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Cardiothoracic anaesthesia in the digital age: The application of artificial intelligence

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Abstract

In the ever-evolving landscape of medical technology, the integration of artificial intelligence (AI) has emerged as a transformative force in various specialties, including anaesthesia. Cardiothoracic anaesthesia, a critical domain within cardiovascular medicine, stands to benefit significantly from AI's capabilities. This abstract delves into the burgeoning intersection of cardiothoracic anaesthesia and AI, exploring the manifold applications, challenges, and potential outcomes. AI's capacity to analyze complex data streams swiftly and accurately has paved the way for personalized patient care in the digital age. In the context of cardiothoracic anaesthesia, AI's potential spans preoperative risk assessment, intraoperative monitoring, and postoperative care optimization. Algorithms trained on extensive patient datasets can predict patient-specific responses to anaesthesia, aiding clinicians in tailoring interventions. Furthermore, real-time AI-driven monitoring systems can detect subtle changes in hemodynamic and oxygenation, enabling timely intervention and improving patient safety during surgery. However, this symbiotic relationship between AI and cardiothoracic anaesthesia faces challenges, including data privacy concerns, algorithm interpretability, and integration with existing healthcare systems. Ensuring that AI models are trained on diverse and representative datasets is essential to mitigate biases and promote equitable patient care

Key Words: anaesthesia, artificial intelligence, cardiovascular, operation theatre.

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INTRODUCTION

In the rapidly advancing realm of medical science, the amalgamation of cutting-edge technologies with clinical expertise has paved the way for remarkable transformations across various healthcare disciplines. One such synergy that holds immense potential is the integration of artificial intelligence (AI) within the field of cardiothoracic anaesthesia [1]. Cardiothoracic anaesthesia represents a specialized arena within cardiovascular medicine, addressing the intricate demands of surgical procedures involving the heart and thoracic cavity [2]. The ever-growing complexity of these interventions necessitates precise monitoring, dynamic decision-making, and personalized patient care strategies [3]. The AI is a revolutionary force that thrives on its ability to rapidly analyse copious amounts of data and discern patterns that might elude human observation.

While the previous decade witnessed the dawn of digitalization and electronic health records, the current era is characterized by the rise of AI as an invaluable tool to harness the full potential of available clinical data [4]. AI's prowess in predictive modelling, pattern recognition, and real-time analysis holds significant promise for optimizing various aspects of cardiothoracic anaesthesia. From predicting patient-specific responses to anaesthesia agents to enabling early detection of physiological deviations during surgery, AI ushers in a new era of precision and proactive care [5].

As we embark on this exploration of AI's impact on cardiothoracic anaesthesia, it becomes evident that the integration of machine intelligence has the potential to reshape traditional practices, refine decision-making processes, and enhance patient outcomes. However, this transformation is not devoid of challenges, ranging from the ethical use of patient data to ensuring the transparency and interpretability of AI algorithms [6]. Thus, a comprehensive understanding of these nuances is essential to harness AI's potential fully while upholding patient safety and well-being.

In light of the rapidly evolving landscape of medical science, this article endeavours to not only highlight the transformative potential of integrating AI with clinical expertise in cardiothoracic anaesthesia but also to address the profound disparity that often exists between AI-based research findings and their seamless translation into practical applications within clinical anaesthesia settings. By elucidating key strategies and considerations, this article aims to provide a comprehensive framework for effectively harnessing the power of AI in optimizing patient care in cardiothoracic anaesthesia.

Role of AI in preanaesthesia evaluation of a patient posted for cardiothoracic surgery

The pre-anaesthesia evaluation of patients undergoing cardiothoracic surgery is a crucial step in ensuring the safety and success of the surgical procedure. This evaluation involves a comprehensive assessment of the patient's medical history, physical condition, and various risk factors to tailor the anaesthesia plan accordingly. With the emergence of AI technologies, this process has been revolutionized, offering new avenues for enhanced accuracy, efficiency, and patient care [7].

AI has proven to be a valuable tool in streamlining the pre-anaesthesia evaluation process for cardiothoracic surgery patients. Machine learning algorithms, trained on vast datasets encompassing diverse patient profiles and medical information, can swiftly analyze complex medical records to identify potential risks and predict patient-specific responses to anaesthesia and surgery. This predictive capability enables anaesthesiologists to make informed decisions and devise personalized anaesthesia strategies that minimize complications and optimize patient outcomes [8].

