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Deep learning applications in orthopaedics: a systematic review and future directions

Aplicaciones de aprendizaje profundo en ortopedia: una revisión sistemática y futuras direcciones

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ABSTRACT. **Introduction:** artificial intelligence and deep learning in orthopedics have gained mass interest in recent years. In prior studies, researchers have demonstrated different applications, from radiographic assessment to bone tumor diagnosis. The purpose of this review is to analyze the current literature on AI and deep learning tools to identify the most used tools in the risk assessment, outcome assessment, imaging, and basic science fields. **Material and methods:** searches were conducted in PubMed, EMBASE and Google Scholar from January 2020 up to October 31st, 2023. We identified 862 studies, 595 of which were included in the systematic review. A total of 281 studies about radiographic assessment, 102 about spine-oriented surgery, 95 about outcome assessment, 84 about fundamental AI orthopedic education, and 33 basic science applications were included. Primary outcomes were diagnostic accuracy, study design and reporting standards reported in the literature. Estimates were pooled using random effects meta-analysis. **Results:** 53 different imaging methods were used to measure radiographic aspects. A total of 185 different machine learning algorithms were used, with the convolutional neural network architecture being

RESUMEN. Introducción: la inteligencia artificial (IA) y *deep learning* en ortopedia han ganado un gran interés en los últimos años. En estudios anteriores, se han mostrado diferentes aplicaciones, desde la evaluación radiográfica hasta el diagnóstico de tumores óseos. El propósito de esta revisión es analizar literatura actual sobre IA y *deep learning* para identificar las herramientas más utilizadas en los campos de evaluación, resultados, imágenes y ciencias básicas. **Material y métodos:** se realizaron búsquedas en PubMed, EMBASE y Google Scholar desde enero de 2020 hasta el 31 de octubre de 2023. Se identificaron 862 estudios, de los cuales 595 fueron incluidos. Se incluyeron un total de 281 estudios sobre evaluación radiográfica, 102 sobre cirugía de columna, 95 sobre evaluación de resultados, 84 sobre educación ortopédica y 33 aplicaciones de ciencias básicas. Los resultados primarios fueron la precisión diagnóstica, diseño del estudio y estándares de presentación de informes en la literatura. Las estimaciones se agruparon mediante un metaanálisis de efectos aleatorios. **Resultados:** se utilizaron 53 métodos de imagen diferentes para medir los aspectos radiográficos. Se utilizaron un total de 185 algoritmos diferentes de aprendizaje automático, siendo la arquitectura de red neuronal convolucional la más común

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the most common (73%). To improve diagnostic accuracy and speed were the most commonly achieved results (62%). **Conclusion:** heterogeneity was high among the studies, and extensive variation in methodology, terminology and outcome measures was noted. This can lead to an overestimation of the diagnostic accuracy of DL algorithms for medical imaging. There is an immediate need for the development of artificial intelligence-specific guidelines to provide guidance around key issues in this field.

Keywords: deep learning, artificial intelligence, orthopedics, convolutional network, imaging.

(73%). Mejorar la precisión y la velocidad del diagnóstico fueron los resultados más reportados (62%). **Conclusión:** la heterogeneidad fue alta entre los estudios y se observó una amplia variación en la metodología, terminología y medidas de resultados. Esto puede llevar a una sobreestimación de la precisión diagnóstica de los algoritmos para imagenología. Existe una necesidad inmediata de desarrollar directrices específicas para la IA que proporcionen orientación sobre cuestiones clave.

Palabras clave: aprendizaje profundo, inteligencia artificial, ortopedia, red convolucional, imagenología.

Introduction

Significant advances have been made in deep learning (DL), a subset of machine learning and artificial intelligence (AI), in the field of healthcare, particularly in orthopedic surgery. By comprehending complex algorithms, deep learning has the potential to revolutionize diagnosis, treatment planning, prediction of surgical outcomes, and even surgical procedures.

