Archives of Surgical Research | Systematic Literature Review

Artificial Intelligence in Surgical Education and Training: A Systematic Literature Review

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INTRODUCTION Traditional method of surgical training is centered on apprenticeship and shadowing. Assessment of technical skills is subjective and largely dependent on mentors, merely reflecting trainee's expertise. Certain aspects of this method hinder technical training of the trainees. However, artificial intelligence (AI) can help us revolutionize surgical education and training. Artificial intelligence (AI) is defined as capability of a computer to perform actions analogous to actions performed by human brain. It can be used to objectively evaluate the surgical skills of a training surgeon.

OBJECTIVE of this study was to give a comprehensive outline of impact of artificial intelligence on surgical training and education.

METHODS A systematic computerized search was done on 7 February 2021 in PubMed. Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines were followed to carry out this systematic review. Keywords used for search were ("Artificial intelligence") AND ("Surgical education" OR "Surgical training"). All the articles published from 2019-3-1 to 2021-2-25, which met our inclusion criteria were added. Only articles in English were added. Following PRISMA guidelines 700 articles were identified, out of which 83 articles were selected after reading the title. 30 articles were selected after reading the abstract and 16 articles were finally selected for thematic analysis and literature review after reading the full text paper.

DISCUSSION & CONCLUSION AI can revolutionize surgical education and training. It can be used for Surgical Skill Assessment and optimizing the training of surgeons. It can help in objective assessment of the trainees. AI is extensively used in the field of ophthalmology, plastic surgery and vascular surgery. It has also found its application in radiology and diagnostics.

KEYWORDS Artificial Intelligence, AI, Machine Learning, Neural Networks, Surgical education, Surgical training

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Systematic Literature Review

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Dr. Halstead is esteemed as one of the most innovative surgeons in the history of surgical training. His greatest contribution was the integration of teaching basic sciences and clinical skills in training of young surgeons. His method of training mainly focused on training full time teachers. However, this traditional method of surgical training has several drawbacks. It is mostly centered on apprenticeship and shadowing. Assessment of technical skills is dependent largely on mentor. Active feedback from mentors is subjective and merely a reflection of trainee's work. Different surgical procedures have variable patient volume which becomes a hindrance in the technical training of a surgeon. Moreover, cadavers are expensive and often inaccessible in several countries. Passive learning from classroom is necessary for building foundational knowledge, however, it requires translation of 2D images and textbooks in practical dimension for teaching essential technical skills.

John McCarthy first used the term artificial intelligence (AI) in 1956 [1]. Artificial intelligence (AI) is defined as capability of a computer to perform actions analogous to actions performed by human brain. It can be used to evaluate a surgeon's surgical skills. Deep learning and machine learning are two important branches of AI. Machine learning deals with development of computer programs that improve with experience automatically while deep learning is concerned with development and application of artificial neural networks (ANNs). AI can be incorporated into surgical training and education to provide an objective method for assessment of surgical skills of a trainee, through its application in robotic surgery, virtual reality based surgical training and post-op analysis of surgical videos.

This systematic literature review will provide an outline of the tools available within ML for surgical training, and their efficacy in different fields such as ophthalmology, neurosurgery, cardiac surgery, laparoscopic surgery, and endoscopy. In addition, effectiveness in objective skill assessment and calculating accurate learning curves are also reviewed in this article.

