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Comparative analysis of the effects of inhalational and intravenous anesthetics on hemodynamic variability and cardiovascular complications in patients undergoing general anesthesia – a review of current evidence

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Abstract

Background. Patient hemodynamic stability during general anesthesia is a crucial factor, managing which helps avoid many complications, especially cardiovascular ones. Intravenous and inhaled anesthetics affect the human body differently, have different mechanisms of action, and have different durations of action. Due to the diversity of anesthetics, it is essential to match them appropriately to the patient's medical history and current clinical condition to reduce the risk of possible postoperative complications.

Aim. The aim of this study was to analyze the inhalation and intravenous anesthetics used by anaesthesiologists and their impact on the hemodynamic stability of patients and, consequently, the risk of cardiovascular complications.

Material and methods. This paper provides a literature review of inhaled and intravenous anesthetics used in clinical practice. Research papers available in PubMed, Google Scholar, and ScienceDirect were analyzed. The focus was on clinical trials, meta-analyses, and review articles.

Conclusions. Intravenous and inhaled anesthetics differ in their action profile and impact on the circulatory system. Inhaled drugs provide greater hemodynamic stability, while intravenous drugs are characterized by a faster onset of action and a less predictable effect on the patient's vital signs. Due to the advantages of both groups of anesthetics, the selection of anesthesia should be individualized for each patient, taking into account their health status, comorbidities, and the risk of thromboembolic events.

Key words: inhalation anesthetics, intravenous anesthetics, hemodynamic stability, cardiovascular complications, general anesthesia

Introduction

Anesthesia is a complex process that can be divided into several phases: induction, maintenance of anesthesia, and recovery. Each stage is different and requires the administration of different medications with different action profiles. Regardless of the stage of anesthesia, maintaining hemodynamic stability is essential. This stability includes basic vital parameters such as blood pressure, heart rate, respiratory rate, oxygen saturation, diuresis, and body temperature. Maintaining normal values for these parameters helps avoid cardiovascular complications such as hypotension, hypertension, decreased organ perfusion, and increased or decreased cardiac output [13].

Anesthetics used daily by anesthesiology teams can be divided into inhalation and intravenous based on their method of administration. Inhalation medications include sevoflurane, desflurane, and isoflurane, while intravenous medications include propofol, ketamine, and etomidate. Each group of medications differs in its mechanism of action, duration of action, and impact on specific systems [5].

Inhaled forms of anesthetics are characterized by a greater predictability of action, depending on the dose administered to the patient. They primarily minimize vascular resistance, which in turn lowers blood pressure while maintaining a relatively constant cardiac output. They possess cardioprotective properties, which are crucial in patients with coronary artery disease. The second group of drugs are intravenous anesthetics, which have a faster onset of action, allowing physicians to more precisely estimate their dose. However, due to the route of administration, intravenous anesthetics have a more pronounced effect on the circulatory system [15].

Despite advances in anesthesiology, the problem of postoperative complications persists. Many medications, despite their safe profile, can cause adverse effects, which may also be related to the patient's health status. Individuals at high risk of cardiovascular events, such as those who smoke, have hypertension, abnormal lipid profiles, or comorbidities, are more likely to experience postoperative complications. However, to optimize the effects of surgery and the synergistic effects of the medications used, physicians must select appropriate anesthetics for each patient to maximize the safety of the procedure [2].

Review methodology

This publication is a literature review examining the impact of both inhaled and intravenous anesthetics used by physicians on hemodynamic stability and the incidence of cardiovascular complications in patients undergoing general anesthesia. The literature was analyzed based on available sources in the PubMed, Google Scholar, and ScienceDirect databases. The publications were published between 2016 and 2026 to provide the most up-to-date data on these anesthetics, their use, and follow-up. The collected information was qualitatively analyzed, focusing primarily on changes in blood pressure as a consequence of anesthetics, variability in basic vital signs, and the incidence of cardiovascular complications.

