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The Impact of Anesthesia on Cancer Outcomes

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Abstract:
In cancer treatment, anesthesia is commonly used during surgery to remove tumors, as well as for other procedures like biopsies, radiation therapy, and chemotherapy administration. Some research suggests that the choice of specific anesthetic drugs and nerve-sparing techniques can have a significant impact on cancer recurrence rates and overall patient survival. It is well-established that a patient's immune system plays a direct role in postoperative complications and long-term outcomes, highlighting the importance of optimizing anesthesia to minimize potential immune system suppression and improve immune function during cancer surgery. Recent studies have revealed a strong connection between the type of anesthesia used during surgery and the likelihood of cancer relapse and related mortality. Therefore, it is crucial to select the appropriate anesthesia technique for cancer resection, focusing on reversible effects, rapid recovery, and resistance to feedback. The specific anesthetic agents used during surgery have a significant impact on survival rates and the risk of cancer-related mortality. Genetic influences on anesthesia response are significant for improving patient care and achieving better results. Additionally, personalized medicine, which combines diagnostic testing and treatment, is now a clinical reality. Anesthesia's effects on depth, pain signals, vital signs, and the motor system are complex and not fully understood, and many researchers believe that anesthesia is regulated by multiple genes, although further research is needed to identify them and understand how they are regulated. The relationship between anesthesia and cancer is complex and evolving with implications for medical treatment. Limited evidence suggests that anesthesia and surgery-related factors can affect cancer biology and outcomes. Further research is needed to understand these interactions and develop strategies for improving cancer care during surgery. Better understanding can lead to safer and more effective cancer treatment, benefitting patients.

INTRODUCTION

Anesthesia is a medical intervention that induces a reversible loss of sensation and consciousness, allowing for invasive procedures to be performed without causing pain or discomfort to the patient. In the context of cancer treatment, anesthesia is commonly used during the surgical resection of tumors, as well as for other procedures such as biopsies, radiation therapy, and chemotherapy administration (1). While the primary goal of anesthesia is to ensure patient comfort and safety during these procedures, there is growing evidence to suggest that certain anesthetic agents and perioperative factors may have the potential to influence the biological behavior of cancer cells and impact long-term oncological outcomes (2).

The role of anesthesia in cancer surgery is widely acknowledged as life-saving and not linked to cancer recurrence or progression. However, the question remains: can the choice of anesthetic agents and methods impact the perioperative period and tumor microenvironment to influence cancer progression? Cancer is a complex process, with the immune system playing a crucial role. As cancer progresses, the delicate balance between the body's immune defenses and the developing tumor is disrupted, leading to a tolerogenic environment known as cancer immune editing. Anesthesia and surgery can also have a profound impact on the body's immune response, potentially leading to a less effective defense against the tumor and impacting patient outcomes (3). Some studies

suggest that the selection of specific anesthetic drugs and nerve-sparing techniques can exert a significant influence on cancer recurrence rates and overall patient survival. It is now well-established that the immune competence of the patient is directly connected to postoperative complications and long-term therapeutic outcomes, underscoring the importance of optimizing anesthesia protocols to mitigate potential immunosuppressive effects and enhance immune function in the context of cancer surgery. By carefully considering the immunological implications of anesthetic choices and implementing strategies to minimize immunosuppression, healthcare providers may be able to improve patient outcomes and reduce the risk of cancer progression during the perioperative period. The potential interactions between anesthesia and cancer have been a topic of increasing interest and concern in the medical community (4). As anesthesia is a crucial component of cancer surgery and other cancer-related procedures, understanding its potential effects on cancer progression and recurrence is of paramount importance. This paper aims to provide a comprehensive overview of the current understanding of the interactions between anesthesia and cancer, covering various aspects including the impact of different anesthetic agents, perioperative factors, and potential mechanisms underlying these interactions (5).

