Review Article

Open Access

Artificial Intelligence in Surgery: Learning and Applications

Umair Tahir, Iqra Sadaf, Muhammad Ayub, S.A.M Khuzaemah Hashmi, Iqra Tanzeel

ABSTRACT

Artificial intelligence (AI) has transformed the field of surgery; using machine learning algorithms in domains like computer vision and operative robotics can fundamentally alter patient screening, diagnosis, risk assessment, treatment, and follow-up procedures in operating rooms and both before and after surgery. This quick review summarized AI-assisted surgical learning and applications in various surgery sectors. We explained the usefulness of AI in all aspects of surgery learning and competency. Our review focused on implementing AI in several aspects of patient care, including early screening, intra-operation robotics, post-operation monitoring, and follow-up. Horizon scanning of AI technologies in surgery identifies developments that can improve medical procedures and transform future norms. Thus, over the next ten years, experimental progress will quickly translate into practical applications. In comparison, AI may necessitate a change in work procedures. It will also improve surgical safety, learning, and surgical quality for patients while offering surgeons and health systems substantial benefits.

Keywords: Artificial intelligence; surgery learning; AI-assisted surgery; robotics

How to cite this Article:
Tahir U, Sadaf I, Ayub M, Hashmi SAMK, Tanzeel I, Artificial Intelligence in Surgery: Learning and Applications. J Bahria Uni Med Dental Coll. 2025;15(3):253-261 DOI: https://doi.org/10.51985/JBUMDC2025592

INTRODUCTION

The healthcare sector is being revolutionized by artificial intelligence (AI). The term AI refers to a broad range of computational methods that allow computers to completely evaluate clinical studies on their own. Operational robotics, augmented reality, computer vision, and machine learning of organized data are some of these methods.[1,2] AI is the imitation of human intellect in computers. Like human intelligence, the systems can perform tasks such as decision-making, speech recognition, language processing, visual perception, and pattern identification. AI can advance healthcare research by assessing and decoding data from clinical projects to find hidden but significant trends that go beyond conventional wisdom. It can also enhance patients' treatments by assisting in correct decisions.[3]

Machine learning is the process of using programs to anticipate data as well as get better with time. Machine learning is further classified as supervised, un-supervised, and reinforcement learning. In supervised learning, systems are trained using labelled information to forecast an outcome. Conversely, unsupervised learning makes use of unlabeled information to enable systems to investigate unidentified trends or results. Lastly, a trial-and-error method similar to operating conditioning is referred to as reinforced learning.[1,4] Another type of machine learning is deep learning, which makes use of artificial neural networks to examine big data and resolve challenging issues. Deep learning's diagnostic capabilities in medical imaging are among the primary uses that have demonstrated its exceptional capacity for identifying intricate patterns.[5] Computer vision and natural language processing (NLP) are additional subfields that are especially pertinent to surgery. NLP includes the process of turning generated spontaneous language into automated structured text.[4]

All these machine learning techniques have occasionally shown remarkable results in challenging problems like natural language translation and picture categorization.[6] However, these machine learning systems are frequently underreported (no better performance of machine learning over logistic regression)[7], do not show better predictive accuracy than conventional statistical methods for prognostication in traumatic brain injury[8], or predicting major chronic diseases[9], or for discriminating type 1 and

Umair Tahir
Senior Registrar, Department of Surgery
Tertiary Care Hospital, Nishtar-II, Multan
Email: ch.umairtahir@gmail.com

Iqra Sadaf
Senior Registrar, Department of Surgery
Tertiary Care Hospital, Nishtar-II, Multan
Email: ekra043@gmail.com

Muhammad Ayub
Assistant Professor, Department of Surgery
Nishtar Medical University Hospital, Multan
Email: drayub246@gmail.com

S.A.M Khuzaemah Hashmi
Senior Registrar, Department of Surgery
Tertiary Care Hospital, Nishtar-II, Multan
Email: khuzaemah@yahoo.com

Iqra Tanzeel
Resident, Department of Surgery
Nishtar Medical University Hospital, Multan
Email: iqratanzeel62@gmail.com

Received: 02-03-2025 1st Revision:15-03-2025
Accepted: 02-07-2025 2nd Revision: 16-06-2025

type 2 diabetes in young adults.[10]

AI has been exploited in precision medicine, drug development, imaging and diagnosis, genomics, and risk stratification. More recently, AI has been implemented in surgery. AI methods concentrate on recognizing features and automated interventions for before- and after-surgery planning. Numerous supervised algorithms have been created in previous years, including statistical classifiers, atlas-based techniques, and active-shape models.[11] The development of more advanced AI models, for example, AlexNet, has made it possible to use automatic data descriptors for clinical image interpretation. These descriptors have demonstrated better universality and resilience than handcrafted models. As the use of automated machines in surgery grows, AI has the potential to alter the discipline by creating complex functionalities that link robotic control and real-time sensing.[11]

Surgical routes provide concrete and established metrics for performance and outcomes that prioritize patients. They are also clearly defined, evidence-based, and frequently technically enabled at inception. These elements are probably in charge of the high degrees of model stability and the quantity of software (considered as medical devices) that have received regulatory approval and are located at crucial points throughout the surgical process.[4] For example, radiomic gadgets are used for internal scanning and diagnostics, some AI models are used in risk prediction by utilizing extensive clinical information, robot surgical devices assist surgery, few AI models are used that maximize the effectiveness of surgery pathways, and AI systems are used for making correct decisions after surgical procedures and follow-ups. As a consequence, there is a growing likelihood that AI-based workflows will develop across a wide range of surgical fields, backed by data showing improved results and cost reductions.[4]

According to World Health Organization (WHO) and the Coalition for Health AI criteria, AI programs must be testable (enable algorithms and results to be impartially confirmed), useable (easy to use, have no impact on clinical operations, and suitable to patients as well as doctors), reliable (patients and doctors should rely on them to deliver consistent outcomes), beneficial (effective in clinical trials, and must improve patient care. and operable (adequate operator education to assure that operator skill or expertise won't be a barrier to technology adoption).[12,13] The current review article comprehends the use of AI in surgical learning, surgical robots, and preoperative, intraoperative, and postoperative phases. Finally, we summarize the prospects of AI in the field of surgery.

