ARTIFICIAL INTELLIGENCE IN HEALTHCARE, BIOMED AND PHARMA

(ARTIFICIAL INTELLIGENCE IN CARDIOTHORACIC SURGERY)

 Saurabh Agarwal, PGDM in Finance,

 Universal Business School, Karjat, Raigad,

 saurabh.agarwal@ubs.org.in

 Neha Mishra, PGDM in Marketing,

 Universal Business School, Karjat, Raigad,

 neha.mishra@ubs.org.in

 Nandini Gawshinde, PGDM in Finance,

 Universal Business School, Karjat, Raigad,

 nandini.gawshinde@ubs.org.in

 Babu Shourya , PGDM in Finance,

 Universal Business School, Karjat, Raigad,

 babu.shourya@ubs.org.in

**ABSTRACT**

AI has improved patient care and clinical outcomes in healthcare, biomedical, and pharmaceutical industries by analyzing data to identify patterns and anomalies. It has transformed biomedical industry by discovering new drugs and treatments, but data privacy and regulatory frameworks must be addressed for AI to fully revolutionize healthcare. AI is crucial in surgical decision-making, addressing various sources of information for better predictions and integration of human-machine collaboration for improved performance and patient safety in high-tech operating rooms.

The objective of this research paper is to investigate the present condition of AI in Surgery, particularly in Cardiothoracic surgery. It also aims to analyze the possible effects of AI on the medical industry, which is experiencing a high degree of technological advancement due to the increased utilization of artificial intelligence (AI) in numerous sectors.

**1) INTRODUCTION**

Artificial Intelligence (AI) is a group of technologies that can range from those that try to mimic human reasoning to those that rely solely on large datasets to generate solutions. In surgical decision-making, AI is increasingly critical to address various sources of information such as patient risk factors, anatomy, disease progression, patient values, and cost, and help surgeons and patients predict the consequences of surgical decisions accurately. Machine learning (ML) techniques have been used to evaluate physician competence in a range of settings, and the integration of new technologies and the collection of vast amounts of patient surgical care data in the operating room (OR) has given rise to Surgical Data Science (SDS). The primary objective of SDS is to improve the quality and value of interventional healthcare by organizing, capturing, processing, and modeling data that arises from various sources such as patients,

operators, sensors, and domain knowledge. The complexity of the operating room has enabled the augmentation of human cognition at both individual and team levels through the incorporation of non-human systems. The cardiothoracic OR requires coordination of multiple specialized professionals and equipment, making it a high-risk, high-stakes environment. AI systems can collect, process, and make sense of information gathered in the OR. They should understand and adapt their algorithms based on real-time contextual information and provide context-aware assistance. Predictive accuracy is vital to support and guide team cognitive tasks. To monitor cognitive states at both individual and team levels, physiological metrics such as heart rate variability (HRV), electroencephalography (EEG), and near-infrared spectroscopy (NIRS) are commonly used since they allow real-time objective measures of cognitive load. One of the most significant applications of AI in surgery is the assessment of intraoperative performance at both individual and team levels. Current gold standard assessments of intraoperative technical and non-technical skills are subjective and rely on observation and rating by experts, resulting in suboptimal inter-rater reliability and limited reproducibility and scalability. The use of AI, particularly computer vision, provides a promising opportunity to automate, standardize, and scale performance assessment in surgery, including cardiothoracic surgery. Previous studies have established the reliability of video-based surgical motion analyses for assessing laparoscopic performance, including technical skills such as suturing, knot tying, fluidity of motion, tissue handling, and motion economy, as compared to traditional, time-intensive human rater approaches.

In addition to planning and decision-making, AI can also be applied to change surgical techniques. Remote-controlled robotic surgery has been shown to improve the safety of interventions where clinicians are exposed to high doses of ionizing radiation and make surgery possible in anatomical locations not otherwise accessible by human hands. As autonomous robotic surgery improves, surgeons will probably supervise the movements of robots in some situations. Overall, AI has immense potential to enhance the quality and safety of surgical care. However, the integration of AI into the surgical workflow must be done with care, as the surgical field is complex and requires a deep understanding of human physiology and the surgeon's decision-making process. As such, a multidisciplinary approach is necessary to effectively integrate AI into surgical practice. With careful implementation and continued innovation, AI has the potential to revolutionize surgical care and significantly improve patient outcomes.

