Exploration of Medicine

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The impact of esketamine on cardiac function in patients undergoing anesthesia

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Academic Editor: Guo-Chang Fan, University of Cincinnati College of Medicine, USA

Received: November 5, 2024 **Accepted:** January 25, 2025 **Published:** March 4, 2025

Cite this article: Sun E, Liu Y, Wang J. The impact of esketamine on cardiac function in patients undergoing anesthesia. Explor Med. 2025;6:1001291. https://doi.org/10.37349/emed.2025.1001291

Abstract

Esketamine, the *S*-enantiomer of ketamine, has gained prominence as an adjunct in pain management during general anesthesia due to its higher potency and ability to achieve therapeutic effects at lower doses than ketamine. While its benefits for pain relief and mental health are well-established, the specific effects of esketamine on cardiac function during anesthesia remain under investigation. Anesthesia itself induces physiological changes in the cardiovascular system, and esketamine can exacerbate these effects by increasing sympathetic activity, heart rate, blood pressure, and cardiac output. Additionally, it can induce peripheral vasoconstriction, raising systemic vascular resistance. These cardiovascular effects are particularly concerning in patients with pre-existing heart conditions, underscoring the importance of preoperative assessment, continuous monitoring, and potential dose adjustments. This review examined the hemodynamic effects of esketamine, the associated cardiovascular risks, and the clinical implications for patients with cardiac conditions, offering recommendations for its safe use in anesthesia.

Keywords

Esketamine, cardiac function, anesthesia, hemodynamic effects, sympathetic activity

Introduction

Anesthesia has a profound impact on cardiac function, as anesthetic agents can alter key cardiovascular parameters, such as heart rate (HR), blood pressure (BP), myocardial contractility, and vascular tone [1]. Esketamine, an enantiomer of ketamine, is increasingly being used in perioperative management [2]. While esketamine's therapeutic benefits for mental health and pain management are well-established, its specific effects on cardiac function—particularly in patients with pre-existing cardiovascular conditions that remain underexplored. A comprehensive understanding of these effects is crucial for enhancing patient safety and improving surgical outcomes.

Esketamine is primarily recognized for its potent antidepressant properties, which led to its approval by the European Medicines Agency (EMA) and the U.S. Food and Drug Administration (FDA) for the treatment and treatment-resistant depression (TRD) [3]. Its greater potency compared to ketamine allows for effective treatment at lower doses, thereby reducing side effects while maintaining efficacy. Despite these advantages, concerns persist regarding esketamine's cardiovascular effects, especially in the context of anesthesia. Ketamine, for instance, is known to increase HR and BP by stimulating the sympathetic nervous system, while also impairing heart muscle and vessel function through direct effects on myocardial and vascular smooth muscle [4]. Esketamine, on the other hand, is generally associated with fewer cardiovascular side effects due to its more targeted function. However, its potential to increase HR and BP, particularly in patients with pre-existing cardiovascular conditions, continues to raise questions. These complex and sometimes conflicting effects underscore the need for further investigation into whether esketamine's cardiovascular profile aligns more closely with that of ketamine or differs in significant ways, particularly in vulnerable patient populations.

Understanding the detailed impact of esketamine on cardiac function is essential for anesthesiologists to make informed decisions that optimize perioperative safety, especially for patients with compromised cardiac function.

Esketamine's mechanism of action

Ketamine exhibits sympathomimetic effects through direct stimulation of the sympathetic nervous system, resulting in both positive and negative inotropic effects that can significantly influence myocardial contractility and vascular smooth muscle activity [4]. Esketamine is classified as a dissociative anesthetic and primarily acts as an *N*-methyl-*D*-aspartate (NMDA) receptor antagonist. In addition to this primary action, esketamine also demonstrates activity on alpha-amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid (AMPA) receptors and engages brain-derived neurotrophic factor (BDNF) pathways [5].

The pharmacological action of esketamine involves several key pathways. Its antagonism of NMDA receptors results in increased glutamate release, a neurotransmitter vital for synaptic plasticity, which is believed to bolster cardiac resilience during physiological stress [6]. Furthermore, its interaction with AMPA receptors is important for the modulation of neurotransmitter systems that regulate cardiovascular function, suggesting a multifaceted approach to influencing heart health [7]. This intricate network of actions underscores the potential benefits and risks associated with esketamine, particularly in the context of cardiovascular dynamics.

