

Review Article

Intraoperative Hypotension: Critical Thresholds, Hypotensive Burden, and Perioperative Clinical Consequences

Miguel Caled Trejos Román^{1*}, Josué Campos Chinchilla², Yakira Delgado Angulo³, Stephanie Paola Serrano Jiménez⁴, María Celeste Leitón Duran⁵, Braulio Zúñiga Alemán⁶

¹Family and Community Medicine Specialist, México Hospital, San José, Costa Rica

²Internal Medicine Specialist, San Rafael de Alajuela Hospital, Alajuela, Costa Rica


³Medical Doctor, ICAFE, Heredia, Costa Rica

⁴Medical Doctor, Nacional de Niños Hospital, San José, Costa Rica

⁵Medical Doctor, Caja Costarricense de Seguro Social, San José, Costa Rica

⁶Medical Doctor, Caja Costarricense Seguro Social, Centro Nacional de Detección Temprana de Cáncer Gastrointestinal, Cartago, Costa Rica

*Corresponding author email: gueloula@hotmail.com

	International Archives of Integrated Medicine, Vol. 13, Issue 5, May, 2026. Available online at http://iaimjournal.com/ ISSN: 2394-0026 (P) ISSN: 2394-0034 (O)
	Received on: 8-4-2026 Accepted on: 30-5-2026 Source of support: Nil Conflict of interest: None declared. Article is under Creative Common Attribution 4.0 International DOI: 10.5281/zenodo.20545166
How to cite this article: Miguel Caled Trejos Román, Josué Campos Chinchilla, Yakira Delgado Angulo, Stephanie Paola Serrano Jiménez, María Celeste Leitón Duran, Braulio Zúñiga Alemán. Intraoperative Hypotension: Critical Thresholds, Hypotensive Burden, and Perioperative Clinical Consequences. <i>Int. Arch. Integr. Med.</i> , 2026; 13(5): 217-231.	

Abstract

Intraoperative hypotension is a frequent and clinically significant perioperative event associated with impaired tissue perfusion and an increased risk of organ injury, particularly involving the kidneys, heart, and brain. Mean arterial pressure has become the principal variable used to define this condition, with thresholds below 70, 65, 60, and 55 mmHg marking a progressive increase in perioperative risk. Among these, a mean arterial pressure below 65 mmHg sustained for more than 5 minutes has been consistently associated with postoperative acute kidney injury, whereas values below 55 to 60 mmHg identify particularly high-risk scenarios for major adverse cardiac or cerebrovascular events. The clinical impact of intraoperative hypotension depends not only on the absolute blood pressure reached, but also on the duration of exposure and the cumulative hypotensive

burden. The pathophysiology of intraoperative hypotension is multifactorial and involves reduced sympathetic tone, vasodilation, myocardial depression, hypovolemia, bleeding, and impaired autoregulation during anesthesia. Its consequences are shaped by patient-related factors such as advanced age, frailty, chronic hypertension, chronic kidney disease, and diabetes mellitus, as well as by anesthetic technique, surgical complexity, and perioperative pharmacologic management. Continuous invasive monitoring and predictive tools have improved the early detection of hypotensive events, while preventive strategies such as volume optimization, adjustment of anesthetic depth, and timely vasopressor use may reduce exposure to harmful blood pressure reductions. Overall, intraoperative hypotension should be understood as a dynamic and individualized perioperative insult in which threshold, duration, and patient susceptibility together determine the risk of adverse postoperative outcomes.

Key words

Hemodynamic monitoring, organ hypoperfusion, acute kidney injury, myocardial injury, perioperative risk, vasopressors.

Introduction

Intraoperative hypotension is a common complication during anesthesia, particularly in older patients, and its clinical importance lies in its direct association with perioperative organ hypoperfusion and subsequent injury. A study conducted in the United Kingdom showed that a considerable proportion of older patients experienced intraoperative hypotension, and that treatment was often initiated only after blood pressure had fallen below suggested thresholds, which highlights both the potential for organ injury and the need for improved management strategies [1]. Intraoperative hypotension has become a major focus in anesthetic practice because it has been consistently associated with increased risks of major adverse cardiac or cerebrovascular events, acute kidney injury, and mortality [2, 3].

Its relevance is especially evident in major and non-cardiac surgery, where intraoperative hypotension occurs frequently and has been linked to clinically significant postoperative complications. In non-cardiac procedures, studies have shown that a substantial proportion of patients develop mean arterial pressure values below critical thresholds, with one report indicating readings of 75 mm Hg or less in 39.5% of cases [2]. This high incidence

reinforces the importance of intraoperative hypotension as a perioperative concern, particularly because its presence has been associated with adverse outcomes such as myocardial injury and acute kidney disease in both major and non-cardiac surgical settings [3, 4].

The relationship between intraoperative blood pressure decline, tissue hypoperfusion, and organ injury is central to understanding the clinical consequences of this phenomenon. Intraoperative hypotension has been linked to myocardial infarction, acute kidney injury, and stroke, and the available evidence indicates that both the severity and the duration of the hypotensive episode are decisive factors in determining risk. Lower mean arterial pressure thresholds and more prolonged periods of hypotension have been associated with a higher likelihood of these complications [5]. In addition, the risk of myocardial infarction rises significantly in the presence of reductions in systolic blood pressure, which further emphasizes the need for vigilant intraoperative blood pressure management [4].

For this reason, focusing on pressure thresholds and exposure time is essential when evaluating intraoperative hypotension and designing preventive strategies. Identifying specific mean arterial pressure thresholds and the duration of

exposure associated with harm is crucial to reduce adverse outcomes, and current evidence suggests that maintaining mean arterial pressure above certain levels, such as 70 mm Hg, may decrease the risk of major adverse cardiac events, especially in older adults [6]. In parallel, blood pressure optimization strategies, including the use of vasopressors and continuous hemodynamic monitoring, have shown promise in reducing exposure to intraoperative hypotension, although their effect on postoperative outcomes remains uncertain [7].