**2) LITERATURE REVIEW**

(Kilic, 2020) this research provides an overview of artificial intelligence (AI) and machine learning (ML) as they relate to cardiovascular health care. The author explains the terminology and algorithms used in ML and reviews articles published up to August 1, 2019, in the field of AI and ML in cardiovascular medicine. Results show that ML has been applied in the settings of automated imaging interpretation, natural language processing, and data extraction from electronic health records, as well as predictive analytics. The potential role of these approaches in clinical practice is promising, particularly in providing automated imaging interpretation, data extraction, and clinical risk prediction, but requires further refinement and evaluation.

(Jian Zhao, 2018) this study aimed to evaluate the safety and feasibility of robotic gastrotomy with intracorporeal suture for patients with gastrointestinal stromal tumors (GISTs) located at the cardia and sub cardiac region. 11 patients underwent the procedure from January 2014 to August 2016. The mean operative time was 82.7 minutes, and the mean blood loss was 30.0 ml. No complications were reported, and all patients survived with no recurrence or metastasis after a 25.5 month follow-up. The study concludes that robotic gastrotomy with intracorporeal suture is safe and feasible for these types of GISTs

(Hao Shen, 2018) this study aimed to investigate the relationship between technical and non-technical performance in the operating theatre, using laparoscopic Roux-en-Y gastric bypass procedures captured by the Operating Room Black Box® platform. Technical and non-technical assessments were performed using various instruments, and the correlation between the two types of performance was analyzed using Spearman rank-order correlation and N-gram statistics. The results showed a moderate to strong correlation between technical adverse events and rectifications and non-technical performance of the surgical and nursing teams. The study also found that positive non-technical behaviors were exhibited by both the staff surgeon and the scrub nurse after technical errors, events, and rectifications, regardless of the operator.

(Newmarker, 2018) this article focuses on the information that Digital Surgery in London has developed a real-time AI system designed for use in operating rooms that includes surgical procedure roadmaps to make surgery safer and reduce risk. The patented AI platform has already developed algorithms for multiple procedures across surgical specialties like orthopedics and bariatrics. Surgeons have lauded the potential of Digital Surgery, with Dr. Sanjay Purkayastha of Imperial College Healthcare NHS Trust comparing the technology to the advent of laparoscopy. The goal of Digital Surgery is to harness data to improve outcomes, boost access and training, and reduce costs and waste in the healthcare marketplace.

(Jerome Allyn, 2017) this article fives a Comparison of a Machine Learning Model with Euro SCORE II in Predicting Mortality after Elective Cardiac Surgery: A Decision Curve Analysis. - A preliminary unblinded randomized clinical trial conducted in a tertiary center in Amsterdam, the Netherlands, among adult patients undergoing elective noncardiac surgery under general anesthesia and continuous invasive blood pressure monitoring found that the use of a machine learning-derived early warning system in combination with a hemodynamic diagnostic guidance and treatment protocol resulted in less intraoperative hypotension compared to standard care. Among 68 randomized patients, 60 (88%) completed the trial, with a median time-weighted average of hypotension of 0.10 mm Hg in the intervention group versus 0.44 mm Hg in the control group, for a median difference of 0.38 mm Hg. Further research with larger study populations in diverse settings is needed to understand the effect on additional patient outcomes and to fully assess safety and generalizability.

(Geoffrey Rance, 2019) discussed the goal of AI is to create a redundant protection machine of verbal and digital communique to save patients, failure to ventilate mistakes after cardiopulmonary bypass. A software program utility turned into retrieve and interpreted information from the pump and ventilator and cause a programmed clever alarm. The software program is capable of interpret information from the pump and ventilator.

(Germain Forestier, 2012) explained the SPMs constitute Surgical Processes (SPs) which can be formalized as symbolic dependent descriptions of surgical interventions the usage of a pre-described degree of granularity and a devoted terminology. In this context, one foremost undertaking is the introduction of latest metrics for the contrast and the assessment of SPs. Thus, correlations among those metrics and pre-operative facts are used to categorize surgical procedures and spotlight precise data at the surgical operation itself and at the surgeon, consisting of his/her degree of expertise.

(Yohannes Kassahun, 2016) this paper advances in era and computing play a more and more essential position withinside the evolution of contemporary-day surgical strategies and paradigms. This article opinions the cutting-edge position of system learning (ML) strategies withinside the context of surgical operation with a focal point on surgical robotics (SR).