Effects of esketamine on cardiac function

Esketamine, the active *S*(+) enantiomer of ketamine, is frequently compared to its racemic counterpart due to its similar pharmacological profiles [8]. Although both share similar chemical structures, they differ significantly in potency and their effects on cardiac function. Esketamine has roughly twice the anesthetic potency of racemic ketamine, enabling lower dosages to achieve comparable therapeutic effects [8]. This enhanced potency enables the use of reduced doses while ensuring effective treatment, highlighting esketamine's superior efficacy in clinical applications. For example, a single subanesthetic dose of esketamine typically provides therapeutic benefits for major depressive disorder (MDD), including TRD, lasting from 10 to 14 days, with some studies suggesting the potential for even longer durations [9]. This extended efficacy is a critical factor in its therapeutic use.

When comparing side effects, significant differences emerge between esketamine and ketamine. At therapeutic doses, esketamine is associated with fewer psychotropic and dissociative effects. The transient BP elevations often observed are usually asymptomatic and not linked to significant cardiovascular complications [7]. In contrast, ketamine is associated with a wider array of side effects, including agitation, perceptual disturbances, cognitive impairments, and memory deficits [10]. While both agents carry inherent risks, careful dosage management can effectively mitigate these adverse effects, thereby reinforcing esketamine's safety profile in many clinical settings.

The hemodynamic effects of esketamine warrant careful attention. By stimulating the sympathetic nervous system, esketamine increases HR (tachycardia) and BP (hypertension). This occurs through the inhibition of NMDA receptors, and glutamate receptors, which leads to enhanced glutamate release. In turn, the increased glutamate activates receptors with sympathomimetic properties, amplifying sympathetic activity. This results in heightened vascular contraction and an elevated HR. Furthermore, esketamine's sympathomimetic effects also promote the release of catecholamines, particularly norepinephrine, which further contribute to the observed cardiovascular changes by increasing vascular tone and driving systemic vasoconstriction. Clinical trials have shown that approximately 12.8% of patients treated with esketamine experience adverse events related to elevated BP, with an incidence of 11.6% in the esketamine/antidepressant group compared to just 3.9% in the antidepressant/placebo cohort [odds ratio 3.2 (1.9–5.8)] [7]. While around 13% of patients report transient hypertension, this condition typically resolves during the postoperative recovery period. Additionally, significant increases in HR—greater than 10 beats per minute—have been documented in individuals receiving esketamine through both intranasal (IN) and intravenous (IV) routes. Importantly, current evidence suggests that therapeutic doses of esketamine do not cause clinically significant QTc (corrected QT) prolongation [11], which is crucial for maintaining cardiac safety during anesthesia.

Esketamine also enhances cardiac output through elevated HR and improved myocardial contractility. The increased sympathetic activity contributes to higher cardiac output, effectively enhancing oxygen delivery to tissues under stress [12]. Furthermore, esketamine can counteract hypotension induced by other anesthetic agents, such as propofol and sevoflurane [13]. Its vasoconstrictive effects further increase systemic vascular resistance, primarily driven by the overstimulation of the sympathetic nervous system, which raises both HR and vascular resistance [14].

While esketamine provides significant therapeutic benefits, particularly for patients with TRD, it also presents potential risks, particularly in individuals with pre-existing cardiovascular conditions. The hypertension and tachycardia associated with esketamine administration can exacerbate issues like ischemic heart disease and heart failure. Additionally, the vasoconstrictive effects may extend to coronary arteries, increasing the risk of ischemic heart disease and subsequent heart failure [15]. The increased myocardial oxygen demand due to elevated HR and BP may trigger ischemic episodes, particularly in patients with compromised coronary circulation. Although generally more suitable for individuals without cardiovascular conditions, animal studies suggested that esketamine has protective effects against hypoxia/reoxygenation injury in cardiomyocytes, indicating potential therapeutic roles in mitigating myocardial ischemia [16].