DL and machine learning (ML) methods enable computers to learn from data and make decisions or predictions without being programmed to perform specific tasks. In simple terms, ML involves teaching computers to recognize patterns or trends in data, while DL, a subset of ML, uses layers of algorithms called neural networks to analyze these data patterns more deeply.[1]

In the field of medical science, deep learning has become particularly valuable in analyzing medical images. By using neural networks, DL algorithms can detect intricate patterns in images such as X-Rays or MRIs, enabling them to diagnose diseases such as cancer with a high degree of accuracy. This technology acts like an expert radiologist but can work around the clock and process information at speeds and volumes far beyond human capabilities.[2,3]

The integration of DL and ML into medical science, especially in orthopedics, could revolutionize how we diagnose, treat, and develop interventions. These technologies significantly advance patient care, improve treatment outcomes, and drive innovation in medical research and practices. As this field continues to evolve rapidly, it holds great promise for even more remarkable breakthroughs and applications in enhancing health and quality of life.[4]

Advancements in deep learning in orthopedics

Preoperative planning

Deep learning algorithms have been successful in preoperative planning, particularly in predicting outcomes and complications. It also helps in selecting the most appropriate surgical approach.[5]

Image interpretation

Deep learning algorithms have been developed for image interpretation and have achieved expert-level accuracy in diagnosing different orthopedic conditions through MRI, X-Ray, or CT scan readings.[1,2,6]

Prosthesis design

AI can aid in the customization of prosthetics, leading to a better fit and increased functionality for individual patients.[3,7]

Robotic orthopedic surgery

Artificial intelligence-based robotics systems have gained ground in orthopedic surgery, such as hip and knee replacements, leading to greater precision and potentially better patient outcomes.[8]

Material and methods

This systematic review was carried out following the procedures highlighted in the 'PRISMA-DTA' extension for diagnostic validity studies, as well as following systematic review guidelines.[9]

Selection criteria

We sought studies that reveal the diagnostic accuracy and uses of DL algorithms in identifying pathologies or diseases of orthopedic interest. The primary objective was to identify the type of studies and range of diagnostic accuracy metrics. The secondary objectives included the study design and quality of reporting.

Data collection and searches

Electronic literature searches in PubMed, EMBASE and Google Scholar were also conducted from January 1st, 2020, up to October 31st, 2023. The search terms used consisted of Mesh terms and all-field search terms for «orthopedic deep learning» and «neural networks» (examples are DL, convolutional networks, etc.) and specific terms such as «imaging» (such as magnetic resonance, computed tomography, ultrasound, or X-Ray), and the results were used as «diagnostic accuracy metrics» (sensitivity and specificity). We identified 862 studies, 595 of which were included in the systematic review. A total of 281 studies about radiographic assessment, 102 about spine-oriented surgery, 95 about outcome assessment, 84 about basic AI orthopedic education and 33 about basic science application were included for review. Peer-reviewed studies that reported on the accuracy of DL algorithms for identifying pathology using medical imaging were included. Primary outcomes were diagnostic accuracy, study design and reporting standards reported in the literature. Estimates were pooled using random effects meta-analysis *(Figure 1)*.