(Jian Chen, 2019) they reviewed the present-day status; the present-day demanding situations and the destiny wishes of robotic reviews with a focal point on urological applications. Concerns stay concerning green and powerful surgeon training and credentialing. Concluding as there is no universally familiar robot capabilities evaluation presently exists. The reason of evaluation (schooling or credentialing) can also additionally dictate whether manual or computerized general practitioner evaluation is extra suitable.

(Roger D Dias, 2019) as examined by them the dynamics of crew sports may also offer applicable data for expertise the multitude of things that effect surgical overall performance and affected person protection outcomes. Previous studies have proven that positive styles extracted from crew contributor’s role and movement records are expecting crew coordination and cohesion. In this pilot study, we describe a singular integrative technique that captures goal measures of crew cognitive load (coronary heart charge variability), in addition to role and movement metrics from a couple of crew contributors generated via way of means of a pc imaginative and prescient system. Our purpose changed into to research the feasibility of the usage of this novel technique to combine and visualize crew dynamics and cognitive load metrics amassed from the OR crew at some stage in a real-existence cardiac surgery.

(Scott M Lundberg, 2018) In this Research the improvement and checking out of a machine-learning-primarily based totally gadget that, in actual time at some stage in widespread anesthesia, predicts the threat of hypoxemia and offers factors of the threat factors. The gadget can assist enhance the medical knowledge of hypoxemia threat at some stage in anesthesia care through supplying widespread insights into the precise adjustments in threat prompted through positive affected person or process characteristics.

(David P Azari, 2019) As per the Research conducted Computer imaginative and prescient changed into used to are expecting professional overall performance rankings from general practitioner hand motions for tying and suturing tasks. A professional panel of 3 attending surgeons rated tying and suturing videos on non-stop scales from zero to ten alongside 3 assignment measures tailored from the wider OSATS: movement economy, fluidity of movement, and tissue handling. The laptop set of rules continuously anticipated the panel rankings of man or woman tasks and have been extra goal and dependable than man or woman evaluation via way of means of surgical experts.

(Joyce A Wahr, 2013) According to this Research each mortality and morbidity for coronary artery pass surgical operation have reduced all through the beyond decade (Figure 1).1 Nonetheless, the incredibly professional and committed employees in cardiac ORs are human and could make errors. Of the kind of 350 000 to 500 000 sufferers who go through cardiac surgical operation every year, 28 000 can have an negative event, and one 0.33 of deaths related to coronary artery pass graft (CABG) operations can be preventable.

(Tom Vercauteren, 2019) It was examined in this Research that Taking inventory of a number of the maximum thrilling trends in system getting to know and synthetic intelligence for computer-assisted interventions, we spotlight the essential want to take the context and human elements under consideration for you to cope with those challenges. Contextual synthetic intelligence for computer-assisted intervention (CAI4CAI) arises as an rising possibility feeding into the wider discipline of surgical statistics science.

(Hannes G Kenngott, 2017) According to this research in order to triumph over this challenge, pc scientists and surgeons in the interdisciplinary subject of “cognitive surgery” discover and innovate new approaches of statistics processing and management. It explores the opportunities of latest wise gadgets and software program throughout the complete remedy method of sufferers finishing withinside the attention of an “Intelligent Hospital” or “Hospital 4.0”, wherein the borders among IT infrastructures, clinical gadgets, clinical employees and sufferers are bridged with the aid of using technology.

**3) OBJECTIVES**

1) To compare the cutting-edge country of synthetic intelligence (AI) in cardiothoracic surgery, consisting of its cap potential advantages and limitations, and to discover gaps in know-how and regions for in addition research.

2)To check out the accuracy and reliability of AI-primarily based totally diagnostic and remedy gear in cardiothoracic surgery, consisting of their capacity to expect outcomes, enhance affected person safety, and decorate surgical precision.

**4) RESEARCH METHODOLOGY**

The data for the study was obtained from secondary sources such as journals, articles, research papers and internet portals. The available sources provided a rich pool of material related to the investigation of Surgery, regardless of the specific field of exploration. The study focused specifically on the impact of AI on Cardiothoracic surgery and only referred to sources related to this area, with around 15 research papers being arranged according to the paper's structure. The researcher conducted theoretical research on the impact of AI on Cardiothoracic surgery.

