Current understanding on artificial intelligence and machine learning in orthopaedics – A scoping review[☆]

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ABSTRACT

Background: Artificial Intelligence (AI) has improved the way of looking at technological challenges. Today, we can afford to see many of the problems as just an input-output system rather than solving from the first principles. The field of Orthopaedics is not spared from this rapidly expanding technology. The recent surge in the use of AI can be attributed mainly to advancements in deep learning methodologies and computing resources. This review was conducted to draw an outline on the role of AI in orthopaedics.
Methods: We developed a search strategy and looked for articles on PubMed, Scopus, and EMBASE. A total of 40 articles were selected for this study, from tools for medical aid like imaging solutions, implant management, and robotic surgery to understanding scientific questions.
Results: A total of 40 studies have been included in this review. The role of AI in the various subspecialties such as arthroplasty, trauma, orthopaedic oncology, foot and ankle etc. have been discussed in detail.
Conclusion: AI has touched most of the aspects of Orthopaedics. The increase in technological literacy, data management plans, and hardware systems, amalgamated with the access to hand-held devices like mobiles, and electronic pads, augur well for the exciting times ahead in this field. We have discussed various technological breakthroughs in AI that have been able to perform in Orthopaedics, and also the limitations and the problem with the black-box approach of modern AI algorithms. We advocate for better interpretable algorithms which can help both the patients and surgeons alike.

1. Introduction

Artificial intelligence (AI) are machines and algorithms which are supervised, simulate intellectuality like a human, and have rational thinking and self-rectifying potential.[1] One of the major responsibilities in the health delivery system is providing a better quality of care. Artificial intelligence has a broad spectrum of applications in medical science, helping in providing improved healthcare delivery and minimizing medical errors. In orthopaedics, AI helps in the careful evaluation of radiological images, training of surgical residents, and excellent performance of machine-assisted surgeries.[2,3]

In 1956, Prof. John McCarthy put forward the idea of AI, to reproduce the intelligence of humans using a machine/computer with minimal human involvement.[1,4] AI was possible with the help of matching the patterns, algorithms, machine learning, and cognitive computing. It includes information, reasoning, and self-correction capability. With the recent advances in affordable computational power and rapid growth in unusual enormous data sets ("Big Data"), AI has blossomed from mere hypothesis to unquestionable implementation on an exceptional stratum.[4]

AI has a broad spectrum of subcomponents, including machine learning (ML), which consists of a subdivision called deep learning (DL).[5,6] ML is an advanced subset of AI that uses complex computer-based algorithms to model complex relationships between variables.[7] DL is a subset of AI that uses a network of neurons.[8] It uses a combination of units wherein each unit is a neuron cell. With the evolution of technology and the growing use of AI, we feel AI is the future of patient management in Orthopaedics and trauma. This technology has

Table 1
Search strategy and keywords used.

Search strategy	Keywords and MeSH terms
1	**artificial intelligence** artificial intelligence"[MeSH Terms] OR ("artificial"[All Fields] AND "intelligence"[All Fields]) OR "artificial intelligence"[All Fields]
2	**machine learning** "machine learning"[MeSH Terms] OR ("machine"[All Fields] AND "learning"[All Fields]) OR "machine learning"[All Fields]
3	**deep learning** "deep learning"[MeSH Terms] OR ("deep"[All Fields] AND "learning"[All Fields]) OR "deep learning"[All Fields]
4	**((artificialintelligence) OR (machinelearning)) OR (deeplearning)** "artificialintelligence"[All Fields] OR "machinelearning"[All Fields] OR "deeplearning"[All Fields]
5	**(orthopaedics) OR (orthopedics)**
6	**(((artificialintelligence) OR (machinelearning)) OR (deeplearning)) AND ((orthopaedics) OR (orthopedics))** ("artificialintelligence"[All Fields] OR "machinelearning"[All Fields] OR "deeplearning"[All Fields]) AND ("orthopaedic"[All Fields] OR "orthopedics"[MeSH Terms] OR "orthopedics"[All Fields] OR "orthopedic"[All Fields] OR "orthopedical"[All Fields] OR "orthopedical"[All Fields] OR "orthopedics"[All Fields] OR ("orthopaedic"[All Fields] OR "orthopedics"[MeSH Terms] OR "orthopedics"[All Fields] OR "orthopedic"[All Fields] OR "orthopedical"[All Fields] OR "orthopedical"[All Fields] OR "orthopaedics"[All Fields]))

been used in various subspecialties of Orthopaedics successfully. Numerous papers have explained the use of AI. However, only a few systematic reviews highlight AI's role in Orthopaedics and Trauma.[9,10] These have been highly focused studies that have not delineated the complete scope of AI in the vast specialty of Orthopaedics. Hence, this study was conducted to outline the role of AI in the different sub-specialities of orthopedics with relevant examples, and state their specific merits and demerits, if any.

