating 25(OH) D concentrations, all of which are common in surgical candidates [12,14]. In Central and Eastern Europe, including Poland, population studies report that up to 60-90% of individuals have suboptimal 25(OH)D levels during winter and spring months, a finding with direct relevance to the timing of preoperative assessment and supplementation in patients listed for elective procedures [14].

3.2. Vitamin D insufficiency and perioperative infectious complications

Vitamin D has important immunomodulatory functions that extend beyond bone metabolism. Its active metabolites regulate innate immune signaling, antimicrobial peptide synthesis, macrophage activity, and epithelial repair, all of which are relevant to surgical wound healing [12,13,15]. Vitamin D insufficiency is highly prevalent in Europe, with up to 40.4% of the general population having serum 25(OH)D below 50 mmol/L [14]. Clinical studies suggest that low preoperative 25-hydroxyvitamin D concentration is associated with a higher risk of postoperative infectious complications [12,15]. Recent literature has highlighted vitamin D as a modifiable factor affecting tissue healing and regenerative capacity [22].

Clinical evidence from a systematic review and meta-analysis published in 2026 demonstrated a statistically significant association between preoperative

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vitamin D deficiency and increased risk of surgical site infection across diverse surgical populations, with an odds ratio of 1.39 (95% CI: 1.04-1.86; p = 0.02) for patients with 25(OH)D below 30 mg/mL [13]. A separate prospective perioperative cohort found that vitamin D insufficiency was associated with higher rates of wound complications and prolonged hospitalization, particularly in patients undergoing abdominally based reconstruction and gastrointestinal procedures [12,15]. Although not all observational studies have reached statistical significance, likely reflecting heterogeneity in deficiency thresholds, patient populations, and outcome definitions, the direction of effect is consistent across the literature.

3.2.1. Mechanisms linking vitamin D deficiency to postoperative infection risk

Vitamin D receptor signaling regulates transcription of antimicrobial peptides, especially cathelicidin LL-37 and beta-defensins, which are part of the first-line epithelial defense against microbial invasion [12,15,24]. Deficiency weakens the early antimicrobial barrier of skin, fascia, and mucosal tissue exposed during abdominal procedures. Vitamin D also influences macrophage differentiation, neutrophil activity, and the balance between proinflammatory and anti-inflammatory cytokine signaling [12,15]. Experimental and translational evidence suggests that vitamin D supports keratinocyte migration, endothelial function, and local tissue remodeling, whereas deficiency may delay wound closure and prolong the inflammatory phase [12,22,24].

Beyond the mechanistic and immunological aspects, impaired vitamin D signaling may also compromise the physical properties of the surgical wound itself. Vitamin D receptor activation promotes the differentiation of keratinocytes and the deposition of extracellular matrix proteins essential for wound tensile strength. In laboratory models of cutaneous repair, vitamin D-deficient conditions have been associated with slower wound contraction, reduced keratinocyte migration velocity, and impaired re-epithelialization rates [24]. These findings complement the immunological evidence and suggest that vitamin D deficiency acts at multiple stages of the wound healing continuum, from early antimicrobial defense through inflammatory resolution to the proliferative and remodeling phases, making its preoperative correction potentially relevant across a wide range of abdominal procedures.

3.3. Preoperative anemia and surgical outcomes

Preoperative anemia is a common finding among patients awaiting major abdominal procedures and is particularly frequent in colorectal disease, inflammatory bowel disease, malignancy, and elderly surgical populations [16], [17], [18], [19]. Observational evidence shows that anemia is associated with higher postoperative morbidity, increased risk of complications, longer hospital stay, and greater need for perioperative blood transfusion [16,17]. In patients undergoing abdominal surgery for inflammatory bowel disease, anemia has been identified as an independent predictor of worse postoperative outcome [17]. Interventional data further illustrate the complexity of anemia correction. The PREVENTT randomized controlled trial demonstrated that intravenous iron did not reduce transfusion or death at 30 days versus placebo, but improved hemoglobin-related recovery at four weeks postoperatively [19].