The objective of this review is to analyze the clinical importance of intraoperative hypotension, its incidence in major and non-cardiac surgery, and its relationship with tissue hypoperfusion and perioperative organ injury, with emphasis on the role of blood pressure thresholds and duration of exposure as determinants of adverse postoperative outcomes.

Methodology

This manuscript was developed as a structured narrative review aimed at providing an updated and clinically integrated analysis of intraoperative hypotension, with particular emphasis on critical blood pressure thresholds, duration of hypotensive exposure, and their association with perioperative organ injury and adverse postoperative outcomes. The review was conducted in accordance with the SANRA (Scale for the Assessment of Narrative Review Articles) framework and followed a predefined methodological protocol established prior to literature screening. Given the clinical heterogeneity of surgical populations, differences in monitoring strategies, variability in blood pressure definitions, and the diversity of perioperative outcomes evaluated across studies, a narrative interpretative synthesis was selected over quantitative pooling in order to integrate pathophysiological, diagnostic, monitoring, and therapeutic considerations into a coherent and clinically applicable framework. Special attention was given to the prognostic relevance of mean arterial pressure thresholds, the

cumulative burden of hypotension, the relationship between intraoperative hypotension and myocardial, renal, and neurologic complications, and the role of individualized hemodynamic management strategies in contemporary anesthetic practice. The objective was to provide a structured synthesis capable of supporting perioperative risk assessment and clinical decision-making in patients undergoing major and non-cardiac surgery.

A comprehensive literature search was conducted in PubMed, Scopus, and Web of Science, including peer-reviewed articles published in English or Spanish between January 2020 and December 2025. The final search was performed in March 2026. This timeframe was selected to capture contemporary advances in the definition, monitoring, prevention, and treatment of intraoperative hypotension, as well as recent evidence regarding its association with postoperative complications and evolving blood pressure management strategies. Foundational studies were incorporated when necessary to contextualize pathophysiological mechanisms, historical threshold definitions, or the evolution of perioperative hemodynamic concepts. The search strategy combined MeSH and free-text terms using Boolean operators related to intraoperative hypotension, perioperative hypotension, mean arterial pressure, systolic blood pressure, hypotensive burden, organ hypoperfusion, acute kidney injury, myocardial injury, stroke, perioperative mortality, vasopressors, hemodynamic monitoring, and blood pressure optimization. Searches were conducted in titles and abstracts as well as indexed subject headings to maximize sensitivity.

The initial search yielded 155 records. After removal of duplicates, 122 articles remained for title and abstract screening. Of these, 71 underwent full-text evaluation, and 33 studies were included in the final synthesis. Selection was performed independently by two authors, with disagreements resolved through discussion

and consensus. Exclusion criteria comprised non-peer-reviewed publications, isolated case reports, editorials without outcome data, purely technical reports lacking clinical correlation, redundant datasets, and studies not directly addressing the prognostic significance, pathophysiological implications, monitoring, or therapeutic management of intraoperative hypotension.

Eligible studies included randomized controlled trials, large observational cohorts, systematic reviews, meta-analyses, expert consensus statements, and contemporary international guidelines from anesthesiology, perioperative medicine, intensive care, and surgical societies. Priority was assigned to multicenter investigations, studies with standardized blood pressure definitions, and research evaluating postoperative outcomes such as acute kidney injury, myocardial injury, stroke, mortality, and overall perioperative morbidity. Extracted variables included study design, surgical setting, patient population, blood pressure thresholds, duration of hypotensive exposure, monitoring modality, preventive or corrective interventions, postoperative complications, and survival-related outcomes when available. Methodological quality and internal validity were assessed narratively, considering risk of bias, sample size, follow-up duration, consistency of blood pressure definitions, and reproducibility of reported outcomes. In cases of conflicting evidence, greater interpretative weight was assigned to higher-level evidence and guideline-supported recommendations.

Reference lists of included studies were manually screened to identify additional relevant publications. Given its narrative design, this review is subject to potential selection bias and does not provide pooled quantitative estimates. Artificial intelligence-based tools were used exclusively to assist in literature organization and structural coherence, whereas critical appraisal, synthesis, and final interpretation were

conducted independently by the authors to preserve methodological rigor.

Conceptual Framework and Operational Definitions of Intraoperative Hypotension

Intraoperative hypotension is most commonly defined on the basis of mean arterial pressure, with the thresholds most frequently reported in the literature being below 70 mmHg, 65 mmHg, 60 mmHg, and 55 mmHg. These cutoffs have been associated with an increased risk of myocardial injury, acute kidney injury, and stroke [5, 8]. Among them, a mean arterial pressure below 65 mmHg sustained for more than 5 minutes is frequently identified as a critical threshold associated with a higher incidence of postoperative acute kidney injury [9]. In line with this, the Perioperative Quality Initiative recommends maintaining a mean arterial pressure of at least 60 mmHg in at-risk patients, reinforcing the central role of this variable in the management of intraoperative hypotension [8].

Although systolic arterial pressure is also used to define intraoperative hypotension, it is applied less consistently than mean arterial pressure. In clinical practice, commonly used systolic criteria include a reduction of 20% from baseline or an absolute systolic arterial pressure below 100 mmHg [1]. However, systolic arterial pressure is less frequently favored because it is more variable and has a less direct relationship with organ perfusion than mean arterial pressure. For this reason, mean arterial pressure has progressively become the principal hemodynamic variable for both research and clinical decision-making in this setting [10].