The choice of the topic of this work was guided by the desire to analyze the safety of patients undergoing general anesthesia and the impact of modern anesthetics on their bodies. Hemodynamic stability is the most crucial component of sedation, which is why it is so important to observe the effects a given medication has on the cardiovascular system, what complications can occur, and how to prevent them.

Modern inhalation anesthetics

Inhalation anesthetics are considered the foundation of modern anesthesiology, as they are used in the treatment of both adults and children. Among the modern inhalation anesthetics, we can mention sevoflurane, desflurane, and isoflurane. Each of these medications has numerous advantages and side effects. The mechanism of action of inhalation anesthetics and their impact on the human nervous system has not been fully explained and is still a subject of research. To date, it has been found that anesthetic gases primarily act in the following areas: inhibiting the excitability of nerve cells, dampening synaptic conduction, and weakening excitatory transmission. These pharmaceuticals enhance the activity of inhibitory receptors, i.e., GABBA and glycine receptors, while also acting on potassium and sodium channels. In terms of their effects on synaptic transmission, they cause a decrease in glutamate release and intensify the postsynaptic effects of glycine and gamma-aminobutyric acid. The effect of the described mechanisms is a reduction of the patient's pain, loss of consciousness, loss of reactivity to external stimuli and a reduction of muscle tension [24].

Sevoflurane was discovered in the 1960s, but for many years it was shunned and only began to be used by physicians in 1990. It is a modern anesthetic agent used not only for induction but also for maintenance. Due to its pleasant odor, it does not irritate the respiratory tract, making it a popular choice for pediatric patients [11]. It affects the circulatory system by lowering blood pressure, which is a result of its vasodilatory effect, while simultaneously reducing vascular resistance. Because it minimizes brain metabolism and increases blood flow through brain tissue, it has been administered to stroke patients, providing positive treatment effects by protecting the brain and improving patient prognosis [26].

Another drug used in anesthesiology is desflurane, which has a favorable pharmacokinetic profile. It has a low blood/gas solubility coefficient, which translates into better control of the depth of anesthesia and faster recovery from surgery, making it frequently used in outpatient surgery. When analyzing the effects of desflurane on the circulatory system, it's worth noting that it reduces vascular resistance and can slightly lower arterial blood pressure. However, administering the anesthetic too rapidly can contribute to periodic sympathetic stimulation, which manifests in patients with tachycardia and increased blood pressure. Due to this effect, it should be dosed cautiously in patients with cardiovascular conditions to avoid a range of adverse effects [19].

The last anesthetic mentioned is isoflurane, primarily used to maintain sedation. It dilates blood vessels, which leads to a drop in blood pressure. It has a slightly lower blood/gas solubility ratio than its predecessor, resulting in a slower onset of anesthesia and a longer recovery period. A positive aspect of this drug is its cardioprotective effect, thanks to increased tolerance of the heart muscle to oxygen deprivation [3].

Intravenous anesthetics

A cornerstone of anesthesiology, besides anesthetic gases, are intravenous medications. They are used not only to induce anesthesia but also to maintain it. The positive aspects of intravenous anesthetics used in practice include their rapid onset of action, the predictability of their effects, and the ability to efficiently control the depth of anesthesia. However, similarly to inhalation anesthetics, this group of pharmaceuticals, in addition to its many advantages, also has a number of disadvantages and can disrupt the functioning of the human body, manifesting itself in disturbances of circulatory system parameters [8].

The most common intravenous anesthetic is propofol, developed by the British corporation Imperial Chemical Industries. This drug is characterized by a rapid onset of action and an equally rapid elimination process from the body. Its short duration of action allows patients to quickly recover from anesthesia. After intravenous administration, this drug binds to plasma albumin and red blood cells. A small amount of the drug, approximately 1.2-1.7%, constitutes the free fraction of plasma. It can easily cross the blood-brain barrier, thus allowing for rapid loss of consciousness. However, it should be remembered that the rapidity of propofol inducing anesthesia depends on many factors demonstrated by the patient undergoing the procedure, such as cardiac output [20].