2. Methodology

This review was conducted in accordance with PRISMA guidelines.

2.1. Sources of information and literature search

To understand and review the role of AI in Orthopaedics, a thorough search was conducted in Scopus, Embase, and PubMed databases using keywords as summarized in Table 1.

2.2. Selection of studies

Inclusion Criteria:

- Studies which have reported the use of AI in the diagnosis of Orthopaedic diseases.
- Studies that have investigated the use of AI in Orthopaedic surgeries.

Exclusion Criteria:

- Studies in languages other than English.
- Studies that did not report the use of AI.
- Review articles
- Studies reporting the use of AI in fields other than Orthopaedics and trauma.

Deduplicated results from the search were reviewed independently by all the authors. Titles were screened first, followed by the screening of the abstracts. Then the full texts of the shortlisted articles were obtained. Studies were included only if they met the prespecified inclusion criteria. If there was a conflict regarding the inclusion of a particular study, it was resolved by mutual consent.

After finalizing eligible studies, data was extracted by two independent reviewers into pre-defined spreadsheets. Data extracted included the name of the first author, study design, number of cases and demographic data, the subspeciality where AI was used, and relevant outcome parameters. Since the data was found to be heterogenous in nature, a formal meta-analysis could not be conducted, and only qualitative synthesis was done.

3. Results

Our primary and secondary searches yielded 197 results. After an initial assessment, we zeroed down on 63 studies. The full texts of these files were obtained. Out of the 63, we included 40 articles in this study. The full text of the articles were reviewed to summarize the current status and role of AI in Orthopaedics.

3.1. Artificial intelligence in orthopaedics

AI has also been used in the medical field in upgrading professionals and their clinical performance, individualizing management and care of the patients, and advancing the scope of research.[11,12] The research centers on two data set types: single-level (individual) and community-based (population) datasets. Individual based datasets are acquired from research on the analysis of gait by tracking skeletal kinematics and sophisticated radiological evaluation to forecast the early onset of degeneration of major joints (hip and knee). Here AI has the possibility of predicting the early onset of disease, earliest detection of disease, determining disease evolution and course, assisting in treatment protocol with higher performance. At a community level, there has been great accessibility of information (National Joint Registry, National Hip Fracture Database, etc.) which increases the probability of projecting orthopaedics specific patient results including implant longevity, functional and radiological follow-up scores, the possibility of drawbacks/-disabilities, duration of hospital stay, and many more. The objective of such research is two-folded: to advise higher quality of shared decision making, and at a radical and financial level, to ensure the efficacious coordination and execution of health-related undertakings.

Rather than replacing treating physicians, AI assists/helps in increasing the accuracy of diagnosis and minimizing medical errors. AI has been used widely in medical imaging, from the acquisition of data, analysis, and interpretation.[2] By feeding the particulars/data available in the patient's health document/record (clinical presentation, clinical signs, blood tests), AI suggests appropriate management like required radiological investigations and treatment guidelines.[13] AI is helpful in swift data acquisition of magnetic resonance imaging (MRI) and reducing the radiation dose from computed tomography (CT).[14]

AI algorithms have been applied in orthopaedic surgery in various conditions, including diagnosis of fractures, osteoarthritis of hip and knee, and determining the age and strength of bone.[2] Apart from diagnosis, AI has higher accuracy (95.6%) in labeling, and detection and helps in the grading of conditions, like intervertebral disc prolapse, using classification systems on MRI.[15] AI also provides the advantage of improving quantitative image analysis by allowing automatic segmentation of the area of interest; however, it requires vast information/data for training, which is expensive and reduces service equality. One of the major challenges faced during clinical practice is risk assessment and predicting outcomes, AI provides a different approach that helps in overcoming the challenges during clinical practice. ML can be used to guide the management of patients by providing a patient-specific post-operative complication following lumbar surgery.[16]

AI technique assists the treating physician in making a decision or diagnosis for the patients. The cognitive computing system has used ML approaches to create a decision support system for the treatment of cancer in the western world. Clinical decision support helps in the

diagnosis and providing treatment of patients with low back pain.[17] These systems help find faults in the existing system and environment and provide reasonable approaches and information to help in minimizing human errors.