The stimulation of the sympathetic nervous system by esketamine can lead to significant cardiac effects, with overstimulation, there is a potential risk of uncontrolled increases in HR and BP [17]. Therefore, patients with existing cardiac arrhythmias are typically advised to avoid esketamine due to the increased risk of exacerbating their condition.

Clinical and preclinical insights

Clinical studies examining the safety of esketamine in patients with pre-existing cardiac conditions have produced mixed results, highlighting both positive outcomes and potential risks. In controlled settings, esketamine has demonstrated minimal adverse effects, particularly when administered at low doses with proper monitoring.

A 2020 study highlighted significant cardiovascular side effects, such as hypertension, tachycardia, and arrhythmias, particularly when esketamine is used at higher doses or in patients with pre-existing cardiac conditions. This study, which assessed the cardiovascular safety of multiple subcutaneous (SC) esketamine injections in 70 patients with TRD, found slight increases in BP after each injection, with a peak of 4.87/5.54 mmHg within 30 to 45 minutes post-injection, returning to baseline levels by 120 minutes. Despite these minor fluctuations, 14 patients experienced transient hypertension (systolic BP > 180 mmHg and/or diastolic BP > 110 mmHg), leading to the recommendation for BP monitoring for 90 minutes after dosing to manage potential side effects [18].

In contrast, a 2021 study investigated the cardiovascular effects of combining SC or IV esketamine with the monoamine oxidase (MAO) inhibitor tranylcypromine in patients with major depressive episodes. This study, involving 43 patients—14 of whom also received tranylcypromine—found that esketamine did not cause significant increases in BP or HR. Continuous monitoring of vital signs revealed stable hemodynamics during esketamine administration at doses ranging from 0.25 to 0.5 mg/kg body weight, suggesting that esketamine can be safely administered without significant cardiovascular risks when appropriate monitoring is in place [19].

Further insight into the cardiovascular effects of esketamine comes from a 2024 preliminary study involving 18 patients with TRD, which explored the relationship between HR variability (HRV) and treatment outcomes with esketamine nasal spray (ESK-NS). The study found that responders, defined by a ≥ 30% reduction in Beck Depression Inventory scores, exhibited lower HRV at baseline, with HRV values improving after one month of treatment. The study also revealed that baseline HRV could predict treatment response, with a discriminative power of 0.844 based on receiver operating characteristic (ROC) analysis. These findings suggested that HRV could serve as an electrophysiological marker for predicting treatment outcomes, highlighting the need for further research to explore HRV's role in personalized treatment strategies for TRD [20].

In animal models, a 2022 study in guinea pigs investigated the effects of esketamine administered at sub-anesthetic concentrations (0.125, 0.25, and 0.5 $mg \cdot kg^{-1} \cdot h^{-1}$) on the heart's electrophysiological parameters. The study demonstrated dose-dependent changes, including alterations in resting membrane potential, action potential amplitude, and duration. Higher doses led to prolonged action potentials and irregular heart conduction, while lower doses increased HR. The study also observed the impact of esketamine on the expression of Connexin43, a protein essential for cardiac conduction, suggesting that esketamine may influence heart rhythm and conduction. These results highlighted the potential for cardiovascular effects with esketamine use, which should be carefully considered, especially in patients with pre-existing cardiac conditions [21].

Further insights into esketamine's cardiovascular impact were provided by a 2024 study on zebrafish larvae, which examined the drug's effects on cardiac function. The study found that esketamine exposure decreased HR, stroke volume, and cardiac output, suggesting that the drug may influence cardiac function by affecting genes involved in heart development. These findings emphasized concerns about esketamine's potential impact on the heart and blood vessels, especially in patients with underlying cardiovascular conditions [4] (Table 1).

