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RESEARCH ARTICLE

EVOLUTION OF ARTIFICIAL INTELLIGENCE IN ANESTHESIA AND ITS PATH FORWARD

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Abstract

Artificial intelligence (AI) has brought a paradigm shift in patient management in the modern healthcare industry. This narrative literature review aims to explore the evolution of AI in the field of anesthesia and discuss its potential path forward. The increased demand for personalized care, smart decision-making tools, precision in practice, and growth in telemedicine, particularly in the realm of perioperative care, has brought AI to the forefront. By examining the existing research and applications of AI in anesthesia, this review seeks to provide insights into the current state of AI technology, its applications, implications for practicing clinicians, and the challenges and limitations that need to be addressed for its successful integration into perioperative care. This review encourages interdisciplinary teamwork between anesthesiologists, technologists, engineers, and technicians to simplify the complexities of AI implementation, address ethical issues, mitigate risks, and ensure safe perioperative care.

Introduction:-

Artificial intelligence (AI) has emerged as a transformative technology with the potential to revolutionize various industries, including healthcare [1]. In the field of anesthesia, AI holds great promise in enhancing patient care, improving clinical decision-making, and optimizing workflow efficiency [2]. This review aims to provide a comprehensive overview of the principles and evolution of AI in anesthesia, its multifaceted roles involving novel approaches to patient care, recent guidelines on its use, and shed light on its perioperative applications.

Principles of artificial intelligence:

AI is a rapidly evolving technology to research and develop theories, methods, and clinical applications for simulating and extending human intelligence to carry out tasks via algorithms [2]. AI technologies include machine learning (ML), deep learning (DL), natural language processing (NLP), speech and image recognition, and expert systems including robotics. ML is a subset of AI that works using sample data to train computer programs to recognize patterns based on algorithms. DL refers to the core of ML, incorporating computer systems designed to imitate neurons in the brain. [Figure 1] illustrates the relationship of DL as compared to ML and AI [3].

The term “deep” in the DL methodology refers to the concept of multiple levels through which data is processed to build a data-driven model. These multi-stage processes involve multi-layer neural networks, referred to as Artificial neural networks (ANNs). However, unlike ML modeling, feature extraction in DL is huge and automated rather than manual. Large amounts of data can be processed using DL modeling, which enhances its performance significantly and exponentially [Figure 2].

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Figure 1: An approach to illustrate the relationship between Artificial Intelligence (AI), Machine Learning (ML), and Deep Learning (DL).