The main areas in Orthopaedics where AI has played a role:

1. **. Arthroplasty:** The first use of this technology dates back to 1992, when ROBODOC was used in Total Hip Arthroplasty (THA) for making femoral cuts.[18] Various other systems like CASPAR and RIO have been used to make cuts in Total Knee Arthroplasty (TKA). These tools have not only made the surgery more accurate but also have reduced surgical time and blood loss. Borjali et al. created an algorithm that can diagnose implant loosening after THA.[19] Recently, an AI-based model was designed that could help diagnose a prosthetic joint infection.[20] Nowadays, the arthroplasty registries are also maintained with the help of AI, which has improved the data storage and patient monitoring and follow-up.[21]

2. **Ligament injury**: Labbe et al. developed a support vector machine that could grade the pivot shift phenomenon using sensors placed on the iliac crest, femur, and tibia.[22] Bien et al. developed an algorithm that could diagnose intra-articular pathology in the knee like meniscal injuries and cruciate injuries.[23] Several algorithms have been developed that can diagnose injuries to cruciate ligaments based on MRI images with great accuracy.[24–26] The results of these algorithms are easily reproducible and reliable. Li et al. developed another model that could diagnose ACL injuries based on plantar pressure monitoring.[27] Jonmohamadi et al. created an algorithm called U-NET, which utilizes the arthroscopy video to create a segmented real-time image of structures seen by the surgeon.[28] This could help human surgical training and tool tracking in future robotic arthroscopic applications.[28]

3. **Trauma:** Beyaz et al. created a Convolutional Neural Network (CNN) model-based deep learning algorithm to diagnose femoral neck fractures.[29] Bae et al. used residual neural network (ResNet) 18 with convolutional block attention module (CBAM) + + to detect the femoral neck fractures in radiographs.[30] A similar CNN model was developed by Sato et al. for detecting adult hip fractures.[3] Langerhuizen et al. created a deep learning model for the diagnosis of occult scaphoid fractures and the results were encouraging.[31] Li et al. developed an artificial intelligence-based model for detecting fractures in the lumbar spine. The model demonstrated excellent accuracy, sensitivity, and specificity.[32] In 2016, a multi-indication Orthopaedics surgical robot, TianJi, was used for multiple levels of spine fixation, fractures of the pelvis, acetabulum, and long bones.[33–35] Lind et al. designed a ResNet-based neural network that could not only identify injuries around the knee joint but also classify them based on AO/OTA classification system.[36] There have also been algorithms that can diagnose and classify calcaneal fractures.[37]

4. **Spine surgery**: Renaissance and the Rosa robots used in spinal surgeries have shown higher accuracy of pedicle screw placement and limited radiation exposure to the patients and operating team. These systems can assist the surgeons in placing pedicle screws in deformed cases also.

5. **Musculoskeletal Oncology**: Lodwick et al. made the first attempt to diagnose bone tumors using a computer program in 1963.[38] Since then, numerous advancements have taken place in the field of artificial intelligence to improve the diagnosis and treatment of musculoskeletal oncology. Nevertheless, the use of AI is still limited to the diagnosis of tumors only. Burns et al. successfully identified sclerotic lesions in the thoracolumbar spine using Computer-Aided Design (CADe) techniques on CT scan.[39] Wang et al. created a CNN-based model that could detect spinal metastasis.[40] Bandyopadhyay et al. created a CADx-based model that could accurately predict bone-destruction pattern, stage, and grade of cancer in 85% of cases.[41] Do et al. created an AI-based model that accurately detects the presence of bone tumors on a radiograph in most instances.[42]

Han et al. designed a model to predict survival in patients with synovial sarcoma.[43]

6. **Osteoarthritis (OA):** Xue et al. created a CNN model to diagnose OA. This model predicted hip arthritis with great sensitivity and specificity.[44] Conrozier et al. described an automated computer-based method to measure joint space width for early diagnosis of OA in radiographs.[45] This method had excellent reproducibility and sensitivity.

7. **Femoroacetabular impingement (FAI)**: Nepple et al. built a computer-assisted model for diagnosing FAI and hip dysplasia.[46] This model accurately predicted the change in articular surfaces and the arthritis onset.