Another intravenous drug used by anesthesiologists is ketamine, an antagonist of NMDA receptors in the central nervous system, which disrupts glutamatergic transmission. In this situation, we speak of dissociative anesthesia, which involves the separation of the limbic system and the cerebral cortex. The patient remains unconscious, but their muscle tone and protective reflexes in the airways, such as cough, remain intact. Furthermore, ketamine has little effect on the respiratory center, so spontaneous breathing is observed in individuals undergoing this medication. A positive aspect of ketamine's use is its analgesic effect, making it ideal for short surgical and diagnostic procedures, especially in children. Additionally, it has been shown that ketamine leads to a reduction in the reuptake of neurotransmitters - noradrenaline and serotonin, and also affects adrenergic receptors, thereby stimulating the sympathetic nervous system of the human body, which is why it is said to have a sympathomimetic effect [27].

The last of the group of intravenous anesthetics is etomidate, an agonist of GABA receptors present in the brainstem. It is characterized by a rapid and short-acting effect. Its primary use is inducing anesthesia. It is also worth noting that, unlike ketamine, it does not have analgesic effects. A positive aspect of this drug is its negligible effect on the circulatory system, which is why anesthesiologists so readily use it during cardiac surgery and in patients with circulatory system diseases [25].

Hemodynamic stability during anesthesia

Anesthesia is a complex process involving various drug classes and a range of specialized procedures performed by anesthesiologists and nurse anesthesiologists. For everything to function comprehensively, it is essential to monitor the patient's condition, specifically their hemodynamic stability. Hemodynamic stability refers to the proper functioning of the circulatory system, which is assessed using parameters such as blood pressure, heart rate, diuresis, oxygen saturation, skin color, and capillary refill, which provide information about organ perfusion [28].

The first of these parameters is blood pressure, which, if too high or too low, poses a threat to a person's life. Hypertension increases the risk of bleeding during surgery, while too low blood pressure values pose a risk of ischemia of internal organs. Blood pressure during surgery can be monitored not only with a standard cuff connected to a cardiac monitor, but also through invasive measurement by directly inserting a thin catheter into the artery, which provides a continuous pressure reading. The advantage of this solution is greater precision and continuity of measurement, allowing doctors to react quickly in life-threatening situations. Saturation, which determines the percentage of oxygen saturation in the blood, is another parameter measured during the surgical procedure using a pulse oximeter. This device allows for non-invasive and painless measurement. Monitoring these parameters would be impossible without a cardiac monitor, which is essential in every operating room and allows for patient observation. Regarding diuresis, the catheter bag should be monitored for urine output both during and after the procedure. In turn, pink skin color and capillary refill, which is normal up to two seconds, indicate proper perfusion [6].

When preparing a patient for surgery, anesthesiologists must be aware that a number of factors can affect hemodynamic stability. This poses a real threat to the ability to administer specific medications and maintain basic vital parameters within normal limits. Patients with a history of heart failure, coronary artery disease, cardiac arrhythmias, or obesity are particularly vulnerable to hemodynamic instability and are at greater risk of postoperative complications [23].

The influence of anesthetics on the patient's hemodynamic stability

The essence of every procedure is ensuring patient safety, which primarily depends on their hemodynamic stability. Failure to monitor the parameters of patients undergoing anesthesia destabilizes the entire body, contributing to circulatory system disorders, cardiovascular complications, and, ultimately, death. To prevent these risk factors, it is essential to monitor anesthesiologists, their nurses, and other physicians performing sedation and the surgical procedure itself [18].

