J Cell Mol Anesth. 2025 June; 10(2): e164125 https://doi.org/10.5812/jcma-164125

Published Online: 2025 July 12 Review Article

Neuroscience and Anesthesiology: Could Anesthesiologist in the Developing Countries Serve as the Main Applied/Clinical Neuroscientists

Ali Dabbagh [1,2], Mohsen Ariannik [1,2], Firoozeh Madadi [1,2,*], Masoud Nashibi [1,2], Masood Zangi [1,2], Mahdi Amirdosara [1,2], Sogol Asgari [1,2]

[1] Anesthesiology Research Center, Shahid Beheshti University of Medical Sciences, Tehran, Iran
[2] Department of Anesthesiology, School of Medicine, Shahid Beheshti School of Medicine, Tehran, Iran

[*] ***Corresponding Author:*** Anesthesiology Research Center, Shahid Beheshti University of Medical Sciences, Tehran, Iran. Email: fmadadi33@gmail.com

Received: 29 June, 2025; **Accepted:** 29 June, 2025

Abstract

Context: Neuroscience has progressed rapidly in the last few decades. As new technologies and drugs emerge in the field of neuroscience and neurosurgery, anesthesiologists are at the forefront of applying these advancements into practice.

Evidence Acquisition: To enhance translation in the field of neuroscience and apply research in routine practice, the role of anesthesiologists should not be underestimated, especially in developing countries.

Results: In this review, we address issues regarding applied neuroscience in developing countries.

Conclusions: We also discuss some measures that we have taken to solve this problem in the Department of Critical Care and Pain Medicine, SBMU.

Keywords: Neuroscience, Anesthesiologist, Applied Science, Translational Medicine, Developing Countries

1. Context

As cutting-edge drugs and anesthesia techniques emerge, anesthesiologists must understand their mechanisms, optimal application, potential side effects, and mitigation strategies. This knowledge in academic settings can spur future research and groundbreaking solutions. Moreover, advancements in monitoring technologies and drug administration demand that anesthesiologists become well-versed in these concepts (1). Anesthesiologists play a crucial role as the primary physicians responsible for administering drugs that can reversibly alter consciousness and brain function. This places them squarely in the realm of clinical neuroscience, and the field of anesthesiology itself is rightly regarded as applied neuroscience (2, 3).

In light of these concepts, the Department of Anesthesiology, Critical Care, and Pain Medicine (DACCPM), SBMU, Tehran, Iran, aims to elevate the knowledge and appreciation of neuroscience among our anesthesiologists and residents, particularly concerning our field. This initiative will entail close collaboration with other departments and faculties within our university and nearby institutions. It is crucial to recognize that despite significant progress in anesthesiology, pharmacology, and neuroscience, there are still gaps in our understanding of how hypnotic drugs function, the mechanisms of losing and regaining consciousness, and the very nature of consciousness itself (4).

1.1. Historical Perspective and Evolution

1.1.1. Traditional Role of Anesthesiologists

The anesthesiologist plays a crucial role in ensuring patient safety and comfort before, during, and after surgery. Their expanding role includes providing intraoperative support, monitoring the patients, and

How to Cite: Dabbagh A, Ariannik M, Madadi F, Nashibi M, Zangi M, et al. Neuroscience and Anesthesiology: Could Anesthesiologist in the Developing Countries Serve as the Main Applied/Clinical Neuroscientists. J Cell Mol Anesth. 2025; 10 (2): e164125. https://doi.org/10.5812/jcma-164125.

reducing complications. With a strong record of quality and safety performance, anesthesiologists advocate for postoperative care and effectively manage the interplay between anesthesia, pain control, and patient well-being, contributing to a seamless surgical experience.

1.1.2. Emergence of Neuroscience in Anesthesiology

Research on general anesthesia, encompassing amnesia, hypnosis, analgesia, and areflexia, has intrigued scientists for decades. Understanding how anesthetic drugs suppress human consciousness, particularly through hypnosis, has posed challenges for anesthesiologists and neuroscientists (5, 6). Anesthetics reduce cerebral metabolism and blood flow, affecting the brain's thalamus. Even under anesthesia, the brain responds to stimuli in sensory areas to varying degrees. The impact of anesthetics on brain connectivity varies based on the drug type, dosage, and specific brain network (6, 7). Typically, patients under anesthesia experience partial suppression of brain connections rather than complete loss (8).