METHODS

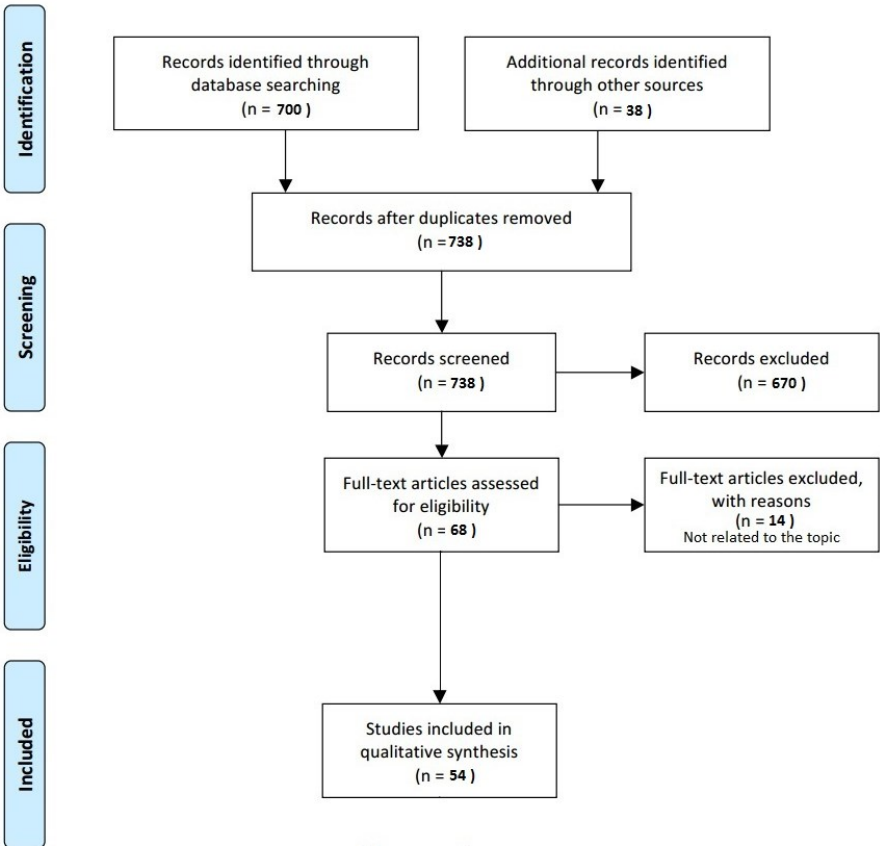
Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines were followed to carry out this systematic literature review

2.1. Literature Search Process: Following PRISMA guidelines, a systematic literature search was done in database of PubMed using search terms ("Artificial intelligence") AND ("Surgical education" OR "Surgical training"). All papers published from 2019-3-1 to 2021-2-25 were filtered out. Additionally, the reference research papers were also included in the review.

2.2. Inclusion of Articles & Data Synthesis: Following PRISMA guidelines 700 articles were identified. No paper was excluded for duplication. 83 articles were selected after reading the title. 30 articles were selected after reading the abstract and 16 articles were finally selected for thematic analysis and literature review after reading the full text paper. Only Full-text English language papers were selected. Studies that were not related to the topic were not included. Selection process is presented in a flow diagram in figure 1.

A thematic analysis of each paper included in the study was done. The themes identified through the analysis is described in the table given in the end.

Figure 1: PRISMA Flowchart- Article selection process through computer literature search and analysis:



RESULTS & DISCUSSION

3.1. Artificial Intelligence Based Surgical Skill Assessment

Evaluation of surgical skill is usually done by reviewers who watch the video of surgical videos postoperatively. Now AI can be used to identify different steps of procedure in the

