Review Article

Physiological effects and postoperative outcomes of prolonged anesthesia in geriatric patients undergoing cardiovascular surgery

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International Archives of Integrated Medicine, Vol. 13, Issue 1, January, 2026.
Available online at http://iaimjournal.com/
ISSN: 2394-0026 (P) **ISSN: 2394-0034 (O)**
Received on: 10-1-2026 **Accepted on:** 22-1-2026
Source of support: Nil **Conflict of interest:** None declared.

DOI: **10.5281/zenodo.18376791**

How to cite this article: Edgardo José Soto Junco, David Diaz Polo, Reiner Serrano Calderón, Cristian Ismael Gomez Saborío, Mariam Ramirez Solano, Daniela Consumi Cordero. Physiological effects and postoperative outcomes of prolonged anesthesia in geriatric patients undergoing cardiovascular surgery. Int. Arch. Integr. Med., 2026; 13(1): 94-105.

Abstract

Population aging has led to a growing number of geriatric patients undergoing cardiovascular surgery, in whom prolonged anesthesia represents a relevant clinical challenge. Aging is associated with structural and functional alterations across multiple organ systems, including increased arterial stiffness, reduced cardiac output, impaired pulmonary mechanics, cognitive vulnerability, and diminished renal reserve. These changes significantly modify the physiological response to anesthesia and increase susceptibility to perioperative complications. Prolonged anesthesia in older adults has been consistently associated with hemodynamic instability, myocardial dysfunction, respiratory depression, neurocognitive impairment, and systemic inflammatory and oxidative stress responses,

which together contribute to adverse postoperative outcomes. Clinical evidence indicates that extended anesthetic exposure in geriatric cardiovascular surgery is linked to a higher incidence of early postoperative complications, particularly arrhythmias, myocardial infarction, respiratory failure, acute kidney injury, postoperative delirium, and persistent cognitive impairment. These complications are further associated with prolonged intensive care unit and hospital stays, increased readmission rates, and potentially higher long-term mortality. Frailty emerges as a critical determinant of risk, outperforming chronological age as a predictor of adverse outcomes, while multimorbidity, anesthetic duration, choice of anesthetic agents, and surgical complexity further modulate perioperative risk. Despite consistent associations between prolonged anesthesia and adverse outcomes, the available evidence is limited by methodological heterogeneity, lack of standardized outcome definitions, and a scarcity of studies specifically focused on geriatric cardiovascular populations. Risk stratification tools currently used in clinical practice show limited predictive accuracy in the oldest-old patients. Overall, the literature highlights anesthetic duration as a potentially modifiable factor and underscores the importance of individualized anesthetic and surgical strategies. Optimizing anesthetic exposure, integrating frailty assessment, and tailoring perioperative management may improve postoperative outcomes in this vulnerable population, while further high-quality, geriatric-focused research is needed to guide evidence-based practice.

Key words

Geriatric anesthesia, Prolonged anesthesia, Cardiovascular surgery, Postoperative outcomes, Frailty, Perioperative risk, Physiological effects of anesthesia.

Introduction

Population aging has led to a marked increase in the number of cardiovascular surgical procedures performed in older adults. This demographic shift is particularly relevant in clinical practice, as elderly patients frequently exhibit diminished physiological reserves and heightened susceptibility to surgical stress and perioperative complications [1, 2]. The burden of surgery in this population is further compounded by the high prevalence of multimorbidity and frailty, both of which have been consistently identified as major predictors of postoperative complications and increased mortality [3].

Geriatric patients are characterized by a progressive decline in physiological reserve across multiple organ systems, rendering them particularly vulnerable to the combined stresses of surgery and anesthesia [2]. Cognitive impairment is a common comorbidity in this population and has been strongly associated with an increased risk of postoperative delirium, prolonged hospital stays, and overall poorer recovery trajectories following surgical interventions [4]. In parallel, frailty highly prevalent among older adults undergoing cardiovascular procedures has emerged as a critical determinant of adverse outcomes, significantly increasing the likelihood of postoperative complications and mortality [3, 5].