One of the primary advantages of AI-driven pre-anaesthesia evaluation lies in its ability to uncover subtle patterns and associations within patient data that might elude human observation [9]. This includes identifying correlations between medical conditions, medications, and patient outcomes that could influence the anaesthesia plan. By considering a multitude of variables, AI systems provide a comprehensive assessment that aids anaesthesiologists in tailoring interventions to each patient's unique needs.

Furthermore, AI can assist in the early detection of potential complications or adverse events. By analysing patient data and risk factors, AI algorithms can generate alerts for specific conditions that might require special attention during the surgery or recovery period. This proactive approach allows healthcare teams to address issues pre-emptively, minimizing the impact on patient health and well-being. However, the integration of AI into pre-anaesthesia evaluation is not without challenges. Ensuring the accuracy and reliability of AI models requires continuous validation against real-world patient outcomes. Additionally, maintaining patient data privacy and security is paramount, necessitating robust data protection measures to uphold patient confidentiality [10].

Current utilization of AI in cardiothoracic surgical unit.

Presently AI utilization in terms of surgical data driven science, which is a quality enhancement endeavours resembles an operating room black box system. This analytical platform facilitates the aggregation and integration of a broad spectrum of intraoperative data, encompassing elements like audio, video, and physiological parameters. This enables the assessment of metrics, employing both human expertise and AI-driven analysis [11].

AI in perioperative 2D and 3D TEE image construction, optimization, and interpretation

AI may play a pivotal role in enhancing the quality and utility of transoesophageal echocardiography (TEE) images during cardiac procedures. AI algorithms are capable of real-time image enhancement, noise reduction, and artifact correction, resulting in clearer visualization of cardiac structures. Moreover, AI-powered image interpretation aids in the accurate identification of anatomical landmarks, allowing anaesthesiologists to make informed decisions regarding patient management during surgery. AI can definitely help for disease identification, functional cardiac evaluation, severity of the disease and also will reduce the human error and time required to evaluate patients [12-15].

Structural heart imaging integration

One of the remarkable applications of AI can be the integration of structural heart imaging from various sources. AI algorithms have the capacity to seamlessly combine data from computed tomography (CT), magnetic resonance imaging (MRI), and 3D TEE to construct multidimensional dynamic images. This integration may facilitate a comprehensive understanding of the patient's cardiac anatomy, which is particularly critical for complex structural heart interventions.

Optimization for structural ieart Interventions like Mitral Clip and TAVI:

AI-driven technologies may help in planning and execution of structural heart interventions. For procedures like mitral clip placement and transcatheter aortic valve implantation (TAVI), AI aids in precise anatomical measurements and device selection. Additionally, it assists in virtual simulations, allowing clinicians to anticipate procedural challenges and optimize the treatment strategy.

Dynamic procedural guidance

During structural heart interventions, AI can provide real-time guidance by tracking the movement of catheters and devices within the heart. This dynamic feedback enhances procedural accuracy and safety, ultimately leading to improved patient outcomes.

Predictive analytics for intraoperative decision-making

AI algorithms can analyse real-time physiological data obtained during surgery to predict potential complications or deviations from the expected course. This empowers anaesthesiologists to proactively address any emerging issues, ensuring a higher level of patient safety.

Role of AI in administering anaesthesia for cardiothoracic surgery

Administering anaesthesia for cardiothoracic surgery is a delicate and intricate task that requires precise monitoring, vigilant decision-making, and personalized care. The emergence of AI technologies has brought about transformative possibilities in enhancing the administration of anaesthesia during cardiothoracic procedures. AI's integration into this critical aspect of surgery holds the potential to optimize patient outcomes, improve safety, and refine the overall surgical experience [16]. AI's role in anaesthesia administration begins with real-time monitoring. Cardiothoracic surgeries can involve complex physiological changes that necessitate continuous monitoring of parameters such as blood pressure, heart rate, oxygen saturation, and anaesthetic depth. AI-powered monitoring systems can detect subtle deviations from baseline values and provide early alerts to anaesthesia providers, enabling them to intervene promptly and mitigate potential complications. These systems also have the capacity to integrate data from multiple sources, facilitating a comprehensive assessment of the patient's condition [17].