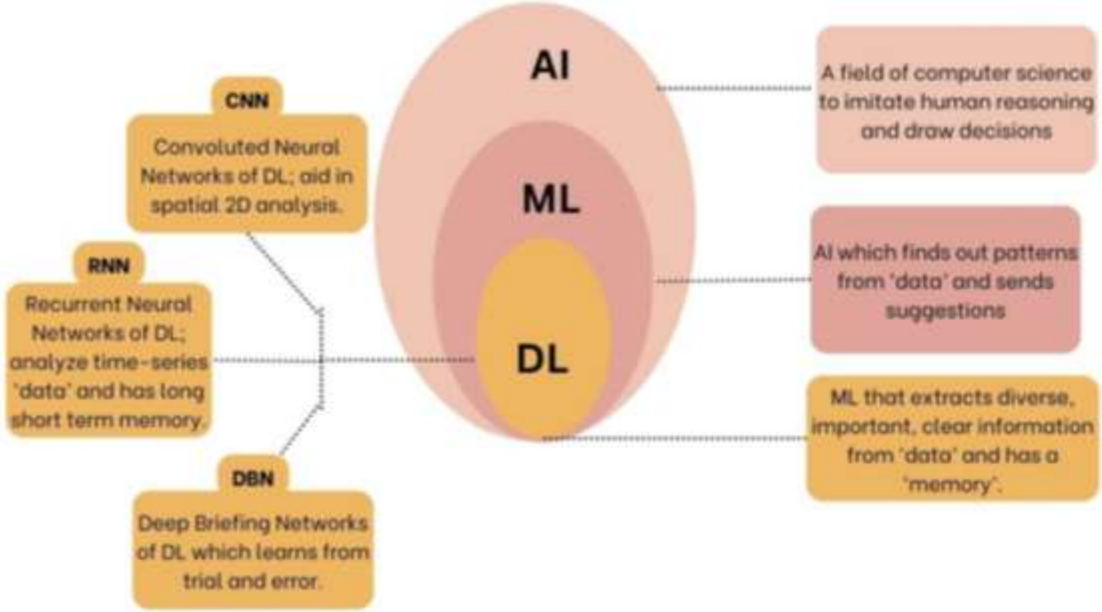
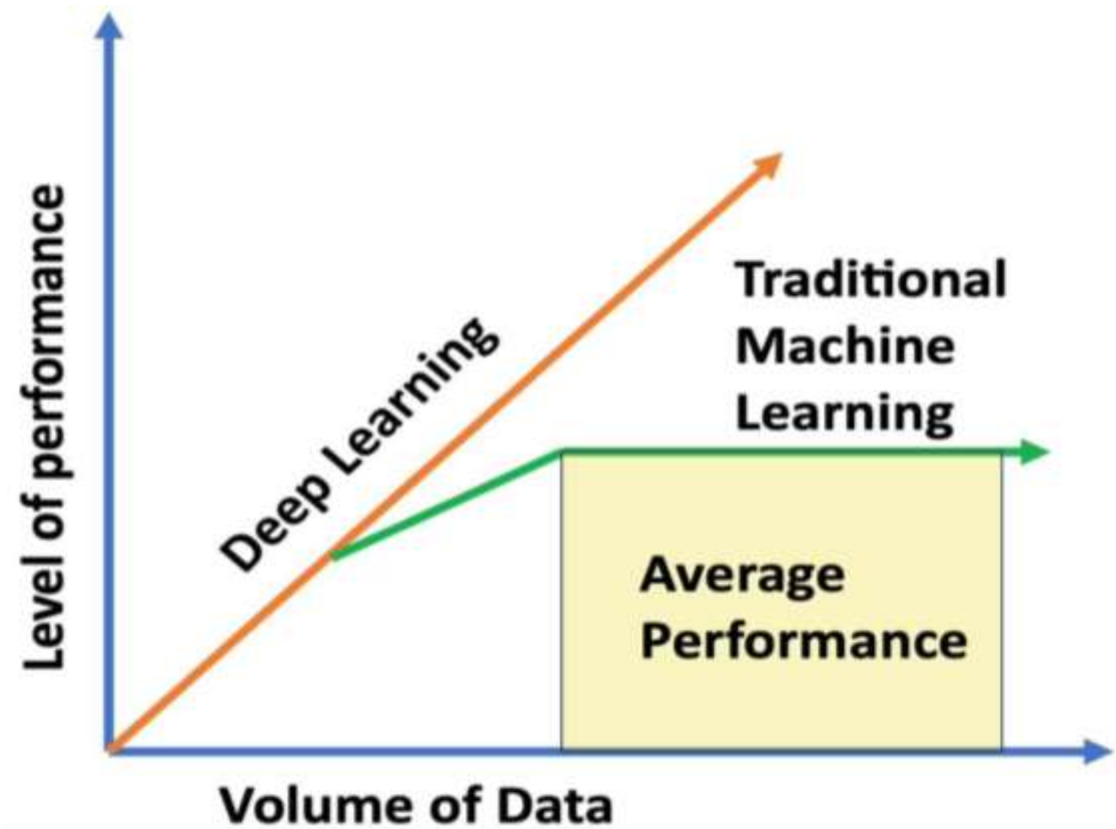


Figure 2:- Comparison of performance of Deep Learning and traditional Machine Learning models considering the amount of data.



A DL model typically follows three processing stages, such as data understanding and preprocessing, model building and training, and validation and interpretation. DL accomplishes the task using convolutional neural networks (CNNs), recurrent neural networks (RNNs), autoencoder (AE), and deep belief networks (DBN) mimicking the complex neural structures of the human brain [Figure 3]. CNNs utilize filters to extract data, followed by correlating features in different layers by utilizing multiple convolutions and pooling layers. CNNs are specifically meant to deal with a variety of 2D shapes and are thus widely employed in image processing, computer vision, and pattern recognition. The RNNs are specialized ANNs where connections between nodes can create a cycle, as the output relies on prior elements in the sequence, allowing it to exhibit temporal dynamic behavior. RNNs tend to have 'memory' that allows them to process the task using information from previous inputs. Machine translation, robot control, speech recognition, and speech synthesis are some of the applications of RNNs [3].