1.2. Anesthesiologist as an Applied/Clinical Neuroscientist

Anesthesiologists possess a unique ability to intentionally manipulate consciousness levels during medical or surgical procedures, whether in the operating room, outside of it, or in the ICU (9, 10). No other clinicians administer pharmaceutical agents in the cerebrospinal fluid to the extent that anesthesiologists do routinely during spinal anesthesia (5). Anesthetic drugs significantly impact neural pathways, underscoring the importance for every anesthesiologist to possess a thorough understanding of neural pathways, neurotransmitters, and brain function to elevate their practice (11, 12). Keeping abreast of the latest scientific advancements is imperative in this swiftly evolving field (5, 13). Key areas, such as the effects of anesthetics on the developing brain and the role of neuroscience in enhancing the management of acute or chronic pain, whether through pharmacological or non-pharmacological means, stand as pivotal focal points in the discipline (14, 15).

The ambitious mission set for anesthesiologists represents a formidable challenge. We are actively addressing these challenges through a range of innovative approaches, including computational neuroscience, neural circuit mapping, EEG brain activity measurements, advanced neuroimaging techniques, and in-depth studies of cellular pathways and neurotransmitters (16-18). This approach underscores the necessity for anesthesiologists to possess expertise in applied or clinical neuroscience. This includes proficiency in neurophysiological monitoring, implementation of brain protection strategies, and adept management of neurological disorders (19). Anesthesiologists are required to possess specialized knowledge and skills in neuroanatomy, neurophysiology, and neuromonitoring tools in order to effectively fulfill their role (20, 21).

1.3. Collaboration in Multidisciplinary Teams

Recognizing the importance of interdisciplinary collaboration and medicine among healthcare professionals is crucial for enhancing patient outcomes. Transitioning from an interdisciplinary to a multidisciplinary approach, and ultimately to a comprehensive transdisciplinary approach, is essential. This necessitates close collaboration with neurologists, neurosurgeons, basic scientists, and related specialists; collaborating with other clinical specialists, such as neurologists and neurosurgeons, is essential for enhancing patient outcomes (22). We have successfully established three academic memoranda of understanding and formal agreements, forging valuable partnerships with the School of Advanced Technologies in Medicine and the Neuroscience Research Center, both of which are affiliated with SBMU, Tehran, Iran.

1.4. Innovative Approaches, Techniques, and Technologies

Equally important is working with basic science departments, as they often require access to patients and face challenges when conducting experiments outside clinical settings without the guidance of experienced physicians (23, 24). Integrating neuroscience into anesthesiology is vital for gaining new insights into pharmacology and drug effects. One such example is ketamine, which has traditionally been viewed as a pro-convulsive agent to be avoided in patients with seizure histories. However, recent studies have demonstrated its effectiveness as an anticonvulsant in patients with refractory seizures, likely due to its interaction with NMDA receptors (6, 25).

Furthermore, neuroscience can help address significant dilemmas in anesthesia, such as the true impact of anesthesia on the developing brain in children, strategies for treating patients with hypoxic brain injuries, and understanding the transition from acute to chronic pain (26). Neuroscience equips anesthesiologists with advanced tools to directly impact the brain, going beyond traditional medication. Techniques like transcranial magnetic stimulation (TMS), transcranial direct current stimulation (tDCS), and photobiomodulation (PBM therapy) offer additional avenues for closely monitoring patients during both neurosurgical and non-neurosurgical procedures (11, 12, 27, 28).

We have successfully established connections with basic science faculties specializing in cellular and molecular biology and neuroimaging. We have actively encouraged them to redirect their research focus towards clinical applications. Recognizing the limitations of available equipment in our developing country, we have prioritized techniques that require less advanced technology. For instance, we are utilizing 1.5 Tesla MRI machines rather than 3 or 7 Tesla machines. This strategic approach has led us to emphasize structural studies such as voxel-based morphometry (VBM) over functional studies (29, 30). Despite encountering challenges, we have embarked on groundbreaking research in neurocritical areas using accessible devices, such as olfactory stimulation in comatose patients (31). While we may lack advanced equipment, we leverage our proximity to a substantial patient population in educational hospitals in the capital to drive impactful advancements in neurology.

