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Artificial intelligence: A new tool in surgeon's hand

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Abstract:

Artificial intelligence (AI) is the future of surgery. Technological advancements are taking place at an incredible pace, largely due to AI or AI-backed systems. It is likely that there will be a massive explosion or “Cambrian explosion” of AI in our everyday life, largely aided by increased funding and resources spent on research and development. AI has also significantly revolutionized the medical field. The concept of machine learning and deep learning in AI is the crux of its success. In surgical practice, AI has numerous applications in the diagnosis of disease, preoperative planning, intraoperative assistance, surgical training and assessment, and robotics. The potential automation of surgery is also a possibility in the next few decades. However, at present, augmentation rather than automation should be the priority. In spite of the allure of AI, it comes with its own price. A robot lacks the “sixth sense” or intuition that is crucial in the practice of surgery and medicine. Empathy and human touch are also inimitable characteristics that cannot be replaced by an AI system. Other limitations include the financial burden and the feasibility of using such technology on a wide scale. Ethical and legal dilemmas such as those involving privacy laws are other issues that should be taken under consideration. Despite all these limitations, with the way technology is progressing, it is inevitable that AI and automation will completely change the way we practice surgery in the near future. Thus, this narrative review article aims to highlight the various applications and pitfalls of AI in the field of surgery.

Keywords:

Artificial intelligence, automation, deep learning, machine learning, robotics, surgery, surgical procedures

Introduction

Technological advancements are taking place at an incredible pace. It is hard to comprehend the advancements that have already taken place and the ones that will take place in the next 20 years or so – in the words of Kurzweil, it is human nature to perceive change as linear and not exponential and hence our assessment of how much progress has actually taken place is grossly underestimated.^[1] These technological advancements are largely due to artificial intelligence (AI) or AI-backed systems. AI can be defined as the study of algorithms that give machines the ability

to reason and perform cognitive functions such as problem-solving, object and word recognition, and decision-making.^[2] It is likely that there will be a massive explosion or “Cambrian explosion,” which is a period of rapid machine diversification, of AI in our everyday life, largely aided by the increased funding and resources spent on research and development in recent years. In fact, the line between science fiction and reality has already thinned out. AI has entered our routine life in the form of virtual assistant devices such as Alexa and Google Assistant – these self-learning devices perform everything from playing music to ordering taxis and controlling all your home or office devices. The concept of machine learning (ML) and deep learning

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in AI is the crux of its success. ML is a subset of AI that uses computational algorithms that use large sets of data inputs and outputs to recognize patterns and effectively “learn,” thereby enabling the machine to make autonomous recommendations or statements.^[3] Deep learning is a new form of AI which utilizes “deep neural networks” [Figure 1]. These models use hierarchical tiers to segregate and manage the final output. Each network has an input tier that progresses to a number of hidden tiers that each responds to different features of the input, thus allowing for deeper understanding of the data. The existing algorithm successfully refines itself as new data are available and are able to make multiple connections similar to neuronal connections from dendritic connections in the brain.^[4]

In recent years, AI has revolutionized the medical field – this was facilitated by increased availability of medical data by way of research and experimentation which AI can develop algorithms from. In the medical field, radiology, pathology, and dermatology have seen the most significant development, resulting in the highest surge in Food and Drug Administration (FDA)-approved AI systems in these fields.^[5] Some of the factors resulting in earlier development and acceptance of AI in these fields include easier input of data and interpretation – digital input of radiographs/images, pathology slides, and clinical dermatology images can be easily put into ML algorithms; radiographic and pathological interpretation additionally does not require real-time interpretation. Similar to facial recognition algorithms, interpretation depends on complex image analysis and ML to differentiate patterns and provide diagnosis. This is in stark contrast to surgical specialties where AI is still being incorporated. Unlike diagnostic specialties, surgical specialties require more complex algorithms which involve real-time decision-making. An apt analogy would be similar to comparing the AI of a facial recognition software to the AI of a self-driving car. The self-driving car has to plan for the trip, make real-time decisions based on data from sensors, and

then analyze performance to improve future trips; it is more of a dynamic process as compared to a facial recognition software which uses image analysis and comes to a fixed conclusion. Similarly, the use of AI in surgery requires more dynamic algorithms and is still a developing field. However, just as autonomous cars now fully function in some parts of the world, AI-driven or AI-backed surgical procedures and technology could be the new reality sooner than we expected. Thus, the authors conducted a narrative review by a thorough literature search concerning AI in surgical practice and elaborated the benefits and limitations.