Within this context, prolonged anesthesia represents an important and potentially modifiable perioperative factor. In cardiovascular surgery, extended anesthetic duration is often required due to procedural complexity and patient-specific considerations, including baseline health status and intraoperative challenges [1]. Prolonged exposure to anesthesia has been identified as a potential risk factor for adverse outcomes, particularly in older adults with limited physiological reserve and established frailty [6]. Additionally, the selection of anesthetic agents may influence postoperative recovery, as differences between agents such as desflurane and sevoflurane have been associated with variations in emergence times and

postoperative complications, although current evidence remains inconclusive [7].

Given these considerations, there is a clear need to integrate physiological insights with clinical evidence to optimize perioperative management strategies for older adults undergoing cardiovascular surgery [2]. A deeper understanding of the interactions between aging, frailty, and prolonged anesthesia has the potential to inform anesthetic and surgical decision-making, ultimately improving patient outcomes while reducing postoperative morbidity and the broader healthcare burden associated with this growing patient population [6].

The objective of this review is to synthesize and critically analyze the available evidence on the physiological effects and postoperative outcomes associated with prolonged anesthesia in geriatric patients undergoing cardiovascular surgery, with particular emphasis on the interaction between aging, frailty, anesthetic exposure, and perioperative risk, in order to inform clinical decision-making and optimize perioperative care in this vulnerable population.

Methodology

This review was conducted following a narrative and integrative bibliographic approach, in accordance with the proposed structure for analyzing the physiological effects and postoperative outcomes of prolonged anesthesia in geriatric patients undergoing cardiovascular surgery. The objective of the methodological strategy was to systematically identify, organize, and synthesize existing evidence addressing age-related physiological vulnerability, anesthetic exposure, and perioperative outcomes in this specific population.

A comprehensive literature search was performed using major scientific databases relevant to anesthesiology, cardiovascular surgery, geriatrics, and perioperative medicine, including PubMed, Scopus, Web of Science, and the Cochrane Library. These databases were selected to ensure broad coverage of clinical, physiological, and outcomes-based studies aligned with the thematic sections of the review. The search strategy employed predefined keywords and controlled terms such as geriatric anesthesia, prolonged anesthesia, cardiovascular surgery, postoperative outcomes, frailty, perioperative risk, and physiological effects of anesthesia.

Inclusion criteria encompassed peer-reviewed studies published between 2020 and 2025 in English or Spanish that focused on patients aged 65 years or older undergoing cardiovascular surgical procedures and that addressed at least one of the following domains: physiological effects of prolonged anesthesia, postoperative outcomes, anesthetic risk modifiers, or perioperative complications. Eligible study designs included observational studies, randomized clinical trials, systematic reviews, and meta-analyses. Exclusion criteria comprised studies involving non-geriatric populations, non-cardiovascular surgeries, pediatric or non-surgical anesthesia contexts, as well as publications lacking empirical data or methodological transparency.

The selected literature was classified according to study design and thematic relevance, corresponding to the sections of the review addressing physiological systems, postoperative outcomes, and risk-modifying factors. When applicable, methodological quality and risk of bias were assessed using established tools such as the Cochrane Risk of Bias instrument and the GRADE framework, in line with the critical synthesis of evidence rather than quantitative aggregation.

Data extraction focused on key variables relevant to the review objectives, including duration of anesthesia, anesthetic techniques and agents, patient frailty and comorbidity profiles, physiological alterations across organ systems, and postoperative outcomes such as complications, length of intensive care and

hospital stay, and mortality. The synthesis of findings followed a qualitative and integrative approach, allowing the identification of consistent patterns, areas of heterogeneity, and gaps in the current literature.