The clinical significance of preoperative anemia is further amplified by its interaction with perioperative blood transfusion. Patients with anemia are substantially more likely to receive allogeneic red blood cell transfusions, which carry their own independent risks, including transfusion-associated immunomodulation, volume overload, transfusion reactions, and transmission of blood-borne pathogens [16,19]. Allogeneic transfusion has itself been associated with increased rates of postoperative infection, prolonged hospital stay, and worse oncological outcomes in colorectal cancer surgery, potentially through immunosuppressive effects mediated by donor leukocytes and cytokines [16,17]. This creates a clinically important double jeopardy effect: anemic patients are both more likely to receive transfusion and independently at higher risk for complications, reinforcing the rationale for preoperative anemia correction as a strategy to reduce both direct and transfusion-mediated surgical morbidity.

The type and etiology of anemia also influence the magnitude of perioperative risk and the appropriate management strategy. Iron deficiency anemia, the most prevalent form in surgical patients, is associated with the most established evidence base for preoperative correction through iron replacement therapy [16,19]. Anemia of chronic disease, driven by inflammatory cytokine-mediated suppression of erythropoiesis and hepcidin upregulation, is more complex to treat and may require combination therapy or erythropoiesis-stimulating agents in selected cases [17,18]. Vitamin

B12 or folate deficiency anemias, though less common in surgical populations, are rapidly correctable through supplementation and should be excluded in the preoperative work-up. Accurate etiological diagnosis through reticulocyte count, ferritin, transferrin saturation, B12, folate, and inflammatory markers is therefore a prerequisite for targeted and effective anemia management before abdominal surgery.

3.4. Interactions between nutritional deficiencies and cumulative risk

Hypoalbuminemia, vitamin D deficiency, and anemia frequently coexist in the same surgical patient. Shared drivers include chronic inflammation, cancer cachexia, reduced oral intake, malabsorption, frailty, and prolonged disease burden [7,8,17]. Because each deficiency affects wound repair, immune competence, and functional recovery through different but overlapping mechanisms, their coexistence may exert a cumulative adverse effect on postoperative outcomes. Structured screening tools such as Nutritional Risk Screening 2002 (NRS-2002), a validated hospital screening tool combining disease severity and nutritional status, help identify patients at increased nutritional risk before abdominal surgery [9]. Literature emphasizes that perioperative nutritional evaluation and tailored support should be integrated into surgical pathways [20,21]. These overlapping mechanisms support the use of structured risk tools to identify patients with multiple concurrent deficiencies before abdominal surgery.

From a mechanistic standpoint, the coexistence of hypoalbuminemia, vitamin D insufficiency, and anemia likely reflects a shared upstream driver: systemic inflammation. Pro-inflammatory cytokines such as IL-6 and TNF-alpha suppress hepatic albumin synthesis, interfere with hepatic 25-hydroxylation of vitamin D precursors, and upregulate hepcidin, thereby simultaneously producing hypoalbuminemia, functionally reduced vitamin D activity, and anemia of inflammation [7,8,17,23]. This shared inflammatory pathway helps explain why the three deficiencies so frequently co-occur rather than arising independently, and why composite inflammation-nutrition indices such as the Prognostic Nutritional Index and the Controlling Nutritional Status (CONUT) score, which incorporate albumin, lymphocyte count, and cholesterol, tend to outperform any single biomarker in predicting postoperative complications [8,9,23]. Clinically, this synergy argues against a silo-based approach to preoperative optimization: correcting one deficiency in isolation, for example administering intravenous iron without addressing concurrent hypoalbuminemia or vitamin D deficiency, may yield only partial benefit if the underlying inflammatory driver of all three abnormalities remains unaddressed [17,20,21]. This reinforces the rationale for a unified, multi-marker screening approach rather than sequential single-deficiency testing in surgical candidates.

3.5. Current state of perioperative nutritional practice

Despite the substantial body of evidence linking nutritional deficiencies to adverse surgical outcomes, the implementation of systematic preoperative nutritional assessment remains inconsistent in everyday clinical practice. Studies assessing adherence to nutritional screening protocols in surgical departments have reported that formal assessment is performed routinely in fewer than 50% of elective admissions, even in centers that have adopted ERAS pathways [7,8]. This implementation gap is attributable to multiple factors, including time constraints during preoperative consultations, limited dietetic resources, lack of standardized documentation systems, and insufficient awareness among surgical teams regarding the clinical relevance of nutritional status beyond overt malnutrition [7,9].