Role of Artificial Intelligence in Surgery

Diagnostic utility

AI has made a significant impact in the diagnosis and subsequent management of disease. In fact, AI has boundless potential in its diagnostic utility. Multiple scoring systems can be seamlessly calculated by AI; prognostic indicators could guide management decisions; radiological data could be evaluated, especially for anatomical anomalies. There are no limits for its applications. Timely diagnosis of a disease is vital in many situations. For instance, in cases of sepsis, time is of the essence. In one study, the mortality rate from septic shock increased by 7.6% with every hour that the treatment was delayed after the onset of hypotension.^[6] Early diagnosis and aggressive management are crucial to prevent progression into shock and multiple organ failure and subsequent mortality. Scoring systems such as targeted real-time early warning score can identify patients approximately 28 h before the clinical onset of septic shock.^[7] AI can be used to calculate these scores in real time, thereby reducing the incidence of sepsis and its related morbidity and mortality. Automation or AI-backed applications can be created in intensive care units to augment the diagnostic capabilities and therapeutic decision-making of the team.

Similarly, AI can be used in the early diagnosis of disease itself; this is most relevant in diseases which are currently diagnosed at irreversible stage or when the damage has already happened, case in point being osteoarthritis. In this disease, there are some subtle patterns on imaging which cannot be detected with the human eye but can be detected with AI – ML can be used to recognize such hidden patterns to predict disease occurrence before it manifests with symptoms or reaches an irreversible stage. Kundu *et al.* used magnetic resonance images of knee cartilage and were able to predict which patients will develop osteoarthritis after 3 years with accuracy of 78% with the help of transport-based learning and statistical pattern recognition.^[8] In cardiac surgery, AI was beneficial in triaging patients with ascending thoracic aortic aneurysms and to differentiate mortality

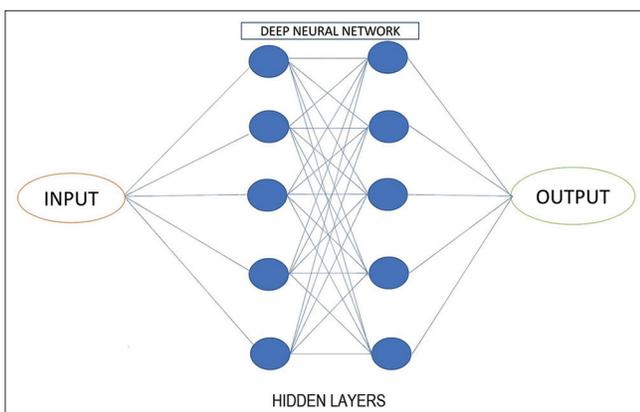


Figure 1: Deep neural network

and other complication risks of congenital heart surgery more accurately than standard risk stratification systems.^[9,10]

Telemedicine

AI-backed telemedicine services are currently being utilized in almost all fields of medicine. In surgery, preoperative workup, postoperative follow-up, long-term follow-up, and provision of expertise to other institutes are some of the major uses of telemedicine. Telerobotics is also an upcoming field although factors such as logistics and funding issues limit its use. Apart from the diagnostic applications mentioned above, AI also has a role in early diagnosis or providing access to care, especially for the geriatric population. The development of smart homes with advances in sensor and telecommunication using AI is an important arena, especially in chronic long-term follow-up patients or the geriatric population. Telemedicine and telehealth are key components of this aspect of AI. This field of AI will continue to grow as the population requiring telemedicine will slowly start to increase as life expectancies steadily increase.^[11] Telemedicine and other AI-backed teleservices have now replaced multiple services, especially in the era of the coronavirus pandemic. To ensure the safety of the patient as well as the health-care staff, many institutes have turned to teleservices. Telemedicine has become a viable option to monitor and ensure timely referral of the coronavirus-infected patients, especially those who are on home isolation. During peaks of the pandemic, health-care institutions get overburdened, thus resulting in interruption of the regular health-care services such as immunization and follow-up care of patients with chronic diseases. In these situations, AI-backed tools and applications can help by providing streamlined information or providing access to health care in the vicinity.^[12] As the pandemic rages on, advances in telemedicine and AI-backed referral systems continue to rise.