Surgery learning

Clinical outcomes could be improved by using AI in surgical learning to improve training effectiveness and quality. It is very possible that the use of AI in surgical training will grow in popularity as both technology and the surgical industry continue to progress. As AI's potential and skills continue to develop, this integration is probably going to happen in ways that are currently hard to predict or understand. AI in surgical education has the potential to completely transform the way surgeons are taught and significantly raise the standard of surgical care overall. The growing application of AI in this industry, however, also raises several practical and ethical concerns that should be taken into account. AI can be incorporated into surgical education to help students become more proficient in surgery and enhance patient care. Collaboration among the surgeon, ethicists, and researchers is also necessary for this integration in order to guarantee the technology's efficacy, safety, and equity. Despite its enormous potential, artificial intelligence has drawbacks, and there hasn't been any clinical use of it up to this point. The growing incorporation of AI into surgical training requires constant observation, assessment, and adjustment.[3]

Competence in surgery includes a broad variety of skills. The elements of understanding, abilities, and mindsets are traditionally considered to be part of competence. AI has the ability to significantly decrease the process of learning for surgical operations and contribute to the growth and enhancement of all aspects of surgical competency, including surgical skills. Training via simulations (SBT) is particularly well-suited for AI.[14,15] In surgical education, SBT has become indispensable, as it enhances students' confidence and performance. AI can offer surgical trainees an accurate and secure setting to practice and refine their technical abilities through the use of simulation software. With the use of SBT, students can practice and become more confident when carrying out procedures without running the danger of endangering real patients.[16] Additionally, SBT can assist the learner remember the abilities and apply them successfully in real-world scenarios. AI can also offer real-time assessment and suggestions, enabling more effective and individualized skill improvement.[17]

AI has demonstrated its usefulness in evaluating movements of the hands and offering advice on how to enhance proficiency using motion-based analysis. It can also identify parts of the process that could need more training.[18-20] Through AI-powered simulation-based training, surgeons can enhance their technical expertise while simultaneously honing non-technical abilities like handling crises and taking decisions under duress. AI could help physicians make clinical decisions by speeding up the procedure and assisting them in comprehending linguistic meanings.[21] A thorough review of present-day standards and scientifically supported approaches to surgical operations can be obtained by using AI-techniques like the processing of natural language to gather and analyze enormous quantities of information from articles.[22]

AI-linguistic processing devices can help with presenting and interpreting difficult study material in ways that are tailored to each trainee's demands and language proficiency.

AI may also help create customized learning resources and study schedules depending on the requirements and understanding gaps of each trainee. AI can be used to evaluate a trainee's progress on mock examinations in order to pinpoint areas of incompetence and provide study guides specifically designed to help them do better in those particular areas. By using AI to analyze learning, educators can target assets derived from traditional evaluation to particular instructional deficiencies. Due to the quick development of AI-applications, educators must stay up to date on the latest developments in AI as well as also modifying their lesson plans to incorporate cutting-edge techniques.[3]

AI can improve mindset training by providing simulated instances of patients and circumstances that let learners hone their analytical and interpersonal abilities while strengthening their capacity to manage challenging ethical dilemmas.[23] Trainees can gain the ability to evaluate many possibilities and successfully convey the choices they make to patients and coworkers by using modelled scenarios. It can keep an eye on the performance of learners throughout training sessions online, though it could be challenging for an educator to watch and give immediate input. It may also give learners immediate advice and guidance on general skills like teamwork and management, as well as assisting them in forming the mindset and habits necessary for achievement in the surgery industry. Since no contemporary surgeon operates alone, they must be taught to collaborate with others from an early age. The learners can get the expertise and compassion necessary to establish a connection and confidence with patients through interacting with AI-generated simulated situations. This will help them traverse the societal and emotional components of surgeries.[24-26]

The precision and effectiveness of clinical diagnosis could be greatly increased by AI. In order to find trends and forecast the best likely diagnosis, algorithms for machine learning can examine vast volumes of information that come from multiple sources, including laboratory test results, patient histories, and medical images.[5,27] Clinicians can make more precise and reliable diagnoses by such algorithms that have been developed on huge databases to identify behaviors and patterns. Particularly in radiology, these algorithms have been shown to give doctors outcomes that are consistent.[28-30]

ChatGPT is currently taking over the realm of the public because of their remarkable capacity for processing and creating narrative prose.[31] Neural networks and NLP models are used by ChatGPT to produce output that is human-like in response to a range of inputs.[32] It could completely change the way that medical education is conducted. Examples of applications for robotic learning procedures include evaluation assessments, instructional assistance, performance of learner's estimation, immediate feedback, and lesson creation. ChatGPT gives trainees and students quick access to clinical data and training materials in an intuitive manner, allowing them to expand their understanding. Surgeons can also provide patients with superior surgical care with the help of produced diagnosis and management recommendations.[33]

Applications of AI surgery

Pre-operation

Hazards prediction

A number of particular to patients and operating variables have led to the development of preoperative risk instruments as crucial supplements to help patients and physicians anticipate the potential hazards of surgery. APACHE-III (mechanism for predicting the death of people in dangerous situations), ACS NSQIP (hazards calculator), and POSSUM (for death and illness) are one of the most commonly used AI instruments for surgical hazards prediction. Nevertheless, renowned tools frequently employ personal input or anticipate linear correlations among factors in their models of mathematics, that is not true in the clinical settings.[34] New advances can increase the prediction power of hazard tools by utilizing machine learning's abilities to analyze vast, varied information and simulate irregular correlations. The danger estimator for urgent laparotomy sufferers uses an machine learning associated optimum categorization tree and outperforms the ACS NSQIP in predicting pre-operation danger for the patient group.[35] Similarly, a study created another machine learning hazard prediction tool named My-Risk-Surgery. It was employed to forecast major complications and death after surgeries.[36]