1.5. Patient Outcomes and Safety

Adopting an approach rooted in applied neuroscience by anesthesiologists is not only a scientifically sound method but also enhances the quality of anesthesia at the patient's bedside. This approach significantly improves the precision of evidence-based medicine for anesthesiologists, particularly in relation to one of the most crucial body systems: The nervous system (32, 33) This safety approach not only involves personalized anesthesia and tailored administration of anesthetic drugs but also enhances the delivery of anesthetics to the developing brain (34-37).

1.6. Educational Initiatives

In August 2023, we successfully hosted the inaugural one-day congress on “Anesthesiology and Neuroscience” in partnership with several prestigious institutes, establishing connections with additional departments such as neurology and neurosurgery, multiple hospitals (including private ones), and institutions outside the health system within the Iranian Ministry of Science.

We have launched a series of engaging lectures and journal clubs focused on neuroscience to instill a neuroscientific mindset among our trainees. Additionally, we are thrilled to announce our new partnerships with the esteemed Neuroscience Research Center at SBMU in Tehran, Iran. Through these collaborations, we have introduced an innovative 15-day course as part of the Neuroanesthesia fellowships curriculum at the Neuroscience Research Center, offering our fellows valuable hands-on experience and expertise.

1.7. Research Opportunities and Research Flagship for Anesthesiology

To truly advance our understanding of neuroscience in anesthesia, it is essential to delve into both basic and clinical research, while also exploring the frontiers of scientific knowledge. With this goal in mind, we have redoubled our research endeavors and forged stronger collaborations in areas such as regenerative medicine, cellular and molecular medicine, and other cutting-edge fields.

2. Discussion

In spite of significant progress in neuroscience research over the last decade, a substantial disparity persists between laboratory findings and practical clinical applications. We have organized our research objectives into the following subcategories.

2.1. Artificial intelligence and neuroscience

Recognizing that artificial intelligence (AI) has advanced by imitating the brain's functions is critical. The AI holds the potential to greatly enhance anesthesia practice by swiftly predicting complications during the perioperative period. Moreover, the parallels between AI and the brain could unveil profound insights into the realm of neuroscience, as neuroscience has already laid the groundwork for AI (38, 39).

2.2. Translational Neuroanesthesia

The field of neuroscience and anesthesia research has encountered significant challenges due to disparities between human and animal models. However, by embracing translational science, we can effectively address these issues (40). Despite considerable progress, the intricate mechanisms of consciousness and anesthesia still harbor numerous enigmas that demand exploration (6). Furthermore, several severe perioperative neurocognitive complications, including delirium, stroke, and postoperative cognitive disorder, remain inadequately diagnosed and treated due to the absence of specific monitors and biomarkers for early detection (8). Even in cases of diagnosis, there is a dearth of evidence to support intervention.

2.3. Monitoring

By incorporating pulse oximetry and capnography, we have already made significant strides in improving patient safety. However, it is crucial to note that current brain state monitoring lacks the ability to provide real-time and precise information about brain function. Furthermore, the absence of direct and reliable nociception monitoring in the operating room is a significant gap. We strongly believe that integrating EEG and other hemodynamic monitors with AI holds great promise for addressing these critical needs (41, 42).

2.4. Guidelines

While there are numerous guidelines available for perioperative management of cardiovascular and respiratory complications, it is important to note the absence of a specific guideline for neurologic complications, with the exception of delirium (43).

The application of neuroscience in anesthesia not only enhances the scientific aspects and research strategies but also significantly expands the field's influence and creates new opportunities (44). This contributes to professional development, strengthening the prestige of the work and having a practical impact on solving patients' problems, leading to specialized clinical roles or academic positions (45, 46). In other words, when new solutions in unique scientific fields translate into clinical approaches, it increases the professional impact of the field. This path serves as an objective example of how anesthesia strengthens the effectiveness of science, advances research goals, and expands helpful science.