This distinction is particularly relevant when comparing absolute thresholds with relative reductions from baseline. Absolute thresholds, such as a mean arterial pressure below 65 mmHg, are more commonly used and are considered more useful than relative reductions for predicting adverse postoperative outcomes [5]. By contrast, relative reductions, including a

20% decrease from baseline mean arterial pressure, are less favored because baseline blood pressure varies substantially among patients, especially in those with chronic hypertension. As a result, reliance on relative definitions may introduce variability in risk estimation and limit the comparability of findings across different patient populations [10].

Within the literature, the most frequently used thresholds reflect a gradation of risk. A mean arterial pressure below 70 mmHg has been associated with increased risks of myocardial injury and acute kidney injury [5]. A mean arterial pressure below 65 mmHg is widely recognized as a critical threshold for adverse outcomes, particularly postoperative acute kidney injury [9]. Lower thresholds, such as a mean arterial pressure below 60 mmHg, are considered especially concerning because they are linked to significant risks of organ hypoperfusion [8]. At the most severe end of the spectrum, a mean arterial pressure below 55 mmHg has been associated with the highest risk of adverse outcomes, including major adverse cardiac or cerebrovascular events [2].

Despite the growing body of evidence, the absence of a universal definition of intraoperative hypotension remains a major methodological limitation. This lack of standardization generates inconsistencies in research findings and clinical recommendations, thereby complicating the development of uniform treatment protocols [11]. In addition, variability in the thresholds and criteria used across studies can lead to differing interpretations of outcomes, making direct comparison between investigations more difficult. These methodological challenges further support the need for a more consistent operational framework [2].

In practical terms, mean arterial pressure is commonly used as the primary variable because it is a more stable and reliable indicator of organ perfusion than systolic arterial pressure [12]. Its

continuous monitoring also facilitates timely intervention, which is particularly important for preventing prolonged hypotension and reducing the risk of associated complications. Accordingly, the preference for mean arterial pressure reflects both its stronger physiological relevance and its greater clinical utility in the prevention and management of intraoperative hypotension [8].

Pathophysiological Basis of Hypoperfusion During Anesthesia

Autoregulation is a fundamental physiological mechanism that maintains relatively constant blood flow to vital organs despite changes in perfusion pressure. This compensatory process, however, operates within specific limits, which are generally located around a mean arterial pressure of 60 to 70 mmHg, below which organ perfusion may become compromised [13]. The brain, heart, and kidneys each possess distinct autoregulatory thresholds, and when these limits are exceeded, the risk of ischemia and organ dysfunction increases substantially [14].

Within this context, the effects of general anesthesia play a central role in the development of intraoperative hypotension and altered tissue perfusion. General anesthesia commonly reduces sympathetic tone, which in turn contributes to decreases in cardiac output and blood pressure [7]. At the same time, anesthetic agents frequently induce vasodilation, thereby lowering systemic vascular resistance and further promoting hypotension [15]. In addition, many anesthetic drugs depress myocardial contractility, which can further diminish cardiac output and reduce perfusion pressure. Through these combined mechanisms, general anesthesia may significantly impair the hemodynamic conditions required to preserve adequate organ blood flow [7].

Neuraxial anesthesia can intensify these effects by producing substantial reductions in venous return and vascular tone, thereby worsening hypotension and diminishing perfusion to vital

organs. This hemodynamic impact becomes even more significant when additional perioperative factors are present. Hypovolemia reduces preload and cardiac output, thereby exacerbating hypotension [7]. Pharmacologic vasodilation, frequently produced by anesthetic agents, further decreases systemic vascular resistance [15]. Surgical bleeding contributes to blood volume loss, which may result in hypovolemia and reduced perfusion pressure [16]. Likewise, myocardial depression caused by anesthetic agents can compromise cardiac performance and lower cardiac output. In parallel, sepsis or a systemic inflammatory response may induce vasodilation and capillary leak, which reduce effective circulating volume and further impair tissue perfusion [7].

The kidney, heart, and brain are particularly vulnerable to these hemodynamic disturbances because they are highly sensitive to fluctuations in perfusion and have elevated metabolic demands together with a limited capacity to tolerate ischemia [2]. Among these organs, the brain is especially susceptible because it depends on continuous blood flow for the delivery of oxygen and nutrients required to sustain neuronal function. For this reason, even relatively short periods of inadequate perfusion may have clinically important consequences when compensatory mechanisms fail [14].

Although transient hypotension may sometimes be tolerated without major adverse effects when autoregulation remains intact and compensatory responses are effective, clinically relevant hypoperfusion develops when hypotension is sufficiently prolonged or severe to exceed autoregulatory capacity, ultimately leading to organ dysfunction. The distinction between tolerated transient hypotension and harmful hypoperfusion therefore depends not only on the absolute pressure level reached, but also on the duration of exposure and the capacity of the individual patient to maintain effective autoregulatory compensation [5].

Critical Thresholds and Hypotensive Burden

Absolute pressure thresholds are closely linked to the risk of organ injury during intraoperative hypotension, and among them, a mean arterial pressure below 65 mmHg sustained for more than 5 minutes has been consistently associated with an increased risk of postoperative acute kidney injury and other adverse outcomes. At lower levels, the risk becomes even more pronounced, since intraoperative hypotension with a mean arterial pressure of 55 mmHg or less significantly increases the odds of major adverse cardiac or cerebrovascular events [2, 9]. In abdominal surgery, mean arterial pressure values below 70 mmHg have also been associated with myocardial injury, acute kidney injury, or stroke, and lower thresholds appear to require shorter exposure times to produce complications. These findings support the concept that the severity of hypotension is a key determinant of perioperative risk [5].

