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Research

Application of Artificial Intelligence in Orthopaedic Training: Current Scenario and Future Perspective

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Abstract

Background: Knowledge and skill enhancement of post graduate students is crucial in Orthopedic Residency training. The conventional Methods of training are based on apprenticeship and methods of assessment are very subjective and time consuming. However, incorporation of different AI techniques can help in reforming orthopedic education and training by an Algorithm based simulators with the assistance of other computational programs. Therefore, this article has been aimed to discuss the status of utility of AI based techniques in orthopaedic surgical training and education.

Methodology: Total 24 research articles have been reviewed. Articles were searched from electronic database like Pub-Med, Medline and Google Scholar. Artificial intelligence, orthopaedic training, Machine learning and simulations were the key words used to ease the search process.

Results & Discussion: Out of 24, 13 articles were selected for writing this article further as those were considered more relevant to the topic. After reviewing all relevant literature, the utility of AI techniques in orthopaedic training can be discussed under following subheadings: i) Artificial intelligence based simulation techniques ii) AI based diagnostic support: iii) Special considerations during pandemic and iv) Limitations of the technique and future applications.

Conclusion: Since last decade, researchers have been designing many studies to validate and establish the AI and machine learning techniques as an important training tool for orthopaedic trainees. These computational techniques have great potential to develop highly effective patient specific simulators to enhance the training and support the assessments. Adequate changes in the curriculum are required to use AI based techniques as the learning tools.

***Keywords:** Artificial intelligence, orthopaedic training, Machine learning and simulations*

1. Introduction

Traditional medical education consists of a mixture of didactic lessons with periodic clinical and surgical apprenticeship based experience. The apprenticeship model is challenging due to the lack of opportunities to trainees for exposure in performing variety of procedures and by the need to ensure patients safety while exposing trainees to new experiences [1].

In the current scenario, there is shift towards competency based curriculum, due to which surgical educational paradigms are evolving which includes assessments and training for further development of surgical skills. Implementation of new technologies offers more objective approach towards surgical skill evaluations [2]. Orthopaedic training involves psychomotor skill development and hands on physical examination techniques [3]. The necessity of incorporation of these technologies in orthopaedic training is accelerating at incredible rate. The use of these technologies allows automation of traditional form of teaching and re-defining educational goals, which helps in understanding complex tasks [4].

Surgical skills are difficult to teach and master as they require more extensive knowledge and challenges to work with junior doctors or surgical fellows [5]. In surgical education, simulation is gaining more and more attention, due to imposition of restriction on working hours, financial pressure, and increased public scrutiny. Simulation provides immediate and detailed feedback that can improve learning efficiency [6]. It includes various methods such as animal models, porcine cadavers, bench top models and virtual reality simulators [7].

Virtual reality simulators quantify multiple aspects of psychomotor skills during surgical procedure. This method is valid and reliable for surgical tasks [8].

Large amount of data is collected from individual technical performance, which is then analysed and provides feedback to the operator. This method is more prone to subjectivity and is highly resource dependent. Hence there is need for objective and automated methods which are capable of analysing extensive amount of information for simulation based training in orthopaedic surgery. Digital technologies along with educational and training plans help ~~in~~ quantify~~ing~~ performance skills and the understanding of complex tasks with a new perspective [9, 10].

The novel and flexible teaching method for teaching simulation based training in orthopaedic is utilizing Artificial Intelligence (AI). It is new technical science for development and formation of methods, techniques for simulation and extension of human intelligence. Artificial Intelligence provides machines the ability to identify pattern, solve problems without explicating programming, which traditionally requires human intelligence. The machine mimics cognitive function of human being such as learning and problem solving. This term was coined by John Mc Carthy in 1956 with aim to allow a machine (computer) to perform a specific task which can match or exceed human performance [11].

AI includes broad range of subfields such as Machine Learning (MI), which in turn contains a subfield called as Deep Learning (DL). These two algorithms are the cornerstone of AI which helps in decision making pathways [12].