**5) ARTIFICIAL INTELLIGENCE IN SURGERY**

The term artificial intelligence (AI) can refer to a range of meanings, from specific types of AI like machine learning to the more far-fetched notion of AI possessing consciousness and sentience. AI systems can range from those that try to mimic human reasoning to solve problems, to those that only rely on large datasets to generate solutions, to those that attempt to incorporate human reasoning without modeling human processes accurately. Machine learning (ML) is a group of statistical and mathematical modeling techniques that can automatically learn and improve the prediction of a target state without explicit programming, using various approaches such as Bayesian networks, random forests, deep learning, and artificial neural networks, each with different assumptions and mathematical frameworks for data input, and learning occurs within the algorithm. In surgical decision-making, AI is increasingly crucial to address various sources of information like patient risk factors, anatomy, disease progression, patient values, and cost, and help surgeons and patients predict the consequences of surgical decisions accurately. For example, a deep learning model was used to determine which individuals with treatment-resistant epilepsy would benefit most from surgery. AI platforms can provide a roadmap to assist the surgical team in the operating room, reduce risk, and enhance surgical safety. In cardiothoracic surgery, previous studies have developed machine learning algorithms that can surpass standard operative risk scores in predicting intrahospital mortality after cardiac procedures. In addition to planning and decision-making, AI can also be applied to change surgical techniques. Remote-controlled robotic surgery has been shown to improve the safety of interventions where clinicians are exposed to high doses of ionizing radiation and make surgery possible in anatomical locations not otherwise accessible by human hands. As autonomous robotic surgery improves, surgeons will probably supervise the movements of robots in some situations. Artificial intelligence (AI) is revolutionizing the field of surgery, offering advanced tools and solutions to assist surgeons in performing complex procedures. From pre-operative planning to intra-operative guidance and post-operative care, AI is transforming the way surgical care is delivered. In recent times, there have been several applications of AI in surgery that have shown promising results. One of the most significant applications of AI in surgery is in the area of pre-operative planning. Using AI-based algorithms and machine learning models, surgeons can now accurately predict the outcome of a surgery, helping them to plan and prepare better. For example, AI can be used to analyze medical imaging data and identify potential complications before surgery, allowing surgeons to adjust their plans accordingly. This can lead to better outcomes and reduced post-operative complications. Another important application of AI in surgery is in the area of intra-operative guidance. With the help of AI-based systems, surgeons can now perform complex surgeries with greater precision and accuracy. For instance, AI can be used to analyze real-time data from sensors and cameras in the operating room, providing surgeons with detailed information about the patient's anatomy and the surgical site. This can help them to make more informed decisions and reduce the risk of complications. AI is also being used to develop new surgical tools and technologies. For example, researchers are working on developing AI-powered robotic systems that can perform minimally invasive surgeries with greater precision and control. These systems use advanced algorithms and machine learning models to analyze data from sensors and cameras, allowing them to adjust their movements and actions based on the surgical site and patient's anatomy. In addition to these applications, AI is also being used in post-operative care. By analyzing data from electronic health records and medical devices, AI can help clinicians to identify potential complications and intervene early to prevent them. This can improve patient outcomes and reduce the length of hospital stays. Despite these promising applications, there are also challenges associated with the use of AI in surgery. One of the biggest challenges is ensuring that the algorithms and models used are accurate and reliable. This requires extensive testing and validation, as well as ongoing monitoring and maintenance. There are also concerns about the ethical and legal implications of using AI in surgery, such as liability for errors and patient privacy. In conclusion, AI is transforming the field of surgery, offering advanced tools and solutions to assist surgeons in performing complex procedures. From pre-operative planning to intra-operative guidance and post-operative care, AI is changing the way surgical care is delivered, improving outcomes, and reducing complications. However, there are also challenges associated with the use of AI in surgery, and ongoing research and development will be required to overcome these challenges and ensure that AI is used safely and effectively in the operating room.