Extensive research has delved into various theories and interventions in pain management, but there is still a need for further clarification on their effectiveness. Understanding and managing pain is a critical focus of neuroscience research. The importance of early diagnosis cannot be overstated, as it is the key to managing and preventing chronic pain. Investigating the exact mechanisms is the crucial first step in achieving these goals (47). Furthermore, the introduction of vaccines for substance use disorders underscores the potential for innovative solutions (48). Protecting the brain, particularly in cases of ischemic brain damage, is a paramount focus for anesthesiologists, irrespective of its origin (49). Despite several interventions showing promise in animal studies, none have proven effective in clinical settings, prompting the need for continued exploration and innovation (50).

The key challenge in applied neuroscience is the financial constraints, especially in developing countries like Iran. The successful integration of neuroscience into clinics relies on the close collaboration between basic scientists and clinicians. Translational scientists are adept at overcoming the unique challenges of translating research into practical applications (51). However, the achievement of goals in applied neuroscience hinges not only on overcoming obstacles but also on meticulous planning (52). In the DACCPM, the neuroscience committee meticulously investigated the neuroscience gap, assessed existing laboratory and clinical facilities, and developed a comprehensive roadmap, instilling confidence in the process.

3. Conclusions

Anesthesia is a vital discipline with deep connections to diverse surgical fields and physiological systems, making it an essential component of every hospital. Our collaborative efforts in anesthesia and neuroscience have notably enriched the training curriculum for our residents and fellows. Through a successful partnership with the Neuroscience Research Center, we have seamlessly integrated a two-week rotation for our Neuroanesthesia fellows, providing them with invaluable training opportunities.

The focus on translation in medical research has become imperative in recent decades. Concurrently, there have been significant advancements in neuroscience and Neuroanesthesia. However, effective communication is crucial for enhancing the population's overall health. Only a few organizations are dedicated to this cause, and none are in developing countries. These countries' significant limitations are the need for more financial support and educated translational scientists. Anesthesiologists are well-equipped to address this challenge due to their professional characteristics, making them influential translational scientists at a lower cost. Instead of establishing new organizations, expanding connections with existing research institutes and obtaining research grants would be more practical by submitting well-designed multidisciplinary proposals.

Additionally, there is a need for more biobanks and extensive datasets, and anesthesiologists can contribute samples due to their consistent exposure to neuroscience. Our research focuses on three key areas: Fundamental neuroscience emphasizing regenerative medicine, technological advancements in AI, and the convergence of these fields. The rapid advancement of medical technology, including AI, robotics, and brain-computer interfaces (BCIs), combined with a deeper understanding of cellular mechanisms, will bring about a revolutionary change in anesthesia practice. Innovations such as personalized anesthesia using BCIs, advanced drug delivery systems, and reliable robotic assistants are poised to bring the most significant transformations.

Footnotes

Authors' Contribution: A. D. and M. A. conceptualized and designed the study. F. M. drafted the manuscript. M. N., M. Z., M. A., and S. A. revised the manuscript.

Conflict of Interests Statement: The authors declare no conflict of interest.

Data Availability: The dataset presented in the study is available on request from the corresponding author during submission or after publication.

Funding/Support: The present study received no funding/support.