The consequences of this gap are clinically significant. Patients with subclinical nutritional deficiencies, those who appear adequately nourished on visual inspection but carry biochemical abnormalities detectable only through targeted laboratory assessment, represent a particularly vulnerable group. Their deficiencies are likely to go unrecognized and uncorrected before surgery, yet they are exposed to the same physiological demands of wound healing, anastomotic repair, and immune activation as overtly malnourished patients [6,8,9]. Bridging the gap between evidence and practice therefore requires not only updated clinical guidelines but also institutional investment in nutrition-focused preoperative care pathways and interdisciplinary collaboration among surgeons, anesthesiologists, internal medicine specialists, and clinical dietitians.

Several professional bodies, including the European Society for Clinical Nutrition and Metabolism (ESPEN) and the ERAS Society, have issued recommendations supporting routine preoperative nutritional screening and correction of deficiencies in surgical patients [4,9]. Implementation of these recommendations has been associated with reductions in postoperative complication rates, shorter hospital stay, and improved patient-reported outcomes in colorectal and upper gastrointestinal surgery. However, the evidence base specifically targeting the preopera-

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tive correction of hypoalbuminemia, vitamin D insufficiency, and iron deficiency anemia as isolated modifiable targets, rather than as components of a broader multimodal prehabilitation program, remains limited. Future trials should be designed to disentangle the individual contributions of each nutritional intervention to postoperative outcome improvement and to establish the most effective implementation frameworks for resource-limited surgical settings.

3.6. Emerging evidence and future directions

Recent years have seen growing interest in the concept of multimodal prehabilitation, defined as a structured preoperative program combining nutritional optimization, physical exercise, and psychological support aimed at enhancing functional reserve before major surgery [4,7]. Within this framework, nutritional optimization is recognized not as an isolated intervention but as one pillar of a broader strategy to improve perioperative resilience. Emerging evidence suggests that the combination of nutritional support, oral immunonutrition supplements enriched with arginine, omega-3 fatty acids, and nucleotides, alongside correction of specific deficiencies such as vitamin D and iron, may produce synergistic effects on postoperative immune function and wound repair that exceed the benefits of any single intervention alone [4].

Biomarker-driven approaches to perioperative nutritional management are also gaining traction. Rather than relying solely on serum albumin as a global nutritional marker, newer frameworks propose the combined assessment of multiple indices, including prealbumin, C-reactive protein, the Prognostic Nutritional Index, and the Controlling Nutritional Status (CONUT) score, to better differentiate nutritional depletion from inflammation-driven hypoproteinemia [8,9,23]. These composite scores may offer improved sensitivity in identifying patients who are most likely to benefit from targeted preoperative nutritional intervention compared with single-marker approaches. Their integration into standardized preoperative pathways for abdominal surgery warrants prospective evaluation in adequately powered clinical trials.

In the domain of vitamin D, pharmacological optimization strategies beyond standard supplementation are under investigation. Loading-dose protocols using weekly or biweekly high-dose cholecalciferol have shown promise in rapidly correcting severe deficiency within two to four weeks, which may be particularly relevant for patients with short preoperative windows [12,14]. Similarly, for anemia management, the development of novel oral and intravenous iron formulations with improved safety and tolerability profiles may expand the feasibility of preoperative iron therapy across a broader range of surgical candidates [16,19]. These pharmacological advances, combined with increasing awareness of the clinical burden of perioperative nutritional deficiencies, are likely to drive significant changes in preoperative assessment and optimization practice over the coming decade.

3.7. Role of immunonutrition in perioperative management

Beyond correction of individual nutritional deficiencies, growing evidence supports the use of immunomodulatory nutritional formulas, commonly referred to as immunonutrition, in the perioperative period of major abdominal surgery. These preparations are enriched with specific nutrients, including arginine, glutamine, omega-3 polyunsaturated fatty acids (fish oil), and ribonucleotides, which have been shown to modulate immune function, reduce systemic inflammation, and accelerate wound healing through distinct but complementary mechanisms [4,21]. Arginine serves as a substrate for nitric oxide synthesis and collagen formation, glutamine preserves intestinal barrier integrity and lymphocyte function, and omega-3 fatty acids shift eicosanoid metabolism toward less pro-inflammatory mediators, collectively contributing to an environment more conducive to tissue repair [4].

