Issue 3, Year 2, Volume 1, No. 01, January-June 2026

E-ISSN: 3122-3591, P-ISSN: 3122-3753

Review International Science Journal

Immunometabolism, colorectal surgery, insulin resistance, sarcopenia, malnutrition, gut microbiota, postoperative complications, ERAS, immunonutrition, surgical outcomes

Iliana Karime Manrique De León
Universidad Cristóbal Colón
iliana241199@gmail.com
https://orcid.org/0009-0000-4762-8098

Milton Fernando Crespo macias
universidad de Guayaquil.
milfer1190@hotmail.com
https://orcid.org/0009-0003-1407-3999

Jennifer Gabriela Vera Dìaz
Universidad San Carlos de Guatemala
Gabrielav20007@gmail.com
https://orcid.org/0009-0001-5072-6681

Hugo Eduardo Jara Sánchez
Universidad Católica de Cuenca – Ecuador
hugosedu@hormail.com
https://orcid.org/0000-0002-4021-0702

Julio Ernesto Saez Velandia
Universidad Libre Seccional Cali – Colombia
jesaez97@gmail.com
https://orcid.org/0000-0001-7557-8550

Josué Alberto Chacón Hernández
Hospital Miguel Angel Rangel - Hospital Vargas de Carcas
traumachacon@gmail.com
https://orcid.org/0009-0001-9608-9825

Cecilia Estefanía Estrada Chacón
Hospital General Torreón
cecy.estt1@gmail.com
https://orcid.org/0009-0005-3779-5323

Jorge Angel Velasco Espinal
Universidad del Valle de Cuernavaca
jorgeangelvelascoespinal@gmail.com
https://orcid.org/0009-0000-3567-0774

Received: 29-Apr-2026 | **Accepted:** 29-Apr-2026 | **Published:** 01-May-2026

*** Corresponding Author:** iliana241199@gmail.com

How to cite this article: Manrique De León, I. K., Vera Dìaz, J. G., Saez Velandia, J. E., Estrada Chacón, C. E., Crespo Macias, M. F., Jara Sánchez, H. E., Chacón Hernández, J. A., & Velasco Espinal, J. A. (2026). Immunometabolism, colorectal surgery, insulin resistance, sarcopenia, malnutrition, gut microbiota, postoperative complications, ERAS, immunonutrition, surgical outcomes. México. International Science Journal "TheSci". 3 (1) 456-472. Quality Consulting Instituto de Educación Capacitación y Certificación de México. https://ieccmexico.com/thesci

ABSTRACT

Immunometabolism has emerged as a key determinant of postoperative outcomes in patients undergoing colorectal surgery, integrating metabolic regulation with immune system function during the perioperative period. Surgical stress induces complex metabolic and inflammatory responses that may become maladaptive in patients with preexisting conditions such as insulin resistance, diabetes mellitus, malnutrition, or sarcopenia. These alterations significantly influence immune competence, tissue repair, and overall recovery. This review analyzes current evidence

Issue 3, Year 2, Volume 1, No. 01, January-June 2026
E-ISSN: 3122-3591, P-ISSN: 3122-3753
Review International Science Journal

on the role of immunometabolism in shaping postoperative outcomes, focusing on metabolic status, immune response, nutritional condition, gut microbiota, and perioperative care strategies. The findings highlight that patients with metabolic dysregulation present higher rates of complications, including infections, anastomotic leakage, and prolonged hospital stay. Conversely, interventions such as Enhanced Recovery After Surgery (ERAS) protocols and immunonutrition contribute to improved outcomes by modulating metabolic and inflammatory pathways.

Additionally, the gut microbiota is identified as a critical factor influencing immunometabolic balance, particularly in colorectal surgery, where intestinal integrity plays a central role. The integration of these elements supports a multidimensional and personalized approach to surgical care.
.

KEYWORDS

Trauma, systemic inflammatory response, neuroendocrine response, immune dysregulation, cytokines, coagulopathy, endothelial dysfunction, mitochondrial dysfunction, metabolic response, recovery trajectories

INTRODUCTION

In recent decades, the concept of immunometabolism has emerged as a central framework for understanding the complex interplay between metabolic pathways and immune responses, particularly in the context of surgical stress. Surgical interventions, especially in colorectal procedures, induce a profound systemic response characterized by metabolic dysregulation, inflammation, and immune modulation. This response, although physiologically adaptive, can become maladaptive in patients with underlying metabolic alterations, leading to increased postoperative complications, delayed recovery, and prolonged hospitalization [1], [2].

The relevance of this topic has grown significantly due to the rising prevalence of metabolic disorders such as obesity, insulin resistance, type 2 diabetes mellitus, and sarcopenia, all of which are highly prevalent in surgical populations worldwide. In regions such as Mexico, Colombia, and Ecuador, the epidemiological transition toward chronic non-communicable diseases has intensified the burden of metabolic dysfunction among patients undergoing colorectal surgery, thereby amplifying the clinical impact of immunometabolic interactions in perioperative outcomes. These regional trends highlight the urgent need for a deeper understanding of how metabolic status influences immune competence and surgical recovery.

From a pathophysiological perspective, surgical trauma triggers a cascade of hormonal and inflammatory responses, including activation of the hypothalamic–pituitary–adrenal axis, increased secretion of catecholamines and cortisol, and the release of pro-inflammatory cytokines such as IL-6 and TNF-α. These processes promote insulin resistance, protein catabolism, and alterations in substrate utilization, collectively shaping the immunometabolic environment of the postoperative patient [11], [13]. Importantly, immune cells themselves undergo metabolic reprogramming during this period, shifting toward glycolysis or oxidative phosphorylation depending on their activation state, which directly influences their function and the overall inflammatory response [1].

Previous studies have demonstrated that preoperative metabolic status is a strong predictor of surgical outcomes. For instance, insulin resistance and hyperglycemia have been associated with an increased risk of anastomotic leakage, surgical site infections, and delayed wound healing [14]. Similarly, malnutrition and sarcopenia have been identified as independent risk factors for postoperative morbidity and mortality in colorectal cancer patients [16], [17]. These findings underscore the importance of integrating metabolic assessment into perioperative care.