Table 1. Cardiovascular effects of esketamine: summary of clinical and preclinical studies

Study	Population/Model	Esketamine dosage	Key findings	Cardiovascular effects	Recommendations
2020 study (esketamine in TRD patients)	70 patients with treatment-resistant depression	0.5–1.0 mg/kg (subcutaneous)	BP increases after each injection, transient hypertension in 14 patients	Slight BP increase (peak 4.87/5.54 mmHg), transient hypertension (SBP > 180 mmHg, DBP > 110 mmHg)	BP monitoring recommended for 90 minutes post-injection
2021 study (tranylcypromine + esketamine)	43 patients with major depressive episodes, 14 of whom concomitantly received tranylcypromine	0.25–0.5 mg/kg	No significant increase in BP or HR, stable hemodynamics	Minimal adverse effects, no significant cardiovascular risks with monitoring	Continuous monitoring recommended
2024 preliminary study (HRV and ESK-NS)	18 patients with TRD	ESK-NS	Responders had lower HRV at baseline, increased HRV after one month	HRV could predict treatment response (AUC = 0.844)	Further research on HRV as an electrophysiological marker for personalized treatment in TRD

Table 1. Cardiovascular effects of esketamine: summary of clinical and preclinical studies (*continued*)

Study	Population/Model	Esketamine dosage	Key findings	Cardiovascular effects	Recommendations
2022 study (esketamine in guinea pigs)	Guinea pigs	0.125, 0.25, 0.5 $mg \cdot kg^{-1} \cdot h^{-1}$	Dose-dependent changes in heart electrophysiology, altered resting membrane potential, action potential amplitude and duration	Prolonged action potentials at higher doses, increased HR at lower doses, altered Connexin43 expression	Caution for potential arrhythmias, especially at higher doses
2024 study (zebrafish larvae)	Zebrafish embryos	Varying concentrations of esketamine	Decreased HR, stroke volume, and cardiac output	Impact on cardiac development genes, reduced cardiac function	Implications for cardiovascular safety, especially in patients with underlying conditions

AUC: area under the curve; BP: blood pressure; DBP: diastolic BP; ESK-NS: esketamine nasal spray; HR: heart rate; HRV: HR variability; SBP: systolic BP; TRD: treatment-resistant depression

Recommendations for esketamine usage during anesthesia

Given the cardiovascular risks associated with esketamine, specific guidelines and recommendations should be adhered to in order to ensure patient safety:

- Preoperative assessment: a thorough cardiovascular evaluation is crucial prior to administering esketamine to all patients undergoing anesthesia, particularly those with known cardiac diseases. Clinicians must carefully assess individuals with existing cardiovascular and cerebrovascular conditions to determine whether the potential benefits of esketamine outweigh the associated risks [22]. In certain cases, administering this drug to patients with pre-existing medical conditions may exacerbate their health issues, making it preferable to explore alternative treatment options. Conducting comprehensive cardiovascular evaluations is essential for ensuring that a patient can safely receive the drug, representing a vital step in the prescription process.
- Continuous monitoring: continuous hemodynamic monitoring during and after esketamine administration is important for managing potential adverse effects. Research indicated that the combination of esketamine and propofol does not significantly increase the blood flow velocity of the middle cerebral artery [23]. Therefore, vigilant monitoring is necessary to mitigate complications related to proper blood flow, such as atherosclerosis, hypotension, and hypertension. Additionally, post-administration monitoring remains critical, as unstable BP may persist even after treatment has concluded.
- Dosage adjustments: modifications to dosages and consideration of alternative anesthetics or antidepressants may be required based on individual patient risk factors. For some patients, esketamine might not be the most suitable option due to specific medical conditions or circulatory issues. Even for those prescribed the drug, dosage adjustments may be necessary based on monitoring results. A study on zebrafish embryos demonstrated that the rates of embryo and larval mortality increased in a dose-dependent manner when exposed to esketamine concentrations of 0.2, 0.4, and 0.8 mg/mL [4]. This highlights the importance of dosage in determining the drug's effects on patients and underscores the necessity for careful dose adjustments to optimize esketamine's efficacy and safety.
- Education and communication: it is essential to educate patients about the potential cardiovascular effects of esketamine and ensure they recognize signs of adverse reactions, such as chest pain, palpitations, or severe headaches, which may indicate hypertensive episodes.
- Collaboration with cardiologists: collaboration with cardiologists is recommended for high-risk patients to optimize perioperative management and identify the most appropriate approach for anesthesia.

- Future research directions: further research is needed to fully elucidate the impact of esketamine on cardiac function, especially in specific patient populations. Larger, multicenter studies could yield more robust data regarding its safety and efficacy, particularly for individuals with cardiovascular risks. Additionally, longitudinal studies could assess the long-term cardiovascular outcomes associated with esketamine use in anesthesia settings. Research aimed at identifying specific patient groups that may benefit from esketamine while minimizing cardiovascular risks is essential for advancing its clinical use.