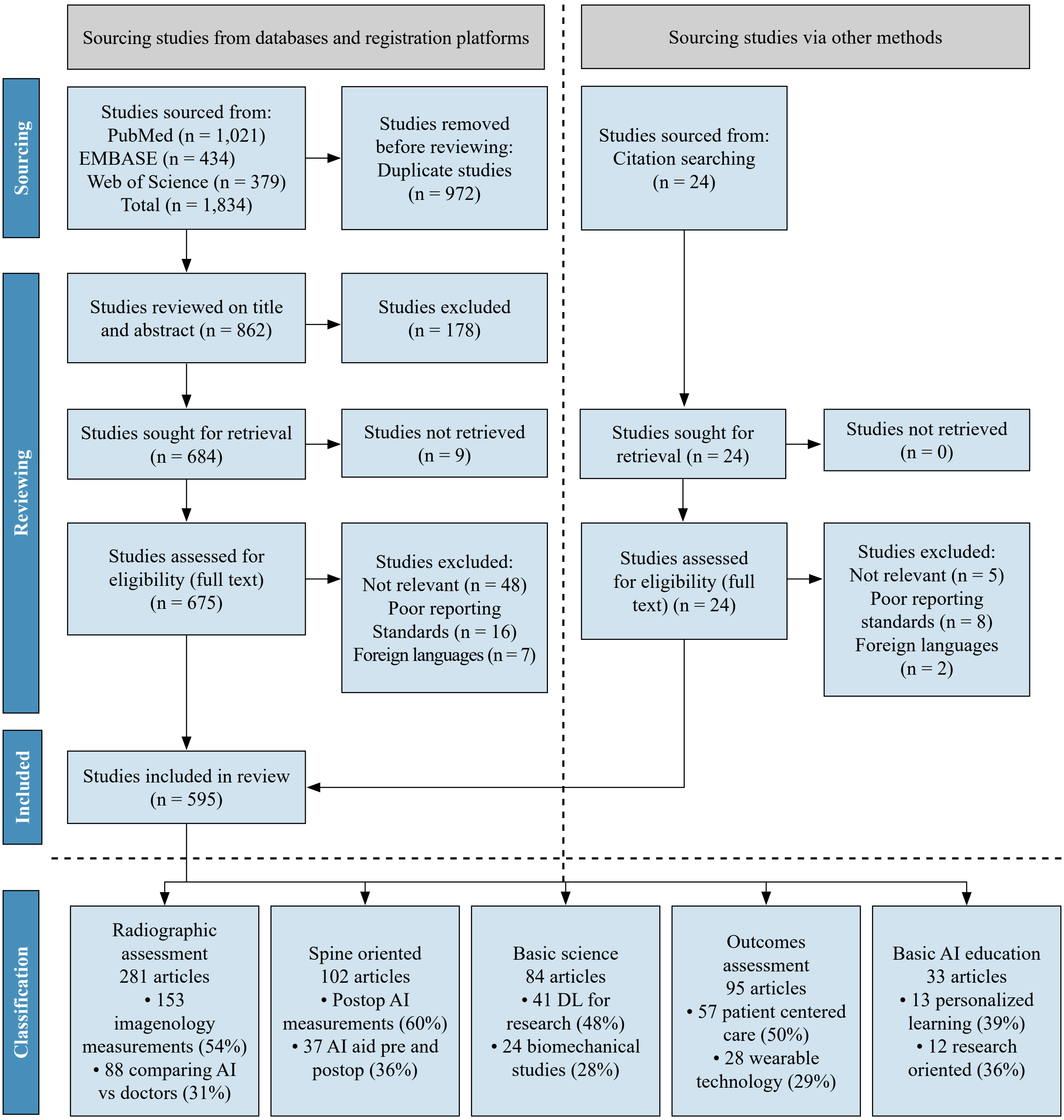

Figure 1: Review stages based on Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) flow diagram and key-oriented classification by authors.
AI = artificial intelligence. DL = deep learning.

Inclusion criteria

Eligible studies included those evaluating the diagnostic accuracy of a DL algorithm in the orthopedic field in general and in subspecialties. Only studies that reported either diagnostic accuracy raw data or sensitivity and specificity data were incorporated in the systematic review. No restrictions were imposed on the date range, and the most recent search took place in November 2023.

Exclusion criteria

Articles not written in English were excluded. Abstracts, conference articles, preprints, reviews, and meta-analyses were not considered as the purpose was to scrutinize the methodology, reporting standards, and quality of primary research studies appearing in peer-reviewed journals.

Selection process

The study selection process entailed an initial review by two different reviewers of all titles and abstracts. This was followed by a second review by the third and fourth authors of the full-text articles. This process ensured that the remaining articles met the inclusion criteria.

A total of 153 different imaging methods for radiographic aspects were identified. A total of 185 different ML algorithms were used, with the convolutional neural network architecture being the most common (73%). Improving diagnostic accuracy and speed was the most common method used (62%)

Review

This review focuses on five principal applications of machines and deep learning methodologies in orthopedics. The key areas of focus include (1) evaluation through radiography, (2) spine-focused surgical interventions, (3) basic orthopedic science, (4) evaluation of outcomes in general orthopedic surgeries, and (5) fundamental artificial intelligence (AI) instruction for orthopedic surgeons. Given the expansive use of AI in orthopedic surgery, it is impractical to cover every facet of this review. Instead, we have opted to concentrate on a select few applications that we believe encapsulate and effectively summarize the enhancements associated with AI and deep learning; we summarize these reviews with examples in *Table 1*.