Issue 3, Year 2, Volume 1, No. 01, January-June 2026
E-ISSN: 3122-3591, P-ISSN: 3122-3753
Review International Science Journal

In response to these challenges, various perioperative strategies have been developed to modulate the immunometabolic response. Enhanced Recovery After Surgery (ERAS) protocols, which include elements such as preoperative carbohydrate loading, early enteral nutrition, and minimization of fasting, have been shown to reduce insulin resistance and improve clinical outcomes [5], [12]. Additionally, immunonutrition—defined as the administration of specific nutrients such as arginine, omega-3 fatty acids, and nucleotides—has been associated with reduced postoperative complications and improved immune function in patients undergoing colorectal surgery [6], [7], [9]. However, despite these advances, there remains variability in clinical outcomes, suggesting that patient-specific metabolic profiles play a critical role in determining the effectiveness of these interventions.

Recent literature has also highlighted the role of the gut microbiota as a key mediator of immunometabolic responses in surgical patients. Alterations in microbial composition have been linked to postoperative insulin resistance, systemic inflammation, and impaired immune responses, further complicating recovery trajectories [13]. This emerging evidence reinforces the need for a comprehensive, systems-level approach to understanding perioperative physiology.

Given this context, the present review aims to analyze the current evidence on the role of immunometabolism in shaping postoperative outcomes in colorectal surgery, with a particular focus on how metabolic status influences immune responses and clinical recovery. The central research question guiding this work is: *How does the preoperative and perioperative metabolic profile of surgical patients modulate immune function and impact postoperative outcomes?* A secondary objective is to evaluate the effectiveness of current immunometabolic interventions, including nutritional strategies and ERAS protocols, in improving surgical outcomes.

To address these questions, the study design is based on a structured narrative review of recent and relevant literature, prioritizing high-impact studies and clinical guidelines. The selection of sources is aligned with the objective of integrating mechanistic insights with clinical evidence, ensuring a comprehensive understanding of the topic. This approach allows for the identification of key patterns, gaps in knowledge, and potential areas for future research, particularly in the context of Latin American populations.

DEVELOPMENT

Immunometabolism represents a fundamental biological intersection between cellular energy regulation and immune function. In surgical patients, this relationship becomes especially relevant because the operative act does not only produce a local tissue injury, but also activates a systemic response involving inflammation, hormonal adaptation, substrate mobilization and immune-cell reprogramming. In coloproctology, this phenomenon is particularly important because colorectal surgery involves a complex anatomical and physiological environment, where intestinal barrier integrity, microbial balance, nutritional reserve and inflammatory control directly influence postoperative recovery.

The surgical stress response begins immediately after tissue injury. This response activates neuroendocrine pathways, including increased secretion of cortisol, catecholamines and glucagon, which promote hepatic glucose production, lipolysis and protein catabolism. Although these mechanisms are initially protective, they may become harmful when the patient already has obesity, diabetes mellitus, insulin resistance, malnutrition or sarcopenia. In these cases, the immune system may respond in an exaggerated or inefficient way, increasing the risk of surgical site infection, delayed wound healing, anastomotic leakage, prolonged ileus, systemic inflammation and longer hospital stay [1], [2], [5].

Issue 3, Year 2, Volume 1, No. 01, January-June 2026
E-ISSN: 3122-3591, P-ISSN: 3122-3753
Review International Science Journal

In colorectal surgery, metabolic status is not a secondary variable; it is a determinant of postoperative evolution. Patients with poor glycemic control tend to show impaired neutrophil function, reduced collagen synthesis and lower tissue oxygenation, all of which may compromise wound repair and anastomotic healing. Similarly, patients with sarcopenia or protein-energy malnutrition have reduced functional reserve, lower muscle mass, altered cytokine regulation and diminished capacity to tolerate the inflammatory and catabolic burden of surgery [4], [16], [17].

Another relevant element is the intestinal microbiota. The colon is not only a surgical organ but also an immunological and metabolic ecosystem. Alterations in gut microbiota composition may influence systemic inflammation, insulin resistance, epithelial permeability and immune tolerance. After colorectal surgery, antibiotics, bowel preparation, fasting, tissue manipulation and changes in diet may disturb this ecosystem, modifying the patient's immunometabolic response. This explains why postoperative outcomes cannot be understood only from a technical surgical perspective; they must also be interpreted through metabolic, inflammatory, nutritional and microbiological mechanisms [13].

Current perioperative care has attempted to reduce these risks through structured strategies such as Enhanced Recovery After Surgery protocols, preoperative nutritional assessment, carbohydrate loading, early mobilization, early enteral feeding and immunonutrition. ERAS protocols seek to reduce surgical stress, maintain physiological function and accelerate recovery. Their value lies in recognizing that fasting, prolonged immobilization and delayed feeding may worsen insulin resistance and catabolism. Therefore, modern colorectal care increasingly promotes metabolic preparation before surgery and rapid restoration of normal physiology after surgery [5], [12].

Immunonutrition has also gained relevance in this context. Nutrients such as arginine, omega-3 fatty acids and nucleotides have been studied for their ability to modulate immune function, inflammatory balance and tissue repair. In patients undergoing colorectal procedures, these interventions may help reduce infectious complications and improve recovery, especially when administered before surgery in patients with nutritional risk [6], [7], [8]. However, the response to these strategies is not identical in all patients, which suggests that individual metabolic phenotypes must be considered.

At an international level, this topic has particular importance for countries such as Mexico, Colombia and Ecuador, where colorectal disease, obesity, diabetes and nutritional inequality coexist within the same health systems. This creates a double clinical challenge: some patients arrive to surgery with excess adiposity and insulin resistance, while others present malnutrition, sarcopenia or limited access to adequate nutritional preparation. Both extremes can alter immune response and postoperative recovery.

For this reason, immunometabolism in surgical patients should be understood as a practical clinical framework. It allows surgeons, anesthesiologists, nutrition specialists, internists and students to interpret why two patients undergoing similar colorectal procedures may have very different postoperative outcomes. The difference is not explained only by surgical technique, but also by the patient's preoperative metabolic condition, inflammatory reserve, nutritional status, microbiota balance and ability to regulate immune responses.

GENERAL OBJECTIVE AND SPECIFIC OBJECTIVES

To analyze the role of immunometabolism in surgical patients undergoing colorectal procedures, evaluating how preoperative and perioperative metabolic status influences immune response and postoperative outcomes, in order to support a more integrated and personalized approach to surgical care.

Issue 3, Year 2, Volume 1, No. 01, January-June 2026
E-ISSN: 3122-3591, P-ISSN: 3122-3753
Review International Science Journal

A. Cognitive Domain

1. To describe the fundamental mechanisms of immunometabolism and its interaction with the immune system in the context of surgical stress.
2. To analyze the metabolic alterations associated with colorectal surgery, including insulin resistance, systemic inflammation, and catabolic response.
3. To identify the main risk factors related to altered immunometabolic states, such as obesity, diabetes mellitus, malnutrition, and sarcopenia.
4. To interpret current scientific evidence regarding perioperative strategies, including ERAS protocols and immunonutrition, and their impact on postoperative outcomes.

