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PERIOPERATIVE RISK STRATIFICATION AND OPTIMIZATION IN ELDERLY SURGICAL PATIENTS: A REVIEW OF MODERN STRATEGIES AND BIOLOGICAL MARKERS IN THE ERA OF VALUE-BASED HEALTHCARE

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ABSTRACT

Background: The aging of the global population has triggered an unprecedented rise in complex surgical procedures for patients aged 80 and over. Traditional risk assessment models frequently fall short of identifying the true biological vulnerability of older adults. This study provides a critical analysis of contemporary risk stratification methods, with a particular emphasis on frailty syndrome, multimorbidity, and inflammatory-nutritional biomarkers.
Methods: We conducted a structured narrative review of literature from 2015 to 2025, indexed in PubMed, MEDLINE, and EMBASE. The analysis included 33 high-impact publications, including the latest 2025 American Society of Anesthesiologists (ASA) guidelines, EAES/SAGES consensus statements, and results from multicenter snapshot studies (SNAP-2, SNAP-3). A narrative synthesis was chosen to allow for a broader pathophysiological interpretation of data characterized by high biological heterogeneity.
Results: Our analysis confirms that frailty syndrome is a more potent predictor of 30-day mortality than chronological age (RR=3.71; 95% CI:2.89-4.77 [Tjeertes et al., 2020]). The data revealed a significant discrepancy between early mortality (approximately 2.0%) and 1-year mortality (13.4% [Gill et al., 2022]), suggesting that surgical trauma often serves as a "tipping point" that initiates a cascade of functional decline.
Biomarkers are essential for identifying this "biological frailty." Specifically, hypoalbuminemia (<35 g/L) is linked to a substantial increase in the risk of postoperative pneumonia (RR=6.18 [Tian et al., 2022]), while a C-reactive protein-to-albumin ratio (CAR≥1.5) doubles the risk of postoperative delirium (OR=2.11 [Kim et al., 2023]). Furthermore, modern multimodal prehabilitation programs effectively reduce complication rates (OR=0.64; 95% CI:0.45-0.92 [McIsaac et al., 2025]).
Conclusions: Effective care for geriatric patients requires the implementation of a hybrid model, one that integrates the traditional ASA classification with structured frailty assessments, such as the Clinical Frailty Scale (CFS), and biochemical profiling. The primary goal of treatment has shifted toward disability-free survival. Achieving this requires personalized care through comprehensive prehabilitation and a robust shared decision-making (SDM) process. The proposed four-layer model offers a practical framework for modern risk stratification in geriatric surgery.

KEYWORDS
Geriatric Surgery, Frailty Syndrome, Value-Based Healthcare, Prehabilitation, Postoperative Delirium

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1. Introduction

1.1. The Demographic Shift and Surgical Volume in the "Oldest Old"

The aging of the global population represents one of the pivotal challenges facing modern perioperative medicine. As the proportion of older adults in society continues to grow, there is a systematic increase in the number of patients being qualified for advanced surgical procedures. This phenomenon is not limited to low-risk interventions; seniors are increasingly undergoing major abdominal and thoracic surgeries, as well as complex vascular and neurosurgical procedures.

Researchers have turned their attention specifically to the cohort known as the "oldest old" (≥80 years). It is within this group that the growth dynamics of surgical volume are most pronounced. This trend concurrently correlates with a significantly higher risk of adverse postoperative outcomes and prolonged recovery periods (Elfrink et al., 2022; Sieber et al., 2025).

1.2. Surgical Epidemiology: Beyond the 30-Day Perspective

Epidemiological data from large national registries are unambiguous: in geriatric surgery, chronological age remains a potent and independent predictor of mortality. An analysis of over 3 million operations performed on seniors in Poland indicates that in-hospital mortality nearly doubles with each passing decade. Specifically, the mortality rate for patients aged 65-74 averages 1.2%, rising to 2.3% for those aged 75-84, and reaching 5.6% in the 85-94 bracket. For patients over the age of 95, this indicator surges to 13.0% (Puzianowska-Kuźnicka et al., 2016).

Such a sharp statistical leap suggests the existence of a biological "tipping point" beyond which the body's physiological reserves are drastically compromised. Similar trends are observed in Western Europe; in the Netherlands, the rate of major morbidity following oncological and vascular resections in octogenarians ranges between 13.0% and 19.0% (Elfrink et al., 2022).

It must be emphasized, however, that the traditional 30-day perspective represents only the initial stage of assessment. The full spectrum of risk to the patient, their caregivers, and the healthcare system only becomes apparent during a longer, one-year observation period. Population-based studies in the United States show that one-year mortality for individuals over 65 years averages 13.4%, with the surgical setting playing a decisive role. This risk escalates sharply in emergency situations. While 7.4% of elective surgery patients die within a year, the rate climbs to 22.3% following urgent operations (Gill et al., 2022). Effectively, nearly one in four seniors undergoing an emergency intervention does not survive the subsequent twelve months. This statistic directly challenges current qualification models for urgent procedures.

At the core of these risks are cardiovascular complications, which account for nearly one-third of deaths following non-cardiac surgery (Devereaux & Sessler, 2015). Modern risk stratification increasingly relies on objective biological parameters, such as N-terminal pro-B-type natriuretic peptide (NT-proBNP). As a marker of myocardial stress, a concentration exceeding 917 pg/mL in seniors undergoing emergency surgery serves as a powerful, independent harbinger of Major Adverse Cardiovascular Events (MACE) (Ma et al., 2015).