Furthermore, AI-driven predictive modelling plays a pivotal role in optimizing anaesthesia dosing and management. By analysing patient-specific characteristics, medical history, and real-time data, AI algorithms can predict how an individual patient will respond to anaesthesia agents. This empowers anaesthesia providers to tailor dosages precisely, minimizing the risk of adverse events and ensuring a smoother induction, maintenance, and emergence from anaesthesia. The implementation of AI in anaesthesia administration also extends to decision support systems. During surgery, unexpected events can arise that require rapid decision-making. AI-based decision support tools can offer evidence-based recommendations, drawing from vast databases of medical knowledge and historical case data. These tools assist anaesthesia providers in making informed choices even in high-pressure situations, thereby improving patient safety and clinical outcomes [18].

Airway management is a critical aspect of patient care, ensuring proper oxygenation and ventilation during various medical procedures and interventions. The integration of AI into airway management has introduced novel approaches that enhance clinical decision-making, optimize patient outcomes, and streamline healthcare processes. AI's role in airway management spans across assessment, prediction, and real-time intervention, revolutionizing this essential aspect of medical practice. AI technologies are increasingly being used to aid healthcare professionals in assessing a patient's airway anatomy and potential challenges [19]. Through image analysis and machine learning algorithms, AI can quickly analyze medical images, such as X-rays, CT scans, and ultrasounds, to identify anatomical variations, potential obstructions, and difficult airway characteristics. This assists clinicians in anticipating difficulties and planning appropriate interventions, ultimately minimizing complications during airway management procedures. Moreover, AI's predictive capabilities are leveraged to estimate the likelihood of difficult intubation or mask ventilation based on patient characteristics and clinical data. By analysing factors such as patient age, weight, medical history, and airway measurements, AI algorithms can provide insights that guide anaesthesia providers in making informed decisions before airway interventions. This proactive approach enhances patient safety and allows for the formulation of tailored airway management strategies [20].

The role of AI in intraoperative monitoring of vitals during cardiothoracic surgery

Intraoperative monitoring of vital signs is a cornerstone of patient safety and successful outcomes in cardiothoracic surgery. The integration of AI into this monitoring process has introduced a new era of precision and proactive care, enabling healthcare professionals to closely track a patient's physiological parameters and respond swiftly to changes. The role of AI in intraoperative monitoring of vitals during cardiothoracic surgery holds significant potential to enhance patient safety, streamline clinical workflows, and optimize surgical outcomes [21].

AI's ability to process and analyse vast amounts of data in real time is particularly valuable in the high-stakes environment of cardiothoracic surgery. Through advanced sensors and monitoring devices, AI systems continuously collect data on parameters such as heart rate, blood pressure, oxygen saturation, and electrocardiographic patterns. AI algorithms then sift through this data to identify trends, deviations from baseline, and potential anomalies that may signify a patient's deteriorating condition. One of AI's remarkable capabilities lies in its power to detect subtle changes that might elude human observation [22]. During cardiothoracic surgery, even minor fluctuations in vital signs can have profound implications for patient well-being. AI-driven monitoring systems excel at pinpointing these changes, issuing alerts to healthcare providers in real time. This early warning system empowers clinicians to intervene promptly, addressing potential complications before they escalate, and ensuring patient safety remains a top priority [23].

Electrocardiogram (ECG) interpretation plays a vital role in monitoring cardiac function during surgery and other medical interventions [24]. The integration of AI into ECG interpretation has introduced transformative capabilities, enhancing the accuracy, speed, and clinical decision-making associated with monitoring a patient's cardiovascular status during procedures. AI's role in intraoperative ECG interpretation encompasses real-time analysis, arrhythmia detection, and predictive insights, revolutionizing how healthcare professionals manage cardiac monitoring in high-stress situations [25].

Real-time ECG analysis using AI-driven algorithms enables rapid and continuous assessment of the patient's cardiac rhythm and electrical activity. AI systems can quickly identify changes in the ECG waveform, such as ST segment shifts, T-wave abnormalities, and arrhythmias, alerting healthcare providers to potential issues that require immediate attention. This real-time feedback enhances the ability to diagnose and address cardiac complications promptly, improving patient safety and outcomes [26]. AI's capacity to detect arrhythmias is particularly valuable in the intraoperative setting. By analysing ECG data in real time, AI algorithms can identify irregular rhythms such as atrial fibrillation, ventricular tachycardia, and atrioventricular block. The ability to detect these arrhythmias early can help guide interventions, optimize anaesthesia and medication management, and ultimately prevent adverse events [27].