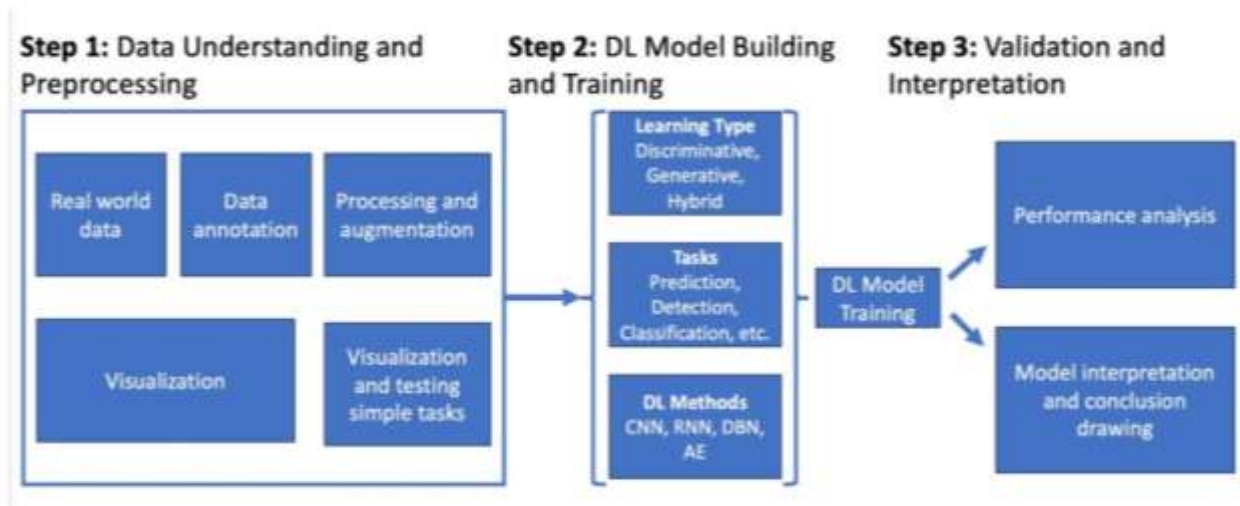


Figure 3:- A typical Deep Learning workflow model. Source (with permission). Deep learning: A Comprehensive Overview on Techniques, Taxonomy, Applications and Research Directions. SN Comput Sci.Â 2021;2(6):420.

Evolution and current applications of AI in Anesthesia:

The early attempts at automation in anesthesia focused on the development of systems for monitoring and control. However, recent advancements in AI, particularly in ML and DL algorithms, have opened up new possibilities for the integration of AI into anesthesia practice [Figure 4]. AI-based systems are being developed relentlessly for various applications of perioperative medicine to tailor anesthesia to individual patient needs, minimize risks, and 'enhance recovery after surgery' (ERAS) [4].

The journey of a surgical patient during the perioperative period is carved here, using the two dynamic, yet intersecting independent fields - anesthesia and AI.

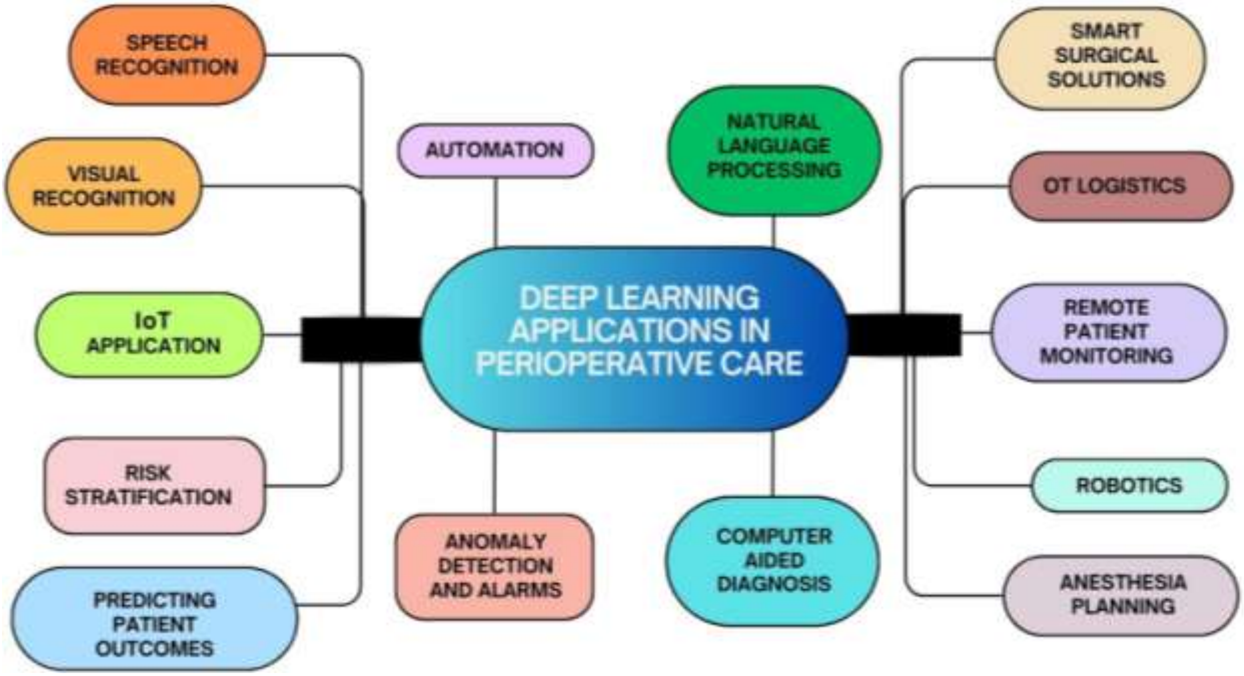
Pre-anesthesia check-up (PAC)

