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REVIEW

AI in Anesthesia: Enhancing Safety Through Ethical Integration and Human Supervision -A Narrative Review

IA en Anestesia: Mejorando la Seguridad mediante la Integración Ética y la Supervisión Humana - Una Revisión Narrativa

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ABSTRACT

Introduction: anesthesia has evolved from enormously from mysterious sleep to intelligent, personalized care and as Artificial intelligence (AI) has led to transformation of healthcare, its applications in anesthesia too has proven of late that how technology and human compassion working together can be smoother, personalized, safer and precise surgical journeys for patients. The AI is field of computer science which use various algorithms and computational resources enabling the machines to simulate human intelligence in its thought process and actions. This revolutionary technology is changing the traditional anesthesia practices of patient risk stratification, anesthesia delivery system, patient peri-operative monitoring, individualized anesthesia plans and image analysis by an automated process. However, the application of AI in anesthesia comes with its own unique limitations of limited data and its quality, lack of guidelines for ethical use, legal concerns and socioeconomic concerns. Therefore, in this review we searched human in loop approach of the hybrid models, as the future of anesthesia will likely to be shaped by a combination of artificial intelligence and human expertise rather than one replacing other.
Method: we searched PubMed, google scholar and Cochrane database search 2019-2024. The evaluation of the retrieved articles was done for effectiveness as well as limitations of AI and deep learning in the field of anesthesia.
Results: the AI will enhance precision, safety and efficiency but human touch of anesthesiologist and ethical use of it will remain essential for decision making, handling complications and providing personalized empathic care. Nonetheless, its effectiveness is influenced by data quality, algorithm generalizability and the absence of standardized ethical frameworks.
Conclusion: the future of anaesthesia will likely combine AI's analytical power with anaesthetist's expertise, ethical judgement and empathy. While AI can improve outcomes and efficiency, the human touch remains essential for decision making, complication management and personalised care.

Keywords: Artificial Intelligence; Anesthesia; Ethical Concerns; Human Critical Thinking.

RESUMEN

Introducción: la anestesia ha evolucionado enormemente y ha pasado de ser un sueño misterioso a convertirse en un cuidado inteligente y personalizado, y al igual que la inteligencia artificial (IA) ha llevado a la transformación de la asistencia sanitaria, sus aplicaciones en anestesia también han demostrado últimamente que el trabajo conjunto de la tecnología y la compasión humana puede conseguir jornadas quirúrgicas más fluidas, personalizadas, seguras y precisas para los pacientes. La IA es un campo de la informática que utiliza diversos algoritmos y recursos computacionales que permiten a las máquinas simular

la inteligencia humana en su proceso de pensamiento y sus acciones. Esta revolucionaria tecnología está cambiando las prácticas anestésicas tradicionales de estratificación del riesgo del paciente, el sistema de administración de anestesia, la monitorización perioperatoria del paciente, los planes de anestesia individualizados y el análisis de imágenes mediante un proceso automatizado. Sin embargo, la aplicación de la IA en la anestesia viene con sus propias limitaciones únicas de datos limitados y su calidad, la falta de directrices para el uso ético, las preocupaciones legales y socioeconómicas. Por lo tanto, en esta revisión buscamos el enfoque humano en bucle de los modelos híbridos, ya que es probable que el futuro de la anestesia esté conformado por una combinación de inteligencia artificial y experiencia humana en lugar de que una sustituya a la otra.

Método: se realizaron búsquedas en PubMed, google scholar y en la base de datos Cochrane 2019-2024. La evaluación de los artículos recuperados se realizó para la efectividad, así como las limitaciones de la IA y el aprendizaje profundo en el campo de la anestesia.

Resultados: la IA mejorará la precisión, la seguridad y la eficiencia, pero el toque humano del anestesiólogo y su uso ético seguirán siendo esenciales para la toma de decisiones, el manejo de las complicaciones y la prestación de cuidados empáticos personalizados. No obstante, su eficacia se ve influida por la calidad de los datos, la generalizabilidad de los algoritmos y la ausencia de marcos éticos estandarizados.

Conclusión: el futuro de la anestesia probablemente combinará la potencia analítica de la IA con la experiencia, el juicio ético y la empatía del anestesista. Aunque la IA puede mejorar los resultados y la eficiencia, el toque humano sigue siendo esencial para la toma de decisiones, la gestión de las complicaciones y la atención personalizada.

Palabras clave: Inteligencia Artificial; Anestesia; Preocupaciones Éticas**;** Pensamiento Crítico Humano.