**A) SURGICAL DATA SCIENCE**

Surgical data science (SDS) was created with the integration of new technologies and the collection of vast amounts of patient surgical care data in the operating room (OR). The primary objective of SDS is to improve the quality and value of interventional healthcare by organizing, capturing, processing, and modeling data that arises from various sources such as patients, operators, sensors, and domain knowledge. AI and ML applications have been developed based on SDS to support surgical decision-making and enhance patient safety. Unlike conventional data modeling methods that mostly use regression techniques, SDS employs machine learning techniques to discover data relationships without much input from human modelers. Machine learning techniques have been used to evaluate physician competence in a range of setting. One example of how SDS can be used for quality improvement is through the OR black box system, which captures and integrates intraoperative data (e.g., audio, video, physiological parameters) for human- and AI-based metrics. Studies have used this platform to investigate technical and non-technical surgical performance and their relationship with patient outcomes. In recent years, machine learning algorithms have demonstrated the feasibility and validity of early prediction of intraoperative complications, such as hypotension and hypoxemia in noncardiac and cardiothoracic surgery. Another data-driven application of AI in surgery is the assessment of intraoperative performance at both individual and team levels. Current gold standard assessments of intraoperative technical and non-technical skills are subjective and rely on observation and rating by experts, resulting in suboptimal inter-rater reliability and limited reproducibility and scalability. The use of AI, particularly computer vision, provides a promising opportunity to automate, standardize, and scale performance assessment in surgery, including cardiothoracic surgery. Previous studies have established the reliability of video-based surgical motion analyses for assessing laparoscopic performance, including technical skills such as suturing, knot tying, fluidity of motion, tissue handling, and motion economy, as compared to traditional, time-intensive human rater approaches. Surgical data science is the application of data science techniques to surgical data, with the aim of improving surgical outcomes and patient care. In recent times, there has been an increasing interest in the applications of surgical data science in cardiothoracic surgery. Cardiothoracic surgery is a complex and high-risk specialty that involves the surgical treatment of diseases and disorders of the heart, lungs, esophagus, and other organs in the chest. One of the key applications of surgical data science in cardiothoracic surgery is in the area of predictive modeling. With the help of machine learning algorithms and predictive modeling techniques, surgeons can now predict the likelihood of complications and adverse events before surgery. This can help them to develop personalized treatment plans and adjust their surgical approach, accordingly, leading to improved outcomes and reduced risks. Another important application of surgical data science in cardiothoracic surgery is in the area of real-time decision-making. With the help of advanced analytics and real-time data monitoring systems, surgeons can now make more informed decisions during surgery, based on real-time data about the patient's physiology and anatomy. For example, surgeons can use data from intraoperative sensors to adjust their surgical approach, such as modifying the position of the patient or adjusting the angle of the surgical instruments. Surgical data science is also being used to develop new surgical techniques and technologies. For example, researchers are working on developing new imaging technologies that can provide more detailed and accurate information about the patient's anatomy, allowing surgeons to plan and perform surgeries with greater precision and accuracy. This can lead to improved outcomes and reduced risks. In addition to these applications, surgical data science is also being used to improve post-operative care. By analyzing data from electronic health records and other sources, surgeons can identify potential complications and intervene early.

**B) AUGMENTED COGNITION IN OPERATING ROOM**

In recent years, humans have made significant and rapid technological advancements that have greatly influenced how surgical procedures are carried out in the operating room (OR). The contemporary OR is now a high-tech environment that incorporates novel computational systems into the clinical workflow, with the aim of improving processes and providing support to the surgical team. This complex computational-based environment generates vast amounts of data that can be used for developing predictive machine learning models. Additionally, it enables the augmentation of human cognition at both individual and team levels, extending cognition beyond the minds of individual team members to include non-human systems involved in the surgery.

Cardiothoracic surgery is a prime example of how artificial intelligence (AI) can be used to support surgical care through cognitive augmentation. The cardiothoracic OR is a high-risk environment where multiple specialized professionals interact with each other, coordinate tasks as a team, and use various equipment, technological devices, and interfaces to provide care for complex patients in need of surgical treatment. This team operates as a complex socio-technical system that performs tasks in a coordinated way, requiring cognitive abilities that go beyond the performance of individual team members. Since each team member does not have control over the team's performance as a whole, cognitive activities are emergent processes of teamwork rather than individual tasks.