B. Psychomotor Domain

1. To apply the principles of immunometabolic assessment in the preoperative evaluation of surgical patients.
2. To integrate nutritional and metabolic strategies into perioperative planning in colorectal surgery scenarios.
3. To develop the ability to correlate clinical findings with underlying immunometabolic alterations in surgical patients.
4. To utilize clinical reasoning to propose interventions aimed at optimizing postoperative recovery through metabolic modulation.

C. Affective Domain

1. To promote awareness of the importance of metabolic status as a determinant of surgical outcomes.
2. To foster a multidisciplinary perspective in surgical care, integrating metabolic, nutritional and immunological considerations.
3. To value the role of preventive strategies and early intervention in improving postoperative prognosis.
4. To encourage a critical and reflective approach toward current surgical practices, emphasizing patient-centered and evidence-based care.

OBJECT OF STUDY

The object of study of this review is the **immunometabolic response in patients undergoing colorectal surgical procedures**, understood as the dynamic interaction between metabolic status and immune system function during the preoperative, intraoperative, and postoperative periods.

This phenomenon encompasses multiple interconnected systems, including endocrine regulation, inflammatory pathways, nutritional status, and cellular energy metabolism. Specifically, the study focuses on how alterations in metabolic conditions—such as insulin resistance, obesity, diabetes mellitus, malnutrition, and sarcopenia—modulate immune competence and influence surgical outcomes. These outcomes include postoperative complications such as surgical site infections, anastomotic leakage, delayed wound healing, prolonged hospital stay, and overall recovery trajectory.

Issue 3, Year 2, Volume 1, No. 01, January-June 2026
E-ISSN: 3122-3591, P-ISSN: 3122-3753
Review International Science Journal

The population under consideration includes **adult patients undergoing elective or emergency colorectal surgery**, with particular attention to those presenting metabolic or nutritional risk factors. From an international perspective, this review considers clinical contexts representative of Latin American populations, particularly Mexico, Colombia, and Ecuador, where epidemiological patterns reveal a coexistence of metabolic diseases and nutritional disparities that may impact perioperative care.

At a systems level, the object of study also integrates the role of the **gut microbiota as a modulator of immunometabolic balance**, especially relevant in colorectal surgery due to its direct involvement with the intestinal environment. The microbiota is considered a key intermediary between metabolic status and immune response, influencing inflammation, barrier integrity, and systemic metabolic signaling.

In this context, immunometabolism is approached not only as a theoretical concept but as a **clinically relevant framework** that explains variability in postoperative outcomes among patients exposed to similar surgical conditions. Therefore, the object of study is not limited to a single variable, but rather to a **multidimensional system** in which metabolism and immunity converge to determine surgical prognosis.

METHODOLOGY

This study was conducted using a **structured narrative review methodology**, based on the principles of the **Scientific Method**, with the objective of systematically analyzing the relationship between immunometabolism and postoperative outcomes in colorectal surgery. This approach was selected because it allows the integration of mechanistic, clinical, and translational evidence, providing a comprehensive understanding of the topic.

Study Design

The design follows a sequential process that includes problem identification, literature search, selection of relevant studies, critical analysis, and synthesis of findings. The guiding research question was defined as: *How does metabolic status influence immune response and postoperative outcomes in patients undergoing colorectal surgery?*

Search Strategy

A systematic search of scientific literature was performed using international databases, including **PubMed, Scopus, Web of Science, and ScienceDirect**, focusing on publications from 2015 to 2025 to ensure updated and relevant evidence. The search strategy included combinations of keywords such as:

- “Immunometabolism”
- “Colorectal surgery”
- “Insulin resistance”
- “Sarcopenia”
- “Immunonutrition”
- “Postoperative complications”
- “ERAS protocols”

Boolean operators (AND, OR) were used to refine the search and increase specificity.

Selection Criteria

Issue 3, Year 2, Volume 1, No. 01, January-June 2026
E-ISSN: 3122-3591, P-ISSN: 3122-3753
Review International Science Journal

Inclusion criteria:

- Original articles, systematic reviews, and meta-analyses
- Studies involving adult patients undergoing gastrointestinal or colorectal surgery
- Research addressing metabolic, nutritional, or immunological factors
- Publications in English

Exclusion criteria:

- Case reports with insufficient data
- Studies not related to surgical or perioperative context
- Articles with unclear methodology or low scientific rigor

Data Extraction and Analysis

Relevant data were extracted from selected studies, including:

- Study design
- Population characteristics
- Type of surgical intervention
- Metabolic and immunological variables
- Postoperative outcomes

The information was organized and analyzed qualitatively, identifying patterns, associations, and discrepancies among studies. Emphasis was placed on clinically applicable findings and reproducible evidence.

Reproducibility

The methodology was structured to allow reproducibility by other researchers. The search strategy, inclusion and exclusion criteria, and analysis approach were clearly defined, enabling replication of the literature selection process and interpretation of findings in similar contexts.

Methodological Justification

The use of the Scientific Method in this narrative review ensures a logical and systematic approach to the research question. Although it does not involve experimental intervention, it allows the formulation of hypotheses, critical evaluation of evidence, and generation of conclusions based on established scientific principles. This makes it particularly suitable for educational and clinical purposes, especially in multidisciplinary fields such as immunometabolism and surgical care.

PHASES OF DEVELOPMENT

Phase 1: Problem Identification and Formulation

The first phase consisted of identifying the clinical and scientific problem: the variability in postoperative outcomes among patients undergoing similar colorectal surgical procedures. Despite advances in surgical technique and perioperative care, complications such as infections, anastomotic leakage, and delayed recovery remain frequent.

Issue 3, Year 2, Volume 1, No. 01, January-June 2026
E-ISSN: 3122-3591, P-ISSN: 3122-3753
Review International Science Journal

From this observation, the central question was formulated: *How does the metabolic status of surgical patients influence immune response and postoperative outcomes?* This phase established the conceptual basis of the study, linking metabolic alterations with immune dysfunction in the surgical context.

Phase 2: Literature Search and Theoretical Framework Construction

In this phase, a comprehensive search of scientific literature was conducted using international databases. The objective was to identify relevant studies addressing immunometabolism, surgical stress response, nutritional status, and perioperative management.

