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The role of artificial intelligence (AI) in paediatric orthopaedic surgery

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ABSTRACT

Artificial Intelligence (AI) technologies are gradually becoming widespread in pediatric orthopedic surgery and contribute to diagnostic and surgical processes, planning, execution, and treatment. This review focuses on new AI technologies that enhance bone age determinations and identification of early musculoskeletal abnormalities. AI contributes to better preoperative planning and helps while performing operations by augmented reality and robotic systems, so operation becomes safer and more accurate. In postoperative care, AI is able to track a patient's progress, modify treatment regimens and oversee chronic illnesses, thus enabling individualized patient attention. This paper aims to review existing usage, future prospects, and the implications of AI in treating children with orthopedic disorders in order to highlight the effectiveness of the tool in enhancing the health of children and the development of pediatric orthopedics as a specialty.

1. Introduction

The specialty of pediatric orthopedics deals with the treatment of disorders that affect the musculoskeletal system in children and teenagers. It covers all types of diseases, cancer of muscular and skeletal systems, growth disorders, congenital anomalies, and many more. Pediatric orthopedics distinguishes itself from adult orthopedics by focusing on the specific needs of growing children, requiring specialized surgical techniques and postoperative treatment.[1] Approximately 50 % of children have a fracture at some time throughout their childhood,[2] with an estimated rate of 133.1 fractures per 10,000 children per year.[3] Additionally, fractures are a major contributor to long-term impairment in children and occur in 55 % of children who have experienced physical abuse.[4] Compared to a specialist pediatric radiologist, emergency physicians may fail to detect approximately 11 % of acute pediatric fractures due to variations in the appearance of children's bones on imaging, which differ from those of adults. These differences can be attributed to variations in bone maturation at different stages and distinct injury patterns, such as bowing deformities, metaphyseal injuries, and buckle/torus fractures.[5,6] Emergency doctors often have the first responsibility of evaluating and responding to imaging results. The majority of them (7.8 %) have the potential to result in unfavorable events and management changes.[6]

With decades of development since its inception, artificial intelligence (AI) has found widespread application in a wide range of fields. In 1956, John McCarthy introduced the concept of artificial intelligence as the science of creating intelligent robots. It is the imitation of intelligent human behavior and critical thought using computer software and machine applications.[7] AI has shown substantial application value and promise in the healthcare industry with the advancement of information technologies.[8] One subfield of artificial intelligence, machine learning (ML) makes use of ever more sophisticated computing techniques. Supervised and unsupervised learning are the two primary ML approaches. Predicting the course of an illness in an untreated patient is the goal of supervised ML systems.[9,10]

Medical imaging anomalies, such as fractures, may now be quickly and precisely identified using AI algorithms. These algorithms may be helpful as an additional tool for interpretation when expert views are not readily accessible.[11] In a comprehensive analysis of AI accuracy for long bone fracture identification in adults using imaging, pooled specificity and sensitivity rates were 94 % and 96 %, respectively.[12] According to another systematic review, when compared to general practitioners and orthopedic surgeons, some AI algorithms were either as good as or better at identifying limb fractures on radiography.[13]

With the rise of AI and digital medicine, pediatric orthopedics has seen new perspectives. It makes pediatric orthopedics smart and

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individualized, which improves the efficacy of diagnosis and treatment outcomes from a variety of angles, including auxiliary disease diagnosis, optimization of surgery, postoperative rehabilitation guidance, and more.[14] Among the many significant uses of AI, bone age assessment stands out. During orthopedic surgery, unanticipated complications might arise, requiring surgeons to act quickly. Surgeons don't always have the time they need to make the best decisions. AI can aid in the diagnosis and management of intraoperative complications during this time.[15]

This review article primarily concentrates on the present state of AI in pediatric orthopedics and its potential future applications.