To analyze how anesthetics affect hemodynamic stability, we must first consider which parameters must be monitored first to detect if something alarming is occurring and the patient's condition is destabilizing. In terms of blood pressure, we pay attention to both systolic and diastolic blood pressure, as well as mean arterial pressure (MAP). Cardiac output, which is the amount of blood ejected from the heart per unit of time, usually one minute, is also monitored. Factors that determine myocardial performance include heart rate and left ventricular stroke volume. The components of stroke volume (SV) that influence its value are:

- preload, which refers to the degree of stretching of the heart muscle fibers at the end of diastole and before the onset of the next contraction,
- afterload, which is defined as the resistance the heart must overcome to eject blood from the ventricles into the arteries,
- contractility of the cardiac muscle, also known as inotropy in the literature, is the heart's ability to contract regardless of preload or afterload. There are a number of factors that can influence inotropy, either intensifying it positively or minimizing it negatively [7].

Other elements of hemodynamic stability include heart rate and vascular resistance. When considering heart rate disturbances, we can encounter a heart rate that is too slow, i.e., bradycardia, or too fast, i.e., tachycardia. Both situations pose a real threat to patients' lives, as they affect the filling of the heart ventricles with blood flowing from the atria, as well as cardiac output. In turn, vascular resistance, which is a measure of the tension in the blood vessel walls, can affect blood pressure. This is the case with inhaled anesthetics, which contribute to a decrease in this resistance and a subsequent drop in blood pressure, developing hypotension in the patient [9].

Another factor that has a fundamental impact on the stability of a patient's basic parameters is the contractility of the heart muscle, which is controlled by the sympathetic nervous system. Among anesthetics, there are also medications that can reduce the heart's ability to contract, such as propofol, but also increase contractility, such as ketamine [12].

All of the above-mentioned aspects have a comprehensive impact on the functioning of human organs. Any disturbances that develop at specific levels can lead to dysregulation of organ perfusion, which carries a number of cardiovascular complications. Complications in the circulatory system, related to the action of specific anesthetics, both intravenous and inhaled, can occur in the form of:

- cardiac arrhythmias – desflurane is an example of a drug that can cause a temporary increase in heart rate, especially if its dosage is not controlled,
- hypotension – a drop in blood pressure, which is caused by dilated peripheral blood vessels, decreased vascular resistance, and a slower heart rate. Anesthetics such as sevoflurane and isoflurane can lead to a decrease in blood pressure, but this can be controlled by administering an appropriate dose of the drug,
- increased circulatory system load – ketamine is an example of a drug that can affect this aspect. Its action is based on the stimulation of the sympathetic nervous system, which in turn stimulates the heart to contract even more, raises blood pressure, and causes an increase in cardiac output. This is a key problem for people struggling with coronary artery disease, as it can lead to the development of myocardial ischemia [21].

The range of complications that anesthetics can cause varies, depending on the type of medication administered to the patient, the route of administration, and the dose used. The most frequently reported adverse effects of sedative drugs include hypotension, disturbances in the transmission of electrical impulses within the heart muscle, and decreased cardiac contractility [17].

Comparison of both groups of anesthetics in terms of hemodynamic stability and cardiovascular complications

The impact of inhaled and intravenous anesthetics on patient hemodynamic stability is fundamental to planning general anesthesia for surgical procedures. These two groups of medications differ in various aspects, including their mechanism of action, the speed at which they induce changes in the body, and their profile of action on the human circulatory system. These different modes of action are therefore reflected in the clinical use of anesthetics [1].

Intravenous anesthetics, which include propofol, ketamine, and etomidate, as well as inhalation anesthetics such as sevoflurane, desflurane, and isoflurane, have a number of advantages and disadvantages that qualify or disqualify them for use in specific types of surgery. The first group of drugs, intravenous, is characterized by a relatively rapid onset of action and a visible impact on the patient's basic parameters. After administration of propofol, patients lose consciousness after just 25-40 seconds. It causes vascular smooth muscle relaxation, allowing blood to dilate and flow more freely, resulting in a drop in blood pressure. Propofol reduces systolic and diastolic blood pressure, as well as mean arterial pressure (MAP) within the first few minutes of anesthesia [22]. Etomidate, which induces anesthesia within 30-40 seconds, helps reduce cerebral blood flow and minimize intracranial pressure. It has a minor effect on blood pressure and cardiac output, so it can be considered more stable in terms of heart rate. Etomidate is effective in hemodynamically unstable patients or those with severe heart disease. However, a negative side to this medication is its inhibitory effect on the adrenal cortex, making it unsuitable for infusion. Ketamine, unlike the aforementioned anesthetics, increases blood pressure by stimulating the sympathetic nervous system, which increases catecholamine secretion and inhibits their reuptake. Ketamine is important in patients with hypotension and shock. However, it should be noted that it is not recommended for patients with serious heart conditions or untreated or poorly controlled hypertension [16].