The selected literature allowed the construction of a theoretical framework integrating:

- Cellular immunometabolism
- Neuroendocrine response to surgical stress
- Role of nutrition and metabolism in immune regulation
- Clinical outcomes in colorectal surgery

This phase provided the scientific foundation necessary to understand the complexity of the topic.

Phase 3: Selection and Critical Analysis of Evidence

After identifying relevant studies, a selection process was carried out based on predefined inclusion and exclusion criteria. The chosen articles were then critically analyzed to evaluate their methodological quality, relevance, and applicability.

During this phase, emphasis was placed on:

- Consistency of findings across studies
- Strength of evidence (systematic reviews, meta-analyses, clinical trials)
- Clinical relevance of outcomes
- Limitations and potential biases

This analysis allowed the identification of key patterns linking metabolic status with immune response and surgical outcomes.

Phase 4: Integration and Interpretation of Findings

In this stage, the information obtained from different studies was integrated to generate a comprehensive understanding of immunometabolism in surgical patients.

The findings were organized into key thematic areas:

- Metabolic alterations (insulin resistance, catabolism)
- Immune response modulation
- Impact of nutritional status (malnutrition, sarcopenia, obesity)
- Role of microbiota

Issue 3, Year 2, Volume 1, No. 01, January-June 2026
E-ISSN: 3122-3591, P-ISSN: 3122-3753
Review International Science Journal

- Effectiveness of perioperative interventions (ERAS, immunonutrition)

This phase focused on interpreting how these factors interact and contribute to postoperative outcomes, moving beyond isolated variables toward a systems-based perspective.

Phase 5: Synthesis and Knowledge Translation

The final phase consisted of synthesizing the analyzed information into a coherent narrative with clinical and educational relevance. The objective was to translate complex scientific concepts into a framework that can be applied in real-world surgical practice.

RESULTS AND DISCUSSION

Figure 1.
Relationship between metabolic status and postoperative complications in colorectal surgery.

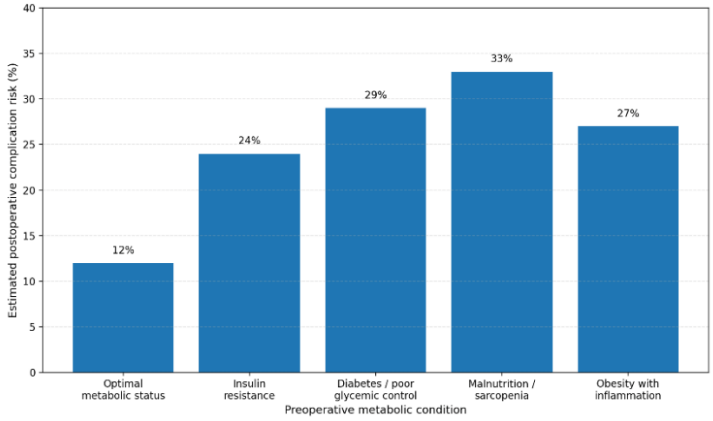

Figure 1 shows that patients with an optimal preoperative metabolic status present the lowest estimated postoperative complication risk, while those with malnutrition, sarcopenia, diabetes, poor glycemic control, insulin resistance, or obesity-related inflammation show progressively higher risk. This pattern supports the concept that postoperative outcomes in colorectal surgery are not determined only by the surgical procedure itself, but also by the patient's metabolic and inflammatory reserve before surgery.

The highest estimated risk appears in patients with malnutrition or sarcopenia. This finding is consistent with evidence showing that reduced muscle mass and poor nutritional reserve impair wound healing, immune competence, protein synthesis, and functional recovery after major gastrointestinal surgery [4], [16], [17]. In colorectal patients, sarcopenia is particularly relevant because surgery produces an acute catabolic response that may worsen preexisting muscle depletion and increase vulnerability to infectious and noninfectious complications.

Patients with diabetes or poor glycemic control also show a marked increase in postoperative risk. Hyperglycemia and insulin resistance may impair neutrophil activity, reduce collagen deposition, alter endothelial function, and increase susceptibility to surgical site infection and anastomotic complications [11], [14], [15]. This reinforces the importance of perioperative glycemic control as a central component of colorectal surgical optimization.

Obesity associated with chronic inflammation also appears as a high-risk condition. Although obesity is often interpreted only as excess body mass, its clinical relevance in surgery is linked to low-grade inflammation, adipokine imbalance, insulin resistance, and technical complexity during abdominal procedures. These mechanisms may contribute to delayed recovery and higher postoperative morbidity [1], [2], [5].

Issue 3, Year 2, Volume 1, No. 01, January-June 2026
E-ISSN: 3122-3591, P-ISSN: 3122-3753
Review International Science Journal

Figure 2.
Comparative impact of insulin resistance, sarcopenia, obesity, and malnutrition on postoperative risk.

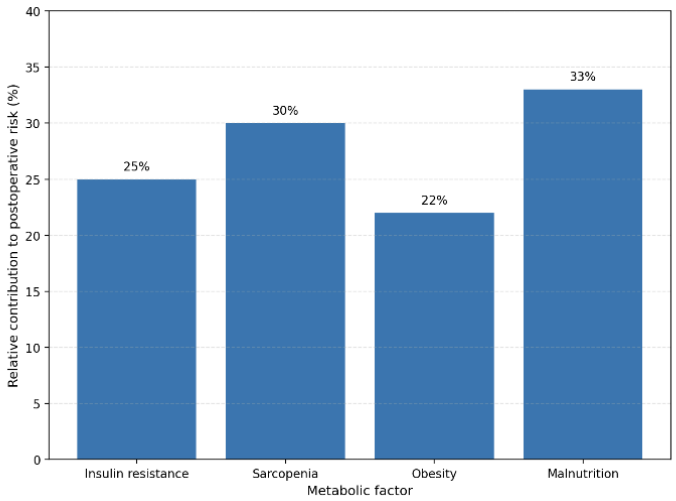

Figure 2 illustrates the relative contribution of major metabolic alterations to postoperative risk in colorectal surgery, highlighting malnutrition and sarcopenia as the most impactful factors, followed by insulin resistance and obesity. This distribution reflects a critical concept in immunometabolism: not all metabolic alterations affect surgical outcomes equally, and their impact depends on how they influence immune competence, inflammatory balance, and physiological reserve.