Overview of Anesthesia in Cancer Surgery

Anesthesia plays a critical and indispensable role in the field of cancer surgery, as it provides an enabling environment for physicians to conduct intricate procedures such as tumor excision and preventing metastasis. Recent retrospective studies, which have charted the course of medical exploration, have illuminated a remarkable link between the type of anesthesia employed during surgical interventions and the long-term likelihood of cancer relapse and related mortality (5). Expanding the boundaries of medical knowledge, researchers have embarked upon a series of animal and cell experiments to unravel the intricate connections between anesthesia, surgical techniques, and postoperative cancer outcomes, thereby opening new frontiers of inquiry within the medical sphere (6, 7). However, it is essential to approach the results of retrospective studies with caution, as inherent biases may be involved. Hence, to corroborate the intricate relationship between anesthesia and cancer, further prospective and randomized controlled experiments are indispensable. The realm of cancer patient management during surgery encompasses a wide array of modern anesthetic agents, each wielding invaluable potential. These agents, including hypnotics, opioids, and local anesthetics, have proven instrumental in effectively managing cancer patients undergoing surgery (8). Beyond their primary purpose, these avant-garde anesthetic agents possess diverse biological effects, which may potentially impact the trajectory of cancer progression. As medical practitioners, it is paramount to strike a delicate balance between the potential risks and benefits of anesthesia to ensure that cancer patients undergoing surgical interventions receive the most efficacious and safe treatment available (9). Against this backdrop, the present review embarks on a comprehensive analysis, primarily focusing on the profound impact of different anesthetic agents and drugs utilized in the realm of cancer surgery. The overarching objective of this exploration is to deepen our understanding of the multifaceted effects these agents exert on cancer operations, thereby providing practical recommendations to guide their appropriate and judicious usage (10).

Types of Anesthesia Used in Cancer Surgery

Cancer surgery involves the utilization of various treatments, such as local ablative therapy and surgical resection, to prevent postoperative metastasis. The growth of malignant tumors requires chronic inflammation and wound repair by different cells in the body. However, the inflammatory response to surgery can interfere with the body's defense against cancer cells(10). Managing postoperative pain is crucial, and non-opioid relief methods are being explored. Anesthesia techniques for cancer surgery are also being revised, with some drugs showing potential for suppressing tumor growth in preclinical trials (11).

Advanced soft tissue surgeries, such as open cholecystectomy and pelvic organ operations, are effective in providing extensive pain relief for postoperative patients. These same surgeries, along with procedures for kidney deformities, are also utilized in the surgical management of solid tumors. It has been observed that the use of general anesthesia is on the rise, but it is associated with poor outcomes for cancer patients, including recurrence and overall perioperative adverse effects. This can be attributed to a combination of factors such as anesthesia, endomorphin, tumor growth factors, and neuroendocrine responses (11, 12). Therefore, selecting the appropriate general anesthesia technique is crucial for cancer resection, with a focus on reversible effects, rapid postoperative recovery, and resistance to feedback. Factors that should be considered in choosing the appropriate anesthesia for cancer patients include endocrine tumor markers, chronic drug use, previous responses to anesthesia, and allergy information. Collaboration between anesthesiologists and attending physicians and surgeons is essential, with medical advice tailored to individual patient needs and professional tolerances (12, 13).

Impact of Anesthetic Agents on Cancer

The relationship between anesthetics, surgery, and

cancer outcomes is currently being explored by a wide range of medical professionals, including surgeons and anesthesiologists. They are investigating how anesthetics interact with the body's inflammatory, immunological, and wound repair processes, all of which play a role in cancer. There is a curiosity about whether anesthesia could help promote beneficial inflammation or reduce harmful inflammation to improve cancer treatment results (12). This could potentially reduce the need for other expensive drugs and treatments that often come with significant side effects. By examining evidence of how anesthesia affects surgical outcomes and identifying potential molecular targets, researchers hope to develop more effective drug regimens for cancer treatment. It is important to look at how cancer and anesthetics interact with inflammation to gain a better understanding of how anesthesia impacts cancer development and progression. Researchers have theorized that cancer utilizes the body's inflammatory system to aid in tumor growth and the spread of cancerous cells to other parts of the body (14).

One of the key areas of research in the field of anesthesia and cancer relates to the impact of different anesthetic agents on cancer progression and recurrence. Studies have investigated the potential effects of volatile anesthetics (such as sevoflurane and desflurane) and intravenous anesthetics (such as propofol) on various aspects of cancer biology, including tumor cell proliferation, migration, and metastasis. While the evidence remains inconclusive, some preclinical and clinical studies have suggested that certain anesthetic agents may exhibit pro- or anti-tumorigenic properties, potentially influencing the behavior of residual cancer cells following surgical resection (14).