surgical video which can be helpful for the evaluation of the surgical skill. [2,3] The surgical action can be detected using AI. One study used deep learning model which could detect the surgical action with mean recall of 94% and a mean precision of 91% and. It was also able to tell the surgical skill level of the operator with the mean recall of 78% and a mean precision of 77%. [4] This type of systems can be used in the surgical training for optimizing the training of surgeons. Several studies show that there is a relation between hand motion of an individual and their skill level in surgery [5,6]. This information can be used to evaluate the surgical skill level of a surgeon. A deep neural network algorithm was developed and trained using data collected with wearable inertial measurement unit sensors attached to the surgeon. The system achieved an accuracy of 98.2% in telling the skill level of the surgeon[7]. Assessment of surgical skill with AI requires a lot of expensive equipment. One study tried to solve this problem by using data in form of videos collected from JIGSAW database. 3D Convolutional neural network (CNN) was trained with that dataset which was able to classify participants based on their skill level with an accuracy of 95.1% to 100%[8]. Robotic surgery has given us an opportunity to gather the kinematic data from the surgical procedures performed by the robot. This data can be used for the assessment of surgical skill by using artificial intelligence. Early studies used kinematic data to extract GMFs (Global Movement Features) such as smoothness of motion, task speed, task completion time etc. but results of those models depend on quality of extracted features [9]. Recent studies do not use GMFs, instead surgical task is broken down into surgical gestures before training phase and then evaluation of the skill of surgeon is done by their performance during the gesture. This technique require manual segmentation into gestures which is an expensive and time consuming process [10]. A recent study used only kinematic data collected from JIGSAW database of surgeons with different surgical skills which was used to train a Convolutional neural network which was able to categorize the surgical skill. Using this approach the amount of expense required for the process can be minimized[11]. Video commentary is another way of evaluation of surgical expertise of a surgeon. In this technique surgeons are shown videos of surgical procedures and they are asked to say all the anatomical landmarks, instruments, and steps of procedure shown in the videos. They are then scored on the basis of video commentary. Machine learning can be used to increase the productivity of this technique. In a study the relation between the PGY level of the surgeon and their individual video commentary (VC) score was investigated. The results of that study demonstrated that a correlation was present between them. However, there are some limitations like ML based system overestimates the skill of PGY1s and underestimates the skill of PGY3s and PGY4s. Selection of video for video commentary (VC) was also a hurdle because selection of video affects the result. The sample size selected for that study was also very small[12]. AI can also be used to optimize the surgical training by its capability to foretell the surgical learning curve of the trainee. A supervised machine learning model was trained by learning curves data taken from virtual basic laparoscopic skill trainer and physical FLS trainer box. This model had the ability to predict surgical learning curve from data collected from first few trials of the trainee. This prediction can help us build a personalized training program designed to train surgeons based on their varying surgical learning curves. Unsupervised machine learning approach was also used which was able to classify surgical trainees in accordance with their different surgical learning curves. Results of that study showed that data from only a few trials is sufficient enough to foretell the total number of trials needed to become proficient. It was also capable of predicting the final skill level of the trainee after the 40th trial[13]. This data can help us model an objective surgical training system where number of surgical procedures each trainee needs to do to achieve proficiency will be assessed by machine learning algorithms. This approach can save time and money of the trainees and trainers.

3.2. Artificial Intelligence in Radiology and Diagnostics

We can train algorithms to detect patterns in the data. This ability can be used in the field of radiology and diagnostics where we can use artificial intelligence to train algorithms to detect pattern in radiological findings. AI has been used to interpret the finding of CT, MRI and PET images[14]. Table 1 shows all the FDA approved AI systems used in different clinical indications[15]. AI can also help in identification of malignancy which can help the surgeon to decide whether a growth is malignant or benign[16,17]. AI can also help in diagnosis of different medical conditions like appendicitis[18,19].

Manufacturing Company	Date of approval by FDA	Indication
Apple	Sep 2018	Detection of Atrial Fibrillation
iCAD	Aug 2018	Breast Density via mammography
Aidoc	Aug 2018	Brain hemorrhage diagnosis on CT
Neural Analytics	May 2018	Diagnosis of stroke
IDx	Apr 2018	Diabetic retinopathy diagnosis
Zebra Medical	Jul 2018	Scoring of coronary calcium
Bay Labs	Jun 2018	Determination of Ejection Fraction on Echocardiogram
Viz.ai	Feb 2018	Diagnosis of stroke on CT
Arterys	Jan 2017	Interpretation of MRI heart
Alivecor	Nov 2017	Watch
MaxQ-AI	Jan 2018	Brain hemorrhage diagnosis on CT

3.3. Artificial Intelligence and Robotics

Surgical Skill Assessment:

With the advances in robotic surgery it is possible to get data from the robot in many forms. It can be in form of video data or in form of kinematic data. Processing this vast amount of data is an expensive and time taking task but with the use of machine learning it is doable. Initial studies used kinematic data for skill assessment. For AI based surgical skill evaluation, kinematic data using global movement metrics i.e. depth perception, task completion time, smoothness of motion, length of path, velocity, curvature etc. have been used[20]. Similarly the surgeon's movement style can also be used to assess the surgical skill. This can be done by using electromagnetic sensors attached on the shoulders, wrists and hands of the surgeon[21]. Robots like Da Vinci can collect data like motion of camera and surgical instrument which can be classified by machine learning according to the surgical skill of trainee [22]. Tool based metrics and cognitive based metrics have also been applied to classify expert and non-expert surgical trainees by machine learning [23, 24].

Haptic Feedback:

Modality of touch is very important in surgical training. Robotics have made it possible to gauge the tactile force being applied by the surgeon. Machine learning has been applied to develop a system which gives warning of suture breakage when the tactile force is strong enough to break the suture. This ML based system was successful in decreasing the rate of suture break [25,26].

Autonomous Robots:

Even though robotics is still very primitive still surgical automation is not so far[27]. Primary focus of Initial efforts have been on deconstruction of the task and carrying out of simple tasks like suturing. Now AI based robot can perform superior bowel anastomoses in porcine tissue [28,29].

3.4. Artificial Intelligence and Surgical Logistics

AI can be used to minimize the cost of procedures and save the precious time. The cost of surgical procedures can be reduced by accurate prediction of operating time[30]. Machine learning can be used for this purpose. A machine learning system has been developed which can predict the operating time with 16.8% accuracy[31].

3.5. Application of AI in the Surgical Procedure

AI can help us detect the important anatomical landmarks in a surgical procedure. A survey involving surgeons was carried out and 40.5% respondents of the survey said that the injury of bile duct they faced during laparoscopic cholecystectomy was due to misidentification of anatomical landmarks[32,33]. An object detection algorithm called YOLOv3 was trained with short videos to detect 4 anatomical landmarks i.e., cystic duct, Lower edge of left medial segment, common bile duct and Rouviere's sulcus. Although, for each landmark average precision was not good but YOLOv3 model detected important landmarks to avoid bile duct injury in 22 of 23 videos[34]. The surgical instrument detection during laparoscopic procedures using AI is also possible which can help us in surgical training. A system using neural network was developed and trained which was able to decipher surgical instruments manipulation in recordings of laparoscopic gastrectomies with an accuracy of 87% and a recall of 83% [35].

3.6. Artificial Intelligence and Virtual Reality (VR)

Virtual Reality can be used as a tool for the surgical training. The data gathered from the procedures done in the VR is sufficient enough to assess the surgical skill of the trainee. In a study, a support vector machine algorithm was used on the data gathered from the hemi-laminectomy done on VR by different surgeons of varying surgical skills. It achieved 97.6% accuracy[36].

AI based VR training has also been used in neurosurgery. Using 4 metrics of safety of safety and movement a framework called virtual operative assistant was created. This provides a metric wise assessment based on weight of each metric. This can be applied to evaluate the skill level of the trainees[37]. Another AI aided VR study was carried out for neurosurgical tumor resection skill assessment. Using machine learning participants were classified into 4 levels based on their skill level with an accuracy of 90%[38]. Similarly VR simulated anterior cervical discectomy was done in which 21 individuals participated. Using 16 metrics neural network was trained which classified the participants according to their skill levels with testing accuracy of 83.3% and training accuracy of 100% [39].

AI based VR systems are very useful for surgical training but it is very difficult to develop them and the inter specialty communication is not good. MLASE (Machine Learning to Assess Surgical Expertise) checklist was designed to bridge the gap between different specialties. The checklist includes 4 sections i.e. quality of discussion, design of the Study, Structure of Data and Supervised Machine Learning which are further divided into subsections which are given certain points. This checklist provides a scoring system to assess the AI based VR system capable of assessing the surgical expertise.