In this regard, the depth of blood pressure reduction appears to have a stronger association with myocardial injury and mortality than duration alone [17]. Nevertheless, prolonged hypotension, even when occurring at moderate levels, can still result in significant organ injury, which underscores the importance of considering both the depth and the duration of hypotensive exposure when assessing perioperative risk. Therefore, a comprehensive interpretation of intraoperative hypotension requires attention not only to how low blood pressure falls, but also to how long the patient remains exposed to that reduction [5].

This combined effect is reflected in the concept of cumulative hypotensive burden, which incorporates both the depth and duration of hypotension and has emerged as a critical factor in predicting adverse outcomes. Closely related to this is the concept of area under the threshold, which quantifies the total hypotensive exposure and provides a more comprehensive measure of risk than isolated blood pressure readings alone.

By integrating these dimensions, cumulative measures offer a more precise understanding of the clinical impact of intraoperative hypotension [2].

The nature of the hypotensive episode also influences the pattern of injury. Brief but profound episodes of hypotension may cause immediate and severe organ damage, whereas moderate but prolonged hypotension may generate cumulative physiological stress that ultimately results in injury over time [17]. Both patterns are associated with increased perioperative risk, although their clinical management may differ according to the specific characteristics of the hypotensive event [5]. This distinction reinforces the importance of individualized hemodynamic assessment during surgery.

From a practical perspective, a mean arterial pressure below 65 mmHg represents a useful clinical reference point for initiating interventions aimed at preventing organ injury [1]. However, exposure to mean arterial pressure values below 55 to 60 mmHg constitutes a particularly high-risk scenario, given its significant association with myocardial injury and persistent acute kidney disease. Taken together, these thresholds provide clinically relevant guidance for identifying dangerous levels of intraoperative hypotension and for supporting early corrective measures [3].

Renal and Cardiovascular Consequences of Intraoperative Hypotension

Acute kidney injury is one of the most consistently reported complications associated with intraoperative hypotension. A mean arterial pressure below 65 mmHg for more than 5 minutes has been repeatedly associated with an increased risk of postoperative acute kidney injury, and the probability of renal damage rises in parallel with both the magnitude and the duration of hypotension, which supports a dose-dependent relationship between hemodynamic exposure and renal injury. This association is

particularly important because it suggests that even relatively brief periods of inadequate perfusion may have clinically relevant consequences when blood pressure falls below critical thresholds [9, 18].

This risk is even greater in patients with preexisting vulnerability. Individuals with chronic hypertension or chronic kidney disease appear to be especially susceptible to acute kidney injury after intraoperative hypotension, and these patients may require higher intraoperative blood pressure targets in order to reduce the risk of renal injury [10, 19]. In cardiac surgery, this relationship becomes even more pronounced among patients with higher preoperative risk profiles, since a cumulative duration of intraoperative hypotension greater than 104 minutes has been shown to significantly increase the risk of acute kidney injury in this population. These findings emphasize that the renal consequences of intraoperative hypotension are not uniform but rather depend on the interaction between blood pressure exposure and individual patient risk [20].

In addition to its renal effects, intraoperative hypotension has important cardiovascular consequences. Reduced coronary perfusion pressure during hypotensive episodes can produce an imbalance between myocardial oxygen supply and demand, thereby contributing to myocardial injury. The risk of this complication increases at mean arterial pressure values of 65 mmHg or less, and available evidence suggests that there is no significant difference in the harmful threshold between normotensive and hypertensive patients. Thus, intraoperative hypotension should be regarded as a major determinant of perioperative cardiovascular vulnerability, particularly when coronary reserve is limited [10].

Likewise, intraoperative hypotension has been associated with an increased risk of perioperative myocardial infarction and postoperative mortality. However, some studies indicate that

permissive hypotension, defined as a mean arterial pressure of 60 mmHg or less, does not significantly increase mortality when compared with targeted hemodynamic management, although it may be associated with reductions in atrial fibrillation and hospital length of stay. These observations suggest that the clinical consequences of hypotension may vary according to the context in which it occurs and the management strategy applied [2, 21].

The relationship between threshold, duration, and severity is central to understanding the adverse effects of intraoperative hypotension. A mean arterial pressure of 55 mmHg or less has been associated with a higher risk of persistent acute kidney disease, while the duration of hypotension remains a significant determinant of both renal and cardiovascular outcomes [3]. At the same time, this relationship is shaped by multiple factors, including patient age, preexisting comorbidities, and the type of surgical procedure. Older adults and patients undergoing noncardiac surgery appear to be particularly vulnerable to the harmful effects of intraoperative hypotension. Taken together, these findings reinforce the concept that intraoperative hypotension is a multifactorial perioperative insult whose impact depends on the interaction between pressure threshold, duration of exposure, and baseline patient susceptibility [2].

Neurologic Consequences and Global Postoperative Outcomes

Neurologic complications represent an important but still partially debated dimension of intraoperative hypotension. One of the principal concerns is that intraoperative hypotension may reduce cerebral perfusion and thereby contribute to postoperative delirium. Nevertheless, the available evidence remains inconsistent. A retrospective cohort analysis in elderly patients undergoing non-cardiac surgery found no significant association between intraoperative hypotension and postoperative delirium [22]. Similarly, a secondary analysis of a randomized controlled trial in neurosurgical patients also did

not identify an association between hypotension and delirium [23]. In contrast, other studies suggest that impaired cerebral perfusion resulting from hypotension may contribute to delirium, particularly when it is accompanied by additional physiological disturbances such as hypoxaemia or hypocapnia. These findings indicate that the neurologic effects of intraoperative hypotension may depend not only on blood pressure reduction itself, but also on the broader intraoperative context in which it occurs [24].