The application of Artificial Intelligence in Orthopaedic training helps in greater learning capability, data processing ability, image recognition, preoperative risk assessment, assisting surgery, guiding rehabilitation etc. [13]. The purpose of the present review is to provide background of AI, relevant application in orthopaedic training and challenges with its use.

2. Methodology

The article has been prepared after reviewing 22 published articles collected from electronic database e.g. PubMed, Medline and Google Scholar. The data search was done with the help of following key words: Artificial Intelligence, Machine learning, Orthopedic training, Simulations. The obtained information had been arranged and discussed under various headings and subheadings.

3. Discussion

3.1 Artificial intelligence based simulation techniques

Simulation based techniques, for example, NeuroVR (NeuroTouch) and Simortho, have been an important part of surgical training for years. However, the assessments of the performance and feed-back generation have been problematic tasks while using such techniques. For the regular assessments, trainees must be dependent on large number of surgical examiners and susceptible to each examiner's subjective approach. (9) Automation of simulation based surgical training techniques can be helpful in providing the instant feed-back with detailed objectives.

The task of automation of educational tools can be performed with the help of artificial intelligence. The extensive amount of data is generated by virtual reality based simulators. AI and machine learning can be applied on that data to quantify the performance and provide the feed-back. Ryan Lohre et al investigated the effectiveness of immersive virtual reality (IVR) based educational tool over the video training in complex skill acquisition. Total 18 senior surgery residents participated in the study for performing the reverse shoulder arthroplasty, along with three expert surgeons as evaluators. By conducting a randomized interventional controlled trial, the researchers demonstrated the superiority of IVR based tools as compared with normal Video instructions.

By using Objective Structured Assessment of Technical Skills tool (OSATS) score as a primary outcome measure, the IVR group of residents had outperformed the control in three key areas: i) acquisition of procedural knowledge, ii) pathology recognition and iii) decision making. In addition, to determine the validity, transfer of training scores (ToT) have been calculated as 59.4% for IVR simulator as compared with the experienced surgeons. ToT represents the reduction in early learning curves by training with simulators. This score was achieved after performing 51 RSA surgeries and can be improved with higher number of performed complex surgeries. (14)

Similarly, in another study, virtual reality based knee arthroscopic simulator was used for the assessment of surgical skills. The simulators were automated by the predefined metrics for five arthroscopic procedures and analysed the performance of 13 naive and 13 experienced arthroscopic surgeons for each procedure type. To test the basic competencies, the VR based simulators were found valid for four out of five procedures that belong to knee arthroscopy with inter case reliability of 0.87. The investigators observed a significant difference between mean z- score of naive and experienced surgeons i.e. 0.0 ± 9.1 and 38.6 ± 27.3 respectively (p value < 0.0005). The study recommends that based on the fed metrics for four arthroscopic procedures, the virtual reality simulator can be used as a valid, reliable and feasible testing tool to check the basic competencies of the performer. (15)

The utility of VR based simulators as an objective measure of the performance of surgical skills has been further supported by a recent study, conducted by Palet M J et al. (16)

The ARTHRO Mentor; a knee arthroscopic simulator was used to determine the validity for surgical training. It was a comparative cross sectional study. Two groups, one was of second year Orthopaedic residents, and another was of expert orthopaedic surgeons. They had to perform the standardized tasks in Knee arthroscopy virtual simulators. Their performance record was generated based on completion time, the accuracy of camera and instrument use, percentage time in partial and perfect alignment, arthroscope path distance, and camera path distance. Camera collisions with the tissue and capsule, blind use of instruments, and iatrogenic chondral damage were the parameters recorded in advanced procedures. The difference between novice and expert group scores were significant for 50% of basic procedures and 64% of the advanced procedures.