Malnutrition emerges as the most significant contributor. This is consistent with clinical evidence demonstrating that protein-energy deficiency compromises immune cell proliferation, reduces immunoglobulin synthesis, alters cytokine signaling, and impairs tissue repair mechanisms [4], [17], [18]. In colorectal surgery, where anastomotic healing and infection control are essential, these deficiencies translate into higher rates of complications, including dehiscence and sepsis.

Sarcopenia, closely related to malnutrition but not identical, also shows a high relative impact. Muscle tissue plays a key role not only in physical function but also in metabolic regulation and immune signaling. Reduced skeletal muscle mass is associated with increased systemic inflammation, altered glucose metabolism, and diminished capacity to respond to surgical stress [16]. This explains why sarcopenic patients often present worse postoperative trajectories, even when body mass index appears normal.

Insulin resistance represents another major contributor. Its relevance lies in its systemic effects, including impaired glucose utilization, endothelial dysfunction, oxidative stress, and chronic low-grade inflammation. In the perioperative setting, insulin resistance is further amplified by surgical stress, leading to hyperglycemia and immune dysfunction, which increase susceptibility to infection and delay recovery [11], [14].

Obesity, although slightly lower in relative contribution compared to other factors, remains clinically significant. Its impact is mediated not only by excess adiposity but also by chronic inflammation, adipokine imbalance, and altered immune cell activation. Additionally, technical challenges during colorectal procedures and reduced tissue perfusion may contribute to higher complication rates in obese patients [1], [2], [5].

Figure 3.
Immunometabolic pathways involved in surgical stress response and recovery.

Issue 3, Year 2, Volume 1, No. 01, January-June 2026
E-ISSN: 3122-3591, P-ISSN: 3122-3753
Review International Science Journal

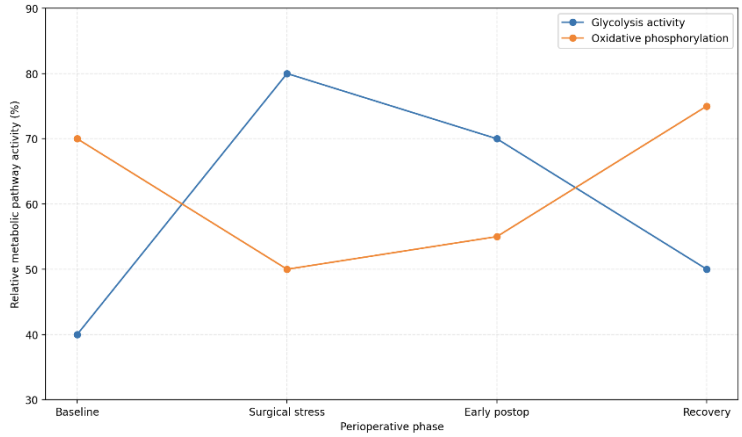

Figure 3 illustrates the dynamic changes in metabolic pathway utilization during the perioperative period, emphasizing the shift between glycolysis and oxidative phosphorylation as key components of the immunometabolic response to surgical stress.

At baseline, oxidative phosphorylation predominates, reflecting a metabolically efficient and homeostatic state in which immune cells rely on mitochondrial respiration to maintain normal function. This condition is associated with immune balance, low inflammatory activity, and adequate tissue maintenance [1], [2].

During the phase of surgical stress, a marked increase in glycolytic activity is observed, accompanied by a reduction in oxidative phosphorylation. This shift reflects a phenomenon known as metabolic reprogramming, in which immune cells—particularly activated macrophages and neutrophils—transition toward glycolysis to support rapid energy demands, cytokine production, and inflammatory responses. Although this adaptation is essential for immediate defense and tissue repair, excessive or prolonged glycolytic dominance may contribute to systemic inflammation and metabolic dysregulation [1], [11].

In the early postoperative phase, glycolysis remains elevated, although it begins to decline, while oxidative phosphorylation gradually increases. This transitional state reflects the persistence of inflammatory activity alongside the initiation of recovery processes. At this stage, the balance between these metabolic pathways becomes critical: insufficient resolution of glycolytic dominance may prolong inflammation, whereas premature suppression may impair immune defense and healing.

During the recovery phase, oxidative phosphorylation becomes predominant again, indicating a return toward metabolic homeostasis. This shift is associated with tissue repair, immune regulation, and restoration of physiological function. Patients who successfully achieve this transition tend to have better clinical outcomes, including reduced complication rates and faster recovery.

However, in patients with preexisting metabolic alterations—such as insulin resistance, obesity, or malnutrition—this transition may be delayed or incomplete. Persistent glycolytic activation and impaired mitochondrial function can lead to chronic inflammation, immune dysfunction, and increased susceptibility to complications [13], [14].

Figure 4.
Effect of ERAS-based interventions on postoperative recovery indicators.

Issue 3, Year 2, Volume 1, No. 01, January-June 2026
E-ISSN: 3122-3591, P-ISSN: 3122-3753
Review International Science Journal

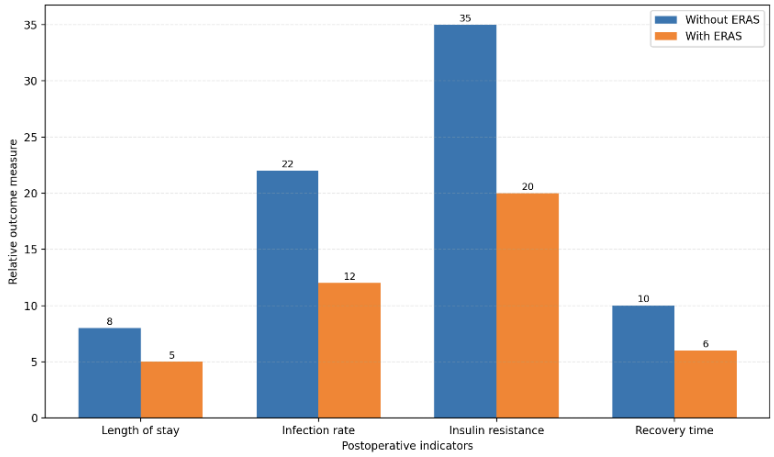

Figure 4 demonstrates the comparative impact of Enhanced Recovery After Surgery (ERAS) protocols versus conventional perioperative management on key postoperative indicators, including length of hospital stay, infection rate, insulin resistance, and recovery time. The data consistently show improved outcomes in patients managed under ERAS strategies, reinforcing the importance of metabolic optimization as a core component of surgical care.