1.3. Biological Vulnerability and the Frailty Paradigm

Nevertheless, chronological age alone rarely explains the vast heterogeneity seen in clinical outcomes. The key to understanding an individual's vulnerability to surgical stress lies in frailty syndrome. Defined as a state of exhausted homeostatic reserves across multiple organ systems, it is estimated to affect approximately 35.0% of the geriatric surgical population (Tjeertes et al., 2020). Meta-analyses demonstrate that frailty is a significantly stronger predictor of mortality than age alone. Patients classified as "frail" face a 30-day mortality risk nearly four times higher than their robust peers (RR=3.71; 95% CI:2.89-4.77 [Tjeertes et al., 2020]).

Recent data from the Sprint National Anaesthesia Project 3 (SNAP-3) study, a multicenter snapshot study evaluating outcomes in over 11,000 seniors, confirm these findings. The study highlights that the degree of frailty, rather than just the number of comorbidities, determines both the length of hospitalization and the risk of losing independence (Swarbrick et al., 2025).

1.4. Value-Based Healthcare and Functional Independence

Contemporary geriatric surgery is evolving toward Value-Based Healthcare (VBHC). This paradigm assumes that the priority of treatment should be the health outcomes that matter most to the patient, rather than merely the technical success of the procedure. For an older patient, maintaining functional independence and mobility is often as important as survival itself. In this context, the concept of disability-free survival becomes paramount. Research has shown that frailty syndrome is the most potent independent predictor of the loss of independence within 90 days of surgery (OR=2.51 [McIsaac et al., 2020]).

Multimorbidity affects as many as 63.1% of the geriatric surgical population (Swarbrick et al., 2025). Modern concepts suggest that simply counting the number of diagnoses is an insufficient method of assessment. Instead, the focus is shifting toward Qualifying Comorbidity Sets (QCS), synergistic combinations of conditions, such as the coexistence of heart failure and chronic kidney disease. These sets amplify mortality risk far more than the sum of individual diseases would suggest (Ramadan et al., 2023). Consequently, there is a pressing need to integrate functional status with biological markers and to apply the updated American Society of Anesthesiologists (ASA) 2025 classification, which emphasizes geriatric specificities and standardized screening (Sieber et al., 2025; Kilhamn et al., 2026).

Laboratory parameters reflecting inflammaging, a chronic, low-grade systemic inflammation linked to aging—play a significant role in modern diagnostics. Hypoalbuminemia (< 35 g/L) is no longer viewed solely as an indicator of malnutrition. It is now defined as a marker of metabolic stress associated with a more than six-fold increase in the risk of postoperative pneumonia (RR=6.18 [Bohl et al., 2017; Tian et al., 2022]).

Composite indices, such as the CRP-to-albumin ratio (CAR), correlate directly with the incidence of postoperative delirium and Systemic Inflammatory Response Syndrome (SIRS) (Vasunilashorn et al., 2017; Kim et al., 2023). Specifically, values of CAR≥0.278 have been associated with a significantly increased risk of developing SIRS (aOR≈1.27), suggesting an intensified immune response to surgical trauma (Chen et al., 2022).

1.5. Study Objective

The objective of this narrative review is to provide a critical analysis of contemporary risk stratification strategies and interventions aimed at reducing complications in elderly patients. Particular emphasis is placed on the population over 80 years of age and on parameters reflecting biological vulnerability. This integrated approach forms the foundation for personalizing care and implementing multimodal prehabilitation in the era of Value-Based Healthcare.

2. Methodology

2.1. Study Design and Search Strategy

This study was conducted as a structured narrative review. The choice of this format was dictated by the need to integrate highly complex and heterogeneous datasets linking biochemical parameters with multidimensional geriatric assessments. Unlike a standard systematic review, this narrative model allows for a broader pathophysiological interpretation of results, a crucial factor for a patient population characterized by significant biological diversity. The review focuses on peer-reviewed publications released between January 2015 and December 2025, with the final literature search concluded in February 2026.

The primary bibliographic source was PubMed/MEDLINE, supplemented by records indexed in EMBASE, Web of Science, and the Cochrane Central Register of Controlled Trials (CENTRAL). The search utilized a combination of Medical Subject Headings (MeSH) and specific keywords, including: elderly, octogenarians, frailty, perioperative risk, albumin, CAR, and non-cardiac surgery.

Particular emphasis was placed on "snapshot" studies, such as the Sprint National Anaesthesia Projects (SNAP-2 and SNAP-3), which provide robust real-world evidence from large multicenter cohorts (Swarbrick et al., 2025; Tjeertes et al., 2020). The search strategy was further augmented by the "snowballing" method, involving the analysis of reference lists from key clinical guidelines issued by scientific societies, including the American Society of Anesthesiologists (ASA) and the European Association for Endoscopic Surgery (EAES) in collaboration with the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) (Keller et al., 2024; Sieber et al., 2025).

2.2. Selection Process and Search Modules

The initial search query identified 412 records. After removing duplicates and performing a preliminary analysis of titles and abstracts, 56 articles were qualified for a full merit evaluation. The quality of the studies was assessed based on their design, sample size, and the relevance of the outcomes to geriatric clinical practice. Ultimately, 33 publications were included in the final synthesis, representing the highest methodological quality and clinical currency.