Inhalation anesthetics are primarily used by anesthesiologists to maintain general anesthesia. Like intravenous medications, they also affect patients' cardiovascular systems. They can affect the heart both directly and indirectly. Inhalation anesthetics differ in certain characteristics, but they share several common features, including:

- minimizing mean arterial pressure (MAP),
- myocardial depression,
- affecting the autonomic nervous system [14].

Among the inhalation anesthetics mentioned are sevoflurane, desflurane, and isoflurane. They are characterized by greater predictability of hemodynamic changes and better control of the depth of anesthesia, therefore their primary use is for maintaining anesthesia. Regarding their effects on the cardiovascular system, isoflurane and desflurane cause tachycardia in patients resulting from sympathetic nervous system stimulation. As the anesthetic concentration increases, cardiac output decreases, which the body begins to compensate by accelerating the heart muscle. This occurs primarily when the drug concentration is increased too rapidly, especially desflurane and isoflurane. The primary effect of this group of anesthetics is a reduction in vascular resistance and a steady decrease in blood pressure. A negative side of these drugs is their effect on QT prolongation, visible on the electrocardiogram. Therefore, in patients with long QT syndrome, malignant arrhythmias, such as torsades de pointes, may be a concern. In such situations, before the induction of anesthesia, patients are given β-blockers, which are intended to protect them from the above-mentioned disorders [10].

Cardiovascular complications remain a significant problem in surgical procedures and general anesthesia. To reduce the risks associated with anesthesia, the anesthesiologist must select the appropriate anesthetic based on the patient's medical history and health status. Properly selected anesthetics ensure hemodynamic stability, minimizing the risk of complications. Therefore, the most beneficial treatment outcomes are achieved by combining both groups of anesthetics, i.e., inhalational and intravenous. In summary, cardiovascular complications that can occur with both groups of drugs include hypotension, bradycardia, decreased cardiac output, myocardial ischemia, and arrhythmias. Ketamine has a slightly different profile of action, stimulating the circulatory system, contributing to hypertension, tachycardia, and increased cardiac oxygen demand. However, it is worth bearing in mind that inhalation anesthetics, especially sevoflurane and isoflurane, have a cardioprotective effect and minimize the risk of reperfusion injury to the heart [4].

Conclusions

1. The intravenous and inhalation anesthetics discussed in this paper have a crucial impact on the human cardiovascular system during the perioperative period, affecting hemodynamic stability. The diversity of actions of individual anesthetic groups depends on their pharmacological properties.
2. Propofol, etomidate, and ketamine, which belong to the group of intravenous anesthetics, are characterized by a faster duration of action and a greater risk of causing dynamic changes in basic vital parameters.
3. Inhalation anesthetics, such as sevoflurane, desflurane, and isoflurane, have a more predictable effect, and their impact on hemodynamic stability depends on the drug dose used.
4. The action profile of inhalation anesthetics primarily involves reducing vascular resistance and moderate myocardial depression.

5. Sevoflurane is the agent with the most favorable hemodynamic profile, while desflurane can transiently stimulate the sympathetic nervous system. Isoflurane is a drug considered cardioprotective because it increases cardiomyocyte resistance to ischemia and reperfusion disorders.
6. Cardiovascular complications are a serious issue in clinical practice, and their risk increases with hemodynamic instability.
7. The most beneficial effects of general anesthesia can be achieved by using a combination of both intravenous and inhalation anesthetics.

Disclosure:

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