Preoperative planning

Surgery involves complex decision-making in terms of requirement of multimodal therapy, type, and timing of surgery. The available medical literature is slowly advancing beyond the capacity of the individual surgeon to maintain up-to-date knowledge, and is continually growing at an accelerated pace. The development of tools such as algorithmic clinical decision support within surgery, with access to large and varied stores of “big data,” along with the use of integration of multiparametric data, allows cross talk between data stores and computer systems that could provide an elegant solution to this issue.^[13] These algorithms only require large data sets of literature without need for real-time inputs and are emerging as a validated tool to enhance the decision-making ability of the surgeon,

especially in oncological practices. IBM Watson, a question-answering computer system, has been shown to match recommendations of expert tumor boards in breast cancer treatment.^[14] This can offer smaller hospitals access to better clinical care recommendations. Current ML systems will be the foundation for AI systems which can potentially provide surgeons with accurate and technical planning almost like a “second opinion,”^[15] thus AI with potentially becomes an important aspect of multidisciplinary teams in decision-making.

Decisions regarding surgical planning can also be aided by AI; three-dimensional (3D) virtual reconstruction has been increasingly used for improved surgical planning. Recently, the IRIS 1.0 System developed by Intuitive Surgical, can produce segmented 3D anatomical models by utilizing computed tomography (CT) imaging, thus providing an individualistic approach to surgical decisions with a better understanding of patients’ anatomy. The Formus platform, a fully automated 3D preoperative planning software based on CT images, can be used to find out optimal implant and positioning for total hip replacement, while still giving the surgeon direct control of the final plan through a web-based 3D interface.

Intraoperative support

AI can provide intraoperative support to surgeons in various forms such as augmenting the information available to the surgeon or recommending the next step in a difficult situation. For instance, during minimal access surgery, there is a loss of tactile feedback, thus decreasing the information available to the surgeon. Scientists have tried to develop AI-backed tools to overcome this limitation of sensory feedback loss. An example, Harangi *et al.* in 2017 developed an artificial neural network (ANN) to distinguish the uterine artery from the ureter during laparoscopic hysterectomy.^[16]

In surgical practice, apart from clinical experience, operative experience is vital and comes only with observing and performing cases over time. Similarly, collective experiential knowledge of multiple surgeons around the world can offer incredible insights if it becomes accessible to an individual surgeon. A surgeon can potentially instantly tap into the collective experience of experts around the world, especially while encountering an unexpected finding during a surgery. Intraoperative warnings or recommendations can be given on real-time surgical videos by automated case retrieval-based AI.^[17] André *et al.* suggested that retrieving cases with existing annotations and corresponding histopathological diagnoses could help surgeons make real-time decisions, such as whether or not to biopsy tissue.^[18] The framework for using collective experience and AI for real-time intraoperative decision