The preoperative phase is undoubtedly the quintessential aspect of perioperative care. The patient's safety begins with the complete medical history and examination by an anesthesiologist. NLP, one of the applications of AI, can be used to extract relevant information from unstructured massive text data. A retrospective study depicted the ability of NLP to extract meaningful data from unstructured electronic medical records (EMR) and generate an automated pre-anesthetic evaluation report. The data produced by NLP was compared with the information collected by an anesthesiologist. NLP could pick up relevant conditions missed by anesthesia professionals in 16.57% of the cases and missed important data procured by anesthetists in only 2.19% of the cases [5].

Assessment of the airway is a routine step in PAC, accomplished by history and physical examination of the patient. AI models enable anesthesiologists to guide difficult airways objectively, using predictive features like body mass index, thyroid distance, computerized facial analysis, and photographs [6,7].

For specific patients, preoperative assessment can be extremely challenging even for an expert in view of identifying risk factors, patient-specific prediction, explaining the risks involved, and designing the real informed consent. With the application of ML algorithms, the AI models process multifaceted data, multiple patterns, and relationships to generate optimized and individualized approaches to patient care.

Figure 4:- Healthcare solutions powered by artificial intelligence to bridge Deep Learning techniques and perioperative care.



Perioperative risk stratification

The counseling of a presurgical patient and obtaining valid well-informed consent requires proper risk stratification. ML methods have been quite successful in grading the risk of patients undergoing high-risk surgeries. Mysurgeryrisk is an ML algorithm that identifies the risk scores for eight perioperative complications (acute kidney injury, sepsis, venous thromboembolism, intensive care unit [ICU] admission for more than 48 hours, mechanical ventilation for more than 48 hours, neurologic, and cardiovascular events) and predicts the mortality risk up to 2 years postoperatively [8].

The American Society of Anesthesiologist's Physical Status (ASA-PS) classification has been used by professionals for more than half a century to explain risk levels to preoperative patients.

ML algorithms have been used to help classify the risk involved in complicated scenarios [9]. Further, Machine Learning Physical Status (ML-PS) is developed to stratify high-risk categories of preoperative patients, independent of the clinician’s decision [10]. The professionals utilize the ML methods to predict postoperative postsurgical mortality and ICU admission, from data, such as patient demographics, medical history, surgical procedures, medications, vital signs, laboratory values, and other clinical factors [11].

Perioperative optimization

The proactive approach of the optimization of a surgical patient has played a significant role in successful outcomes and reduced mortality. AI-driven applications develop tailor-made instructions for a specific patient undergoing a unique kind of surgery, that includes the patient's nutrition, physiotherapy, incentive spirometry, medication adjustments, glucose control, and prophylaxis of deep venous thrombosis to optimize clinical scenarios and mitigate the risks [12]. This personalized and adaptive approach to perioperative care has brought a paradigm shift in the preparation of patients for surgery.