Furthermore, AI's predictive modelling capabilities can provide insights into the likelihood of certain cardiovascular events based on the patient's ECG data and medical history. For example, AI algorithms can predict the risk of myocardial ischemia or other cardiac complications during surgery, enabling anaesthesia providers and surgical teams to take proactive measures and tailor interventions to mitigate these risks [28]. The successful integration of AI into intraoperative ECG interpretation necessitates robust training on diverse patient data and validation against clinical outcomes. AI models must be continuously refined and updated to ensure accuracy across different patient populations and scenarios. Additionally, seamless integration of AI algorithms with existing ECG monitoring equipment and electronic health records is essential to streamline clinical workflows [29].

AI-driven cardiac output monitoring leverages advanced algorithms to process complex data streams, including measurements like heart rate, stroke volume, and arterial pressure. By analysing this data in real time, AI systems can calculate and continuously track cardiac output, offering a comprehensive view of a patient's hemodynamic profile. This real-time monitoring is particularly valuable in critical care settings, intraoperative periods, and postoperative recovery, where timely interventions are essential [30].

One of AI's primary contributions to cardiac output monitoring is its ability to provide insights beyond numerical values. AI algorithms can detect subtle changes and trends in cardiac output and related parameters, alerting healthcare providers to potential shifts in the patient's cardiovascular status. These alerts can help clinicians identify early signs of hemodynamic instability, allowing for prompt intervention and optimized patient care [31].

Moreover, AI's predictive modelling capabilities can forecast cardiac output trends and potential deviations based on historical data, patient characteristics, and medical history. This predictive insight assists healthcare professionals in anticipating changes in cardiac function and planning interventions accordingly [32]. By providing information on potential shifts in cardiac output before they occur, AI-driven monitoring empowers clinicians to proactively manage patients' hemodynamic stability. The AI technology-based assessment of the cardiac output may also help selection of drugs like inotropes or vasopressors or vasodilators.

Within the domain of cardiac anaesthesia, the integration of AI stands as a beacon of progress in refining critical aspects of patient care. One significant area of advancement lies in drug dosage management. AI-powered systems analyse patient-specific factors, such as age, weight, comorbidities, and real-time physiological data, to determine the most accurate and personalized drug dosages. This not only enhances the efficacy of anaesthesia but also minimizes the potential for adverse reactions or complications.

Furthermore, AI-driven solutions play a pivotal role in error management related to drug administration. Through real-time monitoring and predictive analytics, these systems can swiftly identify discrepancies or anomalies in drug dosing, alerting the healthcare team and enabling prompt corrective action. This proactive approach significantly bolsters patient safety and elevates the standard of care in cardiac anaesthesia practice.

In addition to drug dosage optimization, AI has been a transformative force in loop anaesthesia techniques specific to cardiac procedures. By leveraging advanced algorithms, AI systems can enable precise control and modulation of anaesthesia delivery in response to the patient's physiological parameters. This dynamic adjustment ensures that the patient receives the appropriate level of anaesthesia throughout the surgical procedure, enhancing both safety and efficacy. Incorporating AI into the realm of cardiac anaesthesia not only augments the precision and safety of drug administration but also empowers healthcare providers with sophisticated tools to navigate the intricacies of cardiac procedures. As this technology continues to evolve, its impact on the field is poised to be nothing short of revolutionary, ushering in a new era of excellence in cardiac anaesthesia practice.

The convergence of perioperative pharmacogenomics with cardiac anaesthesia and AI, heralds a new era of tailored patient care. By scrutinizing an individual's genetic profile, clinicians can customize drug choices and dosages for optimal responses during surgery. AI complements this approach by rapidly analysing genetic data and providing real-time, personalized medication recommendations. During surgery, AI continuously monitors physiological parameters, adjusting anaesthesia levels to ensure a steady, safe state of sedation. This seamless interplay between genetic insights and AI-driven adaptability not only refines drug administration but also anticipates and mitigates potential complications, setting a new standard for precise and secure cardiac anaesthesia practice.