Screening and Diagnosis

AI tools have been utilized more in breast tumor image analyzing. A variety of AI-powered lesion identification tools, such as Transpara, INSIGHT MMG, and ProFound AI software, have been authorized for use in mammogram testing. Two significant future studies are presently being conducted by INSIGHT MMG and Transpara, both of which have produced encouraging initial results indicating that they are not inferior than two radiologists double reading.[37,38] Thus, it is easy to see a time soon when deep learning algorithms (DLAs) will be used directly as an additional or secondary readers in breast tumors screening. It will increase the probability of breast cancer identification as well as decrease workload of radiologists. Likewise, AI-powdered tools for colorectal and lung cancer detection are also under progress.[39,40] The incorporation of AI-powered tools in the field of molecular biology is still at its early stages. For instance, machine learning model was developed and tested against tumor DNA ML-driven model was tested and independently validated on moving tumor DNAs to identify early stage of hepatocellular via somatic copy number aberrations.[41]

These DLAs have been developed for an accurate diagnosis of various diseases, such as diabetic retinopathy, retinal disease, colorectal polyps, fractures, prostate cancer, intracranial hemorrhages, aneurysms, thyroid cancer, small bowel obstruction, pancreatic disease, and aortic dissection.[34]

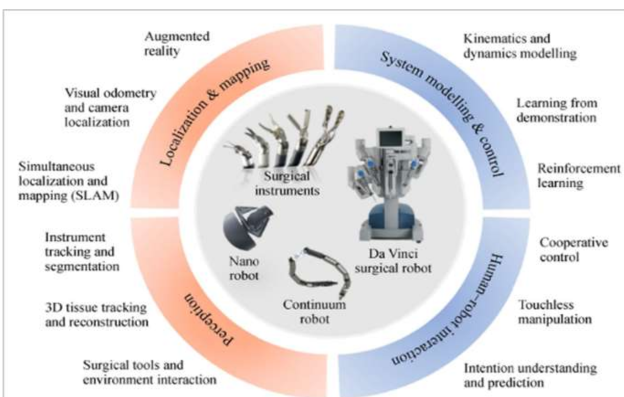
Intra-operation

Surgical robots

In the scientific literature, there has been plenty of debate about using machine vision in surgery video analysis. However, this is now feasible because video-associated, less-invasive surgery methods, including endoscopic, laparoscopic, and robotic, have become widely used. Many regular surgery video recordings can offer an extensive worldwide database of AI algorithms that read, combine, categorize, and evaluate procedural movies. These algorithms rely primarily on advanced machine-learning approaches. Additionally, specialists find it time-consuming to annotate practice sets. There rarely exists unanimous agreement on the actions that should be taken throughout a procedure.[11,42]

A technique of semantic segmentation was utilized to develop DLAs for demonstrating secure or risky areas during special surgeries, such as laparoscopic cholecystectomies, laparoscopic sleeve gastrectomy cataract surgery, and endovascular aneurysm repair. AI-powered three-dimensional anatomical reconstruction can aid preoperative planning and intraoperative navigation of complex operations.[43-46] Recently, the Food and Drug Administration (FDA) authorized an AI tool named as Cydar EV Maps. It was employed to create a complete patient-specific map of arteries anatomy via pre-operation mapping and real-time intraoperation fluoroscopic imaging. It has been demonstrated to lower radiation doses and enhance the effectiveness of difficult aortic aneurysm endovascular reconstruction.[47] Numerous intraoperation advantages come with integrating robotic surgery, such as enhanced agility, design, and an accurate amplified three-dimensional vision. Since then, over 12 million operations have been carried out by 60,000 doctors globally using the Da Vinci surgical robot (**Figure 2**) alone, making robotic surgery the preferred less-invasive method for routine surgeries in comparison to laparoscopy.[4,47] There are 6 stages of autonomy for robotic surgery (**Table 1**). Skin-to-skin surgeries using completely self-contained robots are currently mainly theoretical, but potential advantages involve establishing surgical techniques, stability, precision, removing the possibility of human fatigue, anxiety, and prejudice, and conducting surgery in areas that are considered dangerous or inaccessible to human beings, such as inaccessible regions or battlefields.[4]

Figure 1: AI-assisted surgical robots and their surgery techniques



Post-operation

Discharge and follow-up

Post-operation problems raise morbidity and death rates, lengthen hospital stays, and result in substantial expenses, all of which add to the load on medical systems.[48] Yet, employ traditional statistical methods to forecast the frequency of complications after surgery is inadequate because their root causes are frequently complex in structure.[49] With the help of its strong algorithms and capacity to use many data sources, AI might assess data that includes a variety of patient and process characteristics in order to forecast difficulties. For instance, a study developed machine learning-forest model to forecast anastomotic leakage following anterior resection for rectal cancer.[50] Similarly, such machine learning models were developed for surgical site infections, bleeding after surgery[51,52], complications after bariatric surgery[53,54], and monitoring after surgy of colorectal, liver, and pancreas.[55] On the other hand, a planned and tailored release plan using AI algorithms, such as DESIRE (**Table 2**), can shorten hospital stays, decrease recurrence, and improve patient satisfaction. Similarly, AI algorithms can be utilized in patients' follow-up. For example, a study designed AI system (**Table 2**) for orthopedic patients recovering from surgery via machine learning and voice simulation.[56]

LIMITATIONS

AI has many advantages and enhances surgical education, but it also has drawbacks (**Table 3**). Doctors' roles as

Table 1: Six stages of autonomy for robotic surgery.