Although existing AI systems can collect, process, and make sense of data gathered in the OR, an important requirement for these systems is the ability to understand and adapt their algorithms based on real-time contextual information. This enables them to provide context-aware assistance to the surgical team. Predictive accuracy is also crucial to support and guide team cognitive tasks, and an AI system should anticipate future states by using past and current information from the OR's human and non-human systems. Cognitive state monitoring and human activity recognition are also essential features of an AI system for cognitive augmentation in the OR. Physiological metrics such as heart rate variability (HRV), electroencephalography (EEG), and near-infrared spectroscopy (NIRS) are the most commonly used to monitor cognitive states at both individual and team levels, as they provide real-time objective measures of cognitive load. Figure 1 illustrates the cardiac surgeon's cognitive load, indexed by HRV (LF/HF ratio) during different steps of a cardiac procedure. Artificial Intelligence (AI) is being increasingly used in the field of medicine and healthcare to improve patient outcomes and enhance clinical decision-making. One area where AI is being used is in the augmentation of cognition in the operating room. Here are some applications of AI in augmentation cognition in the operating room in current times: Image Recognition: AI algorithms can be used to analyze medical images, such as X-rays and MRI scans, and provide real-time feedback to surgeons during surgery. This can help to identify potential complications and improve surgical outcomes. Surgical Navigation: AI technology can be used to create 3D models of a patient's anatomy and assist surgeons in navigating complex surgical procedures. This can help to reduce the risk of complications and improve patient outcomes. Predictive Analytics: AI algorithms can analyze large amounts of patient data to predict potential complications during surgery. This can help surgeons to make more informed decisions and reduce the risk of adverse outcomes. Virtual Reality: AI-powered virtual reality systems can be used to create simulated surgical scenarios for training purposes. This can help to improve surgical skills and reduce the risk of complications during real surgeries. Natural Language Processing: AI-powered natural language processing can be used to transcribe and analyze conversations between surgeons and other medical staff during surgery. This can help to improve communication and reduce the risk of errors. Overall, AI has the potential to revolutionize the field of surgery and improve patient outcomes by enhancing the cognitive abilities of surgeons in the operating room.



Source: *‘’Julie A.Shah’s research while affiliated with Massachusetts Institute of Technology and other places’’*

[Figure 1.—](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7959017/figure/F1/)

Surgeon’s cognitive load as measured by the HRV parameter: low frequency (LF)/high frequency (HF) ratio captured by a wearable physiological sensor

**C) COMPUTER VISION IN SURGERY**

Computer vision, an AI technique that extracts and analyzes data from images and videos, shows great promise in the area of human activity recognition, particularly in surgical task segmentation and monitoring team dynamics. This technology has led to the creation of a new interdisciplinary field called “cognitive surgery” or “cognition-guided surgery”, which aims to enhance cognition in the OR using AI. Computer vision technologies have the ability to achieve human-level performance and even surpass human capabilities in certain fields.

In surgery, computer vision has been applied to surgical workflow segmentation, instrument recognition and detection, and image-guided surgical interventions. However, it is now being used to understand individual and team behaviors in team-based complex procedures, such as cardiothoracic surgery. Other fields, including medicine and psychology, are already utilizing automated body position and movement tracking to investigate non-verbal human behaviors. In surgery, this technology has been used to track the gestures and hand motions of surgeons to extract objective metrics of technical psychomotor skills. Recent studies have explored the use of position and motion data generated by computer vision applications to measure team dynamics and coordination in the OR, including metrics such as team centrality and team proximity. Some potential applications include: Image recognition: AI can be used to recognize and classify images from medical imaging devices such as CT scans and MRIs, assisting in the identification of anatomical structures, such as the heart, lungs, and blood vessels. Image segmentation: AI can segment medical images into individual structures, allowing for more precise identification and analysis. This can be particularly useful in cardiac imaging, where structures like the coronary arteries are difficult to distinguish from surrounding tissue. Object tracking: AI can be used to track the movement of objects in medical imaging, such as the movement of a beating heart during surgery. This can provide real-time feedback to the surgeon and assist in the precise placement of instruments. Virtual and augmented reality: AI can be used to create virtual or augmented reality simulations of surgical procedures, allowing surgeons to practice and refine their techniques in a safe, controlled environment. Decision support: AI can provide decision support to surgeons during procedures, providing real-time feedback on vital signs, blood flow, and other metrics that can impact surgical outcomes. Overall, AI has the potential to significantly improve outcomes in cardiothoracic surgery by providing real-time feedback, enhancing precision and accuracy, and improving decision-making.



Source: *“Minerva Cardioangiol,2020 Oct”*

[Figure 2. —](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7959017/figure/F2/)

Computer vision system extracting human body position and motion in the cardiac operating room.