The role of AI in postoperative ICU monitoring of vitals, ventilation and its application for cardio pulmonary bypass machines for cardiothoracic surgery patients

Postoperative ICU monitoring of cardiothoracic surgery patients is a crucial phase in ensuring optimal recovery and identifying potential complications [33]. The integration of artificial intelligence (AI) into postoperative monitoring has introduced transformative capabilities that enhance the accuracy, efficiency, and proactive nature of assessing vital signs and ventilation parameters [34]. AI's role in this context encompasses real-time analysis, early detection of issues, and predictive insights, revolutionizing the way healthcare professionals manage patient recovery [35].

AI-powered postoperative monitoring systems offer continuous analysis of vital signs, including heart rate, blood pressure, oxygen saturation, and respiratory rate. By processing and interpreting this data in real time, AI algorithms can detect deviations from baseline values and alert healthcare providers to potential concerns. This real-time analysis enables timely intervention, ensuring that any emerging complications are addressed promptly, thus improving patient outcomes [36].

In terms of ventilation, AI algorithms can process data from ICU mechanical ventilators to assess parameters like tidal volume, respiratory rate, and positive end-expiratory pressure. These algorithms can detect variations in ventilation patterns and alert healthcare providers to changes that may indicate respiratory distress or inadequate ventilation. This capability aids in preventing postoperative respiratory complications and optimizing patient recovery [37].

Furthermore, AI's predictive modelling capabilities allow for early detection of deteriorating conditions [38]. By analyzing a combination of patient-specific factors, historical data, and real-time monitoring information, AI can forecast potential complications such as respiratory distress, cardiac instability, or sepsis. This predictive insight enables clinicians to take pre-emptive actions, ensuring that appropriate interventions are implemented before complications escalate [39].

Successful integration of AI into postoperative monitoring requires a comprehensive understanding of patient needs, validation of algorithms against real-world outcomes, and continuous algorithm refinement. AI systems should seamlessly integrate with existing monitoring equipment and electronic health record systems to ensure a smooth workflow and efficient data management [40].

AI can optimize the management of Cardiopulmonary Bypass (CPB) by continuously monitoring various physiological parameters. It can provide real-time alerts for potential issues, allowing for timely intervention and ensuring smoother perfusion during surgery. Novel algorithms have been devised to determine the most effective approach for evaluating metabolic parameters. While diverse management algorithms for extracorporeal procedures linked with metabolic monitoring systems are currently available in the market and put into practical use [41].

AI as a decision maker in complex shocks

AI-powered clinical decision support systems can analyse a multitude of parameters to assist in diagnosing and managing complex shock cases. They can offer treatment recommendations based on established protocols and the latest clinical evidence. Artificial intelligence holds significant promise in advancing the practice of heart failure management [42].

Other uses of AI in revolutionizing various aspects of cardiac anaesthesia

Utility in data acquiring and selective sharing and protection:

AI-powered algorithms can efficiently collect and analyse patient data, enabling healthcare providers to make more informed decisions. Advanced encryption techniques and access controls can be implemented to ensure selective sharing and protection of sensitive medical information. The adoption of AI in anaesthesia brings forth a set of associated risks and hurdles. These encompass concerns regarding patient confidentiality and safeguarding of information, the identification of reliable data origins, ethical considerations, scarcity of resources and expertise, and the enigma surrounding the inner workings of AI algorithms, often referred to as the "black box" phenomenon [43].

Voice recognition and auto recording for electronic records:

AI-driven voice recognition systems can accurately transcribe spoken words into text, facilitating seamless documentation of patient interactions and procedures. Auto recording features can capture verbal instructions and discussions, providing a comprehensive electronic record for future reference [44].

Management of operating rooms (ORs) for workflow optimization:

AI can analyse historical data to predict surgery durations, allowing for better scheduling and resource allocation in ORs. Smart OR systems equipped with AI can dynamically adjust lighting, temperature, and equipment settings based on surgical requirements.

Research and academics in cardiac anaesthesia:

AI can assist in analysing large datasets from clinical trials, identifying patterns and correlations that might not be apparent through manual analysis. Simulation modules powered by AI can provide realistic training scenarios for cardiac anaesthesia procedures, allowing practitioners to refine their skills in a risk-free environment. AI can help in creating patient-specific simulations based on medical imaging, enabling practitioners to practice complex interventions virtually. Natural Language Processing (NLP) algorithms can extract valuable insights from medical literature, aiding researchers in staying up-to-date with the latest advancements in cardiac anaesthesia.

