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Research

Application of Artificial Intelligence in Pediatric Orthopaedic

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Abstract

Background: Artificial intelligence has emerged as a promising tool in healthcare. The machine learning algorithms enable accurate diagnosis, imaging and treatment plans. Computer technology and digital software have come a long way in promoting care and prompt management of patients, and thereby enhancing their quality of life. The purpose of this review article is to provide a structured understanding about the current trends in Pediatric Orthopaedics based on the advanced AI led technology.

Methodology: A total of 26 articles have been researched to write the current review, that are published in various journals globally. MEDLINE, PubMed, Scopus, Research Gate, Springer and many magazine blogs are some of the databases used.

Results: The review article explores various AI-based digital tools and computer softwares that play a vital role in the field of pediatric orthopedics. The research is done under the following subheadings i) BoneView ii) Three-dimensional Model Reconstruction iii) BoneXpert iv) Digital X-Ray Radiogrammetry (DXR) v) Deep CNNs for tumor in children vi) Digital Tomosynthesis vii) 3D Printing Technology viii) Robots Assisting in Orthopaedic Surgery ix) OrthoNext Digital Platform.

Conclusion: Currently, there is an increasing demand for quality medical treatment, especially in Pediatric Orthopaedics. The movement into the direction of digitalization and intelligence has begun in this field and computer technology has indeed brought many changes. The emergence of digital software and tools, Pediatric Orthopaedics has become more personalized and accurate. Significant changes have taken place in disease diagnosis, treatment modalities and implementation of surgery. The digital technology has great development potential in pediatric orthopaedics.

Keywords: *Artificial intelligence, machine learning, algorithms, BoneView, BoneXpert, 3D CT/MRI, 3D printing, digital Tomosynthesis, robotic surgery.*

Introduction

Artificial intelligence (AI) has undergone decades of advancement since its emergence and has been extensively used in various aspects of life. Artificial intelligence was first described by John McCarthy in 1956, as a science of making smart machines. It is the use of computer software and machine applications to imitate the intelligent behavior and critical thinking of a human being. With the development of information and data technology, AI has shown significant application value and potential in the field of healthcare (1). AI research is being conducted in many medical fields, and shows great promise in promoting practice efficacy, personalizing patient management, and improving research capacity. Machine learning (ML) is a form of AI that uses computational algorithms that learn and improve with experience. 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. Unsupervised ML is used to identify patterns without training; the algorithm learns the inherent structure of the data by searching for common characteristics (2). Machine learning (ML) algorithms improvise over time at performing tasks, but they still need some human input to improve their performance. Deep learning (DL) is a subfield of machine learning and refers to a model with an artificial neural network structure and mimics the human brain's neural connections (3). Neural networks form the backbone of deep learning algorithms.

It is also known as artificial neural networks (ANNs) mimic the human brain through a set of algorithms. A neural network which consists of more than three layers- including the inputs and outputs; can be considered as deep neural network (DNN)(4). Computer vision assisted deep learning, especially Convolutional Neural Network (CNN) is the most widely used due to improved performance. It is a multilayer network consisting of convolutional layer, pooling layer and fully connected layer (5).

AI tools in healthcare include clinical decision support, mobile health and sensor-based sensor-led technologies, voice assistants and robots. Clinical decision support systems (CDSS) are used to augment supplement clinicians in their complex decision-making process. They are now commonly managed through electronic health records (EHR) (6). Clinical decision support provides timely information about a patient's care. It can effectively improve patient outcomes and lead to higher-quality health care (7). AI techniques have made great improvements in every step of the medical imaging pathway, from acquisition and reconstruction to analysis and interpretation (2). AI finds its application to increase the efficiency of the treatment modalities and management of a particular disease or abnormality through robotic surgeries. The main purpose of continuous development of artificial intelligence (AI) in the healthcare field is to assist professionals and bring innovations in terms of quality in care services based on previous experiences, for instance predicting the course of a disease condition through large database searches (8)