A systematic literature review was done and each selected paper was scored according to the MLASE checklist. Results showed that score of medical articles were lowest in structure of data and supervised machine learning and it was highest in quality of discussion. Engineering papers showed lowest scores in quality of discussion and highest in study design and supervised machine learning [40]. An interdisciplinary communication is necessary to bridge the gap.

Year	Article	Author(s)	Research method	Themes Identified
2020	Video Commentary & Machine Learning: Tell Me What You See, I Tell You Who You Are	Mohamed S Baloul , Vicky J-H Yeh , Fareeda Mukhtar	Secondary Analysis Study	Using AI to find a Correlation between Individual's skill and Video commentary score
2020	Machine Learning and Artificial Intelligence in Surgical Fields	Melissa Egert , James E Steward , Chandru P Sundaram	Literature review	A review of use of ML and AI in different surgical fields
2019	Artificial intelligence and robotics: a combination that is changing the operating room	Iulia Andras , Elio Mazzone , Fijs W B van Leeuwen	Narrative literature review	Application of Artificial intelligence in robotics
2020	Development of an artificial intelligence system using deep learning to indicate anatomical landmarks during laparoscopic cholecystectomy	Tatsushi Tokuyasu , Yukio Iwashita , Yusuke Matsunobu	Prospective study	AI assisted detection of anatomical structures; Application of AI in procedures
2019	Artificial Intelligence in Medical Education: Best Practices Using Machine Learning to Assess Surgical Expertise in Virtual Reality Simulation	Alexander Winkler-Schwartz , Vincent Bissonnette , Nykan Mirchi	Prospective study	AI based skill assessment in Virtual Reality (VR) and Simulations
2020	The era of artificial intelligence and virtual reality: transforming surgical education in ophthalmology	Shaunak K Bakshi , Shawn R Lin , Daniel Shu Wei Ting	Review article	Use of AI in ophthalmology
2020	The digital surgeon: How big data, automation, and artificial intelligence will change surgical practice	James Wall , Thomas Krummel	Review article	Artificial intelligence shaping the future of surgery
2020	VR and machine learning: novel pathways in surgical hands-on training	Domenico Veneziano , Giovanni Cacciamani , Juan Gomez Rivas	Systematic Review	AI based skill assessment in Virtual Reality (VR) and Simulations
2019	Machine Learning Identification of Surgical and Operative Factors Associated With Surgical Expertise in Virtual Reality Simulation	Alexander Winkler-Schwartz , Recai Yilmaz , Nykan Mirchi	Prospective study	AI based skill assessment in Virtual Reality (VR) and Simulations
2020	Evaluation of Deep Learning Models for Identifying Surgical Actions and Measuring Performance	Shuja Khalid , Mitchell Goldenberg , Teodor Grantcharov	Prospective study	AI based surgical skill assessment
2019	Surgical skill levels: Classification and analysis using deep neural network model and motion signals	Xuan Anh Nguyen , Damir Ljuhar , Maurizio Pacilli	Prospective study	AI based surgical skill assessment
2019	Video-based surgical skill assessment using 3D convolutional neural networks	Isabel Funke , Sören Torge Mees , Jürgen Weitz	Prospective study	AI based surgical skill assessment
2020	A machine learning approach to predict surgical learning curves	Yuanyuan Gao , Uwe Kruger , Xavier Intes	Prospective study	AI based prediction of surgical learning curves
2019	Accurate and interpretable evaluation of surgical skills from kinematic data using fully convolutional neural networks	Hassan Ismail Fawaz , Germain Forestier , Jonathan Weber	Prospective study	AI based skill differentiation from kinematic data
2020	Automated Surgical Instrument Detection from Laparoscopic Gastrectomy Video Images Using an Open Source Convolutional Neural Network Platform	Yuta Yamazaki , Shingo Kanaji , Takeru Matsuda	Prospective study	AI based detection of surgical instrument manipulation in video recording
2020	Artificial Neural Networks to Assess Virtual Reality Anterior Cervical Discectomy Performance	Nykan Mirchi , Vincent Bissonnette , Nicole Ledwos	Prospective study	AI based skill assessment in Virtual Reality (VR) and Simulations

Table describing the overview of studies included in the literature review.