Artificial intelligence tools were used as complementary support for the organization, thematic categorization, and integration of the literature, facilitating coherence across sections while preserving the original interpretations and conclusions of the included studies. This methodology enabled a structured and evidence-based synthesis aligned with the conceptual framework and objectives of the review.

Physiological bases of aging relevant to anesthesia

Aging is associated with significant structural and functional changes in the cardiovascular system that have important implications for anesthetic management. Increased arterial stiffness, reduced cardiac output, and impaired baroreceptor sensitivity are commonly observed in older adults, contributing to altered blood pressure regulation during anesthesia and increasing vulnerability to hemodynamic instability [1, 8]. In this context, the hemodynamic response to anesthetic stress is often exaggerated in geriatric patients. Agents such as propofol have been associated with pronounced hypotensive responses, whereas alternatives like remimazolam may provide greater hemodynamic stability [9]. Ketamine has also been highlighted as a potentially advantageous agent in this population due to its relative preservation of cardiovascular function [10].

Age-related changes in the respiratory system further compound perioperative risk. Progressive declines in lung elasticity and chest wall compliance reduce ventilatory capacity and impair gas exchange, thereby increasing the likelihood of hypoxemia during anesthesia. These physiological alterations render older adults particularly susceptible to postoperative pulmonary complications, emphasizing the importance of preventive strategies such as lung-protective ventilation to minimize respiratory morbidity [1, 8].

The central nervous system is also profoundly affected by aging, with cognitive decline being a frequent and often under recognized condition in elderly patients presenting for surgery [11]. Preexisting cognitive impairment increases susceptibility to perioperative neurocognitive disorders, including postoperative delirium and cognitive dysfunction, which are especially prevalent in this population. Anesthetic choice appears to influence these outcomes, as propofol has been associated with a lower risk of delirium compared to sevoflurane in some studies [12]. In parallel, monitoring tools such as the bispectral index have been explored as a means of optimizing anesthetic depth and potentially reducing neurocognitive complications, although evidence regarding their impact on clinical outcomes remains inconclusive [13].

Renal and metabolic alterations represent additional considerations in geriatric anesthesia. Aging is accompanied by a decline in renal reserve, which can impair drug clearance and increase susceptibility to nephrotoxicity, particularly during prolonged anesthetic exposure [1, 8]. Furthermore, age-related changes in metabolism and pharmacokinetics affect the distribution, biotransformation, and elimination of anesthetic agents. These alterations necessitate careful dosing and vigilant monitoring to reduce the risk of drug accumulation and adverse effects in older patients undergoing complex surgical procedures [14].

Physiological effects of prolonged anesthesia

Prolonged anesthesia exerts a significant impact on the cardiovascular system of geriatric patients, frequently leading to hemodynamic instability characterized by fluctuations in blood pressure and heart rate. This instability is often amplified

by the presence of pre-existing cardiovascular conditions commonly observed in older adults, such as hypertension and heart failure, which limit compensatory mechanisms during prolonged anesthetic exposure [8, 15]. In addition to these hemodynamic alterations, anesthetic agents can adversely affect endothelial function, thereby contributing to myocardial dysfunction and ischemia. Elderly patients are particularly vulnerable to perioperative myocardial injury due to an imbalance between increased myocardial oxygen demand and reduced oxygen supply, a process often driven by endothelial dysfunction and heightened oxidative stress [16, 17].

The respiratory system is similarly affected by prolonged anesthesia in this population. Extended anesthetic exposure may result in prolonged respiratory depression, necessitating continued mechanical ventilation in the postoperative period. This issue is especially relevant in older patients, who frequently exhibit diminished pulmonary reserves and are therefore more susceptible to respiratory complications. The requirement for prolonged mechanical ventilation is a common postoperative scenario in geriatric patients undergoing major surgery and is often the consequence of the combined effects of anesthetic agents and underlying chronic respiratory conditions [8].