1.1. AI in diagnostic processes

AI has significantly transformed how medical imaging and diagnostics are approached in pediatric orthopedic surgery. Applications, such as BoneXpert and digital X-ray radiogrammetry exemplify the integration of AI into routine clinical workflows, providing more accurate assessments of bone age and health.

1.1.1. Use of AI for enhanced imaging and diagnosis

- BoneXpert**:** This particular AI application helps in determining the bone age which is essential in planning for children's orthopedic surgery. Within 15 s, it performs the bone age assessment using the Greulich and Pyle and the Tanner and Whitehouse methods for each hand and wrist X-ray.[16] Finally, the form, intensity and texture scores are predicted through applying the results of the principal component analysis. This software has been applied to many ethnic groups/communities: Asian Chinese, Saudi, African American, Hispanic, and Caucasian.[17]
- Digital X-Ray Radiogrammetry (DXR): Advanced DXR tools driven with AI are applied not only for age estimation, but also for bone health analysis. They use X-ray images to assess and monitor alterations in bone mass and structure that are vital in identifying diseases such as pediatric osteoporosis, which is known to have a severe impact on growth.[18]

1.1.2. Role of AI in early detection of orthopedic conditions

- Improved Analysis of Imaging Data: AI technologies make it easier to find and diagnose a wide range of orthopedic diseases at an early stage. For instance, imaging data is analyzed by AI to look for patterns and irregularities that are not easily discernible to the human eye, for example early signs of joint diseases, or small fractures appropriate for early treatment.[19]
- Three-Dimensional Modeling and Reconstruction**:** AI applications translate conventional two-dimensional images from CT or MR scans into three-dimensional ones, which assist orthopedic surgeons in gaining a broader perspective of the body regions involved. This is especially helpful in preparing for the complicated surgeries such as spine or hip surgeries especially when precise details matters the most.[14,20] Tam et al. described a case of a 6-years-old girl with a massive osteochondroma originating from the scapula: The linked symptoms appeared because the tumor restricted the joint's motion and pressed on the tissues simultaneously. In order to minimize the chances of surgical excision a 3D scapula model was developed using CT scans. Subsequently, a model of the lesion was printed using a 3D printer for the purpose of seeing the lesion and planning the surgical resection.[21]

1.2. AI in surgical planning and execution in pediatric orthopedic

The technological advancement in the field of AI is impacting pediatric orthopedic surgery, particularly in terms of preoperative planning and intra-surgical navigation. Due to recent developments in technology, surgeons are now enabled to become more precise and faster thereby decreasing the difficulty and time of surgeries.

- Preoperative Planning: AI technologies are used to develop precise preoperative maps. For example, 3D modeling and augmented reality (AR) systems enable accurate preparation and rehearsal of intricate surgical procedures. These technologies offer the surgeon a live and detailed view of the internal environment of a patient and facilitate intricate planning for a surgery before actually making an incision. This application not only enhances the knowledge of the peculiarities of the patient's anatomy for the surgeon but also increases the predictability of the outcomes of interventions.[22]
- Intraoperative Guidance: In the operating room, deep learning assists the surgeon with real-time data and images enhancing the navigation and accuracy. AR overlays can display important anatomical and procedural data to the surgeon, which can be adjusted and modified in real time. This technology is very helpful in surgical procedures that do not allow direct viewing of the anatomy of the body. Automated instruments such as robotic arm and endoscopes enable the surgeon to be more precise in his/her movements thus minimizing opportunities for complications[11,22]
- Three-Dimensional Printing and Modeling: The application of 3D printing in surgical operations enables the manufacturing of implants and surgical instruments tailored to suit the individual patient. These are designed based on the patient's exact anatomical data, ensuring a perfect fit and potentially reducing the time spent in surgery.[23] Three dimensional models are also used for educational purposes, helping to explain the surgical procedure to patients and their families, thereby improving their understanding and easing pre-surgical anxiety.[24]
- Robots Assisting in Orthopedic Surgery**:** Robot-assisted surgery enhances the stability and precision of operations, leading to higher success rates and improved curative outcomes.[9] Gonzalez et al. conducted a comparison of conventional and robot-assisted techniques for pediatric spine surgery accuracy. The conventional approach achieved a placement accuracy of 90 %, but the use of robots resulted in a much higher accuracy of 98.7 %, with no occurrences of problems associated with screw fixation.[25] In addition, robot-assisted surgery offers several additional benefits. Sensakovic et al. did research in which they created a low dosage CT protocol and used it in conjunction with robot-assisted pediatric spine surgery. The radiation dosage was significantly lowered by 84–91 % compared to the usual strategy.[26]