Conclusions

Esketamine shows promise in treating TRD and managing perioperative pain, but its cardiovascular effects require careful consideration. The impact of esketamine on HR and BP varies across different routes of administration. IV and SC administrations tend to cause more pronounced increases in BP and HR due to their rapid onset, necessitating close monitoring, and potential dose adjustments, especially in patients with pre-existing cardiovascular conditions. In contrast, the IN route generally results in milder fluctuations in cardiovascular parameters, making it a potentially safer option for individuals with less severe cardiovascular concerns. Regardless of the administration route, thorough preoperative cardiovascular evaluations and continuous hemodynamic monitoring during and after administration are essential to ensure patient safety. Personalized dosing, in collaboration with cardiologists, is recommended for high-risk patients to optimize the safety and efficacy of treatment. Further research is needed to better understand the long-term cardiovascular outcomes and refine esketamine use in clinical settings.

Abbreviations

AMPA: alpha-amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid

BP: blood pressure

HR: heart rate

HRV: heart rate variability

IN: intranasal

IV: intravenous

NMDA: *N*-methyl-*D*-aspartate

SC: subcutaneous

TRD: treatment-resistant depression

Declarations

Acknowledgments

The authors would like to thank the Summer Internship Program and Anesthesia Research Center (ARC) from the Department of Anesthesia, Critical Care, and Pain Medicine at Massachusetts General Hospital (MGH) for their valuable support.

Author contributions

ES and YL: Resources, Data curation, Writing—original draft. JW: Conceptualization, Validation, Supervision, Writing—review & editing.

Conflicts of interest

The authors declare that they have no conflicts of interest.

Ethical approval

Not applicable.

Consent to participate

Not applicable.

Consent to publication

Not applicable.

Availability of data and materials

Not applicable.

Funding

Not applicable.

Publisher's note

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References

1. Anesthesia Inhalation Agents and Their Cardiovascular Effects [Internet]. Treasure Island: StatPearls; [cited 2024 Oct 10]. Available from: https://www.ncbi.nlm.nih.gov/books/NBK541090/
2. Min M, Du C, Chen X, Xin W. Effect of subanesthetic dose of esketamine on postoperative rehabilitation in elderly patients undergoing hip arthroplasty. J Orthop Surg Res. 2023;18:268. [DOI] [PubMed] [PMC]
3. d'Andrea G, Pettorruso M, Lorenzo GD, Mancusi G, McIntyre RS, Martinotti G. Rethinking ketamine and esketamine action: Are they antidepressants with mood-stabilizing properties? Eur Neuropsychopharmacol. 2023;70:49–55. [DOI] [PubMed]
4. Huang S, Wang J, Lin T, He C, Chen Z. Esketamine Exposure Impairs Cardiac Development and Function in Zebrafish Larvae. Toxics. 2024;12:427. [DOI] [PubMed] [PMC]
5. Jawad MY, Vincenzo JDD, Badulescu S, Teopiz KM, Tabassum A, Ceban F, et al. The therapeutic role of ketamine and esketamine in treating psychopathological domains of depression. Neuropharmacology. 2023;223:109299. [DOI] [PubMed]
6. Vasiliu O. Esketamine for treatmentresistant depression: A review of clinical evidence (Review). Exp Ther Med. 2023;25:111. [DOI] [PubMed] [PMC]
7. Doherty T, Wajs E, Melkote R, Miller J, Singh JB, Weber MA. Cardiac Safety of Esketamine Nasal Spray in Treatment-Resistant Depression: Results from the Clinical Development Program. CNS Drugs. 2020;34:299–310. [DOI] [PubMed] [PMC]
8. Himmelseher S, Pfenninger E. Die klinische Anwendung von S-(+)-Ketamin - eine Standortbestimmung. Anasthesiol Intensivmed Notfallmed Schmerzther. 1998;33:764–70. [DOI] [PubMed]
9. Xiao C, Zhou J, Li A, Zhang L, Zhu X, Zhou J, et al. Esketamine vs Midazolam in Boosting the Efficacy of Oral Antidepressants for Major Depressive Disorder: A Pilot Randomized Clinical Trial. JAMA Netw Open. 2023;6:e2328817. [DOI] [PubMed] [PMC]