Anesthetic Agents and Their Importance in Surgery

The immune-modulatory effects of different types of anesthetic agents and their impact on cancer cell biology are crucial considerations for healthcare practitioners in perioperative periods. These agents, including general and regional anesthetics, are commonly employed to alleviate pain and immobilize patients during surgery (15). Recent research has revealed that specific anesthetic agents, administered at specific times during surgery, hold the potential to influence the growth and persistence of cancer cells. The long-term patient outcomes from various surgical models further implicate the specific anesthetic agents in determining both survival rates and the risk of cancer-related mortality. One potential mechanism through which these effects occur is the impact of anesthetic agents on immune function (15). By recognizing and proactively addressing postoperative immune function lapses caused by sedating anesthetic agents, medical professionals may significantly enhance the outcomes for cancer patients. As approximately 80% of cancer surgeries currently employ general anesthesia, a comprehensive evaluation of the effects of different anesthetic agents on immune function becomes imperative. This evaluation should include an exploration of their correlation with overall survival rates and cancer-related deaths (16).

Perioperative Factors and Cancer Outcomes

In addition to the specific choice of anesthetic agent, various perioperative factors have been implicated in potentially modulating the interaction between anesthesia and cancer. These factors include the use of regional anesthesia techniques, perioperative pain management strategies, intraoperative blood transfusions, and the perioperative stress response (17). For example, regional anesthesia techniques such as epidural analgesia have been proposed to attenuate the neuroendocrine stress response to surgery, which in turn may have implications for cancer progression and recurrence. Furthermore, the perioperative period is characterized by complex immunological and inflammatory changes, which could potentially impact the host-tumor interaction and influence long-term cancer outcomes (18).

Potential Mechanisms Underlying Anesthesia-Cancer Interactions

The role of anesthesia in cancer progression is receiving increasing attention and raising concerns in both the scientific community and the general public. Many factors, including the type of anesthesia used, methods for pain relief, potential complications, and duration of surgery and recovery, are causing apprehension in the context of cancer surgery. Numerous studies have focused on the short-term effects of perioperative care on cancer outcomes, analyzing each stage from pre-surgery to post-surgery (12). However, there are still many unanswered questions in clinical oncology, highlighting the need for fundamental research in perioperative oncology. Researchers must shift from observational studies to detailed mechanistic analyses and broaden the focus to encompass a comprehensive perioperative approach (19).

While current clinical research provides solid evidence, it is crucial to establish the connection between mechanisms and clinical trials while considering the complex nature of clinical oncology. In doing so, we can begin to unravel the complex relationship between anesthesia and cancer progression, leading to improved patient care, better outcomes, and potentially groundbreaking discoveries in perioperative oncology. Understanding the potential mechanisms underlying the interactions between anesthesia and cancer is

essential for elucidating the biological basis of any observed effects. Several mechanistic hypotheses have been proposed, including the modulation of immune function, effects on angiogenesis and tumor microenvironment, and the influence of anesthetic-induced stress responses on cancer cell behavior (19). For instance, some studies have suggested that certain anesthetic agents may exert immunomodulatory effects, potentially affecting the body's ability to mount an effective anti-tumor immune response. Similarly, anesthesia-induced changes in the perioperative stress response and neuroendocrine signaling pathways may impact tumor biology through mechanisms such as altered gene expression, cell signaling, and metastatic potential (20).

Clinical Implications and Future Directions

Anesthesia is often necessary for cancer patients undergoing surgery, biopsies, or airway evaluations. To ensure optimal patient care, it is important to have a trained anesthesiologist or CRNA administer the anesthesia, as they are best equipped to anticipate and manage any changes in the patient's circulatory and respiratory system (21). This helps reduce the risk of complications from chronic diseases and ensures the patient remains appropriately anesthetized and pain-free during surgery, ultimately leading to a better surgical outcome. Surprisingly, research has shown that anesthetics can also have a significant impact on the primary tumor and its metastases, as well as affecting the long-term outcome for cancer patients. Both positive and negative effects on various aspects of cancer treatment have been observed, along with interference with the antitumor immune response, as demonstrated in animal studies and initial clinical work (22).

The potential interactions between anesthesia and cancer have significant clinical implications for the perioperative management of cancer patients. While the current evidence is largely derived from preclinical studies and retrospective clinical analyses, the findings suggest the need for further research to elucidate the precise nature of these interactions and their impact on long-term cancer outcomes. Future studies should aim to address key knowledge gaps, such as the comparative effects of different anesthetic agents, the influence of perioperative factors, and the underlying mechanistic pathways. Additionally, prospective clinical trials and translational research efforts are warranted to validate the findings from observational studies and to inform evidence-based clinical practice guidelines for the perioperative care of cancer patients (5).