The search process was organized into five thematic modules to ensure comprehensive coverage:

- Demographics: elderly, octogenarians, non-cardiac surgery, value-based healthcare.
- Risk Scales: ASA physical status, Surgical Outcome Risk Tool (SORT), and Portsmouth-Physiological and Operative Severity Score for the enUmeration of Mortality and Morbidity (P-POSSUM).
- Geriatric Syndromes: frailty index, Clinical Frailty Scale (CFS), multimorbidity, and Qualifying Comorbidity Sets (QCS).
- Biomarkers: hypoalbuminemia, CRP-to-albumin ratio (CAR), high-sensitivity C-reactive protein (hs-CRP), NT-proBNP, and troponin levels associated with Myocardial Injury after Noncardiac Surgery (MINS).
- Interventions: multimodal prehabilitation, shared decision-making (SDM), and Comprehensive Geriatric Assessment (CGA).

2.3. Inclusion and Exclusion Criteria

Studies were qualified for analysis if they met the following criteria:

- Population: Patients aged ≥65 years (with a specific focus on cohorts aged ≥80).
- Procedures: Major non-cardiac surgeries.
- Endpoints: Mortality (30-day and 1-year), organ complications such as Systemic Inflammatory Response Syndrome (SIRS), sepsis, or pulmonary complications, hemodynamic instability, and geriatric-specific outcomes including new-onset disability, loss of independence, and delirium (Li et al., 2025; McIsaac et al., 2020).

Exclusion criteria included case reports, studies with a sample size of N<20, and publications focusing exclusively on cardiac surgery due to the specific physiological impact of extracorporeal circulation on inflammatory markers.

2.4. Data Management and the Original Four-Layer Model

Bibliography management was performed using Mendeley software. Statistical data extraction, including odds ratios (OR), relative risks (RR), hazard ratios (HR), Area Under the Curve (AUC), and cutoff points, was conducted using a standardized spreadsheet. All albumin-related data were unified to the unit of g/L for consistency.

Given the heterogeneity of the data, this paper proposes an original interpretive framework, the four-layer model, to integrate various levels of risk:

- Demographic-procedural layer: Age and surgical setting (elective vs. emergency).
- Organ-based layer: Clinical stability as assessed by the ASA scale and multimorbidity indices (e.g., QCS).
- Functional layer: Homeostatic reserve (frailty) and cognitive status.
- Biochemical layer: Objective inflammatory and nutritional markers.

The integration of these layers forms the foundation for personalizing geriatric care and implementing the concept of shared decision-making.

3. Results

3.1. Epidemiology of Mortality and Classical Risk Stratification (ASA, Surgical Setting, and Cardiac Risk)

The analysis of contemporary epidemiological data leads to a fundamental conclusion: in geriatric surgery, chronological age is not merely a simple, linear indicator of risk, but rather a reflection of the rapidly diminishing physiological reserve of the organism. The most extensive evidence in this regard comes from a nationwide analysis of 3,093,254 operations performed on seniors in Poland (Puzianowska-Kuźnicka et al., 2016).

While the average in-hospital mortality for seniors oscillates around 2.0%, its dynamics accelerate sharply after the eighth decade of life. The risk of death nearly doubles with each subsequent decade: from 1.2% in the 65-74 age group, through 2.3% for those aged 75-84, up to 5.6% for the 85-94 range. Particularly striking are the data for the group over 95 years old, where mortality reaches 13.0%.

Such a sharp statistical leap suggests the existence of a biological "tipping point" beyond which compensatory mechanisms are almost entirely exhausted, confirming the need to move away from a "one-size-fits-all" approach toward precise individual assessment.

Table 1. In-hospital mortality after non-cardiac surgeries in Poland
(based on Puzianowska-Kuźnicka et al., 2016)

Age group (years)	In hospital mortality (%)
65-74	1,2%
75-84	2,3%
85-94	5,6%
≥95	13,0%

This relationship is inextricably linked to frailty syndrome, which is currently recognized as a more powerful predictor of outcomes than metric age. A meta-analysis by Tjeertes et al. (2020) demonstrated that in patients considered "frail," the 30-day mortality risk is nearly four times higher (RR=3.71; 95% CI: 2.89–4.77). This vulnerability manifests as early as the surgical procedure itself.

Patients with frailty features exhibit significantly greater hemodynamic instability due to impaired vascular autoregulation and autonomic dysfunction. Clinical observations indicate a more frequent need for pharmacological hemodynamic stabilization with catecholamines and an increased demand for blood product transfusions in this cohort (Saetang et al., 2025). The latest data from the SNAP-3 study (Sprint National Anaesthesia Project 3), involving a cohort of 11,487 patients, confirm that even mild frailty (category 4 on the Clinical Frailty Scale [CFS]) is associated with a significant prolongation of hospitalization, with a median 0.75 days longer compared to CFS 1–3, and a higher risk of postoperative loss of independence (Swarbrick et al., 2025).

The traditional American Society of Anesthesiologists (ASA) classification retains its high prognostic value, although its interpretation in seniors is undergoing a significant evolution. An analysis of the Swedish population (460,046 procedures) allowed for a precise determination of risk based on the surgical setting. It

showed that for 30-day mortality, ASA category 3 (compared to ASA 1) is associated with an approximately 14-fold higher risk of death in both elective (OR=13.7) and acute (OR=14.0) surgery. The greatest discrepancies are visible in category ASA≥4, where the odds ratio reaches 62.2 for elective procedures and 51.1 for emergency cases (Kilhamn et al., 2026).

According to the ASA Practice Advisory 2025, classical physical status assessment must now be supplemented with standardized screening for frailty, malnutrition risk, and cognitive impairment (Sieber et al., 2025).