Meta-analyses of randomized controlled trials have reported that perioperative immunonutrition reduces the incidence of postoperative infectious complications, particularly surgical site infections and pneumonia, in patients undergoing elective gastrointestinal surgery, with relative risk reductions of 30-50% in some series [4]. The magnitude of benefit appears greatest in malnourished and nutritionally at-risk patients, which aligns with the hypothesis that immunonutrition restores impaired immune function rather than simply augmenting an already adequate response. Current ESPEN and ERAS guidelines recommend preoperative immunonutrition for five to seven days before major upper gastrointestinal surgery in at-risk patients, regardless of overall nutritional status [4,9].

The relationship between immunonutrition and the specific deficiencies discussed in this review is clinically relevant. Patients with hypoalbuminemia, vitamin D insufficiency, or anemia are by definition nutritionally compromised and are therefore among those most likely to benefit from immunomodulatory supplementation in the preoperative period. Integrating immunonutrition into a broader preoperative

optimization strategy, alongside albumin repletion, vitamin D correction, and iron therapy, represents a rational, evidence-aligned approach to maximizing perioperative immune competence. However, the evidence base for combined multinutrient prehabilitation protocols in abdominal surgery remains limited, and future trials should address this gap directly [4,21].

3.8. Patient-specific considerations and risk stratification

The clinical impact of preoperative nutritional deficiencies is not uniform across all abdominal surgical patients. Several patient-specific factors modulate the relationship between nutritional status and postoperative outcome, and awareness of these modifiers is essential for individualized perioperative risk stratification. Age is among the most important: older patients are disproportionately affected by protein-energy malnutrition, vitamin D deficiency, and anemia due to reduced dietary intake, impaired absorption, decreased renal activation of vitamin D, and the pro-inflammatory milieu of aging tissues [20,23]. In geriatric surgical patients, even modest biochemical deficiencies may translate into clinically significant functional impairment and markedly increased vulnerability to postoperative complications [20].

Underlying diagnosis also substantially influences the nutritional risk profile. Patients with colorectal malignancy, inflammatory bowel disease, or upper gastrointestinal tumors frequently present with cancer-associated cachexia, chronic inflammation, and disease-related anorexia, all of which independently drive protein depletion, micronutrient deficiency, and anemia [7,17]. In these populations, nutritional deficiencies are not merely incidental findings but reflect the systemic burden of disease, and their correction may require more intensive and prolonged intervention than in otherwise healthy patients undergoing elective procedures. The degree of surgical stress anticipated, emergency versus elective, open versus laparoscopic, and single-organ versus multi-organ resection, further modulates the magnitude of physiological demands placed on nutritional reserves in the postoperative period [1,3,7].

Frailty, defined as a state of increased vulnerability to physiological stressors due to reduced homeostatic reserve, represents a clinical syndrome that frequently encompasses multiple concurrent nutritional deficiencies [20]. Frail patients undergoing abdominal surgery have significantly higher rates of postoperative complications, prolonged hospital stay, and functional decline compared with non-frail counterparts. Nutritional optimization is a cornerstone of frailty-focused prehabilitation programs, and routine assessment of frailty markers alongside nutritional biochemistry may improve risk prediction beyond what is achievable with albumin or hemoglobin measurement alone. Validated instruments such as the Clinical Frailty Scale, the Edmonton Frail Scale, or the Short Physical Performance Battery can be integrated into preoperative assessment without significant resource burden, enabling multidimensional risk stratification that informs individualized optimization strategies [4,7,20].

4. Discussion

4.1. Hypoalbuminemia: clinical significance and evidence quality

The evidence synthesized in this review indicates that preoperative nutritional deficiencies are not marginal laboratory abnormalities but clinically meaningful and potentially modifiable contributors to postoperative morbidity after abdominal surgery. Among the three deficiencies examined, hypoalbuminemia appears to have the most consistent and strongest association with surgical site infection and overall postoperative complications [1,10,11]. This may reflect its dual importance as a marker of both protein depletion and systemic inflammatory burden. In practical terms, albumin functions as a highly-yield perioperative warning sign that identifies patients in whom deeper nutritional assessment and optimization should not be delayed.

Vitamin D insufficiency is supported by a growing body of observational and mechanistic data, although intervention trials remain less definitive [12-15]. Nevertheless, its biological role in antimicrobial defense and epithelial repair provides a compelling rationale for perioperative assessment, particularly in patients with chronic disease, malabsorption, or suspected deficiency [12,15,22]. The combination of high prevalence, relatively low cost of correction, and plausible biological effect makes vitamin D an attractive adjunctive target in prehabilitation strategies.