3.2 AI based diagnostic support

In the field of personalized medical education, AI based educational tools have been observed helpful as predictive or diagnostic tool during the learning years in orthopaedics. Chi-Tung Cheng et al conducted a study on identification of hip fracture based on the image learning procedure. In this retrospective study, they collected a total of 3605 cases, (1975 were with hip fractures and 1630 were without hip fracture) pelvis anteroposterior (AP) view radiographs (PXRs), and developed AI based Hip guide by using deep learning algorithm DenseNet-121. For validation of the developed model, 50 hip fractures and 50 normal PXR were put into the system. The system has shown 91% accuracy and 98% sensitivity in identification of hip fracture. After the validation, the Hip guide model was aimed to apply on fifth year undergraduates to develop their learning while their clinical posting in orthopaedics. Total 34 students were enrolled and divided randomly into AI assisted learning group and conventional learning group. The overall gained score which reflects their ability to identify the hip fracture image accurately was the outcome measures. In CL group, post learning test score (78.66 ± 14.53) was higher than pre learning test score (75.86 ± 11.36) but the difference was not significant. Whereas, in AI group, the post test scores (88.87 ± 5.51) were significantly higher than the pre-test score (75.73 ± 10.58). Hence, in the study of Hip fracture detection, AI assisted learning tools have been observed empowering the students' knowledge and in turn the diagnostic skills. (17)

In another study, Oh et.al. used machine learning along with CT imaging and other clinical features to diagnose and for the prediction of the femoral fracture due to metastatic lung cancer. The efficacy and accuracy of this model in identification of pathology was compared with the use of only CT imaging features. They found the machine learning model with higher predictive ability to detect the prediction of femoral fractures as the manifestation of metastatic lung carcinoma. (18) On prediction of survival, in cases of long bone metastasis, the machine learning's Bayesian Model has been observed with best performance so far. The algorithm is developed based on demographics, tumor characteristics, treatment and outcome data. Many authors have found this useful in decision making and survival prediction for up to one year. (19)

3.3 Special considerations during pandemic

For two years, COVID pandemic had been imposing its profound effects on healthcare education and training. The most impacted are the surgical streams as orthopaedics. Residents were posted in pandemic wards; quarantine periods and elective surgeries had been postponed as a result. This lead to inadequate exposure to the trainees and their training hence falling short of practice.

Simulation techniques loaded with virtual reality (VR) and 3D visualization have a good potential to maintain the skill acquisition and provide psychomotor training for various surgical tasks.

The various modalities in which effective orthopaedic surgical training has been seen are surgical skill laboratories, cadaveric dissection and procedural training; computer based virtual reality training and arthroscopic surgery simulations. The observational studies performed with using such modalities, have found the improved surgical education. The residents who underwent the training offered by intensive surgical skill laboratory have developed significantly higher core surgical skill as compared to other residents who received the traditional training and education. (20)

Hip fracture fixation is one of the first skills that an Orthopedic trainee performs using 2 dimensional x-ray images and corrects it by inserting three dimensional implants in the bone. This skill is possible to learn either in operation theatre under supervision or in dry bone workshops. Availability of both the learning facilities has been hampered in the pandemic situation. The simulation models based on virtual reality can be considered as a promising alternative. Blyth. et al., developed and performed the initial testing of simulation based VR training system for hip fracture fixation. The system comprises of operative segment and assessment segment. The simulators were available for 10 types of operating scenarios according to their complexities. Simulator guided the hip fracture fixation on a virtual hip model with the help of two dimensional radiographic images. A total of 10 orthopaedic surgeons participated and minimum 6 surgeries were performed by each. To check the face validity, the participants had to fill the 26 item feed-back questionnaire form. Most of the participants considered the model useful as it had good face validity, realistic view of operating environment (median score 8.2 / 10) and three dimensional view (median score 7.8 / 10). (21)

3.4 Robotics in Orthopaedics

Tele-operations assisted by robots have been evolved with tremendous growth in the last decade. Along with some certain benefits such as enhancement of accuracy of motion, achievement of ergonomically operating posture, faster recovery and lesser duration of hospital stay, robotic assisted tele-surgeries play a significant role in maintaining the protocols during pandemic. It provides the physical separation between surgeon. The patient and Operating Room staff which will undoubtedly contribute to improving infection control.

Recently, with the advancement in machine learning, the robotic surgeries can be conducted in semi-autonomous and fully autonomous ways. The combination of AI with the teleoperation task can train the model for a certain procedure and can be used to perform that procedure autonomously in the future, although the accuracy of autonomous AI based models have not yet been proven clinically as they are yet in non-clinical developmental stage. However, the integration of AI with robotic procedures seems to be useful in training of novice surgeons.