Pediatric Orthopedics is a subspeciality of Orthopedics. The bones of children are still growing and developing, so the diagnosis and treatment of pediatric orthopedics is considerably different from adult orthopedics and has certain difficulties. The advent of AI and digital medicine has brought a new perspective into Pediatric Orthopedics. From the aspects of auxiliary disease diagnosis, auxiliary optimization of surgery, guidance of postoperative rehabilitation, etc., It makes pediatric orthopedics developing personalized and smart, greatly improving the effectiveness of the diagnosis and treatment outcome. Bone age assessment is another important application of AI (9). AI also has various advantages in auxiliary surgery. It can traverse for surgeons during the operation and its accuracy can greatly reduce the error in the operation and improve the success rate and effect of the operation. Some unexpected emergencies can occur during the pediatric orthopedic surgery, which often need to be dealt with by surgeons in a short time. However, due to shortage of time or other factors, it is sometimes difficult for surgeons to make correct choices. At this time, AI can assist in the judgment and treatment of intraoperative emergencies (10).

AI is mainly used to perform human tasks more easily, and at reduced cost compared to the existing technologies. Nevertheless, many professionals perceive it as a threat to their job due to the lack of expertise and knowledge regarding AI application. For instance, professionals must comprehend the AI mechanism according to different pulmonary conditions sharing similar characteristics and criteria (1).

Therefore, this review mainly aims to describe the scope of AI currently being applied in Pediatric Orthopedics and to focus on future prospective and development in the same.

BoneView AI Software

It is revolutionary artificial intelligence software which is developed by the French company Gleamer. It assists radiologists and emergency physicians in skeletal fracture diagnosis (11). It is also intended for the detection of effusion, dislocations and focal bone lesions on extremities, pelvis, T/L spine and the ribcage for pediatric patients (12). It uses advanced algorithms to detect and localize lesions on X-rays, graphically highlighting areas of interest, before submitting the images to radiologists for validation. Radiographic interpretation suffers from an increasing workload in emergency and radiology departments, while missed fractures represent up to 80% of diagnostic errors in the emergency department. Thus, BoneView was developed in order to overcome the many challenges the radiologists faced due to the conventional imaging techniques. This software significantly reduced the rate of undetected fractures by 30% and reduced the radiograph reading time by 15% (11).

Three-dimensional Model Reconstruction

Medical 3D model reconstruction technology has evolved, due to the advancement in computer software and digital image technology. This 3D model processes the two-dimensional data of Computed Tomography (CT), or Magnetic Resonance Imaging (MRI) of a particular anatomical structure by computer into 3D data in the way of demonstrating, to create a 3D model. The 3D model helps the surgeon to clearly recognize the structure and morphology of the area, accurately locate the lesion and plan the surgical procedure (9). Tam et al, reported the case of a 6- year old girl with the presence of a large osteochondroma arising from the scapula. The movement of the joint was restricted by the tumor and compressed the surrounding tissues at the same time, which led to the appearance of the related symptoms. To minimize the risk of surgical excision, a 3D model of the scapula was created using CT data. Then a realistic model was developed using the 3D printer to visualize the lesion and assisted into planning the surgical excision (13).

The 3D model provides a more reliable approach for determining the parameters of the anatomical structures. By creating a 3D model of the patient, surgeons can decide on the surgical procedure before the operation to improve its accuracy and safety. Storelli et al constructed 3D models of the forearm of the children with forearm deformities and performed surgical simulations to select the optimal osteotomy position and produce patient-specific cutting jigs. This method supported precise planning of complex and multiple osteotomies and lessened the need for making an intraoperative decision. The forearm rotation and distal radioulnar joint stability was highly improved postoperatively (14). This technology can also be effectively used for soft tissues as well. Nerve tissues and vascular tissues are also the application direction of this technology. But this is not yet successful and the surgery is difficult in children, due to the immature development and fragile blood vessels and nerves (9).

BoneXpert- Bone Age Assessment

AI for bone age assessment has been in clinical use for many decades and is an area of interest for many research studies. BoneXpert is the oldest and most commonly used AI tool for bone age assessment. It is an AI-replace software tool. It automatically calculates the bone age according to the Greulich and Pyle and the Tanner and Whitehouse standards in a process which takes less than 15 seconds per hand and wrist radiograph. The prediction is based on the shape, intensity and texture scores that are derived from principal component analysis. BoneXpert is configured as a Digital Imaging and Communications in Medicine (DICOM) node for local pictures archiving and communication systems (PACS) and is an image analysis application only. Currently, in 70% of cases it is used as an AI-assist tool rather than AI-replace tool. This is because BoneXpert rejects radiographs with significant abnormality (poor positioning, poor image quality), it does not reject radiographs with subtle abnormality of morphology or abnormality of texture (15). The software has been tested in multiple populations and ethnicities, including, Caucasian, African American, Hispanic, Asian Chinese and Saudi Arabian populations (16). Other bone age tools have also been tested and found to be reliable and accurate and to reduce reporting times. It is worth noting the successful results obtained of bone age estimation of index finger alone, when using a neural-network-based AI application. This paves way for handheld bone age estimation machines (17).