10. Ketamine Toxicity [Internet]. Treasure Island: StatPearls; [cited 2024 Oct 10]. Available from: https://www.ncbi.nlm.nih.gov/books/NBK541087/
11. National Center for Biotechnology Information. PubChem Compound Summary for CID 182137, Esketamine [Internet]. Bethesda: National Library of Medicine; [cited 2024 Oct 7]. Available from: https://pubchem.ncbi.nlm.nih.gov/compound/Esketamine
12. Borovac JA, D'Amario D, Bozic J, Glavas D. Sympathetic nervous system activation and heart failure: Current state of evidence and the pathophysiology in the light of novel biomarkers. World J Cardiol. 2020;12:373–408. [DOI] [PubMed] [PMC]
13. Zhou N, Liang X, Gong J, Li H, Liu W, Zhou S, et al. S-ketamine used during anesthesia induction increases the perfusion index and mean arterial pressure after induction: A randomized, double-blind, placebo-controlled trial. Eur J Pharm Sci. 2022;179:106312. [DOI] [PubMed]
14. Reich DL, Mittnacht AJ, London MJ, Kaplan JA. Chapter 9 - Monitoring of the Heart and Vascular System. In: Kaplan JA, editor. Essentials of Cardiac Anesthesia. Philadelphia: Saunders; 2008. pp. 167–98.
15. Ischemic heart disease [Internet]. Oak Brook: Advocate Health Care; [cited 2024 Jul 14]. Available from: https://www.advocatehealth.com/health-services/advocate-heart-institute/conditions/ischemic-heart-disease
16. Zhang Y, Lu Q, Hu H, Yang C, Zhao Q. Esketamine alleviates hypoxia/reoxygenation injury of cardiomyocytes by regulating TRPV1 expression and inhibiting intracellular Ca^{2+} concentration. Clinics (Sao Paulo). 2024;79:100363. [DOI] [PubMed] [PMC]
17. Ketamine and esketamine (Spravato) for anxiety [Internet]. Tampa: Florida TMS Clinic; [cited 2024 Jul 15]. Available from: https://www.floridatmsclinic.com/ketamine-esketamine-anxiety
18. Sant LCD, Sarin LM, Magalhães EJM, Lucchese AC, Tuena MA, Nakahira C, et al. Effects of subcutaneous esketamine on blood pressure and heart rate in treatment-resistant depression. J Psychopharmacol. 2020;34:1155–62. [DOI] [PubMed]
19. Ludwig VM, Sauer C, Young AH, Rucker J, Bauer M, Findeis H, et al. Cardiovascular Effects of Combining Subcutaneous or Intravenous Esketamine and the MAO Inhibitor Tranylcypromine for the Treatment of Depression: A Retrospective Cohort Study. CNS Drugs. 2021;35:881–92. [DOI] [PubMed] [PMC]
20. Moccia L, Bartolucci G, Pepe M, Marcelli I, Grisoni F, Brugnami A, et al. Heart Rate Variability as a Potential Predictor of Response to Intranasal Esketamine in Patients with Treatment-Resistant Depression: A Preliminary Report. J Clin Med. 2024;13:4767. [DOI] [PubMed] [PMC]
21. Cao Y, Song Y, Wang Z, Tang J, Yi J, Liu Y, et al. Effects of different dosages esketamine on cardiac conduction and heterogeneity of Cx43: the epicardial mapping in guinea pigs. Ann Transl Med. 2022; 10:772. [DOI] [PubMed] [PMC]
22. Fagiolini A, González-Pinto A, Miskowiak KW, Morgado P, Young AH, Vieta E. Role of trazodone in treatment of major depressive disorder: an update. Ann Gen Psychiatry. 2023;22:32. [DOI] [PubMed] [PMC]
23. Yan S, Li Q, He K. The effect of esketamine combined with propofol-induced general anesthesia on cerebral blood flow velocity: a randomized clinical trial. BMC Anesthesiol. 2024;24:66. [DOI] [PubMed] [PMC]