For preoperative anemia, the clinical significance is well established, but interventional evidence suggests that correction strategies must be appropriately timed and individualized [16-19]. Intravenous iron appears most useful in iron-deficient patients identified sufficiently early before elective surgery. Anemia should be viewed not simply as a laboratory abnor-

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mality to document but as a modifiable physiologic limitation that may compromise oxygen-dependent wound repair. These observations align with perioperative nutrition literature emphasizing that nutritional optimization should begin several weeks before planned surgery [4,20,21].

4.2. Vitamin D: from mechanism to clinical translation

The translation of mechanistic evidence regarding vitamin D from bench to bedside has proven more complex than initially anticipated. Early observational studies consistently documented lower 25(OH)D concentrations in patients who developed postoperative infections, prompting interest in correction strategies [12,15]. However, randomized trials of vitamin D supplementation in general medical and surgical populations have yielded inconsistent results. Several explanations have been proposed: the lag time between supplementation and meaningful restoration of tissue-level vitamin D activity may exceed the short supplementation windows used in perioperative trials; there may be a threshold effect whereby correction is only beneficial when deficiency is severe; and vitamin D interacts with cofactors including magnesium, calcium, and protein status, meaning that isolated supplementation in a context of broader nutritional insufficiency may not yield the expected immunological benefits [14,22,24]. These considerations underscore the need for prospective trials designed with adequate lead time, appropriate dosing strategies, and endpoints sensitive enough to capture differences in wound biology and infectious morbidity.

4.3. Preoperative anemia: risk stratification and intervention timing

The evidence on preoperative anemia is instructive precisely because it combines robust observational data with more cautious interventional findings. There is little disagreement in the literature that anemia increases transfusion requirements, prolongs recovery, and worsens functional outcomes after major abdominal surgery [16-19]. The PREVENTT trial, the largest randomized trial of preoperative intravenous iron in abdominal surgery, demonstrated no significant difference in its primary composite endpoint at 30 days, but suggested possible benefits in patients with confirmed iron deficiency and a longer interval between infusion and surgery [19]. This supports the view that preoperative iron therapy is most likely to be effective when administered at least four to eight weeks before surgery in patients with documented iron deficiency anemia, rather than as a routine last-minute intervention. The implication for clinical practice is that anemia management should begin at the point of surgical listing, not at the preoperative assessment visit.

4.4. Practical recommendations for preoperative nutritional optimization

Based on the evidence reviewed, the following evidence-informed recommendations are proposed for the preoperative nutritional assessment of patients scheduled for elective abdominal surgery. These recommendations are consistent with the Enhanced Recovery After Surgery (ERAS) framework and current perioperative nutrition guidelines [4,9].

- All patients scheduled for elective abdominal surgery should undergo nutritional risk screening at the time of surgical listing using NRS-2002 or MUST [9].
- Patients with NRS-2002 score >= 3 should undergo targeted laboratory assessment including serum albumin, 25-hydroxyvitamin D, full blood count, and serum ferritin or transferrin saturation [9,10].
- Patients with serum albumin below 30 g/L should be referred for dietetic evaluation and oral nutritional supplementation, with a target optimization period of at least four weeks before surgery [4].
- Patients with 25(OH)D below 50 mmol/L (20 ng/mL) should receive vitamin D supplementation in doses consistent with national guidelines, with reassessment before surgery where feasible [12,22].
- Patients with hemoglobin below 130 g/L (men) or 120 g/L (women) with iron deficiency should be considered for intravenous iron therapy, ideally at least four to six weeks before surgery [16,19].
- All at-risk patients should have their surgical date reviewed by the perioperative multidisciplinary team to determine whether a short delay would allow meaningful nutritional optimization [4,7].

An important methodological distinction must also be noted: the literature is stronger for risk stratification than for proof of benefit from correction. There is convincing evidence that patients with these deficiencies do worse after surgery, but less definitive evidence that correcting each deficit will always translate into lower postoperative complication rates. However, even when deficiencies function partly as markers of

disease severity, identifying them remains useful because they enrich preoperative risk assessment and may guide decisions on timing of surgery and supportive care.