Autonomy Stage	Explanation
Stage 0	No autonomy – human operator performs all functions.
Stage 1	Robot assistance – human retains continuous control.
Stage 2	Task autonomy – human has discrete control, with specific tasks given to robot.
Stage 3	Conditional autonomy – human selects autonomous strategy performed by robot.
Stage 4	High autonomy – robot makes decisions but under supervision of human.
Stage 5	Full autonomy – procedure fully performed by robot with no human supervision required.

Table 2: Recently developed AI algorithms for discharge and follow-up of patients.

AI-system	Methods	Results	Reference
DESIRE (Discharge after surgery using artificial intelligence)	The study externally validated the machine learning concept in gastrointestinal and oncology surgery patients admitted to 3 nonacademic hospitals in Four forest models were locally trained and evaluated with respect to area under the receiver operating characteristics curve, sensitivity, specificity, positive predictive value, and negative predictive value.	This study showed that a previously developed machine learning concept can predict safe discharge in different surgical populations and hospital settings (academic versus nonacademic) by training a model on local patient data. Given its high accuracy, integration of the machine learning concept into the clinical workflow could expedite surgical discharge and aid hospitals in addressing capacity challenges by reducing avoidable bed-days.	**57**
AI-assisted follow-up model	The AI-assisted follow-up system was adopted in the Orthopedic Department of Peking Union Medical College Hospital in April 2019. A total of 270 patients were followed up through this system. Prior to that, 2656 patients were followed up by phone calls manually. Patient characteristics, telephone connection rate, follow-up rate, feedback collection rate, time spent, and feedback composition were compared between the two groups of patients.	The effectiveness of AI-assisted follow-up was not inferior to that of manual follow-up. Human resource costs are saved by AI. AI can help obtain comprehensive feedback from patients, although its depth and pertinence of communication need to be improved.	**56**

professional interpreters are altered by AI, which is thought to focus on patients and may be prone to overlooking minute details in patient-doctor interactions. Furthermore, AI needs lifetime supervision for appropriate medical use because it is still far from being suitable for autonomous operation.[58] Additionally, AI may not yet be able to interpret verbal indications, which could aid in directing conversation to the specific levels most appropriate for providing each patient with knowledge in a customised manner.[59] Large volumes of data are necessary for machine learning algorithms to facilitate sound decision-making. The low number of precise diagnoses in certain surgical specialties makes it difficult to apply machine learning in certain scenarios. Large volumes of data are also necessary for machine learning algorithms to learn and perform better. Accurately gathering and labelling this data can be challenging, which could affect how well the AI system performs. Many physicians are not conversant with the vocabulary used in the current medical literature about AI, which may hinder clinical implementation and adaption.[60]

Future Prospects and Challenges

In the future, conversational large-language models (LLMs) that combine NLP, deep learning, and speech recognition, technology may be utilised to respond to questions, counsel patients, and conduct consults with patients on their own. These algorithms may finally recommend proper diagnosis as well as a treatment strategy. Crucially, these AI algorithms will be empathy-based in order to maintain the human dimension in the consultations.[61] Microbots, endoscopic, bioinspired, and stereotaxic robots are the various types of operating robots that have been developed independently. In the far future, these robots might even provide a better substitute for professional-led solutions and represent the pinnacle of best practice, eliminating the requirement for human oversight or management.[62]

AI can help intelligent educational programs by offering guidance and immediate input throughout simulations. These

Table 3: Limitations of AI in medical field.

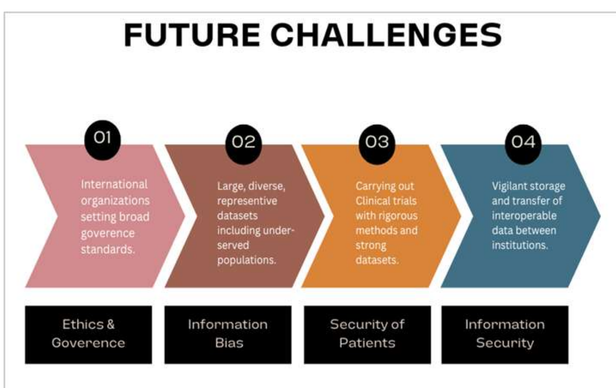
Limitations	**Consequences**
Lack of human judgment	Decisions are based on data, rules, and prior experience, but lacks ability to understand context and nuances
Lack of domain expertise	AI systems may lack deep knowledge and experience, risk of incorrect diagnoses and treatment plans
Bias in data	AI systems rely on the data they are trained on; if data are limited, decisions have weak background and may be biased
Need for interpretability	The decisions made by AI systems may be difficult to interpret and thus trust
High cost	AI systems are expensive to develop, implement, and possibly also to maintain

technologies could evaluate performance metrics, such as tissue interaction and tool motion, to offer thorough and impartial assessments of surgical competency's mindset aspect and skill improvement. AI can also be used to construct guidance systems for medical diagnosis and therapy, which could assist them stay up to date by offering suggestions for optimal procedures. These guidance systems have the potential to simplify the screening and therapeutic process, cutting down on the period of time and assets needed to arrive at a diagnosis and making use of those resources.[3,63,64]

Robots of the future will become smaller in order to be used in a larger range of applications. In the future, assistive technology such as robots powered by AI may be used to carry out confident surgical operations. Practical activities like stitching, incisions, and closure of wounds may fall under this category, freeing up the surgeon to concentrate on the key elements of operation. However, both present and future generations of doctors cannot yet operate entirely automatic surgical robots. Therefore, surgical robots continue to function as tele-manipulator systems under the supervision of skilled doctors.[65,66] These surgical robots can also be operated remotely by the surgeons. In addition to robotic surgery, telemedicine can be utilised for more basic medical care, where AI and machine learning can aid provide medical services in difficult-to-reach places.[67,68]

AI development has been revolutionizing current surgery by enabling more accurate and self-governing interventions for the treatment of both acute and chronic ailments. Significant advancements have been made in surgical robots, intraoperative guidance, and preoperative planning by utilizing these methods. AI holds enormous potential and countless revolutionary applications beyond those mentioned thus far. It's crucial to moderate any hopes that AI will be a magic bullet that will resolve every issue facing the medical field. Since the fundamentals of AI technology have not been explored before, careful preparation will be necessary to integrate them into established healthcare structures safely and morally (**Figure 2**).