References

1. Brown EN, Purdon PL, Van Dort CJ. General anesthesia and altered states of arousal: a systems neuroscience analysis. *Annu Rev Neurosci*. 2011;**34**:601-28. [PubMed ID: 21513454]. [PubMed Central ID: PMC3390788]. https://doi.org/10.1146/annurev-neuro-060909-153200.
2. Alkire MT, Hudetz AG, Tononi G. Consciousness and anesthesia. *Science*. 2008;**322**(5903):876-80. [PubMed ID: 18988836]. [PubMed Central ID: PMC2743249]. https://doi.org/10.1126/science.1149213.
3. Tarnal V, Vlisides PE, Mashour GA. The Neurobiology of Anesthetic Emergence. *J Neurosurg Anesthesiol*. 2016;**28**(3):250-5. [PubMed ID: 26274626]. [PubMed Central ID: PMC4752918]. https://doi.org/10.1097/ANA.0000000000000212.
4. Hudetz AG, Mashour GA. Disconnecting Consciousness: Is There a Common Anesthetic End Point? *Anesth Analg*. 2016;**123**(5):1228-40. [PubMed ID: 27331780]. [PubMed Central ID: PMC5073005]. https://doi.org/10.1213/ANE.0000000000001353.
5. Hudetz AG. General anesthesia and human brain connectivity. *Brain Connect*. 2012;**2**(6):291-302. [PubMed ID: 23153273]. [PubMed Central ID: PMC3621592]. https://doi.org/10.1089/brain.2012.0107.
6. Bonhomme V, Staquet C, Montupil J, Defresne A, Kirsch M, Martial C, et al. General Anesthesia: A Probe to Explore Consciousness. *Front Syst Neurosci*. 2019;**13**:36. [PubMed ID: 31474839]. [PubMed Central ID: PMC6703193]. https://doi.org/10.3389/fnsys.2019.00036.
7. Yi R, Cheng S, Zhong F, Luo D, You Y, Yu T, et al. GABAergic neurons of anterior thalamic reticular nucleus regulate states of consciousness in propofol- and isoflurane-mediated general anesthesia. *CNS Neurosci Ther*. 2024;**30**(6). e14782. [PubMed ID: 38828651]. [PubMed Central ID: PMC11145368]. https://doi.org/10.1111/cns.14782.
8. Montupil J, Cardone P, Staquet C, Bonhomme A, Defresne A, Martial C, et al. The nature of consciousness in anaesthesia. *BJA Open*. 2023;**8**:100224. [PubMed ID: 37780201]. [PubMed Central ID: PMC10539891]. https://doi.org/10.1016/j.bjao.2023.100224.
9. Moody OA, Zhang ER, Vincent KF, Kato R, Melonakos ED, Nehs CJ, et al. The Neural Circuits Underlying General Anesthesia and Sleep. *Anesth Analg*. 2021;**132**(5):1254-64. [PubMed ID: 33857967]. [PubMed Central ID: PMC8054915]. https://doi.org/10.1213/ANE.0000000000005361.
10. Dabbagh A, Elyassi H. Cellular and molecular anesthesia: from bench to bedside. *J Cell Mol Anesth*. 2016;**1**(1):1-2.
11. He T, Huang J, Peng B, Wang M, Shui Q, Cai L. Screening of potential biomarkers in propofol-induced neurotoxicity via bioinformatics prediction and experimental verification. *Am J Transl Res*. 2024;**16**(3):755-67. [PubMed ID: 38586100]. [PubMed Central ID: PMC10994811]. https://doi.org/10.62347/MTAY7931.
12. Hao X, Ou M, Zhang D, Zhao W, Yang Y, Liu J, et al. The Effects of General Anesthetics on Synaptic Transmission. *Curr Neuropharmacol*. 2020;**18**(10):936-65. [PubMed ID: 32106800]. [PubMed Central ID: PMC7709148]. https://doi.org/10.2174/1570159X18666200227125854.
13. Heshmati M, Bruchas MR. Historical and Modern Evidence for the Role of Reward Circuitry in Emergence. *Anesthesiology*. 2022;**136**(6):997-1014. [PubMed ID: 35362070]. [PubMed Central ID: PMC9467375]. https://doi.org/10.1097/ALN.0000000000004148.
14. Obara S. Challenges in database research for anesthetic neurotoxicity. *J Anesth*. 2025;**39**(2):321-2. [PubMed ID: 39215825]. https://doi.org/10.1007/s00540-024-03401-w.
15. Sezari P, Dabbagh A. Personalized medicine: the paradigm shift in medicine mandating lifelong learning. *J Cell Mol Anesth*. 2019;**4**(2). e149586.
16. Mashour GA, Hudetz AG. Neural Correlates of Unconsciousness in Large-Scale Brain Networks. *Trends Neurosci*. 2018;**41**(3):150-60. [PubMed ID: 29409683]. [PubMed Central ID: PMC5835202]. https://doi.org/10.1016/j.tins.2018.01.003.
17. Freye E, Levy JV. Cerebral monitoring in the operating room and the intensive care unit: an introductory for the clinician and a guide for the novice wanting to open a window to the brain. Part I: The electroencephalogram. *J Clin Monit Comput*. 2005;**19**(1-2):1-76. [PubMed ID: 16167222]. https://doi.org/10.1007/s10877-005-0712-z.
18. Yen C, Lin CL, Chiang MC. Exploring the Frontiers of Neuroimaging: A Review of Recent Advances in Understanding Brain Functioning and Disorders. *Life (Basel)*. 2023;**13**(7). [PubMed ID: 37511847]. [PubMed Central ID: PMC10381462]. https://doi.org/10.3390/life13071472.
19. Sorrenti V, Cecchetto C, Maschietto M, Fortinguerra S, Buriani A, Vassanelli S. Understanding the Effects of Anesthesia on Cortical Electrophysiological Recordings: A Scoping Review. *Int J Mol Sci*. 2021;**22**(3). [PubMed ID: 33525470]. [PubMed Central ID: PMC7865872]. https://doi.org/10.3390/ijms22031286.