8. **Foot And Ankle disorders:** Ashkani-Eshfahani et al. used 2 deep convolutional neural network (Inception V3 and Renet 50) to detect ankle fractures using radiographs.[47] Chae et al. developed a model for classifying foot types using the image and numerical foot pressure data.[48] Day et al. described an AI-based tool to evaluate a new artificial intelligence (AI)-based automatic measurement for the M1-M2 intermetatarsal angle (IMA) in hallux valgus (HV) in patients undergoing weight-bearing cone beam CT scan. They compared them with manually measured IMA on digital radiographs.[49] Guss et al. assessed the accuracy, sensitivity, and specificity of 3D volume WBCT evaluation using DCNN algorithms in patients with subtle syndesmotic instability.[50] Merrill et al. used machine learning to predict the outcomes of ankle fractures post open reduction and internal fixation.[51]

3.2. Limitations of AI

An algorithm is as good as the data it is trained upon. AI only learns from the given data of the patient, and therefore accuracy of surgery depends upon the data given. AI technology only does what it has been programmed to do and these machines do not understand emotions, human thought, and reasons to make an accurate decision. It cannot fulfil the requirement of creative thinking in Orthopaedics like a human being because a human being can feel, think, and make a valuable decision. It requires supervision and data capturing during treatment and only reliable data can provide satisfactory results.

'Explainable AI' is one of the hottest topics and emerging concepts and it refers to an AI system in which the developers can understand the results of the solution. This is in contrast to 'Blackbox machine learning, wherein the developer cannot explain how the machine arrived at the results nor analyze the concept behind arriving at the solution. One of the most important aspects that have gained ground in recent times is the effort toward developing an algorithm or system that can help achieve the AI system's needs in medical applications. It is essential for majorly two reasons, first, it helps in designing better algorithms and understanding the science behind them, and second, it helps in conveying the exact reasons for the consultative decisions to the ever-inquisitive and knowledgeable patient, (e.g., an algorithm clearly explaining the possible course of actions in a possible decision is both reassuring to the patient and the doctor). The explanation gains more importance in the case of deep learning (DL) algorithms where a large number of parameters are involved. DL algorithms have been successfully used in critical Orthopaedic applications such as detection of implants mechanical loosening,[19] bone tumor diagnosis,[42] bone disease stage grading.[44] Although the DL algorithms have been shown to outperform the traditional ML algorithms, interpretability is a significant challenge. Recent algorithms such as shap, lime, and DeepShap are a step in this direction.[52–54] The interpretability here is a major challenge and need of the hour because the DL algorithms are effective, and the AI field has gravitated towards this in cases where the exact reasons and causes can be affixed. Finally, there is a need for open repositories and crowdsourcing of the stakeholders (e.g., Computer Scientists and Doctors) to work in this direction so that algorithms, procedures, and legal aspects can be ironed out in case of AI algorithms making or aiding
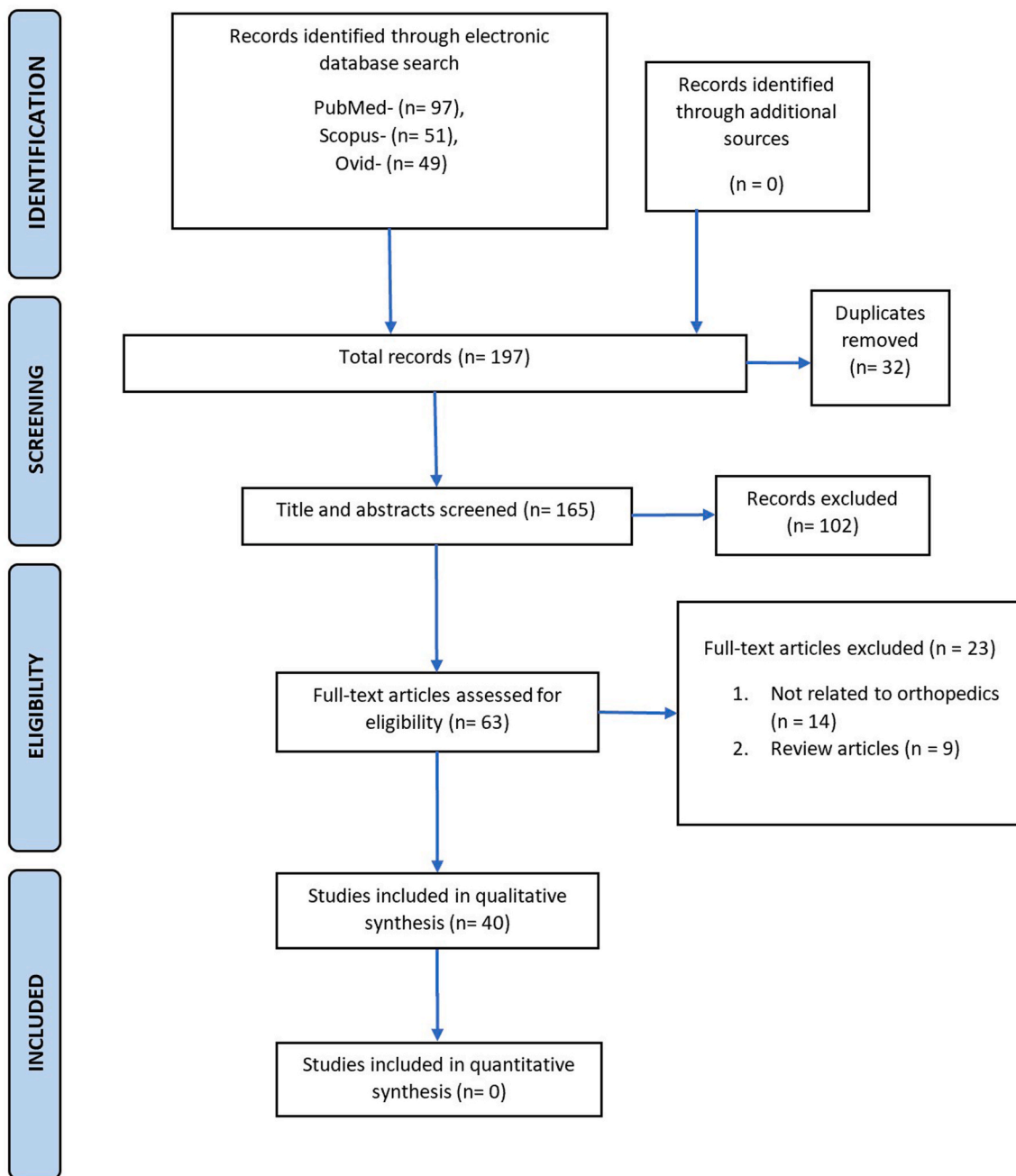
Figure 1. PRISMA Flowchart.