Clinical Decision Support Systems (CDSS)

CDSS refers to a computer-based program that assists anesthesia professionals in clinical decision-making. This methodology assimilates the plethora of data and enables the anesthesiologists to devise patient-specific anesthesia care plans. The care provider uses system-generated advice to make necessary interventions, such as drug dosing, fluid management, ventilatory parameters, and blood transfusion, after analyzing the patient's comorbidities, allergies, and laboratory values [13].

Recently, the application of Anesthesia information management systems (AIMS) has enabled real-time CDSS to provide immediate feedback and advice, in case of any deviation from best medical practices. AIMS was initially introduced for automatic recording of data on a patient's monitor and anesthesia machine parameters for intraoperative documentation. The automated record keeping is analyzed in real-time during surgery involving rapidly changing physiological states of the patient. CDSS, along with AIMS and EMR, has emerged as a beacon of innovation with a promising approach to detecting clinical issues, and alerting anesthesiologists to take necessary steps that ensure patient safety [14].

Depth of Anesthesia (DoA) monitoring

In addition to basic monitoring advised by ASA, it is prudent to always monitor the depth of anesthesia. The incidence of postoperative mortality and adverse events increases with 'too deep' anesthesia [15]. On the contrary, 'too shallow' anesthesia is associated with a high incidence of intraoperative awareness. The widely used bispectral index (BIS), based on analysis of EEG signals provides a crude reading and it lacks the correlation with nociceptive stimulation.

AI promises the DoA monitoring system, based on real-time EEG and DL algorithms, that has the capacity to ensure the ideal anesthetic depth, where the risk of recall is as low as possible, and where the blood pressure and heart rate of the patient are kept optimal for an individual patient. CNN and RNN applications ensure the near-ideal, accurate prediction of DoA within 20ms, with a performance index significantly better than BIS [16].

Automatic drug administration systems

The synergism between AI and medicine has brought a dramatic move towards automation in the field of anesthesia. The closed-loop drug delivery system, especially target-controlled infusion (TCI) is a well-practiced technique. The benefits of volatile anesthesia include a better environmental profile, rapid cognitive recovery, ERAS, and lesser cost. These machines use ML algorithms to aid automatic drug delivery, and hence, are referred to as pharmacological robots [17].

An ideal automatic drug delivery system, powered by AI shall allow the sedation without using a mechanical airway, as well as, too profound loss of consciousness in a closed-loop general anesthesia. The close loop control technology of McSleepy offers management of all stages of anesthesia, hypnosis, analgesia, and muscle relaxation [18].

Operating Room Logistics

By leveraging ML algorithms and predictive analytics, AI systems can analyze vast amounts of data to identify patterns, trends, and potential bottlenecks in the operating room workflow. This can lead to better resource allocation, improved patient outcomes, and enhanced overall efficiency [19]. One of the most compelling benefits of AI in operating room logistics and anesthesia management is its ability to optimize staff allocations. AI algorithms can analyze patient data, such as medical histories, preoperative assessments, and surgical complexity, to predict the optimal team composition for each case. This can result in more efficient use of resources and reduce the risk of over- or under-staffing. For instance, an AI system could recommend that a certain surgical team be assigned to a high-risk surgery, ensuring that the necessary expertise and experience are available to minimize complications [20].

Postoperative monitoring and follow-up

The postoperative period is equally crucial in the journey of a surgical patient to be uneventful.

AI technologies can guide the clinician to make a decision to discharge a vulnerable patient from the recovery room, after analysis of multiple factors simultaneously. The accuracy of predictive models is directly proportional to the amount of data added to the system during the perioperative period. AI techniques identify patterns, and anticipate issues after developing personalized risk profiles, thus preventing postoperative complications significantly [21].

The effective control of pain in the postoperative period reduces complications, decreases the incidence of chronic pain, and increases patient satisfaction. Effective pain assessment at regular intervals and patient-controlled analgesia (PCA) in the postoperative period are keys to success. However, the current PCA is not intelligent enough as information feedback is lacking, and patients suffer from inadequate analgesia, frequent clinical complaints, and a high call-back rate [22].

To increase the efficiency of Acute Pain services (APS), Ai-PCA is introduced, which integrates the Internet Of Things (IoT) technology and AI operation. Ai-PCA sends warning alarms of ‘poor analgesia’ to APS doctors by analyzing the repeated pressing by the patient. APS team members are alerted timely to modify infusion rates of Ai-PCA, to avoid the occurrence of severe pain. Similarly, a ‘blocking alarm’ is meant for decrease in infusion rates, in case a patient has nausea, vomiting, itching, or dizziness, to avoid life-threatening complications. The real-time alarm system of Ai-PCA uses a central analgesia monitoring platform, which may be reviewed by APS team members remotely and at repeated intervals [23].

