Artificial intelligence in orthopedic surgery: current state and future perspective

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Artificial intelligence (AI), first proposed by Prof. John McCarthy in 1956, aims to reproduce human intelligence using computers. Machine learning (ML) is a form of AI that uses computational algorithms that learn and improve with experience.[1] The two main forms of ML are supervised and unsupervised. In supervised ML, algorithms are given labeled data, which is used to predict disease outcomes in a new patient. In contrast, unsupervised ML is used to identify patterns without training; the algorithm learns the inherent structure of the data by searching for common characteristics.[1]

AI has gained tremendous popularity in recent years, and some AI techniques such as search engines, voice recognition software, and autonomous driving vehicles are now part of our daily lives. AI research is also being conducted in many medical fields, and shows great promise in promoting practice efficacy, personalizing patient management, and improving research capacity.[2,3] We aimed to outline the current applications and the future perspective of AI in orthopedics.

AI techniques have made great improvements in every step of the medical imaging pathway, from acquisition and reconstruction to analysis and interpretation.[4] By incorporating information from the patient's medical records (including symptoms, laboratory results, and physical examination findings), AI identifies the most appropriate patient-specific imaging examination and determines the most appropriate protocol.[5] AI can also potentially increase the speed of magnetic resonance imaging (MRI) data acquisition and decrease the computed tomography (CT) radiation dose.[6]

The most popular area of AI research is image interpretation. Rather than replacement of the radiologist, the use of AI helps the radiologist to improve the diagnostic accuracy and prevent errors and observer fatigue. AI algorithms have been applied to various conditions, including the diagnosis of fractures, osteoarthritis, bone age, and bone strength.[4] AI performs as well as or better than orthopedic surgeons in detecting fractures of the proximal humerus, hand, wrist, ankle, and vertebral compression fractures on radiographs.[4,7] AI also has potential applications in the automatic detection of hip or knee osteoarthritis on radiography, with performance comparable to that of an attending radiologist.[8] AI can help automate the grading of lumbar disc pathology on MRI using various classification systems, with an accuracy of 95.6% for disc detection and labeling.[9] Furthermore, AI improves the accuracy of bone age interpretation compared with aging done by a radiologist alone; however, the most accurate values are achieved when AI is used in combination with a radiologist.[10] AI also improves quantitative image analysis by allowing automatic segmentation of the area of interest, and many studies have focused on knee cartilage segmentation, with promising initial results.[11] However, whilst AI-assisted image interpretation can be accurate, it does require large training datasets, which may be costly and attenuate service inequality. With ongoing technological advances, AI in imaging will improve and become more widely applied.

Another major potential use for AI in healthcare is in predicting the clinical outcome of patients based on a clinical dataset, genomic information, and medical images. Risk assessment and outcome prediction have always been challenging in clinical medicine. AI offers a new direction that could potentially overcome these challenges. In orthopedics, ML can be used to guide the management of patients by providing a patient-specific predicted rate of post-operative complications following lumbar fusion surgery.[12] In addition, visual and inertial sensor data

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can be analyzed by ML to predict injury risk patterns associated with dynamic knee valgus.[3]

The AI technique can help the doctor to make a diagnosis or decision. In the United States, the IBM Watson Health cognitive computing system (IBM Corp., Armonk, NY, USA) has used ML approaches to create a decision support system for the treatment of cancer, with the intention of improving diagnostic accuracy and reducing costs using large case volumes. Clinical decision support systems also provide recommendations on the diagnosis and treatment of low back pain[13]; these systems can classify subjects, and further progress could enable the combination of AI plus clinician to make more rigorous classifications than human decision-making alone. Thus, AI may enable more accurate allocation to services in the future, whilst increasing the accessibility and speed of self-referral.

Orthopedic surgery began to incorporate robotic technology in 1992, with the introduction of the ROBODOC system for the planning and performance of total hip replacement.[14] Substantial progression has been made in the use of robots in the past few years. Most orthopedic robots, such as the Mako system, are used for joint replacements such as unilateral knee arthroplasty, total knee arthroplasty, and total hip arthroplasty.[2] A study has shown that the robots are superior to the conventional technique in achieving limb alignment and reducing operation time and blood loss. Most studies about spine surgery have evaluated the Renaissance robot and the Rosa robot.[15] Several studies have proven that the robots have the advantages of improved pedicle screw accuracy and reduced radiation exposure for patients and clinical staff compared with conventional surgery.[16] However, robotic surgery has low cost-effectiveness and fewer indications, which may limit its widespread clinical application.

In 2016, we presented the TianJi Robot, which is a multi-indication orthopedic surgical robot that can be used for all levels of spinal instrumentation and pelvic, acetabular, and limb fracture surgeries.[17-19] The TianJi robot combines a robotic arm with a real-time navigation system and has a high degree of surgical precision. Compared with freehand surgery, the TianJi robot significantly improves the accuracy of instrument placement and improves the clinical results.[17] In July 2019, Prof. Wei Tian performed the world's first multi-center the 5th generation (5G) remote orthopedic surgery using 5G technology. The combination of 5G technology and robotic technology improves the safety and quality of remote surgery, and maybe the future of remote surgery.

AI has revolutionized the face of modern orthopedic surgery, but at present, its use is neither universal nor perfect. The limitations of AI are existing. First, the use of AI is limited by the high capital cost, the time needed for its use (both in preparation and intra-operatively), the variable reliability of AI technologies, and the absence of long-term follow-up studies. Therefore, the cost and time of the AI technique needs to be decreased, and more long-term studies are required. Second, there are ethical considerations regarding the use of ML in orthopedic surgery. Working with bulk datasets increases the risks of breaching patient confidentiality and consent unless safeguards are in place, especially where conflicts exist between patient and commercial interests. Furthermore, in cases of misdiagnosis or maloperation, it is unclear whether the doctor or the robot should be held responsible. Thus, it is important that ML is meticulously studied, managed, and appropriately validated. Third, to date, surgical robots and the AI technique can only be used to perform relatively simple procedures, and possess little autonomy and decision-making authority in treatment; these limitations have caused some people to question the usefulness of AI. However, scientists and engineers are making substantial advancements in AI-assisted procedures from non-autonomic robot assistance to task-autonomy or conditional autonomy and, eventually, full automation. Self-learning machines will be able to directly perform independent tasks in the future. However, there may be circumstances where human clinicians are unable to control or override these procedures made by an AI device. Finally, as AI is a new and emerging field in medicine, patient interests may be at risk due to technological advances invariably preceding proper governance and patient-protective legislation.

Despite its pitfalls and potential shortcomings, ML provides a unique ability to create meaningful change.

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Conflicts of interest

None.

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