20. Gruenbaum BF, Gruenbaum SE. Neurophysiological monitoring during neurosurgery: anesthetic considerations based on outcome evidence. *Curr Opin Anaesthesiol*. 2019;**32**(5):580-4. [PubMed ID: 31145200]. [PubMed Central ID: PMC6863050]. https://doi.org/10.1097/ACO.0000000000000753.

21. Oliva AM, Montejano J, Simmons CG, Vogel SA, Isaza CF, Clavijo CF. New frontiers in intraoperative neurophysiologic monitoring: a narrative review. *Ann Transl Med*. 2023;**11**(11):388. [PubMed ID: 37970609]. [PubMed Central ID: PMC10632568]. https://doi.org/10.21037/atm-22-4586.

22. Rajaei S, Dabbagh A. Interdisciplinary approach and anesthesiology: is there any role? *J Cell Mol Anesth*. 2016;**1**(3):129-33.

23. Franks NP. Molecular targets underlying general anaesthesia. *Br J Pharmacol*. 2006;**147 Suppl 1**(Suppl 1):S72-81. [PubMed ID: 16402123]. [PubMed Central ID: PMC1760740]. https://doi.org/10.1038/sj.bjp.0706441.

24. Tabashi S, Tajbakhsh A, Dahi M, Dabir S, Vosoughian M, Moshari M. Regenerative medicine and perioperative hypoxic organ damage: targeting hypoxia-inducible factors. *J Cell Mol Anesth*. 2022;**7**(1):58-65.

25. Dahi-Taleghani M, Fazli B, Ghasemi M, Vosoughian M, Dabbagh A. Effect of intravenous patient controlled ketamine analgesiaon postoperative pain in opium abusers. *Anesth Pain Med*. 2014;**4**(1). e14129. [PubMed ID: 24701419]. [PubMed Central ID: PMC3961031]. https://doi.org/10.5812/aapm.14129.

26. Browne CA, Lucki I. Antidepressant effects of ketamine: mechanisms underlying fast-acting novel antidepressants. *Front Pharmacol*. 2013;**4**:161. [PubMed ID: 24409146]. [PubMed Central ID: PMC3873522]. https://doi.org/10.3389/fphar.2013.00161.

27. Burt T, Lisanby SH, Sackeim HA. Neuropsychiatric applications of transcranial magnetic stimulation: a meta analysis. *Int J Neuropsychopharmacol*. 2002;**5**(1):73-103. [PubMed ID: 12057034]. https://doi.org/10.1017/S1461145702002791.

28. Hamblin MR. Photobiomodulation for traumatic brain injury and stroke. *J Neurosci Res*. 2018;**96**(4):731-43. [PubMed ID: 29131369]. [PubMed Central ID: PMC5803455]. https://doi.org/10.1002/jnr.24190.