3.7. Artificial Intelligence in Surgical Education in Ophthalmology

A vast amount of literature has been written on the recent boom of application of AI in ophthalmology. FDA has approved a diagnostic system for the diagnosis of diabetic retinopathy[41, 42]. The surgical performance of trainees can be assessed using machine learning. Convolution neural networks (CNNs) have been developed which are capable of detecting surgical tools which gives means of identifying context and stage of the procedure [43,44,45]. This can be used for post op evaluation and assessment of resident's surgical performance. CNNs have also been used to evaluate the trainees' skills in capsulorhexis using cataract surgery videos [46]. Intraoperative guidance and feedback based on AI can be a possibility. One study showed phase recognition in 23 cataract surgeries using inception V3 network. Detection of instrument position and orientation by tool tracking system can also help the surgeon to orient themselves[47]. AI can also predict surgical outcomes. It is already possible to predict endophthalmitis rates after cataract surgery [48,49].

3.8. Role of Artificial Intelligence in Plastic Surgery

Artificial intelligence is being applied in burn surgery, microsurgery, craniofacial surgery, hand and peripheral nerve surgery, and aesthetics. Surgical skill assessment by artificial intelligence is getting accepted in the realm of plastic surgery. The post op outcome is very important when it comes to plastic surgery. AI can help to identify individual technique being applied during the procedure that leads to a particular outcome. Recognizing this relation between the technique and its post op outcome can help the residents to minimize the post op complications[50]. AI is also being applied in the field of aesthetics. AI has been applied to detect what people regard as aesthetic and their emotional reaction to procedures related to cosmetics which can help us in deciding the surgical plan of action and it can also be used in the personalized counselling of the patient [51,52,53].

3.9. Role of Artificial Intelligence in Vascular Surgical Education

With the very fast paced increase in medical literature it is very difficult to stay updated with the recent literature. AI can help in literature search and management of bid datasets which can help in the medical research [54,55]. Laparoscopic training is very important in vascular surgery. Now a laparoscopic training system capable of surgical skill is created by artificial neural network (ANN). With the use of that system an increase in the surgical dexterity and learning curve was observed[56]. Electronic medical records can be used for predictive analysis by AI for the betterment of medical education. To standardize the clinical training AI can be used to predict least number of procedures a trainee should perform to get the desired results [57,58,59]

LIMITATIONS

Not enough literature is available in this area. We need more research done in this aspect to incorporate artificial intelligence in surgical training and education.

ETHICAL CONSIDERATIONS

Existing code of ethics do not consider the use of interactive artificial intelligent agents in our healthcare system. A comprehensive discussion is needed to tackle with the ethical issues of trust, privacy, and safety of the patient.

FUTURE PROSPECTS:

Artificial intelligence is being used in preoperative planning, intraoperative guidance and robotics. Diagnostics is one of the most important field in which AI will play an integral role. Radiomics is a method which uses radiographic imaging and machine learning algorithms to enhance diagnostic accuracy. It has found its application in the field of oncology. It can diagnose different types of cancers with great accuracy [60,-62]. Recently radiomics has been used for detection of Covid-19[63]. Radiomics can help the future medical practitioners in making the correct diagnoses. In future clinical decision making will be a major application of artificial intelligence. Bayesian networks are already able to help us determine if patients with arterial injuries due to limb trauma would benefit from revascularization [64]. This ability of AI to help us in clinical decision is going to improve with time. Another field which has been strongly influence by AI is robotics. Autonomous robots can be utilized in the future to perform surgical procedures all alone without the assistance of specialists.

CONCLUSIONS

Artificial intelligence is still in its primitive stages but a lot of research is focused on the development of this field. Incorporation of AI can revolutionize the surgical training and education. Efforts should be focused on educating the medical professionals about artificial intelligence and bridging the interdisciplinary gap between different fields interested in implementing machine learning in medical training and education.

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