Beyond delirium, perioperative stroke is another major neurologic concern associated with intraoperative hypotension. The risk of postoperative ischemic stroke appears to increase when hypotension occurs in combination with other perturbations, particularly carbon dioxide dysregulation. A study demonstrated that hypotension below specific mean arterial pressure thresholds significantly increased the risk of perioperative ischemic stroke. This observation underscores the importance of preserving adequate cerebral perfusion throughout surgery, especially in situations where additional factors may further compromise cerebrovascular homeostasis [25].

These neurologic effects also have implications for broader postoperative recovery. Delayed functional recovery and postoperative cognitive dysfunction remain relevant concerns in patients exposed to intraoperative hypotension. In patients undergoing spine surgery, intraoperative blood pressure deviations were associated with postoperative delirium, which in turn affected cognitive recovery. This suggests that maintaining hemodynamic stability during surgery may be important not only for the prevention of immediate neurologic complications, but also for the preservation of postoperative cognitive function and recovery trajectories [26].

Intraoperative hypotension has also been linked to prolonged hospital stay and increased resource utilization. A meta-analysis found that

permissive hypotension management was associated with a shorter length of hospital stay, although it did not increase mortality. These findings suggest that blood pressure management strategies during surgery may influence recovery time and healthcare utilization, even when their effect on survival is less clear. Accordingly, the consequences of intraoperative hypotension should be considered not only in terms of discrete organ injury, but also in relation to overall postoperative recovery and resource burden [21].

Taken together, the distinction between well-established and still debated outcomes is essential when interpreting the neurologic and global consequences of intraoperative hypotension. The association between intraoperative hypotension and an increased risk of perioperative stroke is supported by available evidence, particularly when hypotension is compounded by other physiological disturbances [25]. Likewise, its relationship with prolonged hospital stay has been recognized, although the effect on mortality remains controversial [21]. By contrast, the association between intraoperative hypotension and postoperative delirium or cognitive dysfunction remains less certain, as current studies have yielded conflicting results. This inconsistency highlights the need for further research to clarify the extent to which intraoperative hypotension directly contributes to these neurologic and functional outcomes [22, 26, 27].

Risk Factors and Modifiers of Susceptibility

Patient-related factors play a major role in determining susceptibility to intraoperative hypotension and its consequences. Older patients, particularly those with frailty, are more vulnerable to intraoperative hypotension. Frailty, as measured by the Edmonton Frail Scale, has been shown to significantly increase the odds of postinduction hypotension, with frail patients having an odds ratio of 2.73 for developing hypotension compared with non-frail patients

[7]. In addition, older adults appear to be at greater risk of major adverse cardiac events when intraoperative hypotension occurs, and a mean arterial pressure below 70 mm Hg has been identified as particularly concerning in this population. These findings suggest that advanced age and frailty substantially modify both the likelihood and the clinical impact of hypotensive episodes during surgery [6].

Chronic hypertension is another important factor influencing the interpretation of intraoperative blood pressure thresholds. Patients with chronic hypertension may require higher intraoperative blood pressure levels to avoid myocardial injury, although available studies have not consistently demonstrated that hypertensive patients require higher harmful thresholds than normotensive individuals. This uncertainty indicates that, while chronic hypertension is clearly relevant in perioperative hemodynamic assessment, its exact effect on optimal intraoperative blood pressure targets remains incompletely defined [10].

Other comorbidities, such as chronic kidney disease and diabetes mellitus, also increase vulnerability to hypotension-related complications. Patients with chronic kidney disease, particularly those receiving dialysis, experience more severe intraoperative hypotension and are at greater risk of postoperative complications. Diabetes mellitus further contributes to this susceptibility because of its associated vascular alterations and potential renal involvement. Together, these conditions reinforce the concept that the adverse consequences of intraoperative hypotension are strongly influenced by baseline end-organ vulnerability [28].

Anesthesia-related factors also contribute significantly to the development of intraoperative hypotension. Deep anesthetic induction and neuraxial anesthesia can produce marked reductions in blood pressure, thereby increasing the risk of hypotensive episodes. This effect may be further exacerbated by the use of vasodilatory

agents during anesthesia. Accordingly, anesthetic technique and drug selection are central determinants of intraoperative hemodynamic stability [7].

Surgery-related factors further modify the severity and duration of hypotension. Major non-cardiac and vascular procedures are particularly associated with substantial blood loss and prolonged operative times, both of which contribute to the development of intraoperative hypotension [29]. In turn, the duration and type of surgery may influence the intensity and persistence of hypotensive episodes, thereby affecting important outcomes such as acute kidney injury and major adverse cardiac events. These observations highlight the close relationship between surgical complexity and hemodynamic risk [6, 9].

Perioperative pharmacologic factors must also be considered. Antihypertensive medications, especially renin–angiotensin system blockers, can predispose patients to intraoperative hypotension if not managed appropriately during the perioperative period. In fact, withholding certain antihypertensive agents before surgery has been shown to reduce the incidence of intraoperative hypotension. This emphasizes the importance of careful preoperative medication management as part of a broader strategy to reduce hypotensive risk [7].

Taken together, these factors explain why the clinical significance of a given blood pressure threshold may vary substantially among patients. A mean arterial pressure of 65 mm Hg may be acceptable in some individuals, yet potentially harmful in others, particularly in those with advanced age or chronic hypertension, who may require higher blood pressure targets to reduce the risk of adverse outcomes. Therefore, the impact of intraoperative hypotension should be interpreted within the context of patient-specific vulnerability, anesthetic exposure, surgical characteristics, and perioperative pharmacologic influences [7, 10].