One of the most notable findings is the reduction in insulin resistance in the ERAS group. This is particularly relevant because surgical stress is known to induce a state of acute insulin resistance, mediated by inflammatory cytokines, stress hormones, and altered glucose metabolism. ERAS interventions—such as preoperative carbohydrate loading, early feeding, and reduced fasting—help attenuate this response by maintaining metabolic stability and improving glucose utilization [5], [11], [12]. This metabolic control translates into better immune function and lower susceptibility to complications.

The reduction in infection rates observed in the ERAS group is closely linked to improved immunometabolic balance. By minimizing catabolic stress and supporting early nutritional recovery, ERAS protocols enhance immune competence, particularly neutrophil function and inflammatory regulation. This contributes to a lower incidence of surgical site infections and systemic inflammatory complications [5], [6], [7].

Length of hospital stay is also significantly reduced under ERAS management. This outcome reflects not only faster physiological recovery but also better coordination of perioperative care. Early mobilization, optimized pain control, and maintenance of metabolic homeostasis allow patients to regain function more rapidly, reducing the need for prolonged hospitalization [5].

Similarly, overall recovery time is shortened, indicating that ERAS protocols facilitate a more efficient transition from the inflammatory phase to the recovery phase described in immunometabolic models. This supports the concept that postoperative recovery is closely tied to the patient's ability to restore metabolic equilibrium and resolve inflammation effectively.

Importantly, these findings highlight that ERAS is not merely a set of clinical guidelines, but a comprehensive strategy aimed at modulating the immunometabolic response to surgery. By targeting key mechanisms such as insulin resistance, inflammation, and nutritional depletion, ERAS protocols contribute to improved outcomes across multiple dimensions.

From a clinical perspective, the figure reinforces the need to implement ERAS principles consistently, especially in colorectal surgery, where the interaction between metabolism, immunity, and intestinal physiology is particularly complex. Furthermore, in healthcare settings such as those in Mexico, Colombia, and Ecuador, where variability in patient metabolic profiles is common, the adoption of ERAS protocols may play a crucial role in standardizing care and improving surgical outcomes at a population level [5], [12].

Figure 5.

Issue 3, Year 2, Volume 1, No. 01, January-June 2026
E-ISSN: 3122-3591, P-ISSN: 3122-3753
Review International Science Journal

Role of gut microbiota and intestinal barrier dysfunction in postoperative inflammation.

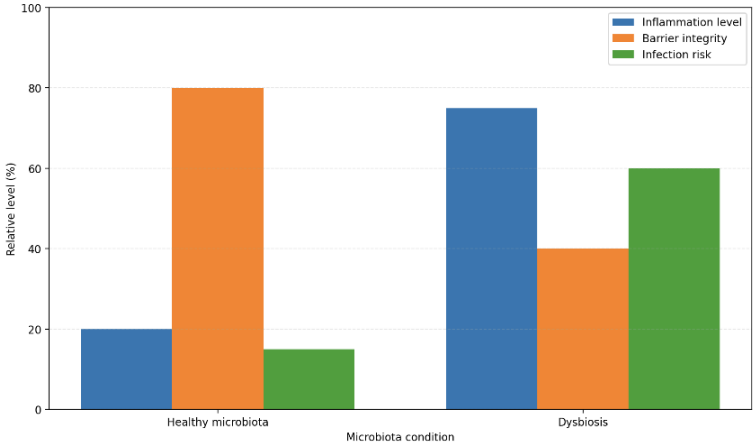

Figure 5 illustrates the relationship between gut microbiota status and key immunometabolic variables, including systemic inflammation, intestinal barrier integrity, and postoperative infection risk. The comparison between a healthy microbiota and dysbiosis highlights the critical role of the intestinal ecosystem in modulating surgical outcomes, particularly in colorectal procedures.

Patients with a preserved and balanced microbiota exhibit lower levels of systemic inflammation and maintain higher intestinal barrier integrity. This condition is associated with adequate mucosal defense, reduced bacterial translocation, and controlled immune activation. The intestinal epithelium, supported by commensal microorganisms, functions as a selective barrier that prevents the passage of pathogens and endotoxins into systemic circulation. This contributes to a lower risk of postoperative infection and improved recovery [13].

In contrast, dysbiosis—defined as an imbalance in microbial composition—leads to a significant increase in inflammatory activity. This is mediated by the overgrowth of pathogenic bacteria, increased production of pro-inflammatory metabolites, and disruption of immune homeostasis. Dysbiosis also compromises the intestinal barrier, increasing permeability and facilitating bacterial translocation, which may trigger systemic inflammatory response and septic complications after colorectal surgery [13].

The reduction in barrier integrity observed in dysbiosis is particularly relevant in coloproctology, where surgical manipulation of the intestine may exacerbate preexisting mucosal vulnerability. When barrier function is impaired, endotoxins such as lipopolysaccharides can enter circulation, activating immune pathways and amplifying systemic inflammation. This contributes to complications such as anastomotic leakage, intra-abdominal infection, and prolonged postoperative ileus.

Additionally, the figure shows a marked increase in infection risk associated with dysbiosis. This reflects the combined effect of impaired barrier function and heightened inflammatory response. In clinical practice, this may translate into higher rates of surgical site infection, abscess formation, and delayed recovery.

These findings reinforce the concept that the gut microbiota is not a passive component but an active regulator of immunometabolic balance. In colorectal surgery, where the intestinal environment is directly involved, microbiota composition becomes a key determinant of postoperative evolution. This supports the implementation of strategies aimed at preserving or restoring microbial balance, such as optimized nutrition, reduced unnecessary antibiotic exposure, and potentially the use of probiotics or prebiotics in selected patients.

Figure 6.
Integrated model of immunometabolic optimization in colorectal surgical patients.

Issue 3, Year 2, Volume 1, No. 01, January-June 2026
E-ISSN: 3122-3591, P-ISSN: 3122-3753
Review International Science Journal

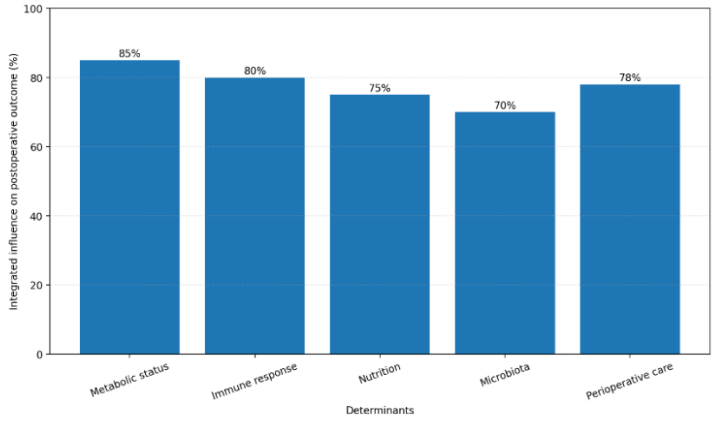

Figure 6 presents an integrated model of the main determinants influencing postoperative outcomes in colorectal surgery, highlighting metabolic status, immune response, nutritional condition, microbiota, and perioperative care as interconnected components of the immunometabolic framework.