The surgical setting remains a critical risk multiplier. Emergency operations in patients over 80 years old represent a massive physiological burden, as indicated by a one-year mortality rate of 22.3%, whereas in elective settings, it stands at 7.4% (Gill et al., 2022). This disproportion stems from the lack of time for optimization and the overlapping of acute stress onto chronic multimorbidity, which affects as many as 63.1% of operated seniors (Swarbrick et al., 2025). Modern stratification focuses on so-called Qualifying Comorbidity Sets (QCS), where, for instance, concurrent renal and circulatory failure creates a synergistic "risk triad," generating a threat far more potent than the simple sum of individual diagnoses (Ramadan et al., 2023).

Table 2. One-year mortality in seniors (≥ 65 years) depending on the surgical setting (based on Gill et al., 2022)

Surgical setting	12-month mortality (%)
Elective	7,4%
Emergency	22,3%
General average	13,4%

Cardiovascular complications remain the primary cause of death in this population (Devereaux & Sessler, 2015). The most insidious threat is Myocardial Injury after Noncardiac Surgery (MINS). It is a deceptive phenomenon because, in over 90.0% of seniors, it occurs without typical chest pain symptoms, often due to neuropathy, analgesic use, or the masking of symptoms by delirium. MINS is associated with a nearly 10.0% 30-day mortality rate.

In identifying patients with extremely low cardiac reserve, preoperative biochemical markers prove superior to clinical assessment. An N-terminal pro-B-type natriuretic peptide (NT-proBNP) concentration > 917 pg/mL in seniors operated on in an emergency setting is a strong, independent predictor of Major Adverse Cardiovascular Events (MACE) (Ma et al., 2015).

Ultimately, contemporary stratification redefines treatment success through the lens of disability-free survival. Prospective studies indicate that frailty syndrome is the strongest predictor of the composite endpoint, death or new disability within 90 days of intervention (OR=2.51 for the CFS scale) (McIsaac et al., 2020).

In summary, a reliable geriatric risk assessment must constitute a triad integrating clinical status (ASA and QCS), the procedural context (emergency vs. elective), and the functional reserve of the organism (frailty and biomarkers). Such integrated diagnostics prevent the dangerous underestimation of risk in patients for whom surgical trauma is the ultimate test of their biological endurance.

3.2. Predictive Models and Clinical Judgment - The Boundaries of Standardization in the Geriatric Population

The development of predictive models has emerged as a direct response to the need for objective perioperative risk assessment and the elimination of cognitive biases, such as anchoring or overconfidence. While these algorithms are intended to provide a reproducible and measurable evaluation of surgical threat, they encounter significant limitations within the geriatric population, which is characterized by profound biological heterogeneity.

The primary shortcoming of classic scales, such as the Surgical Outcome Risk Tool (SORT) or the Portsmouth-Physiological and Operative Severity Score for the enUmeration of Mortality and Morbidity (P-POSSUM), lies in their static nature. Most of these tools rely on organ stability at a single point in time, largely ignoring dynamic shifts and functional reserve, the organism's capacity to return to homeostasis following the acute trauma of surgery.

3.2.1. The Power of Clinical Intuition: The SNAP-2 Study

Crucial insights into the role of a physician's "intuition" were provided by the international prospective study SNAP-2: EPICCS (Sprint National Anaesthesia Project: Epidemiology of Critical Care after Surgery). The study revealed a phenomenon significant to the psychology of decision-making: despite the widespread availability of advanced algorithms, in nearly 90.0% of cases (88.7%), clinicians continue to base their decisions on Subjective Clinical Judgment (SCJ).

More strikingly, the discriminative capacity of clinical judgment alone, as measured by the Area Under the Receiver Operating Characteristic curve (AUROC) (AUROC=0.89; 95% CI: 0.86–0.91), proved almost identical to that of the rigorous SORT model (AUROC=0.90).

This suggests that experienced physicians possess a subconscious ability to synthesize hundreds of subtle clinical signals, ranging from a patient's gait and speech tempo to a general impression of "biological attrition", which traditional mathematical models fail to fully quantify (Wong et al., 2020). However, the highest "net gain" in identifying high-risk patients was achieved by combining both methods (AUROC=0.92), underscoring that predictive models should function as Clinical Decision Support Systems (CDSS) rather than final arbiters.

3.2.2. Redefining Success: Beyond 30-Day Mortality

The evolution toward personalized medicine necessitates an understanding of why general models often fail when applied to seniors. These tools rarely account for frailty syndrome, which is a far more potent predictor of outcomes than chronological age. Modern geriatric surgery is redefining treatment goals according to the Value-Based Healthcare (VBHC) paradigm, where success is measured not merely by survival, but by the preservation of autonomy.

Traditional models focused on 30-day mortality are inherently flawed in this context, as they completely overlook disability-free survival. Frailty remains the strongest harbinger of functional independence loss within 90 days of a procedure (OR=2.51; McIsaac et al., 2020).

3.2.3. Measuring the Immeasurable: Frailty Screening Tools

An additional challenge is the lack of methodological consensus in measuring frailty itself. A comparative study of seven screening instruments revealed a startling discrepancy: the proportion of patients classified as "frail" varied from 13.4% to as much as 73.8% depending on the scale utilized (Fagard et al., 2025).

- G8 Screening Scale: Boasts high sensitivity (81.5%), making it effective for initial selection, but its low specificity (30.8%) generates a high volume of false positives.
- Clinical Frailty Scale (CFS): Proven to be the most practical and balanced tool for daily practice, despite only moderate predictive ability for complications on the Clavien-Dindo scale (Fagard et al., 2025).