The main limitation of the available evidence is heterogeneity in study design, deficiency definitions, patient populations, and surgical procedures. Many studies are observational, which limits causal inference. Evidence specifically evaluating combined correction of multiple deficiencies in abdominal surgery remains scarce. Future research should focus on prospective trials of integrated nutritional optimization protocols with clearly defined biochemical thresholds, adequate lead time before surgery, and clinically relevant endpoints such as surgical site infection, anastomotic leak, length of stay, and readmission.

4.5. Strengths and limitations of this narrative review

This review has several strengths, including the integration of evidence across three distinct but mechanistically interconnected nutritional deficiencies, a synthesis spanning basic wound-healing biology through to practical screening recommendations, and an explicit attempt to translate heterogeneous evidence into an actionable preoperative pathway consistent with the research problems and hypotheses set out in the Introduction. Nevertheless, several limitations should be acknowledged. As a narrative rather than a systematic review, this work did not follow a PRISMA-based protocol, was not registered prospectively, and did not employ a formal risk-of-bias or GRADE-based certainty-of-evidence assessment; consequently, some degree of selection emphasis in identifying and weighting eligible studies cannot be excluded. The restriction to English-language publications may have excluded relevant regional evidence, particularly population-specific prevalence data from non-English-language literature. Furthermore, the included evidence base is dominated by observational studies, which limits causal inference, and definitions of hypoalbuminemia, vitamin D insufficiency, and anemia vary across studies, limiting direct comparability of pooled effect estimates. Finally, gray literature, conference abstracts, and unpublished trial data were not systematically searched, which may have introduced publication bias favoring studies with statistically significant findings. These limitations should be considered when translating the conclusions of this review into clinical protocols and reinforce the need for the prospective, adequately powered trials called for throughout this manuscript.

5. Conclusions

Preoperative hypoalbuminemia, vitamin D insufficiency, and anemia are prevalent and clinically relevant modifiable risk factors for postoperative complications following abdominal surgery. Hypoalbuminemia currently has the strongest evidence base as a predictor of infectious and wound-related complications, while vitamin D insufficiency and anemia also contribute meaningfully to impaired recovery and higher perioperative risk.

Returning to the research hypotheses that framed this review, the evidence synthesized here supports the hypothesis that hypoalbuminemia, vitamin D insufficiency, and anemia each independently increase postoperative risk, most robustly for hypoalbuminemia and anemia and more provisionally for vitamin D. The hypothesis that coexisting deficiencies produce a cumulative adverse effect is supported mechanistically through their shared inflammatory pathway (Section 3.4) and by the superior predictive performance of composite nutritional indices relative to single biomarkers, although direct outcome data quantifying this cumulative effect in abdominal surgery remain limited. The hypothesis that early recognition and correction of these deficiencies can reduce preventable postoperative morbidity is biologically plausible and supported by intervention evidence for anemia and protein-energy malnutrition, but requires further confirmation for isolated vitamin D correction. Taken together, these findings validate the original research problems posed in the Introduction while highlighting that the strength of evidence differs meaningfully across the three deficiencies examined.

Routine nutritional screening before abdominal surgery should include structured risk assessment and targeted laboratory evaluation, particularly in patients with malignancy, chronic inflammatory disease, frailty, or suspected malnutrition. Early identification and correction of nutritional deficiencies may represent an important opportunity to reduce preventable postoperative morbidity and improve surgical recovery. Further well-designed randomized controlled trials are required to establish definitive causal relationships between preoperative correction of nutritional deficiencies and reduction in hard surgical endpoints, and to evaluate the cost-effectiveness of structured nutritional optimization protocols within perioperative care systems.

The growing adoption of multimodal rehabilitation programs in elective abdominal surgery provides a practical framework within which nutritional

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optimization can be systematically delivered. Collaboration among surgical teams, clinical dietitians, and internal medicine specialists is essential to translate the evidence reviewed here into measurable improvements in perioperative care quality. Routine biochemical screening at the time of surgical listing, rather than at the immediate preoperative assessment, offers the most realistic opportunity for meaningful correction of nutritional deficiencies within the available therapeutic window.

Implementation of structured nutritional optimization pathways is not only clinically warranted but also economically justified. Malnourished surgical patients generate substantially higher costs due to prolonged hospitalization, increased rates of reoperation, and greater need for postoperative rehabilitation. Investment in preoperative nutritional screening and targeted correction is therefore likely to yield favorable cost-effectiveness outcomes at the institutional and health system level, further supporting its integration into standard surgical care protocols [5,7].

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