Genetic Factors in Anesthetic Response

The response to anesthesia is a complex concern in toxicology that is influenced by genetics. Genetic variation greatly impacts how an individual metabolizes and reacts to anesthesia. The study of genetic influences on anesthesia response is of utmost significance for optimizing patient care and achieving better outcomes (18). This in-depth chapter specifically emphasizes the crucial role of genetic influences on propofol response, shedding light on the intricate interplay between an individual's genetic makeup and their response to this widely used anesthetic. Furthermore, it delves into the realm of nano-poisons and prion-controlled drugs, exploring the genetic factors associated with these substances and their impact on anesthesia response (23). It is essential to recognize that environmental factors also contribute to anesthesia response, thus warranting thorough consideration. By comprehending and intricately studying these genetic influences in the field of anesthesia, healthcare professionals can enhance patient outcomes and provide truly personalized care that takes into account each individual's unique genetic profile (24).

The Impact of Molecular Medicine on Cancer Treatment

The utilization of cutting-edge advancements in molecular medicine plays a crucial role in the anesthesia management of cancer patients. Molecular medicine focuses on personalized treatment, targeted therapeutics, and early detection of various diseases, including cancer, cardiovascular issues, genitourinary conditions, and laparoscopy. Anesthesiologists must adapt to the evolving field of molecular diagnostics, effectively implementing and controlling molecular-level therapies (25). Additionally, theranostics, a subset of molecular medicine and personalized treatment, combines diagnostic testing and treatment in a unified approach. Personalized medicine is now a clinical reality. It has led to improvements in drugs and therapies, resulting in better outcomes and safety for patients. It also holds promise for less toxic interventions in cancer treatment (26). Molecular medicine is connecting genomics and pharmacology with clinical results. Anesthesiologists recognize the need for unique approaches to cancer patients receiving anesthesia. These approaches help avoid complications and improve surgical and anesthetic procedures for patients with different types of cancer (27).

Personalized Anesthesia

Anesthetic drugs can have various effects, both helpful and harmful, such as pain relief, immobility, and potentially negative impacts on cardiac and skeletal muscle function and breathing. These effects depend on factors like drug dosage, duration of action, protein binding, and distribution in the body. Patient-specific factors such as age, sex, body mass, blood volume, and existing conditions also play a role (20). While there

is a good amount of knowledge about anesthetic drugs and potential patient-specific variables, it has been challenging to develop and utilize unified analyses of individual patients. However, a combination of systems biology and pharmacology can be used to predict patient-specific responses to anesthetic drugs, helping to enhance our understanding of how different combinations of drugs cause different reactions (20, 28). By applying network-based approaches and utilizing system pharmacology models, machine learning, and Bayesian methods, it is possible to collect and analyze patient-specific response data and develop personalized strategies for anesthetic drug prescription. This approach is demonstrated through the creation of a simplified patient-specific response network, pointing the way towards a better understanding of anesthetic drug response biology and the potential for developing personalized treatments (20).

Personalized anesthesiology intends to realize a targeted and efficient approach to drug therapy to collectively achieve the aims of anesthesia: unconsciousness (pain suppression), amnesia (short-term memory deactivation), and surgical skeletal muscle paralysis. Tailoring anesthetic protocols according to individual patient needs is not achievable. A "one size fits all" or "magic bullet" approach is commonly used in clinical anesthesia, despite significant between-patient variability and uncertainty concerning the detailed processes that may underpin physiologic changes in response to anesthetics, and also between individuals. The additional fact that anesthetic drugs have many non-specific effects reduces the strength of this strategy (29).

While personalized medicine has the potential to improve the precision and optimization of clinical procedures, personalized anesthesia has the potential to improve patient safety because the principles of precision mechanistic approaches and systems biology, including the involvement with genome-wide association and pharmacogenomic approaches, may reveal the reasons for such unpredictability, showing the patient's vulnerability to possible unwanted complications (30). Providing anesthetics using a personalized approach, utilizing the principles of precision medicine, takes into account each patient's specific variables that may contribute to their unique vulnerabilities, offering an alternative approach to the standard dosing strategy, based on the use of age and/or weight as dimensions in pharmacokinetic and pharmacodynamic models (31).