When considering neurological complications, the leading cause of independence loss in seniors, the precision of the assessment tool becomes critical. The Frailty Index (FI), based on the cumulative deficit model, shows a significantly stronger and independent correlation with the incidence and severity of postoperative delirium than the simplified physical phenotype (RR=2.13 vs. 1.61; Deiner et al., 2024). This suggests that the aging brain does not react to isolated physical weakness, but rather to the aggregate exhaustion of reserves across all physiological systems.

3.2.4. Multimorbidity and Qualifying Comorbidity Sets (QCS)

Parallel to this, a shift in the approach to multimorbidity is essential. Data from the SNAP-3 study indicate that this issue affects 63.1% of patients (Swarbrick et al., 2025). Modern stratification is moving away from a simple arithmetic of diagnoses toward the identification of specific Qualifying Comorbidity Sets (QCS) with high prognostic value. For example, clusters combining heart failure, chronic kidney disease, and anemia create a synergistic effect that amplifies the risk of death and delirium much more severely than the sum of those conditions evaluated in isolation (Ramadan et al., 2023).

3.2.5. Future Directions: AI and Machine Learning

The future of geriatric risk stratification lies in Machine Learning (ML) algorithms capable of integrating static data from electronic health records with dynamic data from intraoperative monitoring. These models could update the risk of delirium or Myocardial Injury after Noncardiac Surgery (MINS) in real-time, allowing for immediate intervention.

However, until these technologies achieve full clinical validation, a hybrid model, merging classic parameters, modern frailty assessment, and experienced clinical judgment, remains the gold standard of care (Sieber et al., 2025; Keller et al., 2024).

3.3. The Biological Dimension of Frailty - Integrating the Geriatric Phenotype with Inflammatory-Nutritional Biomarkers

Contemporary perioperative medicine is undergoing a fundamental paradigm shift. The center of gravity is moving from the evaluation of isolated, organ-specific diseases toward a holistic view of the senior's biological vulnerability. Data concerning annual mortality, alongside the impact of frailty and cognitive impairment on treatment outcomes, unequivocally prove that classic risk stratification based solely on the American Society of Anesthesiologists (ASA) scale is unable to capture the full spectrum of geriatric hazards (Gill et al., 2022; Sieber et al., 2025). Within this context, an extended preoperative assessment becomes a clinical necessity, allowing for the identification of patients with significantly diminished physiological reserves.

3.3.1. The Clinical Expression of Vulnerability

The cornerstone of this assessment is frailty syndrome, understood as a multidimensional construct reflecting the accumulation of deficits across multiple organ systems. Meta-analyses confirm that frailty is a much stronger predictor of adverse events than chronological age (Tjeertes et al., 2020).

The latest data from the Sprint National Anaesthesia Project 3 (SNAP-3) indicate that even mild degrees of frailty, corresponding to category 4 on the Clinical Frailty Scale (CFS), are associated with a significant prolongation of hospitalization. In these cases, the median stay is 0.75 days longer compared to robust patients, and they face a higher risk of postoperative loss of independence (Swarbrick et al., 2025).

A senior's biological vulnerability manifests dynamically during the surgical procedure itself. Patients with frailty traits more frequently experience intraoperative hemodynamic instability and exhibit a higher demand for blood product transfusions (Saetang et al., 2025). These incidents serve as direct evidence of the exhaustion of the body's homeostatic mechanisms.

According to data from McIsaac (2020), frailty syndrome is the strongest harbinger of a composite endpoint including death or the onset of a new disability within 90 days of intervention (OR=2.51), making it a critical parameter in discussions regarding the patient's projected quality of life.

3.3.2. Metabolic and Nutritional Markers

An integral component of metabolic reserve is nutritional status, for which albumin remains the most sensitive laboratory indicator. Preoperative hypoalbuminemia (concentration < 35 g/L) affects nearly half of the seniors undergoing orthopedic surgery (Bohl et al., 2017). The consequences of this deficit are multi-organ in nature. Low albumin levels (threshold ≤ 34 g/L) are associated with a twofold increase in 30-day mortality and a significantly higher risk of postoperative pneumonia (RR=6.18; 95% CI: 3.15–11.98; Nipper et al., 2022; Tian et al., 2022).

However, the influence of albumin goes deeper, serving as a laboratory correlate for what is termed "brain frailty." Research has demonstrated that an albumin concentration below the threshold of 38.4 g/L is strongly linked to the risk of subsyndromal delirium (OR=6.13), particularly when baseline cognitive deficits coexist (Li et al., 2025). This mechanism is explained by the concept of neuroinflammaging, chronic inflammation leading to increased blood-brain barrier permeability.

Albumin, acting as the primary plasma antioxidant, protects neurons from oxidative damage during surgical stress; its deficiency leaves the senior's brain defenseless against pro-inflammatory cytokines such as interleukin-6 (IL-6) or tumor necrosis factor-alpha (TNF-α).

3.3.3. Inflammaging and the CRP-to-Albumin Ratio (CAR)

Modern risk stratification also assigns a key role to chronic inflammatory activation, known as aging-related inflammation (inflammaging). Preoperative elevation of C-reactive protein (CRP ≥ 3 mg/L) is associated with a 1.4-fold higher risk of delirium and increased severity of the condition (Vasunilashorn et al., 2017). In response to the need for integrating data on inflammation (destruction) and metabolism (protection), composite indices such as the CRP-to-albumin ratio (CAR) have emerged.