29. Xin M, Qu Y, Peng X, Zhu D, Cheng S. A systematic review and meta-analysis of voxel-based morphometric studies of fibromyalgia. *Front Neurosci*. 2023;**17**:1164145. [PubMed ID: 37229427]. [PubMed Central ID: PMC10203234]. https://doi.org/10.3389/fnins.2023.1164145.

30. Nichols TE, Holmes AP. Nonparametric permutation tests for functional neuroimaging: a primer with examples. *Hum Brain Mapp*. 2002;**15**(1):1-25. [PubMed ID: 11747097]. [PubMed Central ID: PMC6871862]. https://doi.org/10.1002/hbm.1058.

31. Salimi M, Javadi AH, Nazari M, Bamdad S, Tabasi F, Parsazadegan T, et al. Nasal Air Puff Promotes Default Mode Network Activity in Mechanically Ventilated Comatose Patients: A Noninvasive Brain Stimulation Approach. *Neuromodulation*. 2022;**25**(8):1351-63. [PubMed ID: 35088756]. https://doi.org/10.1016/j.neurom.2021.11.003.

32. Brown EN, Pavone KJ, Naranjo M. Multimodal General Anesthesia: Theory and Practice. *Anesth Analg*. 2018;**127**(5):1246-58. [PubMed ID: 30252709]. [PubMed Central ID: PMC6203428]. https://doi.org/10.1213/ANE.0000000000003668.

33. Cao Y, Sun Y, Liu X, Yu K, Gao D, Yang J, et al. A bibliometric analysis of the neurotoxicity of anesthesia in the developing brain from 2002 to 2021. *Front Neurol*. 2023;**14**:1185900. [PubMed ID: 37181567]. [PubMed Central ID: PMC10172642]. https://doi.org/10.3389/fneur.2023.1185900.

34. Aksenov DP. Early exposure to general anaesthesia: considerations for age-related vulnerability and behavioural outcomes. *Lancet Respir Med*. 2024;**12**(9):662-3. [PubMed ID: 38851196]. [PubMed Central ID: PMC11365747]. https://doi.org/10.1016/S2213-2600(24)00181-4.

35. Liu X, Ji J, Zhao GQ. General anesthesia affecting on developing brain: evidence from animal to clinical research. *J Anesth*. 2020;**34**(5):765-72. [PubMed ID: 32601887]. [PubMed Central ID: PMC7511469]. https://doi.org/10.1007/s00540-020-02812-9.

36. Niu Y, Yan J, Jiang H. Anesthesia and developing brain: What have we learned from recent studies. *Front Mol Neurosci*. 2022;**15**:1017578. [PubMed ID: 36479527]. [PubMed Central ID: PMC9720124]. https://doi.org/10.3389/fnmol.2022.1017578.

37. Wu Z, Yu W, Song Y, Zhao P. General anaesthesia, the developing brain, and cerebral white matter alterations: a narrative review. *Br J Anaesth*. 2023;**131**(6):1022-9. [PubMed ID: 37833128]. https://doi.org/10.1016/j.bja.2023.09.008.

38. Hassabis D, Kumaran D, Summerfield C, Botvinick M. Neuroscience-Inspired Artificial Intelligence. *Neuron*. 2017;**95**(2):245-58. [PubMed ID: 28728020]. https://doi.org/10.1016/j.neuron.2017.06.011.

39. Macpherson T, Churchland A, Sejnowski T, DiCarlo J, Kamitani Y, Takahashi H, et al. Natural and Artificial Intelligence: A brief introduction to the interplay between AI and neuroscience research. *Neural Netw*. 2021;**144**:603-13. [PubMed ID: 34649035]. https://doi.org/10.1016/j.neunet.2021.09.018.

40. Mohamed WMY, Alghamdi BS, Alexiou A. Editorial: Translational neuroscience and reverse translational neuroscience: What's giving us hope? *Front Neurosci*. 2023;**17**:1149819. [PubMed ID: 36908775]. [PubMed Central ID: PMC9992888]. https://doi.org/10.3389/fnins.2023.1149819.