Key Genes and Pathways Involved in Anesthesia

Revealing the underlying key genes and pathways of mechanisms in the administration of anesthesia has potential importance in medical science by detecting changes inherent in the body during anesthesia and elucidating how the brain generates consciousness. It is also essential to uncover potential molecular targets for optimizing the clinical outcome of the methods. These methods can be performed by preferred functional strategies involving sophisticated statistical tests for RNA expression studies, and available hubs can be identified for experimental validation (32). The effects of various general anesthetic drugs on anesthesia depth, pain signals, vital signs, and motor system are complex and not fully understood. Many researchers believe anesthesia is regulated by multiple genes, but we have yet to identify which genes and how they are regulated. To address these questions, researchers have analyzed gene expression data from the GEO database and conducted experiments at the molecular and functional levels. This has led to the identification of differentially expressed genes and significant pathways (33).

CONCLUSION

In conclusion, the potential interactions between anesthesia and cancer represent a complex and evolving area of research with important implications for clinical practice. While the current understanding of these interactions is still incomplete, the available evidence suggests that anesthesia and perioperative factors may have the capacity to influence cancer biology and long-term oncological outcomes. As such, further research is needed to elucidate the mechanistic underpinnings of these interactions and to inform evidence-based perioperative strategies for optimizing cancer care. By advancing our understanding of the interplay between anesthesia and cancer, we can strive to improve the safety and efficacy of cancer treatment and ultimately enhance patient outcomes.

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Authors' Contribution

Mahtab Dolatabadi and Yasaman Vojgani were involved in the conceptualization, design and writing of the manuscript draft. All authors read and confirmed the final manuscript.

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REFERENCES

1.Efremidou E, Zachou M-E, Kaprana A, Koukourakis M, Chloropoulou PJJoS, Research S. The effects of anesthesia on cancer progression and anti-tumor immunity. A review. 2024;10(1):014-21.

2.Dodds C. General anaesthesia: practical recommendations and recent advances. Drugs. 1999;58(3):453-67.

3.Allan N, Siller C, Breen A. Anaesthetic implications of chemotherapy. Continuing Education in Anaesthesia Critical Care & Pain. 2011;12(2):52-6.

4.Kurdi MS, Agrawal P, Thakkar P, Arora D, Barde SM, Eswaran K. Recent advancements in regional anaesthesia. Indian journal of anaesthesia. 2023;67(1):63-70.

5.Xia SH, Zhou D, Ge F, Sun M, Chen X, Zhang H, et al. Influence of Perioperative Anesthesia on Cancer Recurrence: from Basic Science to Clinical Practice. Current oncology reports. 2023;25(2):63-81.

6.Ødemark J, Engebretsen E. Challenging medical knowledge translation: convergence and divergence of translation across epistemic and cultural boundaries. Humanities and Social Sciences Communications. 2022;9(1):71.

7.Broniatowski DA, Magee CL. The Emergence and Collapse of Knowledge Boundaries. IEEE transactions on engineering management. 2017;64(3):337-50.

8.De Sanctis V, Soliman AT, Daar S, Tzoulis P, Fiscina B, Kattamis C, et al. Retrospective observational studies: Lights and shadows for medical writers. Acta bio-medica : Atenei Parmensis. 2022;93(5):e2022319.

9.Varkey B. Principles of Clinical Ethics and Their Application to Practice. Medical principles and practice : international journal of the Kuwait University, Health Science Centre. 2021;30(1):17-28.

10.Cave E. Protecting Patients from their Bad Decisions: Rebalancing Rights, Relationships, and Risk. Medical law review. 2017;25(4):527-53.

11.Wyld L, Audisio RA, Poston GJ. The evolution of cancer surgery and future perspectives. Nature Reviews Clinical Oncology. 2015;12(2):115-24.

12.Alam A, Rampes S, Patel S, Hana Z, Ma D. Anesthetics or anesthetic techniques and cancer surgical outcomes: a possible link. Korean journal of anesthesiology. 2021;74(3):191-203.

13.Liu X, Wang Q. Application of Anesthetics in Cancer Patients: Reviewing Current Existing Link With Tumor Recurrence. Frontiers in oncology. 2022;12:759057.