A high CAR≥1.5 heralds a higher incidence of delirium (OR=2.11) and an increase in overall mortality (Hazard Ratio [HR] = 1.44; Kim et al., 2023). Conversely, CAR values above 0.278 correlate with the risk of developing Systemic Inflammatory Response Syndrome (SIRS) within the first three days after surgery, suggesting an intensified immune response to surgical trauma in the senior (Chen et al., 2022).

3.3.4. Redefining Multimorbidity

Parallel to this, a redefinition of the approach to multimorbidity is required. Data from SNAP-3 prove that this phenomenon affects up to 63.1% of the geriatric population (Swarbrick et al., 2025). However, from a prognostic standpoint, it is not the simple sum of diagnoses, but specific Qualifying Comorbidity Sets (QCS) that determine treatment outcomes. Clusters of diseases, such as concurrent heart failure and chronic renal

failure, create a synergistic effect that amplifies mortality risk much more strongly than the arithmetic sum of the diseases evaluated separately (Ramadan et al., 2023).

The evolution toward a hybrid model allows for a transition from "averaged" medicine to truly personalized perioperative care. In the oldest-old population (≥ 80 years), the integration of a structured frailty assessment, such as the Frailty Index (FI), which shows a stronger and more independent association with delirium (RR=2.13) than simplified phenotypic models, with biochemical inflammatory-nutritional profiling provides an essential diagnostic compass (Deiner et al., 2024).

3.4. Preoperative Optimization in Older Adults – From Identification to Intervention

Modern geriatric surgery is currently compelled to transition from a reactive paradigm, centered on treating complications after they arise, toward a proactive strategy rooted in early risk identification and aggressive modification. Comprehensive Geriatric Assessment (CGA) is no longer merely an academic construct; it has gained tangible clinical value as an "engine" that drives specific, targeted interventions.

In the population of patients over the age of 80, a group characterized by severely diminished physiological reserves, the precise preparation of the patient for surgical stress has become a decisive prognostic factor. In many instances, this preparation outweighs the significance of the surgical technique itself (Keller et al., 2024; Sieber et al., 2025).

3.4.1. Nutritional Conditioning: The Metabolic Foundation

Nutritional intervention stands as the bedrock of this optimization process. Preoperative hypoalbuminemia (albumin concentration < 35 g/L) should no longer be viewed as a static, passive indicator of malnutrition. In the landscape of contemporary perioperative medicine, we define it as a critical warning signal indicating the exhaustion of metabolic reserves.

The data are stark: low albumin levels are associated not only with higher mortality (RR=1.52; 95% CI: 1.22-1.89), but also with a drastically increased risk of sepsis (RR=1.92) and postoperative pneumonia (RR=6.18; 95% CI: 3.11-12.28; Bohl et al., 2017; Tian et al., 2022). Recent reports point toward the existence of a devastating "vicious cycle": hypoalbuminemia increases the risk of pulmonary infection (OR=7.96), which, by intensifying systemic inflammation and catabolism, further drains the senior's protein resources (Wang et al., 2025).

For elective procedures involving patients at high nutritional risk, the European Society for Clinical Nutrition and Metabolism (ESPEN) guidelines recommend the implementation of a nutritional therapy protocol lasting 7 to 14 days prior to surgery. Key components include:

- Protein intake: 1.2–1.5 g/kg of body weight per day.
- Vitamin D supplementation: acting as a modulator of both innate immunity and muscle strength.

Such "metabolic conditioning," as recommended by the EAES/SAGES (2024), tangibly strengthens the body's regenerative capacity and mitigates the risk of anastomotic leaks or surgical site infections.

3.4.2. Managing "Inflammaging" and Neuroprotection

Equally critical is the management of age-related chronic inflammation, commonly referred to as "inflammaging." A preoperative elevation of C-reactive protein (CRP ≥ 3 mg/L) serves as the biological fuel for postoperative cognitive disorders (Vasunilashorn et al., 2017). Hybrid markers, such as the CRP-to-albumin ratio (CAR), function as an early warning system for "biological frailty." A CAR≥1.5 is associated with a significant increase in delirium risk (OR=2.11), while values exceeding 0.278 herald the onset of Systemic Inflammatory Response Syndrome (SIRS) within the first 72 hours following surgery (Chen et al., 2022; Kim et al., 2023).

The identification of these markers should necessitate the immediate implementation of neuroprotection protocols in accordance with the ASA 2025 guidelines (Sieber et al., 2025). These protocols encompass non-pharmacological interventions:

- Early mobilization and strict sleep hygiene.
- Ensuring access to hearing aids and glasses.
- Consistent reorientation in the hospital environment.

Furthermore, knowledge of the senior's biological status must translate into a personalized intraoperative strategy. Patients with frailty syndrome exhibit a significant propensity for hemodynamic instability and higher transfusion requirements (Saetang et al., 2025). Proactive blood pressure management, aiming to maintain the mean arterial pressure (MAP) at levels close to the patient's baseline (goal-directed therapy), is vital for protecting the "frail brain" from hypoperfusion.

3.4.3. Prehabilitation and Shared Decision-Making

Modern optimization is redefining the ultimate goals of treatment by shifting the emphasis toward disability-free survival. The ASA (2025) guidelines place immense weight on the process of shared decision-making (SDM). This is particularly vital given the data from the SNAP-3 study, which reveal that one year after surgery, nearly one in three frail seniors (29.4%) either dies or suffers from a new, permanent disability (Swarbrick et al., 2025).

In this context, multimodal prehabilitation acts as a catalyst for change. It is built upon three fundamental pillars:

- The Physical Pillar: combating sarcopenia through resistance training (e.g., three 45-minute sessions per week).
- The Nutritional Pillar: optimizing protein and micronutrient intake.
- The Neuropsychological Pillar: cognitive training and stress reduction to build cerebral reserve.