INTRODUCTION

Anesthesia has evolved from enormously from mysterious sleep to intelligent, personalized care and as Artificial intelligence (AI) has led to transformation of healthcare, its applications in anesthesia too has proven of late that how technology and human compassion working together can be smoother, personalized, safer and precise surgical journeys for patients. The artificial intelligence being an ever-evolving field of computer science that empowers machines to simulate human intelligence in critical thinking and actions by using various algorithms and computational resources[1]. The machine learning which is a subset of AI works up on enabling the machines to learn from data and its algorithms analyze the data, train from it and then apply that learning in decision making and predictions.[1,2,3] Deep learning is another subset of AI which trains artificial neural networks having multiple layers which recognizes patterns in the data.[3,4,5,6] There has been tremendous growth in artificial intelligence applications in recent years in medical field and anesthesia being one of the important medical disciplines too has been benefitted from AI and its subfields like robotics, machine learning, deep learning and large language models enables computers to mimic the decision-making abilities of a human brain and integrate new tasks for which the computers were not initially programmed.[2]

Globally the peri-operative complications contribute to as estimated 4,2 million deaths/year and anesthesia related factors contribute to it significantly particularly in Lower middle-income countries (LMIC) where the skilled workforce in anesthesia is low approximately 0,44 per 100,000, whereas in High income countries (HIC) is 20 per 100,000. In India perioperative mortality rates have wide variations with some studies reporting 0,5-2 % in tertiary centers thus underscoring the urgent need for precision enhancing and decision supporting AI based tools[7,8].

The integrations of AI and its subsets into anesthesia has set new frontiers for it and proven transformational force in the field of anesthesia[2]. The applications which have proven of immense benefits include analyzing patients records for risk stratification, tailoring various anesthetic regime with increased precision, monitoring patients, calculating drug doses and precisely administering them and also in carrying out mechanical procedure and ultimately leading to better surgical and critical care outcomes.[3,4,5] In this review article we critically analyze various anesthesia information system applications in peri- operative area, patient risk stratification models, applications predicting postoperative ICU admissions, targeted controlled infusion method, algorithms that evaluate depth of anesthesia, monitoring, AI patient controlled analgesia, AI integrated ultrasound guided regional anesthesia and robots designed to perform mechanical task like ventilation, intubation etc.[6,7,8,9,10,11,12,13,14] This review take into consideration various challenges of the use of AI in anesthesia which include problem with data, limitations with technology , moral and legal aspects, bias generation if data is not accurate.[13,14]

In this review, analysis were made about the AI and its application not only in anesthesia but medical field as a whole and when discussing the advantageous aspect of AI in streamlining of tasks like data entry,

patient scheduling, enhanced diagnostic accuracy of imaging, better treatment planning and its role in tele medicine outreach in rural and remote regions of developing nations , there is limited literature available which discusses that automation may lead to joblessness and economic burden of skill shifting of AI system management which is more relevant for over populous developing countries thus advocating human in loop approach in the use of AI in anesthesia and other medical fields. However more effort and adoption to be done in augmentation rather than automation.[15,16,17,18,19]

METHOD

In this narrative review a search was done in database search engines of PubMed, Cochrane Library, Embase and Scopus using key words Artificial intelligence, Machine learning, Anaesthesia, AI models in anaesthesia, ethical concerns of AI, Human empathy, Human critical thinking. Bolan operators (AND, OR and NOT) were used for the purpose of refining the results. Articles published up to December 2024 in English were included. In addition to this, there was manual searching was done in the reference lists of the selected studies to identify additional potentially relevant publications.

AI Applications in anaesthesia

Anaesthesia has come a long way starting from days of ether anaesthesia to today's advanced monitoring systems and anaesthesia work stations. The history of AI in anaesthesia spans decades beginning with algorithms which aided drug administration and patient monitoring, "Diprifusor" propofol target-controlled infusion system which was developed in late 1990's which maintains desired plasma drug levels using pharmacokinetic models.[20]

The artificial intelligence integration into the field of anaesthesia has set new frontiers for it and proven transformational force in the field of anaesthesia and as we delve into its various practical applications and performance in anaesthesia and summarise them in tabulated form.[2]

Preoperative assessment

As every patient has unique anatomical and physiological traits AI can help the anaesthetist to tailor the protocols by utilizing patient data, lab reports and radiology images, thus preoperative planning can be done and also patient at risk can be identified by using artificial intelligence in analysis of this information, thus enabling the anaesthetist management planning and risk stratification.[21] Important aspect of preoperative assessment is risk assessment through predictive analysis and few applications including analysis of surgical risk, difficult intubation and difficult laryngoscopy are summarised in table 1.