Figure 2: Obstacles and difficulties in integrating AI technology into surgical execution



CONCLUSION

The enormous potential of AI in surgery has been described in this paper, with the goal of enhancing or revolutionizing every facet of surgical patient care. AI-assisted surgical learning and its applications in the field of surgery were summed up in this brief article. We discussed the value of AI in every facet of surgical proficiency and learning. Our review concentrated on applying AI to a number of patient care domains, such as early screening, intra-operative robotics, post-operative monitoring, and follow-up. Innovations that have the potential to enhance medical practices and change future standards are found through horizon scanning of AI technology in surgery. The field of surgery has always aimed to innovate, from carrying out intricate procedures that were previously thought to be difficult to accomplish to bringing about the advent of surgical procedures using minimally technologically enabled instruments. AI has the potential to usher in an entirely novel phase of medical care, and the surgery community worldwide has to welcome it.

Authors Contribution:
Umair Tahir: Corresponding Author and study design
Iqra Sadaf: Co-author, Manuscript writing
Muhammad Ayub: Editor Manuscript
S.A.M Khuzaemah Hashsmi: Acknowledged contributor, critical revision
Iqra Tanzeel: Acknowledged contributor, figures and tables

REFERENCES

1. Hashimoto DA, Rosman G, Rus D, Meireles OR. Artificial intelligence in surgery: promises and perils. Annals of surgery. 2018;268(1):70-6. DOI: https://doi.org/ 10.1097/SLA.0000000000002693
2. Yu KH, Beam AL, Kohane IS. Artificial intelligence in healthcare. Nature biomedical engineering. 2018;2(10): 719-31. DOI: https://doi.org/10.1038/s41551-018-0305-z
3. Pakkasjärvi N, Luthra T, Anand S. Artificial intelligence in surgical learning. Surgeries. 2023;4(1):86-97. DOI: https://doi.org/10.3390/surgeries4010010
4. Guni A, Varma P, Zhang J, Fehervari M, Ashrafian H. Artificial intelligence in surgery: the future is now. European Surgical Research. 2024;65(1):22-39. DOI: https://doi.org/ 10.1159/000536393
5. Aggarwal R, Sounderajah V, Martin G, Ting DS, Karthikesalingam A, King D, Ashrafian H, Darzi A. Diagnostic accuracy of deep learning in medical imaging: a systematic review and meta-analysis. NPJ digital medicine. 2021;4(1):65. DOI: https://doi.org/10.1038/s41746-021-00438-z
6. Harrison CJ, Sidey-Gibbons CJ. Machine learning in medicine: a practical introduction to natural language processing. BMC medical research methodology. 2021;21(1):158. DOI: https://doi.org/10.1186/s12874-021-01347-1
7. Christodoulou E, Ma J, Collins GS, Steyerberg EW, Verbakel JY, Van Calster B. A systematic review shows no performance benefit of machine learning over logistic regression for clinical prediction models. Journal of clinical epidemiology. 2019;110:12-22. DOI: https://doi.org/10.1016/ j.jclinepi.2019.02.004