support are being built on the basis of ability to interpret streaming video feeds. Tian S *et al.* in 2015, developed a system named VeBIRD to track and classify cataract grade on videos of phacoemulsification surgeries.^[19] They proposed that the system could eventually be used to control the amount of ultrasonic energy released to emulsify the cataracts, a decision currently made by experienced ophthalmological surgeons. Some literature has also demonstrated potential for AI to provide an intraoperative pathological recommendation using various imaging modalities such as probe-based confocal laser endomicroscopy (pCLE), hyperspectral imaging, optical coherence tomography (OCT), and contrast-enhanced ultrasonography. With development of these imaging techniques, the need for the current method of resection and frozen histopathological examination can be significantly reduced. Li *et al.* used CNN model to interpret pCLE images and video data to distinguish glioblastoma from meningioma.^[20] They were able to achieve up to 99.49% accuracy on test sets. Another such example of using AI to classify OCT images comes from a study of Hou *et al.*; they used an ANN to distinguish metastatic lymph nodes from normal tissues in thyroidectomy patients on images of resected neck tissues taken using OCT; the accuracy of lymphatic metastasis diagnosis was 90.1%.^[21] Thus, there are exciting new possibilities for the use of AI in intraoperative assistance.

Surgical assessment and training

Surgeons are often evaluated on the basis of outcomes such as complication rate, length of hospital stay, estimated blood loss, patient recovery time, and readmission rates. These evaluations are generally done by surveys or video review by research participants. However, these methods are subjective and are prone to bias; an objective evaluation of a surgeon's competence is a difficult task. AI and ML are potential objective tools being used to assess technical skills in surgery. Various ways of assessment that can be used include electromagnetic sensors over instruments, force and torque sensors, and movement trackers. It can also be evaluated with the help of da Vinci recording device. These data can be analyzed using ML algorithms to identify movement patterns which can objectively measure surgical skill and predict outcomes.^[22] Using video recordings of surgeries, AI can be used to calculate the time required to complete a critical part of the procedure, rather than the whole procedure itself. Every step of critical task can be analyzed and compared. Analysis can be done within the first 10 s of the task.^[23] This is accomplished mainly by the use of sensor technology that can track movements. A large volume of research has focused on movement tracking, and data have shown that reducing surgical variation and inefficiencies can result in better outcomes. ML is now being applied to rich data sets from training

to stratify surgical skill and recommend personalized training strategies to improve individual deficiencies. Apart from assessment, AI also has huge implications in training. Augmented reality and virtual reality aid in creation of accurate simulations for surgical trainees without risk for compromising patient care.^[24,25] Thus, surgical training and assessment modalities is a relatively low-risk area for introduction of AI and can form the base for the incorporation of AI in the field of surgery.

Autonomous surgical robots

Robotic surgery is now a well-established field; current robots are based on the master and slave concept where the surgeon has the full control. However, many new systems are being developed with incorporation of AI subsets such as ML and reinforcement learning to perform autonomously. With autonomous robots, surgical performance can be standardized, which can reduce variability between different surgeons and different centers, thus potentially leading to improved outcomes. The concept of autonomous robots is certainly not new – intelligent robots have been in place in surgery since 1980. PUMA 560 was used for conducting neurosurgical biopsies in 1985. ROBODOC, used for hip replacement surgeries, was the first intelligent robot approved by FDA.^[26] Robots can learn by watching videos or live surgeries; the unfortunate truth is that an autonomous robot can learn a procedure much faster than a human being. Initial attempts for surgical automation have focused on task deconstruction and autonomous performance of simple tasks such as suturing. In 2014, Leonard *et al.* showed the ability of an AI-driven robot to perform a superior bowel anastomosis to expert surgeons in porcine tissue as measured by the consistency of suturing informed by the average suture spacing, the pressure at which the anastomosis leaked, the number of mistakes that required removing the needle from the tissue, completion time, and lumen reduction.^[27] A similar approach has been taken by the Aquablation system (Procept Surgical, Redwood City, CA, USA) for the treatment of benign prostatic hypertrophy. The system uses preoperative planning and real-time intraoperative ultrasound to perform an automated prostatic ablation with a precise waterjet technology. Initial trials show equivalent urinary flow with potential benefits to the precision approach in terms of functional outcomes.^[28,29] A robotic surgical device has learned to autonomously navigate inside a beating heart. Pierre Dupont *et al.* have created a robotic catheter widely used in surgeries to deliver devices or drugs. They used 2000 images of the interior of a heart to train an algorithm to control the movement of the catheter. It was then tested in five pigs with leaky heart implants. Out of 83 trials, it was successful in 95% of cases to reach the appropriate location.^[30] Benjamin *et al.* are

developing artificial skin which will have a sense of touch. A demonstration showed that it was able to differentiate between stress balls and plastic as soft and hard structures. This skin when applied to robotic arms, can give robots a new transformation, enabling them to differentiate between healthy tissue and tumor and make decisions accordingly.^[31] Thus, the future of surgery may be entirely transformed in the next decade.