Table 1. Artificial Intelligence based application for predictive analysis in anaesthesia

Application	Use in Anaesthesia	Example
Predictive analysis for surgical risk	It is utilised to predict patient outcome and potential complications	IBM Watson health which implements predictive analysis for evaluating surgical risks[22,23]
Predictive analysis for difficult intubation	This Identify patients who might be difficult to intubate and outperform traditional methods of assessing like Mallampati test etc.	Tavolara et.al a Deep Learning model[24]
Predictive analysis for difficult laryngoscopy	Identify patients who will have difficult laryngoscopy	Kim et al convolutional neural network[25]

However there are many aspects as outlined American society of Anaesthesiologist physical status classification system and majority of them which brings important perspective in assessing patient physiological status and potential operative risk are not been dealt by the artificial Intelligence yet.[26,27,28]

Intraoperative and post operative utility of AI

Other cognitive Machine learning models which are also used in preoperative risk evaluation by pinpointing risk factors, proving comprehensive informed consent and determination of necessity for ICU admission after surgery thus enabling the anaesthesiologist plan and tailor the perioperative patient management.[25] Anaesthesia information system makes use of AI algorithms to analyse the patient to take preventive action in case of any unfavourable events thus modifying anaesthesia plan or increasing the frequency of monitoring.[2,16]

The Artificial intelligence based Anaesthesia information system and other cognitive models are summarized in table 2.

These models needs further training and build up for precision moreover robust heath data safety procedures need to be developed and ethical concerns need to be addressed. This may augment teaching and training of health personnel involved in anaesthetic pre operative assessment of patient.[35]

Table 2. Artificial intelligence based Anaesthesia information system and other cognitive models

Application	Use in Anaesthesia	Example
Risk evaluation	ASA-PS (American Society of Anaesthesiologists-Physical status) prediction of risky physical status	Zhang et al automated system[29] Hofer et al DNN model that even outperformed ASA-PS [30]
Prediction of induced hypotension	Forecast likelihood of hypotension following anaesthesia	Kendale et al. ML algorithms [31]
Anaesthesia Information system	Assistance in intraoperative monitoring and highlighting key changes	Muravchik S.et al. and Vigoda MM AI-AIMS models [32,33]
AIS-Quality assurance	Assist in documentation error detection and notification	Spring SF automated and error detection model [34]

Anaesthesia dose management and administration

The AI incorporation in anaesthesia can calculate and tailor appropriate drug dosages which is essential for safe and efficient anaesthesia as per patient need.[36,37] These various artificial intelligence applications through targeted controlled infusion pumps, targeted attainment of specific anaesthetic drug levels, muscle relaxant delivery system, propofol delivery models and vasopressor administration AI empowered models enables the anaesthesiologic to obtain desired pharmacodynamic effect, thus offering faster more precise anaesthesia management[5,17,22] The AI based anaesthesia dose management models are summarised in table 3.

Table 3. AI based anaesthesia dose management models

Application	Use in Anaesthesia	Example
Target controlled infusion pumps	TCI pumps based on pharmacological model	Diprifusor [38,39]
Precision to attain specific levels of anaesthetic agents	Anaesthetic drug administration systems which are designed to precisely dispense to attain specific levels of anaesthesia	CLAD [40]
Concurrent management of sedation, pain, and muscle relaxation	Anaesthesia drug management system developed to concurrently manage sedation, pain and muscle relaxation using drugs propofol, remifentanil and rocuronium.	Mcsleepy[41]
Propofol administration	An AI system devised to deliver propofol medication by doctors even who are not even formally trained in anaesthesia	SEDASYS[42]
Vasopressor and fluid administration	AI models administrating fluid boluses and vasopressor titration based on patient parameters like stroke volume, BP etc.	Goal directed fluid therapy models [43]

While these models enhances anaesthetist's expertise, literature consistently notes that broader integration demands further validation. In spite of extensive study few systems are commercially available thus highlighting a gap. When compared to other medical fields it underscores the need for stronger collaboration between researcher, regulators and engineers.[43]

Mechanical Robotic systems

The mechanical task like intubation, ventilation and nerve blocks are being carried out by AI trained robots. The tasks like intubation, nerve block, endoscope placement are mainly done by trained physicians and precision with which the procedure is being carried out depends on expertise. So these automated robotic models increase the spectrum of users and also increases the accuracy of procedure being done.[19,44]

The summary of application of these automated mechanical robotic systems are shown in table 4.