8. Gravesteijn BY, Nieboer D, Ercole A, Lingsma HF, Nelson D, Van Calster B, Steyerberg EW, Åkerlund C, Amrein K, Andelic N, Andreassen L. Machine learning algorithms performed no better than regression models for prognostication in traumatic brain injury. Journal of clinical epidemiology. 2020;122:95-107. DOI: https://doi.org/10.1016 /j.jclinepi .2020.03.005
9. Nusinovici S, Tham YC, Yan MY, Ting DS, Li J, Sabanayagam C, Wong TY, Cheng CY. Logistic regression was as good as machine learning for predicting major chronic diseases. Journal of clinical epidemiology. 2020;122:56-69. DOI: https://doi.org/ 10.1016/j.jclinepi.2020.03.002
10. Lynam AL, Dennis JM, Owen KR, Oram RA, Jones AG, Shields BM, Ferrat LA. Logistic regression has similar performance to optimised machine learning algorithms in a clinical setting: application to the discrimination between type 1 and type 2 diabetes in young adults. Diagnostic and prognostic research. 2020;4:1-0. DOI: https://doi.org/10. 1186/ s41512-020-00075-2
11. Zhou XY, Guo Y, Shen M, Yang GZ. Application of artificial intelligence in surgery. Frontiers of medicine. 2020;14:417-30. DOI: https://doi.org/10.1007/s11684-020-0770-0
12. Coalition for Health AI T. Blueprint for trustworthy AI implementation guidance and assurance for healthcare. DOI: https://www.chai.org/wp-content/uploads/2024/05/blueprint-for-trustworthy-ai_V1.0-2.pdf
13. Guidance WH. Ethics and governance of artificial intelligence for health. World Health Organization. 2021 Jun 28. DOI: https://iris.who.int/bitstream/handle/10665/341996/978924 0029200-eng.pdf
14. Pakkasjärvi N, Krishnan N, Ripatti L, Anand S. Learning curves in pediatric robot-assisted pyeloplasty: a systematic review. Journal of clinical medicine. 2022;11(23):6935. DOI: https://doi.org/10.3390/jcm11236935
15. Winkler-Schwartz A, Bissonnette V, Mirchi N, Ponnudurai N, Yilmaz R, Ledwos N, Siyar S, Azarnoush H, Karlik B, Del Maestro RF. Artificial intelligence in medical education: best practices using machine learning to assess surgical expertise in virtual reality simulation. Journal of surgical education. 2019;76(6):1681-90. DOI: https://doi.org/10.1016/ j.jsurg.2019.05.015
16. Seil R, Hoeltgen C, Thomazeau H, Anetzberger H, Becker R. Surgical simulation training should become a mandatory part of orthopaedic education. Journal of Experimental Orthopaedics. 2022;9(1):22. DOI: https://doi.org/10.1186/ s40634-022-00455-1
17. Gazis A, Karaiskos P, Loukas C. Surgical gesture recognition in laparoscopic tasks based on the transformer network and self-supervised learning. Bioengineering. 2022;9(12):737. DOI: https://doi.org/10.3390 /bioengineering912 0737
18. Alonso-Silverio GA, Perez-Escamirosa F, Bruno-Sanchez R, Ortiz-Simon JL, Muñoz-Guerrero R, Minor-Martinez A, Alarcón-Paredes A. Development of a laparoscopic box trainer based on open source hardware and artificial intelligence for objective assessment of surgical psychomotor skills. Surgical Innovation. 2018;25(4):380-8. DOI: https://doi.org/10.1177/ 1553350618777045
19. Moglia A, Morelli L, D'Ischia R, Fatucchi LM, Pucci V, Berchiolli R, Ferrari M, Cuschieri A. Ensemble deep learning for the prediction of proficiency at a virtual simulator for robot-assisted surgery. Surgical Endoscopy. 2022 ;36(9):6473-9. DOI: https://doi.org/10.1007/s00464-021-08999-6
20. Oquendo YA, Riddle EW, Hiller D, Blinman TA, Kuchenbecker KJ. Automatically rating trainee skill at a pediatric laparoscopic suturing task. Surgical endoscopy. 2018;32:1840-57. DOI: https://doi.org/10.1007/s00464-017-5873-6
21. Secinaro S, Calandra D, Secinaro A, Muthurangu V, Biancone P. The role of artificial intelligence in healthcare: a structured literature review. BMC medical informatics and decision making. 2021;21:1-23. DOI: https://doi.org/10.1186/s12911-021-01488-9
22. Schwalbe N, Wahl B. Artificial intelligence and the future of global health. The Lancet. 2020;395(10236):1579-86. DOI: https://doi.org/10.1016/S0140-6736(20)30226-9
23. Milne-Ives M, de Cock C, Lim E, Shehadeh MH, de Pennington N, Mole G, Normando E, Meinert E. The effectiveness of artificial intelligence conversational agents in health care: systematic review. Journal of medical Internet research. 2020 ;22(10):e20346. DOI: https://doi.org/10.2196 /20346
24. Tanaka H, Nakamura S. The acceptability of virtual characters as social skills trainers: usability study. JMIR human factors. 2022;9(1):e35358. DOI: https://doi.org/10.2196/35358
25. Shorey S, Ang E, Yap J, Ng ED, Lau ST, Chui CK. A virtual counseling application using artificial intelligence for communication skills training in nursing education: development study. Journal of medical Internet research. 2019;21(10):e14658. DOI: http://www.jmir.org/2019/11/ e17064
26. Antel R, Abbasgholizadeh-Rahimi S, Guadagno E, Harley JM, Poenaru D. The use of artificial intelligence and virtual reality in doctor-patient risk communication: A scoping review. Patient Education and Counseling. 2022;105(10):3038-50. DOI: https://doi.org/10.1016/j.pec.2022.06.006
27. Modarai B. Progressive guidance on the modern management of abdominal aorto-iliac artery aneurysms. European Journal of Vascular and Endovascular Surgery. 2019;57(1):4-5. DOI: https://doi.org/10.1016/j.ejvs.2018.12.00
28. Kuo RY, Harrison C, Curran TA, Jones B, Freethy A, Cussons D, Stewart M, Collins GS, Furniss D. Artificial intelligence in fracture detection: a systematic review and meta-analysis. Radiology. 2022;304(1):50-62. DOI: https://doi.org/10.1148 /radiol.211785
29. Li MD, Ahmed SR, Choy E, Lozano-Calderon SA, Kalpathy-Cramer J, Chang CY. Artificial intelligence applied to musculoskeletal oncology: a systematic review. Skeletal Radiology. 2022:1-2. DOI: https://doi.org/10.1007/s00256-021-03820-w
30. Kelly BS, Judge C, Bollard SM, Clifford SM, Healy GM, Aziz A, Mathur P, Islam S, Yeom KW, Lawlor A, Killeen RP. Radiology artificial intelligence: a systematic review and evaluation of methods (RAISE). European radiology. 2022;32(11):7998-8007. DOI: https://doi.org/10.1007/s00330-022-08784-6
31. Clusmann J, Kolbinger FR, Muti HS, Carrero ZI, Eckardt JN, Laleh NG, Löffler CM, Schwarzkopf SC, Unger M, Veldhuizen GP, Wagner SJ. The future landscape of large language models in medicine. Communications medicine. 2023;3(1):141. DOI: https://doi.org/10.1038/s43856-023-00370-1