Implication of AI in robotic Orthopedic surgery can improve the learning of residents and undergraduates at the preclinical level and bedside both. During lab practices, robotic simulators based on virtual reality system help advance the students' surgical skills. In the more advanced forms, the dual-user teleoperated system provides real time feedback to novice surgeons by generating haptics-enabled cues. Therefore it gives the opportunity of learning which is comparable to being under the supervision and guidance of an experienced surgeon. Mimics, developed by experience team trainer, are one of the examples of such technique which provides the bedside assistance to improve the co-ordination between surgeon and assistant. (22)

Due to non-performance, motor and cognitive loss of surgical kills is another ill effect of COVID -19 pandemic. AI based simulations may fill the gap in education and surgical practice with providing evaluations by trained computational models. (23)

3.5 Limitations of the technique and future applications

There are four levels of Miller's model of learning and assessment of a medical student:

i) Knowing that is acquiring knowledge about the procedure.

ii) Know how, that is the ability to describe the procedure.

iii) Show how, that is the ability to demonstrate the task at laboratory level and lastly

iv) Doing, that is the ability to perform on real patients.

As the model progresses towards advanced levels, the use of AI based simulation procedures becomes more significant. When compared with normal laboratory practical set up, the simulations loaded with machine learning techniques provide more hands on experience for simple to complex surgeries with more objective evaluation of residents as well. (16)

Orthopedic training involves psychomotor skill development and hands-on physical examination techniques along with the development of diagnostic abilities and prediction of outcomes. As per the reviewed literature, the learning with AI based simulators happens quickly with being more informative and objectively assessed. However, there are few technical and functional limitations while its application to train the orthopaedic residents. The first technical limitation is regarding the simulation burr and suction instruments which are not similar to the real surgical devices. Secondly, for more complex procedures, the haptic feedback system can't provide the adequate discrimination among the operators. However, the inclusion of objective structured assessment of technical skills (OSATS) while training the model can be a better evaluation tool. Third, to implement the AI and VR based modelling in the curricula, the validation of the learning tools is required which is still in developmental phase. (10) More studies, varying in types of procedures, their complexities and higher sample sizes can offer better and reliable results for implementing the AI techniques into learning tools.

The limitations regarding functionality arise due to lack of efficient integration of AI based learning tool into formal course design, implementation and course evaluation. Khamis et.al. designed a six step of curriculum development for designing the simulation based courses and assessed the usage, user friendliness and perceived effectiveness of the curriculum model.

The steps were following:

i) Problem identification and general needs assessment,

ii) Targeted needs assessment,

iii) Goals and objectives,

iv) Educational strategies,

v) Individual Assessment and Feedback and

vi) Program evaluation.

The feed- back collected from various centres regarding the 6 step curriculum model has shown that it has been found to be user friendly and helpful in providing the systemic and comprehensive approach for designing and objective assessment of the simulation based programmes. It was a multiprofessional and multinational study, including the respondents from educational institutes, healthcare facilities and scientific societies. The highest reported benefit while implementing the stepwise simulation based curriculum plan was the knowledge gain (63%), followed by learners' satisfaction (50%). (24) Such multi-dimensional structure of educational plan can be developed and assessed on a larger cohort of institutions before its future implications.

Conclusion

AI assisted techniques can act as complementary process of skill enhancement providing repetitive practice without putting any harm to the patient. Future of applications of AI techniques in orthopedic training is found promising as indicated by various studies which are being performed to validate AI based virtual models and tools. These techniques have great potential to develop high fidelity patient specific simulators to complement the residency training. In addition to that, the AI can help in the development of non-simulating training tools such as tele-mentoring by robotic methods to provide real time knowledge transfer to build the orthopedic competencies. With the rapid advancement of incorporating technology into surgeries, it is the need of time to conduct large randomized controlled prospective studies along with optimal curricular changes to transform the studied techniques into established learning and assessment tools.

Conflict of Interest

The author declares no conflict of interest.

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