41. Hakim U, De Felice S, Pinti P, Zhang X, Noah JA, Ono Y, et al. Quantification of inter-brain coupling: A review of current methods used in haemodynamic and electrophysiological hyperscanning studies. *Neuroimage*. 2023;**280**:120354. [PubMed ID: 37666393]. https://doi.org/10.1016/j.neuroimage.2023.120354.

42. Myatra SN, Jagiasi BG, Singh NP, Divatia JV. Role of artificial intelligence in haemodynamic monitoring. *Indian J Anaesth*. 2024;**68**(1):93-9. [PubMed ID: 38406336]. [PubMed Central ID: PMC10893816]. https://doi.org/10.4103/ija.ija_1260_23.

43. Patel MB, Bednarik J, Lee P, Shehabi Y, Salluh JI, Slooter AJ, et al. Delirium Monitoring in Neurocritically Ill Patients: A Systematic Review. *Crit Care Med*. 2018;**46**(11):1832-41. [PubMed ID: 30142098]. [PubMed Central ID: PMC6185789]. https://doi.org/10.1097/CCM.0000000000003349.

44. Mathis MR, Schonberger RB, Whitlock EL, Vogt KM, Lagorio JE, Jones KA, et al. Opportunities Beyond the Anesthesiology Department: Broader Impact Through Broader Thinking. *Anesth Analg*. 2022;**134**(2):242-52. [PubMed ID: 33684091]. [PubMed Central ID: PMC8423864]. https://doi.org/10.1213/ANE.0000000000005428.

45. Ghaly RF. Do neurosurgeons need Neuroanesthesiologists? Should every neurosurgical case be done by a Neuroanesthesiologist? *Surg Neurol Int*. 2014;**5**:76. [PubMed ID: 24949219]. [PubMed Central ID: PMC4061581]. https://doi.org/10.4103/2152-7806.133106.

46. Gerritsen JKW, Rizopoulos D, Schouten JW, Haitsma IK, Eralp I, Klimek M, et al. Impact of dedicated neuro-anesthesia management on clinical outcomes in glioblastoma patients: A single-institution cohort study. *PLoS One*. 2022;**17**(12). e0278864. [PubMed ID: 36512593]. [PubMed Central ID: PMC9746943]. https://doi.org/10.1371/journal.pone.0278864.

47. Cao B, Xu Q, Shi Y, Zhao R, Li H, Zheng J, et al. Pathology of pain and its implications for therapeutic interventions. *Signal Transduct Target Ther*. 2024;**9**(1):155. [PubMed ID: 38851750]. [PubMed Central ID: PMC11162504]. https://doi.org/10.1038/s41392-024-01845-w.

48. Lu T, Li X, Zheng W, Kuang C, Wu B, Liu X, et al. Vaccines to Treat Substance Use Disorders: Current Status and Future Directions.

Pharmaceutics. 2024;**16**(1). [PubMed ID: 38258095]. [PubMed Central ID: PMC10820210]. https://doi.org/10.3390/pharmaceutics16010084.

49. Saceleanu VM, Toader C, Ples H, Covache-Busuioc RA, Costin HP, Bratu BG, et al. Integrative Approaches in Acute Ischemic Stroke: From Symptom Recognition to Future Innovations. *Biomedicines*. 2023;**11**(10). [PubMed ID: 37892991]. [PubMed Central ID: PMC10604797]. https://doi.org/10.3390/biomedicines11102617.

50. Xu SY, Pan SY. The failure of animal models of neuroprotection in acute ischemic stroke to translate to clinical efficacy. *Med Sci Monit Basic Res*. 2013;**19**:37-45. [PubMed ID: 23353570]. [PubMed Central ID: PMC3638705]. https://doi.org/10.12659/msmbr.883750.

51. Lewis AS, Nobis WP. Narrowing the translational research gap by aligning replication concepts in basic and clinical neuroscience. *J Neurosci Methods*. 2023;**392**:109878. [PubMed ID: 37169225]. [PubMed Central ID: PMC10214459]. https://doi.org/10.1016/j.jneumeth.2023.109878.

52. Bharadwaj S, Palaniswamy SR. Translational Research in Perioperative Neurosciences. *Asian J Anesthesiol*. 2020;**60**(3).