**D) AUTONOMOUS ROBOTIC SURGERY**

Surgical procedures are on the brink of being revolutionized by robotic technology. Robots are expected to become the norm for many common procedures, such as coronary bypass and abdominal surgery. Autonomous and semi-autonomous modes are being investigated and implemented to automate various phases of surgery. These tasks are becoming more complex, with high-level autonomous features like complex endoscopic surgical maneuvers and shared-control approaches in stabilized image-guided beating-heart surgery. Future progress will require interdisciplinary work, with nanorobots expected to enter the field. The development of machine-learning-empowered instrumentation for robotic-assisted surgery is being intensely investigated. Expert knowledge is typically supplied by experienced surgeons for machine learning surgical skill development. Implicit imitation learning is a type of supervised learning, which aims to accelerate reinforced learning through the observation of an expert mentor. Hidden Markov models, neural networks, and fuzzy nets have been developed for modeling human skill from sets of recorded data. AI is being increasingly used in the field of autonomous robotic surgery to enhance the precision, safety, and efficacy of surgical procedures. Some of the applications of AI in this field include Image analysis: AI can be used to analyze medical images such as X-rays, CT scans, and MRI scans, and assist the surgeon in identifying important structures and landmarks during surgery. Robotic control: AI algorithms can be used to control the movement of surgical robots, enabling them to perform complex maneuvers with high accuracy and precision. Surgical planning: AI can help surgeons to plan and prepare for complex surgical procedures by analyzing patient data and identifying the best approach for the surgery. Real-time feedback: AI algorithms can provide real-time feedback to the surgeon during the surgery, helping them to adjust their technique and optimize outcomes. Predictive analytics: AI can be used to analyze patient data and predict the likelihood of complications during surgery, allowing surgeons to take proactive measures to prevent them. Overall, the integration of AI into autonomous robotic surgery is expected to revolutionize the field of surgery, enabling surgeons to perform procedures with greater precision, speed, and safety, and improving patient outcomes.

**E) HUMAN-MACHINE TEAMING IN OPERATING ROOM**

With the increasing presence of computational systems in our workplaces, such as in the cardiothoracic operating room, new forms of interaction, communication, and coordination have emerged. Efficient design and operation of computer-based systems in the OR can have a significant impact on workflow efficiency, cognitive load of clinicians, and ultimately, surgical performance. Integrating AI systems in a complex OR environment creates opportunities for human-machine teaming, which can lead to new cognitive engineering opportunities. These opportunities have the potential to enhance patient safety and improve clinical outcomes in team-based surgeries that are complex in nature. AI has numerous applications in human-machine teaming in the operating room, some of which are: Surgical Assistance: AI can assist surgeons during procedures by analyzing data from medical imaging devices and providing real-time feedback to guide the surgeon's actions. For example, AI algorithms can help identify the location of critical structures like blood vessels, nerves, and organs, and provide guidance on the safest and most efficient way to access them. Predictive Analytics: AI can also help predict patient outcomes based on various data inputs, such as medical history, vital signs, and surgical procedures. This information can be used by surgical teams to develop personalized treatment plans and optimize patient outcomes. Virtual Reality Training: AI can also be used to develop virtual reality simulations that allow surgeons and surgical teams to practice procedures in a safe and controlled environment. This can help reduce the risk of errors during actual procedures and improve overall patient outcomes. Robotic Surgery: AI-powered robots can be used in the operating room to perform minimally invasive surgeries with greater precision and accuracy than human surgeons. These robots can be programmed to perform specific procedures with minimal human intervention, which can reduce the risk of human error and improve patient outcomes.

**6) CONCLUSION**

In recent years, research has been focused on creating intelligent machine teammates by utilizing innovative computational algorithms and human cognitive models for AI. These efforts have resulted in new forms of human-machine collaboration across various industries, such as healthcare, transportation, manufacturing assembly lines, and defense.In the field of cardiac surgery, researchers have developed new systems that aim to integrate the physiological data of clinicians, which serves as a measure of their cognitive performance, with patient data and medical devices in the OR. Some studies have also explored the use of data-driven approaches that involve both human and non-human agents to optimize surgical coordination and team communication, with the goal of enhancing safety and reducing errors in cardiothoracic surgeries. Overall, AI has the potential to revolutionize the way surgeries are performed and improve patient outcomes in the operating room. By leveraging the power of machine learning algorithms, surgical teams can work more efficiently, safely, and effectively to deliver the best possible care to their patients

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