Pitfalls of the Use of Artificial Intelligence in Surgery

The use of AI is a two-edged sword – on the one hand, it can significantly alter the way surgeons work for the better, but on the other hand, it has the potential to be dangerous. The power of intuition and experience matters – no matter how much ML or deep learning a robot does, it is still not capable of full independent thinking – what it does is a mimicry of what humans can do, albeit faster and more logic based. Surgeons often work by intuition and that human touch cannot be replaced by AI – at least not yet.

Another major limiting factor for the use of AI in surgery is the financial burden of using such technology. It is not feasible to utilize such technology in all countries – thus, standardization of treatment and equal access to health care will be affected with its subsequent ethical implications.

The translation of AI and automation to different environments can also pose significant challenges. Performing simple automated tasks is entirely different from independently performing complex surgeries. ML can also be faulty or give nonsensical results – for instance, during an early attempt in applying ML to the diagnosis of pneumonia, the systems were given two sets of chest radiographs from two different hospitals, with and without pneumonia, in order to learn to differentiate between the two. The algorithm quickly determined that the most predictive feature of pneumonia was the mark used to indicate right and left sides on the radiograph, which turned out to be different between the two hospitals.^[5] Thus, at this stage of development, ML still needs to be supervised.

More importantly, most of the uses of AI are still in its infancy stage – strict guidelines and standardized protocols for the use of AI are yet to be developed. Ethical and legal dilemmas are still not ironed out; in order to undergo analysis and deep learning, colossal amounts of data need to be provided. Thus, privacy issues and privacy laws come into factor here. Thus, administration and implementation of AI guidelines should be brought into focus otherwise it is not feasible to use these ventures in routine clinical practice.^[32]

The rise of automation is a huge threat to a surgeon's technical and dexterity skills and must be proactively addressed. Effective countermeasures should be undertaken to avoid loss of skills; workshops, modules, and continued medical education can be enforced on a regular basis.

There is also the simple aspect of the human touch – using AI to enhance our capabilities is entirely different from using an automated fully functioning robot to perform full surgeries – most individuals will be uncomfortable with the use of a machine to make such complex decisions and entrust their lives to a machine. Trust is the key issue; it implies the placement of something valuable in the responsibility of another during times of vulnerability or uncertainty. This definition is particularly true of an ideal doctor–patient relationship. Patients place their health in the hands of the physician and trust and believe in the physicians' benevolent motives. AI does not possess this – it cannot be said to have motives of character – this is the inherent flaw leading to a lack of trust. For how can you trust something that does not have a character? By sacrificing elements of trust, personalized care, which is crucial to a doctor–patient relationship, is foregone.^[33] Thus, all these issues contribute to the lack of feasibility in general clinical practice at this time. However, as this study aims to elaborate, the potential of AI to overcome these limitations is a definite possibility, although one can only speculate how AI can overcome some of the ethical and moral dilemmas at this time.

Conclusion

AI and automation has the potential to completely change the way we practice surgery in the near future – AI has already cemented its entry into the health-care system. Surgeons must be prepared to adapt to the new age of technology and robotics. The next decade could see substantial differences in the landscape of surgery and medicine, especially with the use of big data and innovative technology for image processing. In the subsequent decades, automation may be a routine part of our health-care system. However, at present, augmentation rather than automation should be the priority, particularly in becoming the first route to achieving incorporation of AI into surgical practice. However, despite the significant advances made in multiple fields of health care, stringent policies and regulations have to be kept in place in order for AI to be incorporated into our routine health-care systems.

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Conflicts of interest

There are no conflicts of interest.

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