There is ongoing research pertaining to tasks such as fracture detection (appendicular and vertebral), scoliosis and leg-length discrepancy measurements. Other areas of interest in pediatric research include determining bone health using the bone health index and diagnosing metopic craniosynostosis and developmental dysplasia of the hip. But there is very little evidence of research study in areas such as inflicted injury (child abuse) and skeletal dysplasia.

Digital X-Ray Radiogrammetry (DXR)

Osteoporosis is a skeletal disorder which results in bone fragility, and is associated with fractures, morbidity and mortality. Pediatric osteoporosis is classified as primary and secondary forms. Secondary form and secondary low bone quality in children is due to systemic disease, their treatment, or indirect effects of systemic disease such as immobilization, poor nutrition etc. The course of osteoporosis in children is different than in adults due to varying bone mass (bone mass density, BMD) with age (18).

Dual-energy X-ray absorptiometry (DXA) is the golden standard for bone quality measurement in children as well as adults. This exhibits good precision, reproducibility and availability of normative data (19). Different skeletal sites are sites described for BMD measurements in children. However, DXA has its own limitations. Disrupting factors such as movement during measurement, metallic implants, contractures and sometimes scoliosis can also cause non-interpretable results. To overcome these challenges, clinically available "Digital X-Ray Radiogrammetry" (DXR) is used, which is a feasible alternative. Using a web-based software like BoneXpert, it can assess both bone age and bone quality, expressed as bone health index (BHI). BHI is a measurement of cortical thickness and mineralization. This efficiently yields accurate representation of bone quality. DXR is less stressful, easy to obtain and does not involve additional exposure to ionizing radiation (20).

Deep CNNs for Tumors in Children - Detection, Classification and Personalised Therapies

Deep CNNs (convolutional neural networks) effectively detect and classify various non-neoplastic abnormalities in children, which also includes detecting delayed bone age on hand radiographs and pneumonia in chest radiographs. Similar principles can be used for detection of malignant tumors; CNN can be trained in the differentiation of normal and abnormal scans. Tumor lesions can be automatically identified segmented and measured (21). Helm et al, used a computer-aided system to detect pulmonary nodules on chest CTs of pediatric patients (22). Deep CNNs have also been used to characterize tumors. Tu et al (23) and Chen et al (24) used machine learning algorithms to differentiate benign and malignant lung nodules on chest CT (23) scans and PET/CT scans (24). Machine learning algorithms are well suited to detect patterns in big data sets for radiomic radio-genomic analysis. Deep CNNs can associate increasingly complex genetic and molecular tumor characteristics with specific macroscopic tumor features on imaging tests (21).

Deep CNNs can help clinicians to plan personalized therapies and predict the impact of genomic variations on the sensitivity of normal and tumor tissue to chemotherapy or radiation therapy (25). Machine learning algorithms have been utilized to predict survival in children with cancer and improve long-term outcomes.

Digital Tomosynthesis (DTS)

It is an emerging technology that provides cross-sectional, three-dimensional imaging similar to computed tomography (CT) at a fraction of the radiation dose and cost. DTS imaging is used to clinically manage fracture healing. This technology fills an imaging sweet spot between radiographs and CT. DTS uses a standard x-ray tube, a flat-panel detector overlaid with an anti-scatter grid, and a motorized tube crane to move the X-ray tube. A reconstruction algorithm allows production of multiple cross-sectional images at a much lower dose than that of CT. This technology holds great promise in pediatric orthopedic imaging (26).