decisions.

4. Future directions

AI needs to meet the ever-increasing demands of an orthopaedic surgeon, and AI is needed in every field, right from diagnosis to treatment to detection of outcomes. Until now, most of the work in the field of AI has been on the diagnostic aspect. There is a need to build an algorithm to help a surgeon detect and intervene with unfavourable outcomes in the intraoperative period. Since most of the surgeries in Orthopaedics involving Artificial Intelligence and machines need human assistance, we can modify them and make them more independent. Using AI protocols in the intraoperative period will help a less experienced surgeon perform more complex surgeries with ease and minimal mistakes. In the field of oncology, a device should be able to detect the tumor margins to enable an R0 resection. In the future, we can also think

of an AI that can interview patients, make a diagnosis, conduct relevant tests and reveal results.

5. Limitations of our study

We acknowledge the fact that there are limitations to our study. First and foremost, our search strategy included only three databases (PubMed, Scopus, and EMBASE); therefore, it is possible that some studies which were not indexed by these databases could have been missed. However, we chose PubMed and EMBASE databases as it has been shown that searching these two databases can yield more than 93% of the relevant literature.[55] Moreover, increasing the number of databases also increases the number of records to be screened and may therefore not be practical.(Figure. 1)

6. Conclusion

AI can aid in advancing the research and patient management in Orthopaedics significantly. Whatever the misgivings regarding interpretability, job loss, mechanization, etc., we believe that this novel technology is here to stay, and researchers, practitioners globally have started accepting it, driven either by the governments or private companies. AI currently plays a role in various subspecialties such as arthroplasty, spine surgery, oncology, trauma, foot and ankle and various other areas, which have been discussed in detail. However, it should be kept in mind that human interaction should not be drowned out in the glittering of technology.

Contribution of each author

1. Vishal Kumar: Proof reading.
2. Sandeep Patel: Conceptualized the idea, structure of manuscript.
3. Vishnu Baburaj: Wrote the manuscript.
4. Aditya Vardhan: Wrote the manuscript.
5. Prasoon Kumar Singh: Article search.
6. Raju Vaishya: Proof reading.

Declaration of competing interest

None.

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