Network meta-analyses confirm the efficacy of such programs, showing that the odds ratio for the occurrence of complications when utilizing full prehabilitation is OR=0.64 (95% CI: 0.45-0.92; McIsaac et al., 2025). Even in emergency settings, where the window for intervention is limited, objective biochemical parameters (albumin, CRP, troponin, NT-proBNP) remain the most reliable tools for supporting critical decisions. They allow for the rapid identification of patients who require referral to intensive care units, providing the senior with a genuine chance not only to survive the operation but, most importantly, to return to a dignified and independent life.

4. Discussion

The analysis presented here demonstrates that modern perioperative risk stratification for seniors must evolve toward a multi-layered model firmly rooted in the paradigm of Value-Based Healthcare (VBHC). In this contemporary framework, priority is no longer restricted to the technical precision of a procedure or surviving the immediate in-hospital stay. Instead, the focus shifts toward maximizing health outcomes that are truly meaningful to the patient, such as the restoration of mobility, the preservation of functional independence, and the minimization of suffering, relative to the risks and costs of the intervention.

4.1. Beyond Chronological Age: Frailty and the Tipping Point of Survival

The primary conclusion derived from this synthesis of data is that chronological age is an insufficient, and often misleading, predictor of individual surgical outcomes. Biological frailty possesses significantly higher discriminative power in predicting death and complications than metric age (Chan et al., 2022; Tjeertes et al., 2020). In patients classified as "frail," the risk of 30-day mortality is nearly four times higher (RR=3.71; 95% CI: 2.89-4.77), indicating that the organism's biological state and the degree of homeostatic reserve exhaustion should be the primary determinants in surgical qualification decisions.

A critical phenomenon revealed by this analysis is the stark discrepancy between early and long-term mortality. The 30-day perspective, where the risk of death hovers around 2.0% (Puzianowska-Kuźnicka et al., 2016), represents only the tip of the geriatric burden iceberg. The full picture of a senior's biological vulnerability emerges only on a one-year scale, when mortality escalates to 13.4% (Gill et al., 2022). This six- to seven-fold increase suggests that surgery in the elderly is often a "tipping point" that initiates a cascade of adverse multi-organ and metabolic events.

Consequently, surgical success requires a fundamental redefinition. As demonstrated by McIsaac et al. (2020), for a senior, the onset of a new, permanent disability is a clinical outcome of comparable gravity to death. Frailty syndrome proves to be the strongest predictor of this loss of functional independence (OR=2.51; 95% CI: 1.50-4.21), necessitating a shift in focus toward disability-free survival.

The surgical setting remains an essential multiplier of risk, particularly in the geriatric population where time for necessary optimization is often non-existent. Emergency operations are associated with a one-year mortality rate of 22.3% (Gill et al., 2022). For the "oldest old" (≥80 years), the absence of a "golden window" for prehabilitation and the correction of metabolic deficits poses a severe threat. This vulnerability manifests even intraoperatively; frail patients exhibit impaired vascular autoregulation, leading to a more frequent need for hemodynamic stabilization and higher transfusion requirements (Saetang et al., 2025). While the classic American Society of Anesthesiologists (ASA) classification remains a foundational pillar of physical status assessment (Kilhamn et al., 2026), it fails to capture these dynamic changes unless supplemented by functional parameters and structured geriatric screening, as advocated by the ASA Practice Advisory 2025 (Sieber et al., 2025).

A significant contribution of this analysis is the redefinition of the approach to multimorbidity, which affects as many as 63.1% of elderly surgical patients (Swarbrick et al., 2025). However, the mere counting of diagnoses loses prognostic value in favor of identifying specific Qualifying Comorbidity Sets (QCS). For example, clusters combining renal failure with heart disease and anemia amplify mortality risk far more aggressively than their simple sum would suggest (Ramadan et al., 2023).

Integrating such a structural assessment of organ burden with frailty measurement helps avoid the trap of "apparent stability" in patients who may seem clinically compensated but possess extremely low adaptive reserves. The choice of frailty measurement tool is also critical; the popular G8 scale is characterized by high sensitivity (81.5%) but low specificity (30.8%), suggesting its role should be limited to initial screening before a Comprehensive Geriatric Assessment (CGA) is performed (Fagard et al., 2025).

4.2. Biological Vulnerability: From "Brain Frailty" to Inflammatory Markers

A profound pathophysiological insight is the link between frailty and neurocognitive complications, often referred to as "brain frailty." Evidence shows that the Frailty Index (FI), based on the accumulation of deficits, is a more robust predictor of the incidence and severity of postoperative delirium (RR=2.13; 95% CI: 1.23-3.70) than simplified phenotypic models (Deiner et al., 2024). The biochemical expression of this risk is inflammaging, a chronic, low-grade inflammatory state. Preoperative elevation of C-reactive protein (CRP ≥3 mg/L) not only heralds the onset of delirium but directly correlates with its longer duration and greater severity (Vasunilashorn et al., 2017). Combined with hypoalbuminemia (<35 g/L) and a high CRP-to-albumin ratio (CAR≥1.5), these parameters form an objective early warning system for homeostatic collapse (Kim et al., 2023; Li et al., 2025). This mechanism, rooted in neuroinflammation and increased blood-brain barrier permeability, explains why seniors with metabolic deficits tolerate surgical trauma so poorly.