1.3. AI in postoperative care

AI significantly enhances postoperative care by monitoring vital signs and surgical sites to detect early signs of complications such as infections or improper healing. Predictive analytics, fueled by AI, play a crucial role by analyzing historical data to predict potential postoperative issues before they become critical. This approach makes it easier for any complications to be addressed on time, possibly cutting down the recovery period and enhancing the results.[19]

Additionally, AI enhances the management of long-term care since it analyzes new data from the patient as the condition changes and makes recommendations on how the treatment plan should be changed. This aspect of AI is increasingly useful in chronic conditions that may develop in pediatric patients after orthopedic surgeries, because it is able to maintain care that evolves according to changing health features of the patients.[27]

1.4. Ethical, legal and societal aspects (ELSA) of AI Implementation

AI application in pediatrics and pediatric surgery has numerous ethical, legal, and social concerns. Such issues are significant especially when offering care to preterm and critically ill neonates and pediatric patients. Till et al. note that the usefulness of the algorithms can be significantly increased by optimizing them. These algorithms significantly improved the diagnosis of wrist fractures using radiographic methods due to the optimization of the pre-processing phase.[28] When concerning this, it is crucial to discuss the problematic aspects like the possibility of algorithm bias and the question of its accountability to minimize its negative impact on vulnerable pediatric population groups.[29]

Moreover, it is also important to have strict policies to safeguard the patient's confidentiality. From a social perspective, the use of AI tools should transcend socio-economic inequalities and ensure equal access to these revolutionary technologies.[30] At the same time, it is important to use education as a prevention measure, which provides a person with knowledge needed in order to work with the tools. To integrate AI into pediatric care, it is crucial to build trust to make it an asset rather than a potential worry. AI brings about shifts in medical negligence and responsibility as a function of the legal field.[31] Nevertheless, by paying enough attention to the social and legal concerns, it is possible to organize the integration of AI into pediatrics seamlessly. Such integration might result in betterments that benefit patients, all the while preserving the ethicality, sociability, and legal compliance.[32,33]

2. Conclusion

This review aimed to discuss the emerging role of AI in pediatric orthopedic surgery in terms of its diagnostic capabilities, use in surgical planning and execution, as well as the postoperative period. AI has helped make imaging and diagnostics more precise and accurate through tools such as BoneXpert and digital X-ray radiogrammetry and contributed to improving the accuracy of bone age determination and early diagnosis of musculoskeletal abnormalities. AI has not only helped in preoperative planning by offering better simulation but also in intraoperative precision by use of augmented reality and robotic surgery to reduce complication rates and improve surgical results. In the post-operative stage, AI contributes by constantly assessing the patient's state and adjusting treatment programs depending on patient requirements, indicating a future with patient-tailored care. The continued advancement of AI in medical practices points to even more improvement in pediatric orthopedic practices as well as effectiveness in patient treatment, making it a paradigm shift in the field of medical treatment.

Authors contributions

All authors are equally conceived and designed the study, conducted the research, provided the research materials, and collected and organized, analyzed and interpreted data. All authors have critically reviewed and approved the final draft and are responsible for the content.

Ethical consideration

Review articles are exempted from an institutional review board (IRB)/Ethical approval.

Patient's consent

Not applicable.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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