A key limitation noted across studies in that AI- enabled robotic applications have been trained exclusively on mannikin and though the results in this setting are promising in comparison to other medical AI domains, there is clear need for human-subject research to ensure clinical validity.[2,4,35]

Pain management

Pain assessment is integral part of anaesthesia which determine whether treatment is effective or not, especially acute post- surgical pain management because if not managed properly may transit into chronic post-surgical pain. The conventional self-reported methods has limitations of objectivity and standardisation moreover dependant on communication between physician and patients. The AI offer an automated and accurate promising avenue and is devoid of these limitations.[51,52] The various Artificial intelligence applications concerned with pain assessment is summarized in table 5.

Table 4. Automated mechanical robotic systems using AI Anaesthesia application system.		
Application	**Use In Anaesthesia**	**Example**
For fibreoptic intubation	Used in anaesthesia experimentally for fibreoptic intubation	DaVinci surgical system[44]
For intubation	A joy stick-controlled, robotic arm guided intubation	Kepler intubation system [45]
For intubation and robotic endoscope placement	Endotracheal intubation with real time visualization and guiding placement of endoscope towards glottis	REALITI [46,47]
Aspiration syringes	Syringes devised to aspirate stop flow with pressure	SAFIRA[48]
Nerve blocks	Ultrasound guided robotic needle placement in nerve blocks	Magellan system[49]
Nerve block 40	Facilitated needle insertion during training and clinical setting for ultrasound guided nerve block procedures	UGRA[50]

Table 5. Artificial intelligence applications concerned with pain assessment		
Application	**Use in anaesthesia**	**example**
Pain assessment	Pain assessment by analysing spontaneous facial expression through image classification	J.huo et al. computer vision pain assessment by facial expression [51]
Neurophysiological Pain detection	Pain evaluation by AI assisted behavioural and neurophysiological(EEG,EMG and EDA) data.	Cascella M et al automatic pain assessment model[12]
Patient controlled analgesia	AI-PCA alerts the anaesthesia staff to adverse events like excessive sedation and insufficient analgesia	Song B et al AI clinical safety model in anaesthesia[19]

Automated pain assessment and management tools currently suffer from limited datasets and validation metrics when compared to more established AI applications, this evidently gap highlights the need for robust, targeted studies to strengthen their clinical reliability[19,51,52]

Limitations, Ethical concerns and need of human touch

The application of Artificial intelligence in Anaesthesiology is becoming increasing widespread and has immense potential as it is being anticipated to have significant developments and new applications. However there are certain drawbacks like transparency of algorithms , multiple layer of neural networks as human life are being dealt, wrong results from these models can prove fatal to patients, lack of diverse dataset on which these models are trained create biases, lack of uniform and clear guidelines and regulations for use of these models to prioritize patient safety , ethical and legal issues are addressed so that benefits of artificial intelligence are shared fairly and the potential drawbacks are managed effectively. The automation of artificial intelligence and its subsets raises concerns about the job displacement putting previously secure positions at risk, these concerns are more evident for populous developing countries[16,21]. Few of these limitations are summarised in table 6.

Table 6. Ethical, legal and other limitation of AI		
Ethical and Legal issues[1,3,5,16]	Liability	Legal frame does not address with whom the responsibility should be fixed in case of AI system error.
	Biasness	If AI algorithms are trained on data that is biased then it may lead to disparities in anaesthesia management
	Patient autonomy and informed consent	Patients have right to be made aware i about the role of AI in their anaesthesia care and informed consent needs to be taken from the patient.
	Data privacy and security	Need of encryption and stringent cybersecurity measure to compliance ensurity with data protection laws so that unauthorized access or misuse of sensitive patient data is prevented
Empathic human judgement[1,5]	Clinical decision making and critical thinking	AI algorithms lack human intuitions and reasoning in complex anaesthesia cases
	Personalised patient care	AI may not fully capture the individual physiological and psychological factors to tailor anaesthesia plans

Current literature notes unresolved ethical-legal gaps in AI for anaesthesia form unclear liability and biased datasets to consent and data security issues. When compared with other medical fields, these challenges are intensifies by anaesthesia's need for empathetic judgement and personalised care.[2,5,16]

CONCLUSION

The artificial Intelligence and Machine learning in anaesthesia holds transformative potential but requires addressing workforce, ethical, legal and validation challenges, thus ensuring its complements rather than replaces human expertise.

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CONFLICT OF INTEREST

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