Neurological consequences represent another critical dimension of the physiological impact of prolonged anesthesia in older adults. Changes in mental status, including confusion and disorientation, are commonly observed following extended anesthetic exposure and tend to be more pronounced in elderly individuals due to age-related cognitive decline [17]. Postoperative delirium is a particularly frequent complication after cardiac surgery in this population. Although certain anesthetic regimens, such as those incorporating dexmedetomidine, have been investigated for their potential neuroprotective effects, current evidence suggests that they may not significantly reduce the incidence of postoperative delirium, even if they appear to influence its duration [14, 18].

Beyond organ-specific effects, prolonged anesthesia contributes to a broader systemic response characterized by inflammation and physiological stress. Surgical procedures and anesthetic exposure trigger a systemic inflammatory cascade marked by the release of pro-inflammatory cytokines and activation of neutrophils, processes that can precipitate organ injury. This inflammatory response is particularly detrimental in geriatric patients, who often have baseline inflammatory states and reduced physiological resilience [19]. In parallel, anesthetic agents may exacerbate oxidative stress by increasing the production of reactive oxygen species, leading to endothelial dysfunction and raising the risk of multiorgan dysfunction or failure. These mechanisms are of particular concern in older adults, whose organ systems may already be compromised by aging and chronic disease [16].

Associated postoperative outcomes

Prolonged anesthesia in geriatric patients undergoing cardiovascular surgery is associated with a higher incidence of early postoperative complications affecting multiple organ systems. Cardiovascular complications are particularly relevant, as extended anesthetic exposure can contribute to hemodynamic instability, thereby increasing the risk of arrhythmias and myocardial infarction. The combined physiological stress of surgery and anesthesia may exacerbate pre-existing cardiac conditions commonly present in older adults, ultimately leading to increased postoperative morbidity and mortality [4, 17].

Respiratory complications also represent a major concern in the early postoperative period. Elderly patients are especially vulnerable due to age-related declines in pulmonary function and the depressive effects of anesthesia on respiratory drive. As a consequence, prolonged mechanical ventilation is frequently required, and the

incidence of postoperative pneumonia is increased, further complicating recovery and prolonging hospitalization [4].

Renal function is similarly affected in this population. Geriatric patients exhibit a reduced renal reserve, which predisposes them to acute kidney injury in the postoperative setting. This risk is heightened by prolonged anesthesia and by exposure to potentially nephrotoxic anesthetic agents and adjunct medications used during cardiovascular surgery, contributing to adverse renal outcomes and increased postoperative morbidity [4].

Neurological complications constitute another significant dimension of postoperative outcomes in elderly patients. Postoperative delirium is a common and serious complication following cardiac surgery, with incidence rates markedly higher among individuals with pre-existing cognitive impairment. Factors such as anesthetic depth and systemic inflammatory responses have been implicated in the development of delirium, underscoring the multifactorial nature of this condition [17, 20, 21]. Beyond acute delirium, persistent postoperative cognitive impairment is frequently observed, with reported incidences ranging from 11.8% to 35.7% in elderly patients undergoing cardiac surgery. Advanced age, prolonged anesthetic exposure, and neuroinflammatory mechanisms are consistently identified as key risk factors for this prolonged cognitive decline [22, 23].

These complications have important implications for global clinical outcomes. Prolonged anesthesia has been associated with extended stays in the intensive care unit and in hospital overall, largely due to complications such as delirium and respiratory dysfunction. Preoperative cognitive impairment further exacerbates this effect, increasing length of stay by approximately 0.4 days. Although prolonged anesthesia does not appear to significantly increase 30-day mortality directly, the heightened risk of postoperative complications contributes to higher readmission rates and may influence long-term mortality. In this context, postoperative delirium and cognitive impairment emerge as critical determinants of adverse outcomes in the geriatric cardiovascular surgical population [4, 24].