Tele-anesthesia

Automated anesthesia delivery systems can be controlled remotely and have the potential to provide anesthesia at a distance, which is referred to as ‘tele-anesthesia’. The essential components of tele-anesthesia include continuous audio-video communication with local healthcare providers, a continuous video feed of important monitoring systems, and remote control of a local anesthesia system. It is pertinent to have complete preoperative check-up of the patient using audio-visual communication. Transcontinental anesthesia could help to overcome the shortage of specialists in remote areas, potentially reduce travel costs, and improve patients’ accessibility to professional treatments[24].

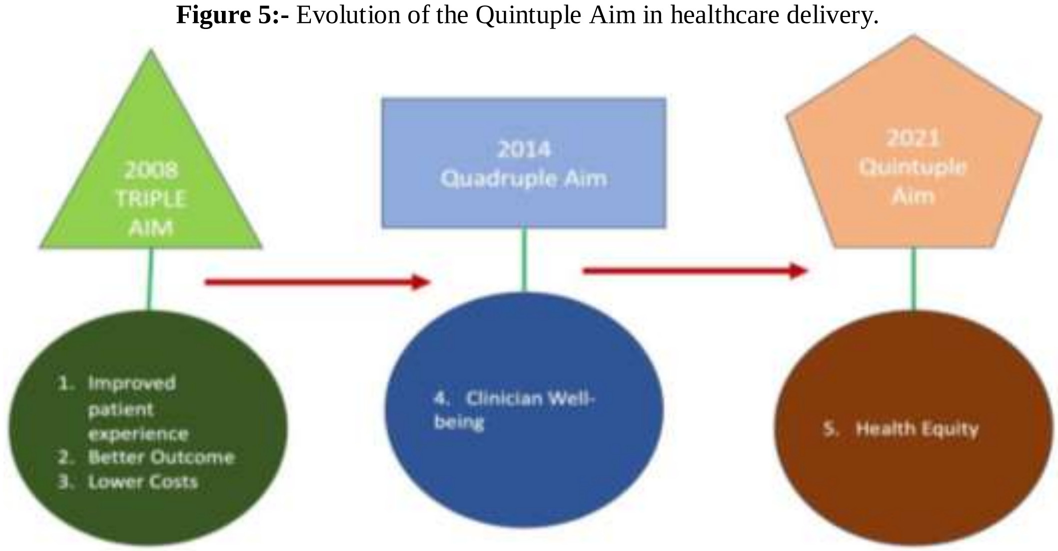
Streamlining the anesthesia process remotely, the Kepler Intubation System (KIS) is a dependable technique. The system consists of a joystick, a computer as the ‘electronic brain,’ a carbon fiber robotic arm, and a bespoke piece that allows attachment of the video laryngoscope.

These are referred to as mechanical robots. Complete robotic anesthesia seems feasible using the combination of pharmacological (McSleepy) and mechanical robots (KIS) [17]. An automated airway intubation robot, REALITI is developed on the principle of real-time image recognition function. AI-based active visual tracking technology appreciates the first anatomical sign, switches itself from manual to automatic mode, and the endoscope moves towards the glottis. Once the glottis is entered, the structural image of the tracheal rings is ready for manual confirmation [25].

“Quintuple Aim” and AI

The Institute for Healthcare Improvement introduced the idea of Improved patient experience, better population health, and lower costs. Later, the clinician's well-being was included as a bundle to address the burnout of professionals. To deliver high-quality, biomedical ethics, and safe patient care for populations, ‘Health Equity’ was proposed as the fifth aim recently [26] [Figure. 5].

Figure 5:- Evolution of the Quintuple Aim in healthcare delivery.



AI can play a crucial role in perioperative patient safety through the lens of the Quintuple Aim. The anesthesia professional needs to adopt the applications of AI in the perioperative management of surgical patients, within the framework of the Quintuple Aim to improve safety and quality [Figure 6]. The application of AI tools shall help the anesthesiologist rapidly navigate data from disparate sources, and by actively guiding the individual in making better, scientific, and evidence-based medical decisions within the intricate healthcare system [27].