4.3. The Four-Layer Model: Bridging Theory and Clinical Practice

Based on the evidence gathered, we propose an original four-layer model for perioperative risk stratification in seniors, designed to serve as an interpretative framework for medical personnel:

- Demographic Layer: Age and surgical setting as baseline statistical multipliers.
- Clinical Layer: The ASA physical status (including QCS) as a measure of organ burden.
- Functional Layer: Frailty (assessed via Clinical Frailty Scale [CFS] or FI) and cognitive status, reflecting true adaptive reserve.
- Biochemical Layer: Inflammatory-nutritional markers (CAR, albumin) and cardiac markers (NT-proBNP) as dynamic correlates of vulnerability.

However, implementing such comprehensive models faces significant systemic barriers, particularly within the Polish healthcare context. The primary challenge remains the shortage of geriatricians within perioperative teams and the dominant "siloed" model of care, where surgeons, anesthesiologists, and internists rarely integrate their assessments into a single, cohesive strategy. Although the CGA process is time-consuming, VBHC demonstrates that investing time in preoperative evaluation translates into shorter hospital stays and fewer complications.

A critical component of this Discussion is the ethical aspect of shared decision-making (SDM). In light of data showing that nearly 30.0% of frail seniors lose their independence within one year of surgery (Swarbrick et al., 2025), physicians face a profound dilemma: is every technically feasible operation truly beneficial for the patient? True informed consent in the elderly must include a candid discussion regarding the risk of "new disability," not just the risk of death.

The limitations of this analysis must be acknowledged. The included studies exhibit significant methodological heterogeneity, particularly regarding the definitions of frailty and the cutoff points for biomarkers (e.g., CAR values ranging from 0.278 to 1.5), which complicates the creation of a single, universal algorithm. Nevertheless, the consistency of the trends is striking and points toward the urgent need for hybrid qualification models.

According to guidelines from the EAES/SAGES (2024) (Keller et al., 2024), optimizing the senior via multimodal prehabilitation (physical training, immunonutrition, and psychological support) is no longer a luxury but a standard that transforms the patient from a passive recipient of care into an active participant in their recovery. Network meta-analyses confirm that such approaches reduce the overall rate of complications by nearly 35.0% (OR=0.64; 95% CI: 0.45-0.92 [McIsaac et al., 2025]).

In summary, optimal care for the geriatric patient requires a move away from clinical intuition toward biologically justified stratification. Only the integration of clinical status, structured frailty assessment, and an inflammatory profile will allow physicians to accurately balance benefits and risks, thereby protecting the senior’s quality of life and providing a genuine opportunity to return to independence after leaving the operating room.

5. Conclusions

The synthesis of contemporary data from 2015-2025 demonstrates that perioperative medicine for older adults requires a fundamental departure from traditional, organ-centric risk assessment in favor of a model oriented toward the biological and functional vulnerability of the organism. The primary conclusion of this analysis is that chronological age, while remaining a relevant statistical reference point, possesses significantly less predictive power than frailty syndrome. It is the degree of homeostatic reserve exhaustion, expressed clinically through frailty and biochemically through inflammatory and metabolic markers, that should form the axis of modern risk stratification.

Recognizing frailty as a primary multiplier of mortality (RR=3.71) and the strongest determinant of the loss of independence (OR=2.51; McIsaac et al., 2020) compels a radical redefinition of surgical success. In the era of Value-Based Healthcare (VBHC), the ultimate goal of treatment for the elderly is no longer merely the technical success of a procedure, but the achievement of optimal disability-free survival.

Achieving this objective in clinical practice necessitates the implementation of a hybrid assessment model that integrates the clinician's experience with objective decision-support systems. The use of biochemical markers, such as hypoalbuminemia (< 35 g/L) and an elevated CRP-to-albumin ratio (CAR≥1.5), allows for the precise identification of patients with a "frail biological profile" who face significantly higher risks of major pulmonary (RR=6.18) and neurological complications (Tian et al., 2022; Kim et al., 2023).

Such multi-layered diagnostics, combining the American Society of Anesthesiologists (ASA) classification with Qualifying Comorbidity Sets (QCS) and structured geriatric screening, prevents the dangerous underestimation of threat in seniors who, despite apparent clinical stability, are on the brink of homeostatic collapse (Ramadan et al., 2023; Sieber et al., 2025).

A cornerstone of modern perioperative strategy for patients over 80 is the transition from a reactive model to proactive optimization. The detection of functional or metabolic deficits during the preoperative phase should not serve as grounds for automatic disqualification; rather, it must become the immediate trigger for multimodal prehabilitation.

As network meta-analyses confirm, integrated physical training aimed at combating sarcopenia, targeted nutritional support consistent with ESPEN guidelines, and neuropsychological optimization significantly reduce complication rates (OR=0.64; 95% CI: 0.45-0.92 for comprehensive interventions; McIsaac et al., 2025). This optimization is particularly critical given the high one-year mortality following emergency procedures (22.3%), where the margin for error in managing biological reserves is minimal (Gill et al., 2022).

Ultimately, robust risk stratification based on the proposed four-layer model (demographics, clinical parameters, functional status, and biomarkers) serves more than just the improvement of technical outcomes. It facilitates a genuine process of shared decision-making (SDM). In the face of a real threat of "new disability," the dialogue between physician and patient must be grounded in evidence regarding projected quality of life.

The full integration of the biology of aging, evidence-based medicine, and individual senior preferences enables ethical, clinically effective, and empathetic perioperative care in the 21st century, transforming geriatric surgery into a discipline that generates high health value.

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