32. Kung TH, Cheatham M, Medenilla A, Sillos C, De Leon L, Elepaño C, Madriaga M, Aggabao R, Diaz-Candido G, Maningo J, Tseng V. Performance of ChatGPT on USMLE: potential for AI-assisted medical education using large language models. PLoS digital health. 2023;2(2):e0000198. DOI: https://doi.org/10.1371/journal.pdig.0000198
33. Yan L, Sha L, Zhao L, Li Y, Martinez-Maldonado R, Chen G, Li X, Jin Y, Gaševiæ D. Practical and ethical challenges of large language models in education: A systematic scoping review. British Journal of Educational Technology. 2024;55(1):90-112. DOI: https://doi.org/10.1111/bjet.13370
34. Guni A, Varma P, Zhang J, Fehervari M, Ashrafian H. Artificial intelligence in surgery: the future is now. European Surgical Research. 2024;65(1):22-39. DOI: https://doi.org/10.1159/000536393
35. El Hechi MW, Maurer LR, Levine J, Zhuo D, El Moheb M, Velmahos GC, Dunn J, Bertsimas D, Kaafarani HM. Validation of the artificial intelligence-based predictive optimal trees in emergency surgery risk (POTTER) calculator in emergency general surgery and emergency laparotomy patients. Journal of the American College of Surgeons. 2021;232(6):912-9. DOI: https://doi.org/10.1016/j.jamcollsurg.2021.02.009
36. Bihorac A, Ozrazgat-Baslanti T, Ebadi A, Motaei A, Madkour M, Pardalos PM, Lipori G, Hogan WR, Efron PA, Moore F, Moldawer LL. MySurgeryRisk: development and validation of a machine-learning risk algorithm for major complications and death after surgery. Annals of surgery. 2019;269(4):652-62. DOI: https://doi.org/10.1097/SLA.0000000000002706
37. Dembrower K, Crippa A, Colón E, Eklund M, Strand F. Artificial intelligence for breast cancer detection in screening mammography in Sweden: a prospective, population-based, paired-reader, non-inferiority study. The Lancet Digital Health. 2023;5(10):e703-11. DOI: https://doi.org/10.1016/S2589-7500(23)00153-X
38. Lång K, Josefsson V, Larsson AM, Larsson S, Högberg C, Sartor H, Hofvind S, Andersson I, Rosso A. Artificial intelligence-supported screen reading versus standard double reading in the Mammography Screening with Artificial Intelligence trial (MASAI): a clinical safety analysis of a randomised, controlled, non-inferiority, single-blinded, screening accuracy study. The Lancet Oncology. 2023;24(8):936-44. DOI: https://doi.org/10.1016/S1470-2045(23)00298-X
39. Mitsala A, Tsalikidis C, Pitiakoudis M, Simopoulos C, Tsaroucha AK. Artificial intelligence in colorectal cancer screening, diagnosis and treatment. A new era. Current Oncology. 2021;28(3):1581-607. DOI: https://doi.org/10.3390/curroncol28030149
40. Schreuder A, Scholten ET, van Ginneken B, Jacobs C. Artificial intelligence for detection and characterization of pulmonary nodules in lung cancer CT screening: ready for practice?. Translational lung cancer research. 2021;10(5):2378. DOI: https://doi.org/10.21037/tlcr-2020-lcs-06
41. Tao K, Bian Z, Zhang Q, Guo X, Yin C, Wang Y, Zhou K, Wan S, Shi M, Bao D, Yang C. Machine learning-based genome-wide interrogation of somatic copy number aberrations in circulating tumor DNA for early detection of hepatocellular carcinoma. EBioMedicine. 2020;56. DOI: https://doi.org/10.1016/j.ebiom.2020.102811
42. Hashimoto DA, Ward TM, Meireles OR. The role of artificial intelligence in surgery. Advances in Surgery. 2020;54:89-101. DOI: https://doi.org/10.1016/j.yasu.2020.05.010
43. Madani A, Namazi B, Altieri MS, Hashimoto DA, Rivera AM, Pucher PH, Navarrete-Welton A, Sankaranarayanan G, Brunt LM, Okrainec A, Alseidi A. Artificial intelligence for intraoperative guidance: using semantic segmentation to identify surgical anatomy during laparoscopic cholecystectomy. Annals of surgery. 2022;276(2):363-9. DOI: https://doi.org/10.1097/SLA.0000000000004594
44. Hashimoto DA, Rosman G, Witkowski ER, Stafford C, Navarette-Welton AJ, Rattner DW, Lillemoe KD, Rus DL, Meireles OR. Computer vision analysis of intraoperative video: automated recognition of operative steps in laparoscopic sleeve gastrectomy. Annals of surgery. 2019;270(3):414-21. DOI: https://doi.org/10.1097/SLA.0000000000003460
45. Nespolo RG, Yi D, Cole E, Valikodath N, Luciano C, Leiderman YI. Evaluation of artificial intelligence–based intraoperative guidance tools for phacoemulsification cataract surgery. JAMA ophthalmology. 2022;140(2):170-7. DOI: https://doi.org/10.1001/jamaophthalmol.2021.5742
46. Li A, Javidan AP, Namazi B, Madani A, Forbes TL. Development of an artificial intelligence tool for intraoperative guidance during endovascular aneurysm repair. Journal of Vascular Surgery. 2022;76(4):e114-5. DOI: https://doi.org/10.1016/j.jvs.2022.07.034
47. Patel RJ, Lee AM, Hallsten J, Lane JS, Barleben AR, Malas MB. Use of surgical augmented intelligence maps can reduce radiation and improve safety in the endovascular treatment of complex aortic aneurysms. Journal of vascular surgery. 2023;77(4):982-90. DOI: https://doi.org/10. 1016/j.jvs. 2022.12.033
48. Ludbrook GL. The hidden pandemic: the cost of postoperative complications. Current anesthesiology reports. 2022:1-9. DOI: https://doi.org/10.1007/s40140-021-00493-y
49. Stam WT, Goedknegt LK, Ingwersen EW, Schoonmade LJ, Bruns ER, Daams F. The prediction of surgical complications using artificial intelligence in patients undergoing major abdominal surgery: a systematic review. Surgery. 2022;171(4):1014-21. DOI: https://doi.org/10. 1016/j .surg. 2021.10.002
50. Wen R, Zheng K, Zhang Q, Zhou L, Liu Q, Yu G, Gao X, Hao L, Lou Z, Zhang W. Machine learning-based random forest predicts anastomotic leakage after anterior resection for rectal cancer. Journal of gastrointestinal oncology. 2021;12(3):921. DOI: https://doi.org/10.21037/jgo-20-436
51. Azimi K, Honaker MD, Chalil Madathil S, Khasawneh MT. Post-operative infection prediction and risk factor analysis in colorectal surgery using data mining techniques: a pilot study. Surgical infections. 2020;21(9):784-92. DOI:
52. Chen D, Afzal N, Sohn S, Habermann EB, Naessens JM, Larson DW, Liu H. Postoperative bleeding risk prediction for patients undergoing colorectal surgery. Surgery. 2018;164(6):1209-16. DOI: https://doi.org/10.1089/sur.2019.138
53. Cao Y, Fang X, Ottosson J, Näslund E, Stenberg E. A comparative study of machine learning algorithms in predicting severe complications after bariatric surgery. Journal of clinical medicine. 2019;8(5):668. DOI: https://doi.org/10.3390/jcm8050668