"The Quintuple Aim" Addressed By AI In The Perioperative Period

	Improved Patient Health	Better Outcomes	Lower Costs	Clinician Well-Being	Health Equity
Preoperative	- Leveraging AI for improved preoperative communication of important health and event notifications. - AI to drive text messaging to communicate perioperatively.	- Understanding population health risk factors to help with anesthesia and surgical scheduling and planning. - Leveraging large datasets to safely triage patients to an ambulatory surgery center.	- Use of AI to analyze factors related to operating room logistics such as OR time scheduling.	- AI algorithms to improve anesthesia staff scheduling on electronic platforms. - Optimizing staffing ratios based on predictive factors of patient perioperative risk and clinical load.	- Using AI to study demographic, socioeconomic, and environmental risk factors that may be predictive of perioperative morbidity and mortality.
Intraoperative	- Using AI to assist in successful placement, on the first attempt, of vascular access and nerve blocks using ultrasound guidance. - AI to assist in difficult airway management risk stratification.	- Use of AI to help inform which patients need type and screen and/or cross match.	- Use of AI for anesthesia depth monitoring and optimization to reduce waste.	- Use of AI to reduce cognitive load in clinical care environments with smart alarms and clinical decision support tools. - Decreasing unnecessary interactions with the electronic medical record through optimizing charting with natural language processing.	- AI recommendation algorithms to reduce variation in care among different populations.
Postoperative	- AI decision support for postoperative risk stratification and disposition to optimize inpatient and critical care resources.	- Leveraging AI to assist in optimizing hospital bed management efficiency including time to discharge.			- Using large datasets to study race/ethnicity disparities in care among a large health care system.

Figure 6:- Framework applying Quintuple Aim in applications of artificial intelligence aiding patient safety across the perioperative continuum. Source (with permission). Tan JM, Cannesson MP. Artificial intelligence, patient safety, and achieving quintuple aim in anesthesiology. APSF newsletterÂ 2023;38(1);1-4.

Implications for Practicing Clinicians:

It is crucial for practicing clinicians to have a solid understanding of the basics of AI to effectively utilize and interpret the outputs of AI systems. The integration of AI in clinical practice is a complex process that requires careful consideration and planning. Clinicians will need to assess the feasibility of incorporating AI technologies into their daily workflows, taking into account factors such as software compatibility, user-friendliness, and data security [28].

As AI systems become more prevalent in healthcare, clinicians have the responsibility to ensure that patient data is not just entered correctly but also remains safe and inaccessible to anyone outside the concerned healthcare team. Clinicians must also cross-check all functionings, results, monitoring, and outputs themselves and avoid blind reliance.

Challenges, limitations, and path forward:

While the potential benefits of AI in anesthesia are significant, there are several challenges and limitations that need to be addressed. As an anesthesiologist, incorporating AI into clinical practice presents both strengths and weaknesses, even threats.

One major challenge is the lack of data standardization and interoperability within healthcare systems. In order for AI algorithms to effectively analyze and interpret data from EMR, imaging studies, and monitoring devices, consistent data formats and protocols need to be established across different platforms [29].

Fixing the limitations in the accuracy and reliability of AI algorithms in clinical decision-making is a major consideration. To date, there are a limited number of DL programs with external validation in medicine. The incomplete, biased, or incorrect data, fed to ML shall produce false results without an alarm, leading clinicians to make irrational decisions [16]. One of the primary ethical concerns with using AI in anesthesiology is the issue of accountability. When errors occur in anesthesia administration, who is ultimately responsible – the human anesthesiologist or the AI system? This question becomes even more complex when considering that AI systems are programmed by humans and can potentially contain biases or errors themselves. Anesthesiologists must not have overconfidence in the recommendations provided by AI systems, as any errors or misinterpretations could have serious consequences for patient safety [30].

Furthermore, there are ethical considerations surrounding the use of AI in anesthesia. Anesthesiologists must grapple with questions of autonomy, accountability, and transparency when relying on AI systems to assist in clinical decision-making. In order to hold algorithms accountable, the internal bias should be addressed. However, it may become impossible as ML cannot answer how the results are generated, referred to as the "black box" phenomenon [31].

Additionally, there may be concerns about data privacy and security when sensitive patient information is stored and processed by AI algorithms. Unethical hacking is another massive hurdle in data processing with artificial intelligence that can create huge data leaks and breaches which results in multidimensional catastrophes for both patients and healthcare providers [30].

In response to the growing need to responsibly manage the rapid rise of AI health technologies, the World Health Organization (WHO) outlines the following six areas for regulation of AI for health [32].