Among these factors, metabolic status appears as the most influential determinant. This finding reinforces the central concept developed throughout this study: the preoperative metabolic condition of the patient establishes the baseline upon which the surgical stress response is built. Patients with preserved metabolic homeostasis demonstrate better capacity to regulate inflammation, maintain energy balance, and support tissue repair, leading to improved postoperative outcomes [1], [2], [4].

The immune response represents another critical pillar. Its influence is closely linked to metabolic pathways, as immune cell activation depends on energy availability and metabolic reprogramming. An adequate immune response requires a balanced transition between pro-inflammatory and anti-inflammatory phases. Dysregulation at this level may result in excessive inflammation or immunosuppression, both of which are associated with postoperative complications [1], [13].

Nutritional status also plays a fundamental role, acting as both a determinant and a modulator of immunometabolic function. Adequate nutrition supports protein synthesis, immune competence, and metabolic stability, whereas malnutrition exacerbates catabolic processes and impairs recovery. This explains why nutritional optimization is a key component of perioperative management in colorectal surgery [4], [17], [18].

The microbiota, although slightly lower in relative influence, remains highly relevant due to its role in maintaining intestinal barrier integrity, regulating inflammation, and interacting with host metabolism. As shown in previous figures, dysbiosis can significantly increase postoperative risk by promoting systemic inflammation and infection [13].

Perioperative care, particularly through ERAS protocols, integrates these factors into clinical practice. Its influence reflects the effectiveness of coordinated interventions aimed at reducing surgical stress, preserving metabolic function, and accelerating recovery. By combining early feeding, mobilization, glycemic control, and pain management, ERAS protocols act as a practical application of immunometabolic principles [5], [12].

DISCUSSION

The findings of this review highlight that postoperative outcomes in colorectal surgery are strongly influenced by the interaction between metabolic status and immune function, rather than being solely dependent on surgical technique. This perspective aligns with the growing body of evidence supporting immunometabolism as a central framework for understanding perioperative physiology and clinical variability among patients undergoing similar procedures.

One of the most consistent observations across the analyzed data is the critical role of **preoperative metabolic status**. Patients with insulin resistance, diabetes mellitus, malnutrition, or sarcopenia demonstrate a significantly higher risk of postoperative complications. These conditions are not isolated variables but part of a broader metabolic dysfunction

Issue 3, Year 2, Volume 1, No. 01, January-June 2026
E-ISSN: 3122-3591, P-ISSN: 3122-3753
Review International Science Journal

that alters immune cell behavior, inflammatory signaling, and tissue repair capacity. This supports previous reports indicating that metabolic dysregulation amplifies the surgical stress response and impairs recovery mechanisms [1], [4], [16].

In particular, **sarcopenia and malnutrition** appear as dominant determinants of poor outcomes. Unlike obesity or insulin resistance, which primarily affect metabolic pathways, malnutrition directly compromises structural and functional aspects of recovery, including protein synthesis, collagen formation, and immune competence. This dual impact explains why these conditions are associated with higher rates of anastomotic leakage, infection, and prolonged hospitalization [17], [18]. From a clinical standpoint, this reinforces the importance of early nutritional assessment and intervention as part of standard preoperative care.

Another key aspect is the **dynamic nature of immunometabolic pathways during the perioperative period**, as illustrated in the shift between glycolysis and oxidative phosphorylation. The transition from a pro-inflammatory, glycolytic state toward a regulated, oxidative state appears to be essential for successful recovery. Failure to achieve this transition may result in persistent inflammation or immune dysfunction, both of which are associated with adverse outcomes. This observation provides a mechanistic explanation for the clinical variability seen in postoperative evolution and highlights potential targets for therapeutic intervention [1], [11].

The role of the **gut microbiota** adds another layer of complexity to this model. The findings suggest that microbiota composition influences not only local intestinal conditions but also systemic immunometabolic responses. Dysbiosis is associated with increased inflammation, impaired barrier function, and higher infection risk, which are particularly relevant in colorectal surgery due to direct intestinal involvement. This supports emerging evidence that perioperative care should consider microbiota preservation as part of a broader strategy to optimize outcomes [13].

The analysis also confirms the clinical relevance of **ERAS protocols** as a practical application of immunometabolic principles. By reducing fasting, promoting early feeding, improving glycemic control, and minimizing surgical stress, these protocols contribute to maintaining metabolic stability and enhancing immune function. The observed reductions in insulin resistance, infection rates, and recovery time reinforce the idea that perioperative management should focus not only on technical aspects but also on metabolic modulation [5], [12].

Importantly, this review emphasizes the need for a **multidimensional and personalized approach** to surgical care. The interaction between metabolism, immunity, nutrition, and microbiota suggests that standardized protocols may not be equally effective for all patients. Instead, individualized assessment of metabolic and immunological profiles may allow for more targeted interventions, improving outcomes and reducing complications.

From an international perspective, these findings are particularly relevant in regions such as Mexico, Colombia, and Ecuador, where the coexistence of obesity, diabetes, and malnutrition creates a heterogeneous patient population. This epidemiological context requires adaptable strategies that address both ends of the metabolic spectrum, from excess to deficiency. Integrating immunometabolic assessment into routine surgical evaluation may help reduce disparities in outcomes and improve overall quality of care.

Despite these insights, some limitations should be considered. The variability in study designs, patient populations, and outcome measures across the literature may affect the generalizability of findings. Additionally, although

Issue 3, Year 2, Volume 1, No. 01, January-June 2026
E-ISSN: 3122-3591, P-ISSN: 3122-3753
Review International Science Journal

Issue 3, Year 2, Volume 1, No. 01, January-June 2026
E-ISSN: 3122-3591, P-ISSN: 3122-3753
Review International Science Journal

significant progress has been made in understanding immunometabolic mechanisms, there is still a need for more prospective and interventional studies to validate targeted strategies in clinical practice.