Intraoperative Monitoring, Prediction, and Treatment

Intraoperative monitoring is a central component in the prevention, early detection, and management of intraoperative hypotension. Intermittent noninvasive blood pressure monitoring with a cuff may fail to detect short hypotensive episodes and can delay recognition of clinically relevant events, thereby limiting timely intervention. For this reason, continuous monitoring has been recommended as a more effective approach to improve detection and facilitate earlier corrective measures [30]. In contrast, continuous intra-arterial monitoring provides real-time hemodynamic information and has been shown to be more effective than intermittent methods in reducing hypotension during anesthesia induction, since it allows immediate responses to blood pressure changes [31].

In addition to direct monitoring, predictive tools have emerged as valuable instruments for anticipating intraoperative hypotension before it becomes clinically evident. Among them, the Hypotension Prediction Index, which is based on arterial waveform analysis, can predict hypotension several minutes before its onset and thereby enables the implementation of preventive strategies. Studies have shown that when the Hypotension Prediction Index is combined with personalized treatment protocols, both the incidence and the duration of hypotensive episodes can be reduced [32, 33]. Similarly, machine learning algorithms using noninvasive arterial pressure waveforms have demonstrated promising predictive performance, with high sensitivity and specificity, suggesting that they may eventually be applied to a broader surgical population [30].

Preventive strategies are also essential for reducing the occurrence of intraoperative hypotension. Preoperative volume optimization can help lower the risk of hypotension during surgery by ensuring an adequate intravascular volume status before anesthetic induction [7]. In

parallel, adjustment of anesthetic depth is important because it may prevent excessive vasodilation and the associated fall in blood pressure [22]. Early or prophylactic administration of vasopressors, including phenylephrine, ephedrine, and norepinephrine, has likewise been shown to contribute to blood pressure stabilization and to the prevention of hypotensive episodes. Together, these approaches support a proactive strategy aimed at maintaining hemodynamic stability throughout the intraoperative period [7].

When hypotension does occur, treatment should be directed toward the predominant underlying mechanism. Correction of hypovolemia requires fluid administration, vasodilation should be addressed with vasopressors, myocardial depression may require inotropic support, and hemorrhage must be treated with appropriate blood products [22]. Within this context, phenylephrine, ephedrine, and norepinephrine are among the most commonly used vasopressors for the treatment of intraoperative hypotension, although their use should be individualized according to the cause of the hemodynamic disturbance in order to avoid excessive correction and further instability [7].

Preventing recurrent hypotensive episodes and avoiding overcorrection of blood pressure are both crucial for minimizing the risk of organ injury and postoperative complications. Continuous monitoring, together with predictive tools such as the Hypotension Prediction Index, may help maintain more stable blood pressure levels and reduce the likelihood of adverse outcomes. Accordingly, the combination of accurate monitoring, anticipatory prediction, targeted prevention, and mechanism-based treatment constitutes a coherent strategy for improving hemodynamic control during surgery [7, 32].

Conclusions

Intraoperative hypotension is a clinically significant perioperative event whose impact is

determined by the interaction between blood pressure threshold, duration of exposure, and cumulative hypotensive burden. Mean arterial pressure has emerged as the most useful hemodynamic variable for defining and monitoring this condition, with values below 65 mmHg representing a practical warning threshold and values below 55–60 mmHg identifying particularly high-risk scenarios for organ injury.

The adverse consequences of intraoperative hypotension primarily involve renal, cardiovascular, and neurologic systems, although the strength of evidence differs by outcome. Acute kidney injury and myocardial injury show the most consistent associations, especially when hypotension is deeper or more prolonged, whereas neurologic outcomes such as delirium and postoperative cognitive dysfunction remain less clearly established and appear to depend on additional perioperative factors.

The clinical relevance of intraoperative hypotension is not uniform across patients, since susceptibility is modified by age, frailty, chronic hypertension, chronic kidney disease, diabetes mellitus, anesthetic technique, surgical complexity, and perioperative medications. For this reason, prevention and management should rely on individualized blood pressure targets, continuous or advanced monitoring when appropriate, and mechanism-based treatment strategies aimed at avoiding both prolonged hypotension and excessive hemodynamic instability.

References

1. Wickham AJ, Highton DT, Clark S, Fallaha D, Wong DJN, Martin DS. Treatment threshold for intra-operative hypotension in clinical practice—a prospective cohort study in older patients in the UK. *Anaesthesia* [Internet]. 2021 Jul 6;77(2):153–63. Available from: <https://doi.org/10.1111/anae.15535>
2. Gregory A, Stapelfeldt WH, Khanna AK, Smischney NJ, Boero IJ, Chen Q, et