Risk-modifying factors

Patient-related factors play a central role in determining postoperative outcomes in geriatric patients undergoing cardiovascular surgery. Advanced age is traditionally considered a risk factor; however, growing evidence indicates that frailty, rather than chronological age alone, is a more accurate predictor of adverse outcomes. Frailty has been consistently associated with increased vulnerability to surgical stress and has been shown to confer a four-fold increase in one-year mortality following cardiac surgery [3]. In addition, frail patients exhibit significantly higher rates of perioperative cardiac arrest and postoperative complications, underscoring the prognostic relevance of frailty assessments in this population [5].

Multimorbidity further compounds perioperative risk in elderly surgical patients. Chronic conditions such as coronary artery disease are highly prevalent and substantially increase the likelihood of perioperative cardiac complications. The coexistence of multiple comorbidities reduces physiological reserve and limits compensatory mechanisms during prolonged anesthesia and complex surgery. Consequently, comprehensive preoperative evaluations are essential to identify, stratify, and optimize these risks in order to improve postoperative outcomes [25].

Anesthetic-related factors also significantly influence perioperative and postoperative trajectories in geriatric patients. Prolonged anesthetic duration has been associated with an increased risk of postoperative cognitive disorders in older adults, highlighting the importance of both exposure time and anesthetic management strategies. The depth of anesthesia

represents a critical consideration, although current evidence suggests that excessively deep and relatively light anesthesia may exert similar effects on the incidence of postoperative delirium and long-term cognitive outcomes [26, 27].

The choice of anesthetic agents further modulates recovery and complication rates. Certain approaches, such as the use of local anesthesia for specific procedures like endovascular aortic aneurysm repair in octogenarians, have been associated with improved outcomes when compared to general anesthesia, including faster recovery and fewer complications [28].

Surgical factors represent an additional layer of risk modulation. Increased procedural complexity, particularly surgeries involving extracorporeal circulation, is associated with higher complication rates and prolonged recovery periods. Frail patients are disproportionately represented among those undergoing complex cardiovascular procedures, which further amplifies their perioperative risk [5]. Moreover, longer surgical durations have been linked to an increased incidence of postoperative complications, especially in frail individuals. Strategies aimed at optimizing surgical efficiency and minimizing operative time may therefore play a critical role in mitigating adverse outcomes in this vulnerable population [29].

Critical synthesis of the evidence

Prolonged anesthesia has been shown to exert relevant physiological effects in geriatric patients, particularly at the neurocognitive and cardiovascular levels. One of the most consistently reported consequences is delayed neurocognitive recovery, reflecting the increased vulnerability of the aging brain to prolonged anesthetic exposure. Although postoperative delirium remains a multifactorial condition, some studies indicate that specific pharmacological strategies, such as the use of dexmedetomidine, may reduce the risk of delayed neurocognitive recovery without significantly altering the overall incidence of delirium [30].

From a hemodynamic perspective, age-related cardiovascular changes substantially influence the physiological response to anesthesia. Older patients frequently exhibit altered autonomic regulation and reduced cardiovascular reserve, conditions that may be exacerbated by prolonged anesthetic exposure. As a result, extended anesthesia duration can intensify hemodynamic instability and increase the risk of perioperative cardiovascular complications, including myocardial injury [30].

Postoperative outcomes further reflect the impact of prolonged anesthesia in this population. An extended duration of anesthesia has been associated with a higher incidence of postoperative complications, particularly respiratory failure and confusion, effects that are especially pronounced in frail geriatric patients. In addition, anesthetic duration appears to influence recovery trajectories, including length of stay in the intensive care unit and overall postoperative recovery time. Emerging evidence suggests that certain approaches, such as nonopioid anesthesia protocols, may offer benefits by reducing complications and facilitating recovery, although these strategies require further validation [2, 31].