1. To foster trust, the importance of transparency and documentation, such as through documenting the entire product lifecycle and tracking development processes is stressed.
2. For risk management, the issues like 'intended use', 'continuous learning', human interventions, training models, and cybersecurity threats, must all be comprehensively addressed, with models made as simple as possible.
3. Externally validating data and being clear about the intended use of AI helps assure safety and facilitate regulation.
4. A commitment to data quality, such as through rigorously evaluating systems pre-release, is vital to ensure that the systems do not amplify biases and errors.
5. The challenges posed by important, complex regulations are addressed with an emphasis on understanding the scope of jurisdiction and consent requirements, in service of privacy and data protection.
6. Fostering collaboration between regulatory bodies, patients, healthcare professionals, industry representatives, and government partners, can help ensure products and services stay compliant with regulation throughout their life cycles.

To harness the full potential of AI in anesthesia, collaboration between clinicians, researchers, and industry experts is essential. Clinicians should actively engage in the development and implementation of AI technologies, ensuring that they align with the needs and priorities of clinical practice. Continued research and innovation in AI algorithms, data collection, and integration with existing clinical systems are crucial for the successful integration of AI into anesthesia practice. Furthermore, ongoing education and training programs should be established to equip clinicians with the necessary skills to effectively utilize AI technologies [Figure 7].

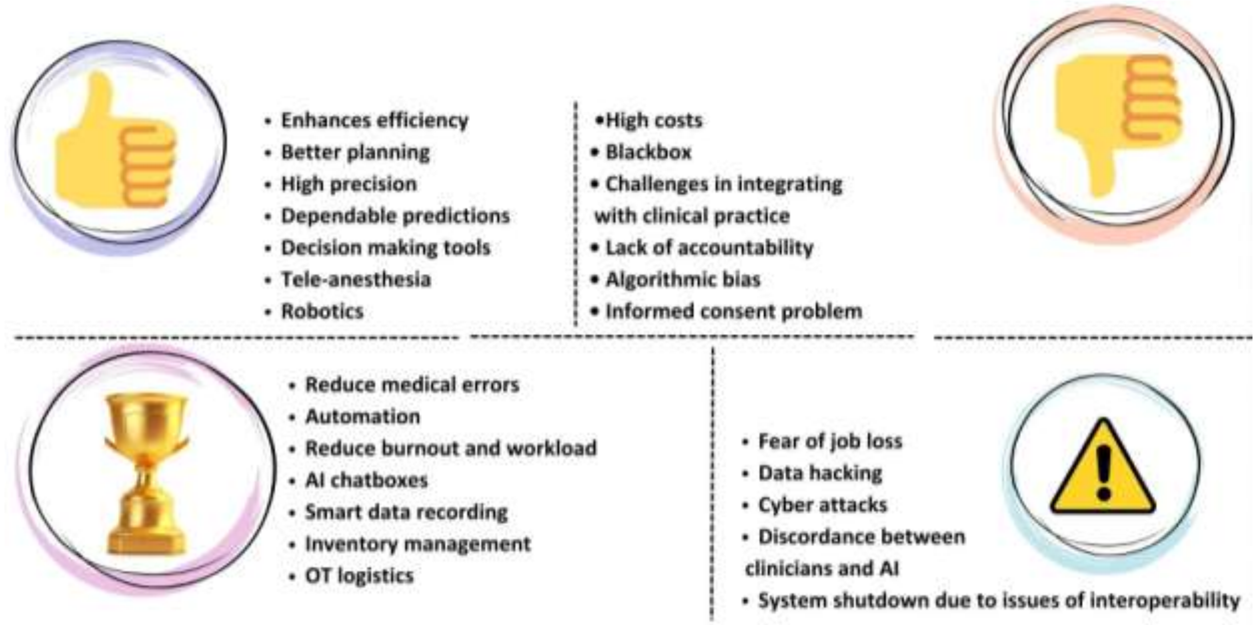


Figure 7:- SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis of artificial intelligence in anesthesia.

Conclusion:-

The evolution of AI in anesthesia holds immense potential for improving patient care, enhancing clinical decision-making, and optimizing workflow efficiency. While there are challenges and limitations that need to be addressed, the path forward involves collaboration, research, and education. By embracing AI technology and actively participating in its development, practicing clinicians can shape the future of AI in anesthesia and ensure its successful integration into clinical practice.

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