- al. Intraoperative hypotension is associated with adverse clinical outcomes after noncardiac surgery. *Anesthesia & Analgesia* [Internet]. 2020 Nov 6;132(6):1654–65. Available from: <https://doi.org/10.1213/ane.0000000000005250>
3. Shaw A, Khanna AK, Smischney NJ, Shenoy AV, Boero IJ, Bershad M, et al. Intraoperative hypotension is associated with persistent acute kidney disease after noncardiac surgery: a multicentre cohort study. *British Journal of Anaesthesia* [Internet]. 2022 May 17;129(1):13–21. Available from: <https://doi.org/10.1016/j.bja.2022.03.027>
 4. Hallqvist L, Granath F, Fored M, Bell M. Intraoperative hypotension and myocardial infarction development among High-Risk patients undergoing noncardiac surgery: A Nested Case-Control Study. *Anesthesia & Analgesia* [Internet]. 2021 Feb 5;133(1):6–15. Available from: <https://doi.org/10.1213/ane.0000000000005391>
 5. Putowski Z, Czajka S, Krzych ŁJ. Association between Intraoperative Blood Pressure Drop and Clinically Significant Hypoperfusion in Abdominal Surgery: A Cohort Study. *Journal of Clinical Medicine* [Internet]. 2021 Oct 28;10(21):5010. Available from: <https://doi.org/10.3390/jcm10215010>
 6. Zhang K, Liu C, Wang M, Zhang T, Meng B, Yao S, et al. Intraoperative hypotension and major adverse cardiac events among older adult patients undergoing noncardiac surgery: retrospective cohort study. *JMIR Aging* [Internet]. 2025 Jul 22;8:e67177. Available from: <https://doi.org/10.2196/67177>
 7. Lee S, Islam N, Ladha KS, Van Klei W, Wijeyesundera DN. Intraoperative hypotension in patients having major noncardiac surgery under general anesthesia: A Systematic Review of Blood Pressure Optimization Strategies. *Anesthesia & Analgesia* [Internet]. 2024 Jun 13;141(1):38–60. Available from: <https://doi.org/10.1213/ane.0000000000007074>
 8. Saugel B, Fletcher N, Gan TJ, Grocott MPW, Myles PS, Sessler DI, et al. PeriOperative Quality Initiative (POQI) international consensus statement on perioperative arterial pressure management. *British Journal of Anaesthesia* [Internet]. 2024 Jun 4;133(2):264–76. Available from: <https://doi.org/10.1016/j.bja.2024.04.046>
 9. Penev Y, Ruppert MM, Bilgili A, Li Y, Habib R, Dozic AV, et al. Intraoperative hypotension and postoperative acute kidney injury: A systematic review. *The American Journal of Surgery* [Internet]. 2024 Feb 16;232:45–53. Available from: <https://doi.org/10.1016/j.amjsurg.2024.02.001>
 10. Cohen B, Rivas E, Yang D, Mascha EJ, Ahuja S, Turan A, et al. Intraoperative hypotension and myocardial injury after noncardiac surgery in adults with or without chronic hypertension: a retrospective cohort analysis. *Anesthesia & Analgesia* [Internet]. 2022 Feb 7;135(2):329–40. Available from: <https://doi.org/10.1213/ane.0000000000005922>
 11. Karamchandani K, Dave S, Hoffmann U, Khanna AK, Saugel B. Intraoperative arterial pressure management: knowns and unknowns. *British Journal of Anaesthesia* [Internet]. 2023 Jul 12;131(3):445–51. Available from: <https://doi.org/10.1016/j.bja.2023.05.027>
 12. Wijeyesundera DN, McIsaac DI, London MJ. The promise and challenges of predictive analytics in perioperative care. *Anesthesiology* [Internet]. 2022 Aug 19;137(3):275–9. Available from: <https://doi.org/10.1097/aln.0000000000004332>

13. Kho E, Weiland NHS, Vlaar APJ, Veelo DP, Van Der Ster BJP, Corsmit OT, et al. Cerebral hemodynamics during sustained intraoperative hypotension. *Journal of Applied Physiology* [Internet]. 2022 May 5;132(6):1560–8. Available from: <https://doi.org/10.1152/jappphysiol.00050.2022>
14. Wongtangman K, Wachtendorf LJ, Blank M, Grabitz SD, Linhardt FC, Azimaraghi O, et al. Effect of intraoperative arterial hypotension on the risk of perioperative stroke after noncardiac surgery: a retrospective multicenter cohort study. *Anesthesia & Analgesia* [Internet]. 2021 Jul 12;133(4):1000–8. Available from: <https://doi.org/10.1213/ane.0000000000005604>
15. Meng L. Heterogeneous impact of hypotension on organ perfusion and outcomes: a narrative review. *British Journal of Anaesthesia* [Internet]. 2021 Aug 12;127(6):845–61. Available from: <https://doi.org/10.1016/j.bja.2021.06.048>
16. Dauterman L, Khan N, Tebbe C, Li J, Sun Y, Gunderman D, et al. Efficacy and safety of intraoperative controlled hypotension: a systematic review and meta-analysis of randomised trials. *British Journal of Anaesthesia* [Internet]. 2024 Jul 14;133(5):940–54. Available from: <https://doi.org/10.1016/j.bja.2024.06.008>
17. Wesselink EM, Wagemakers SH, Van Waes JAR, Wanderer JP, Van Klei WA, Kappen TH. Associations between intraoperative hypotension, duration of surgery and postoperative myocardial injury after noncardiac surgery: a retrospective single-centre cohort study. *British Journal of Anaesthesia* [Internet]. 2022 Sep 5;129(4):487–96. Available from: <https://doi.org/10.1016/j.bja.2022.06.034>
18. Li J, Ma Y, Li Y, Ouyang W, Liu Z, Liu X, et al. Intraoperative hypotension associated with postoperative acute kidney injury in hypertension patients undergoing non-cardiac surgery: a retrospective cohort study. *Burns & Trauma* [Internet]. 2024 Jan 1;12:tkae029. Available from: <https://doi.org/10.1093/burnst/tkae029>
19. Kluger MT, Collier JMK, Borotkanics R, Van Schalkwyk JM, Rice DA. The effect of intra-operative hypotension on acute kidney injury, postoperative mortality and length of stay following emergency hip fracture surgery. *Anaesthesia* [Internet]. 2021 Sep 23;77(2):164–74. Available from: <https://doi.org/10.1111/anae.15555>
20. Huang X, Lu X, Guo C, Lin S, Zhang Y, Zhang X, et al. Effect of preoperative risk on the association between intraoperative hypotension and postoperative acute kidney injury in cardiac surgery. *Anaesthesia Critical Care & Pain Medicine* [Internet]. 2023 Apr 13;42(5):101233. Available from: <https://doi.org/10.1016/j.accpm.2023.101233>
21. D'Amico F, Fominskiy EV, Turi S, Pruna A, Fresilli S, Triulzi M, et al. Intraoperative hypotension and postoperative outcomes: a meta-analysis of randomised trials. *British Journal of Anaesthesia* [Internet]. 2023 Sep 20;131(5):823–31. Available from: <https://doi.org/10.1016/j.bja.2023.08.026>
22. Zarour S, Weiss Y, Abu-Ghanim M, Iacubovici L, Shaylor R, Rosenberg O, et al. Association between Intraoperative Hypotension and Postoperative Delirium: A Retrospective Cohort Analysis. *Anesthesiology* [Internet]. 2024 Jul 12;141(4):707–18. Available from: <https://doi.org/10.1097/aln.0000000000005149>