54. Nudel J, Bishara AM, de Geus SW, Patil P, Srinivasan J, Hess DT, Woodson J. Development and validation of machine learning models to predict gastrointestinal leak and venous thromboembolism after weight loss surgery: an analysis of the MBSAQIP database. Surgical endoscopy. 2021;35:182-91. DOI: https://doi.org/10.1007/s00464-020-07378-x

55. Merath K, Hyer JM, Mehta R, Farooq A, Bagante F, Sahara K, Tsilimigras DI, Beal E, Paredes AZ, Wu L, Ejaz A. Use of machine learning for prediction of patient risk of postoperative complications after liver, pancreatic, and colorectal surgery. Journal of Gastrointestinal Surgery. 2020 ;24(8):1843-51. DOI: https://doi.org/10.1007/s11605-019-04338-2

56. Bian Y, Xiang Y, Tong B, Feng B, Weng X. Artificial intelligence–assisted system in postoperative follow-up of orthopedic patients: exploratory quantitative and qualitative study. Journal of Medical Internet Research. 2020;22(5): e16896. DOI: https://doi.org/10.2196/16896

57. van de Sande D, van Genderen ME, Verhoef C, Huiskens J, Gommers D, van Unen E, Schasfoort RA, Schepers J, van Bommel J, Grünhagen DJ. Optimizing discharge after major surgery using an artificial intelligence–based decision support tool (DESIRE): An external validation study. Surgery. 2022;172(2):663-9. DOI: https://doi.org/10.1016/ j.surg. 2022.03.031

58. van der Niet AG, Bleakley A. Where medical education meets artificial intelligence:'Does technology care?'. Medical Education. 2021;55(1):30-6. DOI: https://doi.org/10.1111 /medu.14131

59. Rampton V, Mittelman M, Goldhahn J. Implications of artificial intelligence for medical education. The Lancet Digital Health. 2020;2(3):e111-2. DOI: https://doi.org/10.1016 /S2589-7500(20)30023-6

60. Moglia A, Georgiou K, Morelli L, Toutouzas K, Satava RM, Cuschieri A. Breaking down the silos of artificial intelligence in surgery: glossary of terms. Surgical Endoscopy. 2022;36(11):7986-97. DOI: https://doi.org/10.1007/s00464-022-09371-y

61. Inkster B, Sarda S, Subramanian V. An empathy-driven, conversational artificial intelligence agent (Wysa) for digital mental well-being: real-world data evaluation mixed-methods study. JMIR mHealth and uHealth. 2018;6(11):e12106. DOI: https://doi.org/10.2196/12106

62. Ashrafian H, Clancy O, Grover V, Darzi A. The evolution of robotic surgery: surgical and anaesthetic aspects. BJA: British Journal of Anaesthesia. 2017;119(suppl_1):i72-84. DOI: https://doi.org/10.1093/bja/aex383

63. Loftus TJ, Tighe PJ, Filiberto AC, Efron PA, Brakenridge SC, Mohr AM, Rashidi P, Upchurch GR, Bihorac A. Artificial intelligence and surgical decision-making. JAMA surgery. 2020;155(2):148-58. DOI: https://doi.org/10.1001 /jamasurg.2019.4917

64. Zhao B, Waterman RS, Urman RD, Gabriel RA. A machine learning approach to predicting case duration for robot-assisted surgery. Journal of medical systems. 2019;43(2):32. DOI: https://doi.org/10.1007/s10916-018-1151-y

65. Alip SL, Kim J, Rha KH, Han WK. Future platforms of robotic surgery. Urologic Clinics. 2022;49(1):23-38. DOI: https://doi.org/10.1016/j.ucl.2021.07.008

66. Jamjoom AA, Jamjoom AM, Thomas JP, Palmisciano P, Kerr K, Collins JW, Vayena E, Stoyanov D, Marcus HJ, iRobotSurgeon Collaboration. Autonomous surgical robotic systems and the liability dilemma. Frontiers in Surgery. 2022 ;9:1015367. 9: p. 1015367. DOI: https://doi.org/10.3389/ fsurg.2022.1015367

67. Egert M, Steward JE, Sundaram CP. Machine learning and artificial intelligence in surgical fields. Indian journal of surgical oncology. 2020;11(4):573-7. DOI: https://doi.org/ 10.1007/s13193-020-01166-8

68. Li J, Yang X, Chu G, Feng W, Ding X, Yin X, Zhang L, Lv W, Ma L, Sun L, Feng R. Application of improved robot-assisted laparoscopic telesurgery with 5G technology in urology. European urology. 2023;83(1):41-4. DOI: https://doi.org/10.1016/j.eururo.2022.06.018