Incorporating AI into cardiac anaesthesia not only enhances the quality of patient care but also empowers healthcare professionals with powerful tools for research and education. However, it's crucial to ensure that these technologies are implemented in a manner that prioritizes patient privacy and safety. Additionally, ongoing training and education for healthcare providers are essential to maximize the benefits of AI in this specialized field.

Challenges and implications of AI integration in clinical practice:

In the era of digital advancements in cardiothoracic anaesthesia, the integration of AI holds great promise. However, it is crucial to acknowledge the challenges and potential implications associated with this transformative technology.

Problems with AI Utilization:

One significant consideration in the application of AI in clinical practice is the potential for technological limitations and shortcomings. These may include issues related to data quality, algorithm accuracy, and the need for continuous monitoring and calibration.

Ethical and Legal Considerations:

The utilization of AI in healthcare raises important ethical and legal questions. This encompasses concerns about patient privacy, consent, and the responsibility of healthcare professionals in the decision-making process.

Transparency and Interpretability:

Ensuring transparency and interpretability of AI algorithms is paramount. Clinicians must be able to understand and trust the decisions made by AI systems, and this requires clear documentation of the algorithms' functioning.

Implementation Challenges:

Integrating AI into existing clinical workflows and infrastructure can be a complex task. This includes considerations regarding compatibility with current systems, staff training, and workflow redesign.

Patient Safety and Well-being:

Above all, the primary focus should be on maintaining and enhancing patient safety. While AI has the potential to improve outcomes, it is essential to rigorously assess its impact on patient care and ensure it does not compromise safety.

In the rapidly evolving landscape of cardiothoracic anaesthesia, leveraging the capabilities of AI is paramount to optimizing patient care and outcomes. Here are key strategies to achieve targets in this dynamic field:

Comprehensive data integration:

Integrate diverse sources of patient data, including preoperative assessments, imaging, and real-time monitoring, to provide a holistic view of the patient's condition.

Predictive modelling:

Develop AI algorithms capable of forecasting patient-specific responses to anaesthesia agents and anticipating physiological changes during surgery. This proactive approach enhances precision and patient safety.

Real-time monitoring and feedback:

Implement AI-driven monitoring systems that continuously analyse patient data, providing real-time feedback to anaesthesiologists. This empowers timely intervention and adjustment of anaesthesia protocols.

Personalized anaesthesia plans:

Utilize AI to generate tailored anaesthesia plans based on individual patient profiles, incorporating factors like comorbidities, medication history, and surgical complexity.

Enhanced surgical workflow:

Integrate AI to streamline surgical processes, ensuring seamless coordination between the anaesthesia team and surgical staff, thereby optimizing efficiency and reducing surgical duration.

Adaptive anaesthesia delivery:

Implement AI-controlled anaesthesia delivery systems capable of dynamically adjusting drug dosages in response to real-time patient data, maintaining optimal anaesthesia depth.

Risk assessment and mitigation:

Employ AI-driven risk assessment tools to identify and address potential complications or adverse events, enabling proactive mitigation strategies.

Continuous learning and improvement:

Foster a culture of continuous learning and refinement by leveraging AI-powered analytics to review outcomes, identify areas for improvement, and adjust protocols accordingly.

Ethical considerations and transparency:

Prioritize ethical use of patient data and ensure transparency in AI algorithms to uphold patient confidentiality and trust.

Interdisciplinary collaboration:

Facilitate collaboration between anaesthesiologists, surgeons, and AI experts to harness collective expertise and ensure seamless integration of AI into clinical practice.

CONCLUSION

In the era of digital healthcare, the integration of artificial intelligence (AI) into cardiothoracic anaesthesia offers transformative possibilities. AI's predictive insights enhance pre-anaesthesia evaluation, while real-time monitoring optimizes anaesthesia administration, ensuring patient safety during procedures. Intraoperative vitals monitoring, powered by

AI, enables early detection of deviations and proactive intervention. Postoperatively, AI-driven monitoring maintains vigilance, predicting patient needs for timely care. Challenges of ethics, data privacy, and validation accompany this evolution. In embracing this symbiosis of AI and medical expertise, the future of cardiothoracic anaesthesia holds the potential for precision, innovation, and improved patient outcomes.

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