14.Debela DT, Muzazu SG, Heraro KD, Ndalama MT, Mesele BW, Haile DC, et al. New approaches and procedures for cancer treatment: Current perspectives. SAGE open medicine. 2021;9:20503121211034366.

15.Boavista Barros Heil L, Leme Silva P, Ferreira Cruz F, Pelosi P, Rieken Macedo Rocco P. Immunomodulatory effects of anesthetic agents in perioperative medicine. Minerva anestesiologica. 2020;86(2):181-95.

16.Zhang Y, Lu J, Qin M, Xu M, Luo W, Li B, et al. Effects of different anesthesia methods on postoperative immune function in patients undergoing gastrointestinal tumor resection. Scientific Reports. 2023;13(1):243.

17.Hyland SJ, Brockhaus KK, Vincent WR, Spence NZ, Lucki MM, Howkins MJ, et al. Perioperative Pain Management and Opioid Stewardship: A Practical Guide. Healthcare (Basel, Switzerland). 2021;9(3).

18.Cusack B, Buggy DJ. Anaesthesia, analgesia, and the surgical stress response. BJA education. 2020;20(9):321-8.

19.Amend SR, de Groot AE, Torga G, Axelrod HD, Reyes DK, Valkenburg KC, et al. Ten unanswered questions in cancer: "If this is true, what does it imply"? American journal of clinical and experimental urology. 2018;6(2):26-31.

20.Ackerman RS, Luddy KA, Icard BE, Piñeiro Fernández J, Gatenby RA, Muncey AR. The Effects of Anesthetics and Perioperative Medications on Immune Function: A Narrative Review. 2021;133(3):676-89.

21.Montejano J, Jevtovic-Todorovic V. Anesthesia and Cancer, Friend or Foe? A Narrative Review. Frontiers in oncology. 2021;11:803266.

22.AbdulRaheem Y. Unveiling the Significance and Challenges of Integrating Prevention Levels in Healthcare Practice. Journal of primary care & community health. 2023;14:21501319231186500.

23.Virolainen SJ, VonHandorf A, Viel K, Weirauch MT, Kottyan LC. Gene-environment interactions and their impact on human health. Genes and immunity. 2023;24(1):1-11.

24.Gasciauskaite G, Lunkiewicz J, Spahn DR, Von Deschwanden C, Nöthiger CB, Tscholl DW. Environmental sustainability from anesthesia providers' perspective: a qualitative study. BMC Anesthesiology. 2023;23(1):377.

25.Chehelgerdi M, Chehelgerdi M, Allela OQB, Pecho RDC, Jayasankar N, Rao DP, et al. Progressing nanotechnology to improve targeted cancer treatment: overcoming hurdles in its clinical implementation. Molecular Cancer. 2023;22(1):169.

26.Belge Bilgin G, Bilgin C, Burkett BJ, Orme JJ, Childs DS, Thorpe MP, et al. Theranostics and artificial intelligence: new frontiers in personalized medicine. Theranostics. 2024;14(6):2367-78.

27.Min H-Y, Lee H-Y. Molecular targeted therapy for anticancer treatment. Experimental & Molecular Medicine. 2022;54(10):1670-94.

28.Rong LQ, Audisio K, O'Shaughnessy SM. Guidelines and evidence-based recommendations in anaesthesia: where do we stand? British journal of anaesthesia. 2022;128(6):903-8.

29.Puccetti M, Pariano M, Schoubben A, Giovagnoli S, Ricci M. Biologics, theranostics, and personalized medicine in drug delivery systems. Pharmacological Research. 2024;201:107086.

30.Krzyszczyk P, Acevedo A, Davidoff EJ, Timmins LM, Marrero-Berrios I, Patel M, et al. The growing role of precision and personalized medicine for cancer treatment. Technology. 2018;6(3-4):79-100.

31.Akhoon N. Precision Medicine: A New Paradigm in Therapeutics. International journal of preventive medicine. 2021;12:12.

32.Horta MAC, Pimenta RJG, Almeida DA, Rosolen RR, Aono AH, Filho JF, et al. Chapter 1 - Transcriptomic analysis of genes: expression and regulation. In: Ajmal Ali M, Lee J, editors. Transcriptome Profiling: Academic Press; 2023. p. 1-41.

33.Shin TJ, Kim PJ, Choi B. How general anesthetics work: from the perspective of reorganized connections within the brain. Korean journal of anesthesiology. 2022;75(2):124-38.