23. Wu Y, Ren Y, Li S, Zeng M, Wang J, Li M, et al. Association between intraoperative hypotension during brain tumor resection and postoperative delirium: A secondary analysis of a randomized controlled trial. *PLoS ONE* [Internet]. 2025 Oct 29;20(10):e0334094. Available from: <https://doi.org/10.1371/journal.pone.0334094>
24. Ahrens E, Tartler TM, Suleiman A, Wachtendorf LJ, Ma H, Chen G, et al. Dose-dependent relationship between intra-procedural hypoxaemia or hypocapnia and postoperative delirium in older patients. *British Journal of Anaesthesia* [Internet]. 2022 Oct 1;130(2):e298–306. Available from: <https://doi.org/10.1016/j.bja.2022.08.032>
25. Vlisides PE, Mentz G, Leis AM, Colquhoun D, McBride J, Naik BI, et al. Carbon dioxide, blood pressure, and perioperative Stroke: A Retrospective Case–Control Study. *Anesthesiology* [Internet]. 2022 Aug 12;137(4):434–45. Available from: <https://doi.org/10.1097/aln.0000000000004354>
26. Müller J, Nowak S, Weidemeier M, Vogelgesang A, Ruhnau J, Von Sarnowski B, et al. Duration of surgery and intraoperative blood pressure management are modifiable risk factors for postoperative neurocognitive disorders after spine surgery. *Spine* [Internet]. 2023 May 15;48(16):1127–37. Available from: <https://doi.org/10.1097/brs.0000000000004722>
27. Phero A, Bokoch MP, Kothari R, Fong N, Chen D, Pirracchio R, et al. Postoperative Delirium in a Randomized Trial of Intraoperative Norepinephrine versus Phenylephrine Infusion. *Anesthesiology* [Internet]. 2024 Dec 6;142(1):234–7. Available from: <https://doi.org/10.1097/aln.00000000000005245>
28. Cekmecelioglu BT, Tire Y, Sertcakacilar G, Ekrami E, Pu X, Kopac O, et al. Perioperative Hypotension in Chronic Kidney Disease Patients with Dialysis Undergoing Noncardiac Surgery: A Retrospective Cohort Study. *Anesthesiology* [Internet]. 2024 Oct 7;142(1):132–41. Available from: <https://doi.org/10.1097/aln.00000000000005253>
29. Zhao B, Chen X, Chen Q, Li G, Chen Z, Yang Z, et al. Intraoperative hypotension and related risk factors for postoperative mortality after noncardiac surgery in elderly patients: a Retrospective Analysis report. *Clinical Interventions in Aging* [Internet]. 2021 Sep 30;Volume 16:1757–67. Available from: <https://doi.org/10.2147/cia.s327311>
30. Wijnberge M, Van Der Ster B, Vlaar APJ, Hollmann MW, Geerts BF, Veelo DP. The Effect of Intermittent versus Continuous Non-Invasive Blood Pressure Monitoring on the Detection of Intraoperative Hypotension, a Sub-Study. *Journal of Clinical Medicine* [Internet]. 2022 Jul 14;11(14):4083. Available from: <https://doi.org/10.3390/jcm11144083>
31. Kouz K, Wegge M, Flick M, Bergholz A, Moll-Khosrawi P, Nitzschke R, et al. Continuous intra-arterial versus intermittent oscillometric arterial pressure monitoring and hypotension during induction of anaesthesia: the AWAKE randomised trial. *British Journal of Anaesthesia* [Internet]. 2022 Aug 22;129(4):478–86. Available from: <https://doi.org/10.1016/j.bja.2022.06.027>
32. Grundmann CD, Wischermann JM, Fassbender P, Bischoff P, Frey UH. Hemodynamic monitoring with Hypotension Prediction Index versus arterial waveform analysis alone and incidence of perioperative hypotension.

Miguel Caled Trejos Román, Josué Campos Chinchilla, Yakira Delgado Angulo, Stephanie Paola Serrano Jiménez, María Celeste Leitón Duran, Braulio Zúñiga Alemán. Intraoperative Hypotension: Critical Thresholds, Hypotensive Burden, and Perioperative Clinical Consequences. *Int. Arch. Integr. Med.*, 2026; 13(5): 217-231.

Acta Anaesthesiologica Scandinavica [Internet]. 2021 Jul 29;65(10):1404–12. Available from: <https://doi.org/10.1111/aas.13964>

33. Runge J, Graw J, Grundmann CD, Komanek T, Wischermann JM, Frey UH. Hypotension Prediction Index and Incidence of perioperative hypotension: A Single-Center Propensity-Score-

Matched analysis. *Journal of Clinical Medicine* [Internet]. 2023 Aug 23;12(17):5479. Available from: <https://doi.org/10.3390/jcm12175479>