Across the literature, there is a substantial degree of consistency regarding the association between prolonged anesthesia and increased risks of neurocognitive disorders and hemodynamic instability in elderly patients [30, 32]. However, discrepancies persist, particularly concerning the extent to which specific anesthetic agents or tailored protocols can attenuate these risks. Some studies suggest that targeted anesthetic strategies may partially mitigate adverse physiological effects, underscoring the need for further research to establish standardized, evidence-based guidelines [31].

Taken together, these findings emphasize the clinical relevance of anesthetic duration as a potentially modifiable variable in perioperative care. Optimizing anesthetic exposure and tailoring protocols to the individual characteristics of geriatric patients may improve postoperative recovery and reduce complication rates. This approach aligns with the growing recognition that individualized anesthetic management is essential for enhancing outcomes in elderly populations undergoing complex surgical procedures [2, 31].

Limitations of the available evidence

The interpretation of current evidence on the effects of prolonged anesthesia in geriatric patients is challenged by significant methodological heterogeneity across studies. Variations in study design, patient selection, and anesthetic techniques complicate direct comparisons of outcomes. Differences between general and regional anesthesia exemplify this issue, as studies in hip fracture surgery have reported higher rates of pulmonary complications with general anesthesia, whereas regional anesthesia has been associated with an increased incidence of cardiac complications, illustrating how anesthetic modality can differentially influence postoperative outcomes [32].

In addition to heterogeneity in anesthetic approaches, limitations in perioperative risk stratification tools further complicate interpretation. Commonly used indices such as the Revised Cardiac Risk Index and the Geriatric Sensitive Cardiac Risk Index have demonstrated limited predictive accuracy for postoperative cardiac events in older adults. These findings suggest that existing tools may not adequately capture the complex physiological vulnerability of geriatric patients, underscoring the need for more individualized and age-sensitive risk assessment models [33].

Another important limitation is the lack of standardized definitions for key clinical outcomes. In particular, there is no clear consensus on how postoperative myocardial injury should be defined or measured, which hinders the assessment of anesthesia-related cardiovascular effects. Variability in cardiac biomarker responses, as observed in studies comparing anesthetic agents such as desflurane and sevoflurane, further illustrates the difficulty in establishing uniform outcome measures [7].

The current literature is also limited by a shortage of studies specifically focused on geriatric patients undergoing cardiovascular surgery. Much of the available evidence is derived from non-cardiac surgical populations or employs broad age categories that fail to capture the unique risks faced by the oldest-old patients. This gap is particularly evident given that commonly used risk indices, including the Revised Cardiac Risk Index and the Geriatric Sensitive Cardiac Risk Index, do not adequately predict outcomes in this subgroup [33].

Isolating the independent effects of anesthesia from those of surgical stress remains a major challenge. Perioperative complications such as myocardial injury are influenced by a complex interplay between anesthetic management and surgical factors, including procedural complexity and intraoperative stress responses. This interdependence highlights the necessity of adopting comprehensive perioperative care strategies that consider anesthesia and surgery as integrated contributors to postoperative outcomes rather than isolated variables [34].

Conclusion

Available evidence demonstrates that prolonged anesthesia in geriatric patients undergoing cardiovascular surgery is consistently associated with significant physiological alterations at the cardiovascular, respiratory, neurological, and renal levels, increasing the risk of early and late postoperative complications, as well as prolonged stays in intensive care units and hospitalization.

Frailty and multimorbidity emerge as central determinants of perioperative risk, surpassing chronological age as predictors of adverse outcomes. Modifiable factors such as anesthetic duration, selection of anesthetic agents, and surgical complexity play a key role in postoperative outcomes, highlighting the need for comprehensive geriatric assessment and individualized anesthetic strategies.

Despite the overall consistency of the findings, the interpretation of the evidence is limited by methodological heterogeneity, the lack of standardized definitions of clinical outcomes, and the scarcity of specific studies in geriatric cardiovascular patients. High-quality prospective research is needed to optimize risk stratification and define personalized anesthetic protocols aimed at improving clinical outcomes in this vulnerable population.

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