3D Printing Technology

This technology is based on digital model files and uses bonded materials such as powdered metal or plastic to construct objects by printing layer by layer. The models are built by computer modelling software and a 3D printer is used for printing layer by layer. Hence, 3D printing is often used in combination with computer-aided design (CAD) which can convert the designed 3D digital model into a physical model. The 3D printed models have been widely used in clinical treatment due to their benefits of personalization and precision, which are very necessary in personalized treatment in Pediatric Orthopaedics (27). 3D technology is widely used in the fabrication of customized surgical templates. Zheng et al, studied the feasibility of 3D printed navigation template in femoral osteotomy in older children with developmental dysplasia of hip (DHH), and found that compared to the control group, the 3D printed navigation template group required less operative time, Intraoperative x-ray exposure times, and incidence of iatrogenic physical injury, and post-operative follow-up showed that this group was better than control group with regards to their therapeutic effect. Thus, this simplified the operation and enhanced the surgical accuracy (28)

In addition, 3D printing technology is also used in pediatric plastic surgery. Bone defects are common in children with craniofacial fissure, and such defects are usually very complicated. Personalized aids are also the application range of 3D printing technology (9).

Robots Assisting in Orthopaedic Surgery

Surgery is an important treatment in pediatric Orthopaedics, and robots are widely used in auxiliary surgery. Robot-assisted surgery can improve the stability and accuracy of operation and increases the success rate and curative effect of surgery (9). Gonzalez et al, compared the accuracy of robot-assisted and traditional methods for pediatric spinal surgery. The placement accuracy of the traditional method was 90%, while with the assistance of robots it was as high as 98.7%, without any screw fixation-related complications (29). The robot-assisted surgery has other advantages too. A study was conducted by Sensakovic et al, who developed a low dose CT protocol combined with robot-assisted pediatric spinal surgery. Compared to the traditional protocol, the radiation dose was reduced by 84-91% (30). Surgical Robot can assist the operator to choose the optimal surgical approach and surgical angle and enhance surgical accuracy. The robotic arm is controlled by artificial intelligence to ensure stability of the procedure and optimize the choice of surgical operation at the same time. This improvises the clinical effect of the surgery, which is an important direction of the development of orthopedic surgery in the future. However, the cost of robotic surgery is high, and not all patients have the condition to use it. There is still a long way to go before the large-scale application of surgical robots (9).

OrthoNext Digital Platform

The OrthoNext digital platform is developed by the Orthofix global medical device company, which recently got its approval from the FDA (Food and Drug Administration). This is the only software tool in the market for deformity analysis and preoperative planning for pediatric orthopedic procedures. Developed specifically for use with the JuniOrtho Plating System, the OrthoNext digital platform software enables the surgeon to accurately plan the osteotomy position to visualize the implant in relation to the anatomy. This is designed to streamline the selection of the precise size of device and enable optimal positioning for the patient's body prior to the surgical procedure. Created specifically for pediatric patients, the JuniOrtho Plating System is designed to address the demands of advanced deformity and trauma reconstruction of the lower extremities (31).

Conclusion

AI has proven to improve digital image quality and even go a step further to develop a 3D image to increase the accuracy of diagnosis and provide a detailed and precise description of the bone lesions or fracture. The speed of processing of data not only prevents physician fatigue but also speeds the process of obtaining a diagnosis and reducing backlog thereby allowing treatment to be initiated much quicker when compared to the current practice.

The ability of developing a 3D image and hence a 3D model can help in presurgical planning and practice for the correction of deformities or complex fractures thereby improving outcomes for the patients.

This makes Pediatric Orthopaedics more accurate, and great changes have taken place in disease diagnosis, treatment plan formulation, or implementation of surgery and other treatment modalities in the treatment process. Presently, there is an increased demand for minimally invasive surgical techniques which utilize the digital softwares and technologies. These procedures are less painful with faster recovery. It also considerably reduces the hospital stay of the children, who would otherwise not cooperate with the surgeons and the medical staff. AI intervention will enhance performing these procedures by providing precision, accuracy and preplanning of such procedures.

Possible future developments have been identified in pediatric Orthopaedics in fracture detection and management, spine deformities, leg-length discrepancy measurements. There are ongoing research studies to evaluate the effectiveness of artificial intelligence in determining bone health using the bone health index and diagnosing metopic craniosynostosis and developmental dysplasia of the hip. But there is very little evidence of research study in areas such as inflicted injury (child abuse) and skeletal dysplasia which yet to be worked upon.

Conflict of Interest

The author declares no conflict of interest.

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