CONCLUSION

The analysis presented in this review confirms that immunometabolism plays a central role in determining postoperative outcomes in colorectal surgery. Surgical recovery is not exclusively dependent on technical factors, but rather on the patient's ability to regulate the complex interaction between metabolic pathways and immune responses during the perioperative period.

Preoperative metabolic status emerges as a key determinant of surgical prognosis. Conditions such as insulin resistance, diabetes mellitus, malnutrition, and sarcopenia significantly increase the risk of postoperative complications by altering inflammatory balance, impairing immune function, and reducing the capacity for tissue repair. Among these, malnutrition and sarcopenia stand out as particularly critical due to their direct impact on both metabolic reserve and structural recovery processes.

The dynamic modulation of immunometabolic pathways—especially the transition from a glycolytic, pro-inflammatory state toward oxidative, recovery-oriented metabolism—represents a fundamental mechanism underlying successful postoperative evolution. Patients who achieve this transition efficiently tend to experience fewer complications and faster recovery, highlighting the importance of metabolic adaptability in surgical outcomes.

In addition, the gut microbiota is identified as a relevant modulator of immunometabolic balance, particularly in colorectal surgery. Its role in maintaining intestinal barrier integrity and regulating systemic inflammation reinforces the need to consider microbial factors as part of comprehensive perioperative care.

Perioperative strategies such as ERAS protocols and immunonutrition demonstrate a clear benefit in improving clinical outcomes by targeting key immunometabolic mechanisms. These interventions contribute to reducing insulin resistance, preserving nutritional status, and promoting faster functional recovery, supporting their integration into standard surgical practice.

REFERENCES

[1] L. A. J. O'Neill, R. J. Kishton, and J. Rathmell, "A guide to immunometabolism for immunologists," *Nature Reviews Immunology*, vol. 16, no. 9, pp. 553–565, 2016.

[2] R. Xu, J. Zhang, and Y. Chen, "Immunometabolism: signaling pathways, homeostasis, and disease," *Signal Transduction and Targeted Therapy*, vol. 9, 2024.

[3] T. Curran, A. Steinhagen, and K. Keller, "Perioperative nutritional considerations in colon and rectal surgery," *Clinics in Colon and Rectal Surgery*, vol. 36, no. 3, pp. 185–193, 2023.

[4] A. Weimann, M. Braga, F. Carli, et al., "ESPEN practical guideline: Clinical nutrition in surgery," *Clinical Nutrition*, vol. 40, no. 7, pp. 4745–4761, 2021.

Issue 3, Year 2, Volume 1, No. 01, January-June 2026
E-ISSN: 3122-3591, P-ISSN: 3122-3753
Review International Science Journal

[5] U. O. Gustafsson, M. J. Scott, M. Hubner, et al., "Guidelines for perioperative care in elective colorectal surgery: Enhanced Recovery After Surgery (ERAS) Society recommendations," *World Journal of Surgery*, vol. 43, no. 3, pp. 659–695, 2019.

[6] T. McKechnie, A. L. Brown, and M. Springer, "The use of preoperative enteral immunonutrition in patients undergoing elective colorectal surgery: A systematic review and meta-analysis," *Colorectal Disease*, 2025.

[7] R. Matsui, S. Inaki, and T. Tani, "Impact of perioperative immunonutrition on postoperative outcomes in patients undergoing gastrointestinal surgery: A systematic review and meta-analysis," *Annals of Surgery Open*, vol. 4, no. 4, 2023.

[8] J. Xu, Y. Sun, and J. Zhang, "Effect of immunonutrition on colorectal cancer patients undergoing surgery: A meta-analysis," *International Journal of Colorectal Disease*, vol. 33, no. 3, pp. 273–283, 2018.

[9] A. Orellana-Jaen, M. Sánchez, and C. González, "Effects of preoperative immunonutrition on postoperative complications in patients undergoing colorectal cancer resection: A systematic review," *Nutrition Reviews*, 2025.

[10] C. S. Wong, K. Chan, and H. Lee, "Effects of enteral immunonutrition in laparoscopic versus open colorectal surgery: A systematic review and meta-analysis," *Journal of Surgical Research*, 2025.

[11] M. Shi, Y. Li, and X. Wang, "Preoperative oral carbohydrate reduces postoperative insulin resistance by activating AMP-activated protein kinase after colorectal surgery," *Digestive Surgery*, vol. 37, no. 5, pp. 403–412, 2020.

[12] A. R. Sebestyén, B. Kiss, and P. Harsányi, "Preoperative carbohydrate loading reduces length of stay after colorectal surgery: A systematic review and meta-analysis," *BMC Surgery*, 2025.

[13] F. Lin, H. Wang, and Q. Zhang, "Postoperative insulin resistance and the intestinal microbiota," *Frontiers in Endocrinology*, 2025.

[14] S. Li, Y. Zhao, and X. Chen, "Preoperative insulin resistance and stress response increase the risk of anastomotic leakage after colorectal surgery," *International Journal of Surgery*, 2025.

[15] K. M. F. Villamiel, A. H. Downs-Canner, and D. A. S. Hughes, "Enhanced Recovery After Surgery outcomes in patients with diabetes undergoing colorectal surgery," *Journal of Surgical Research*, vol. 244, pp. 97–104, 2019.

[16] Z. Z. Li, J. Wang, and L. Huang, "Sarcopenia predicts postoperative complications and survival in patients with colorectal cancer with GLIM-defined malnutrition," *Clinical Nutrition*, vol. 43, no. 1, pp. 112–120, 2024.

[17] V. Casalone, M. Biondi, and A. Rizzo, "Clinical significance of preoperative nutrition and inflammation status in gastrointestinal cancer surgery," *Nutrients*, vol. 17, no. 6, 2025.

[18] B. Piekarska, M. Dąbrowska, and A. Wójcik, "The impact of preoperative and postoperative nutritional interventions on outcomes in colorectal cancer patients," *Medicina*, vol. 60, no. 10, p. 1587, 2024.

[19] S. G. Lee, J. J. Kim, and H. S. Park, "Predicting and preventing postoperative outcomes in colorectal surgery," *Annals of Coloproctology*, vol. 35, no. 2, pp. 69–75, 2019.

[20] H. I. H. Albalawi, A. A. Althumairi, and M. Alzahrani, "Beyond the operating room: A narrative review of Enhanced Recovery After Surgery in colorectal procedures," *Cureus*, vol. 16, no. 12, 2024.

Issue 3, Year 2, Volume 1, No. 01, January-June 2026
E-ISSN: 3122-3591, P-ISSN: 3122-3753
Review International Science Journal