Application 1: radiographic assessment

DL, an AI technology, possesses the ability to analyze and interpret complex medical imaging, a capability that paves the way for more accurate diagnoses and patient-specific treatments.[10] Studies have shown that DL can process X-Rays, CT scans, and MRI images effectively to identify specific pathologies, such as fractures, osteoarthritis, bone tumors, deformities, and degenerative diseases.[11,12] Radiographic parameters are instrumental for accurately determining disease progression, planning surgeries, and predicting postoperative outcomes. Moreover, this approach has the potential to analyze biomechanical data and perform automated measurements, which are traditionally time-consuming.[13]

In addition to improving diagnostic accuracy, its application also brings forth the potential for expedited and optimized medical workflows. With its ability to swiftly analyze large volumes of radiographic data, clinicians can rapidly plan treatment trajectories and focus intensively on critical patient care.[14,15] Moreover, DL models can easily facilitate the detection of subtle or complex patterns in images, which may be challenging even for experienced radiologists. This could enhance early detection and intervention for debilitating conditions, eventually improving patient outcomes. Additionally, DL can serve as an educational tool to aid trainees and junior clinicians in enhancing their understanding and interpretation of orthopedic imaging.[16] Certainly, key challenges must be considered, such as ensuring the ethical use of patient data, maintaining transparency in AI decision-making processes, and eliminating interoperability issues among various healthcare systems.

However, despite its promising advantages, DL implementation in orthopedics must be approached with caution due to its dependency on the quality and size of the dataset used for training. Hence, additional research is necessary to overcome these potential limitations and standardize the use of DLs in orthopedic radiographic assessments in pursuit of precision medicine. Overcoming these obstacles will be crucial for fully realizing the potential benefits and advancements that DL offers to the field of orthopedic radiographic assessment.

Application 2: spine-oriented surgery

DL has presented significant advancements, particularly in spine-oriented surgical procedures. Researchers and practitioners are actively exploring and utilizing DLs to assist in areas ranging from diagnosis to surgical planning and prognosis prediction.[17] Specific examples include the detection and classification of spinal disorders such as scoliosis, spondylolisthesis, and intervertebral disc degeneration from radiographic images. DL models have also been designed to assist in surgical planning by predicting pedicle screw placement, reducing the chances of iatrogenic injury.[18,19]

In addition to its use in diagnostic and treatment planning, the role of DL in enhancing intraoperative guidance and postoperative rehabilitation in spinal surgeries also demonstrates significant promise. With its advanced pattern recognition capabilities, DL can potentially provide real-time feedback during spinal surgeries, thereby increasing the precision and safety of procedures.[20,21] For instance, DL algorithms can aid in identifying anatomic landmarks, enhancing visualization, and assisting tool navigation, subsequently reducing the risk of medical errors.

Table 1: Summary of deep learning techniques applied to orthopedic literature.

Study	Aims	Deep learning method	Application
Staartjes, et al.[5]	Evaluate the feasibility of deriving robust deep learning-based predictive analytics from single-center, single-surgeon data	Deep neural network-based and logistic regression-based prediction models	Basic AI education Outcomes assessment
Kang, et al.[7]	Develop a machine learning–based implant recognition program and to verify its accuracy	Object detection and clustering. Model training with Keras deep learning platform	Basic AI education
Moon, et al.[14]	Automatically, rapidly, and accurately detect lower limb alignment by using anteroposterior standing X-Ray	YOLOv5 (Vision AI) HarDNet-MSEG image segmentation model	Radiographic assessment
Tan, et al.[23]	Identify biomarkers and develop an integrated diagnostic model for predicting the onset of early intervertebral disc degeneration	LASSO, random forest, and support vector machine recursive feature elimination	Basic science
Anastasio, et al.[24]	Identify combinations of orthobiologic factors applied to bone healing/fusion	Artificial neural networks	Basic science Basic AI education
Yan, et al.[25]	Segment chondrocytes from histological images of cartilage	U-Net (convolutional neural network)	Basic science
Melgoza, et al.[26]	Report a new robust quantitative mouse intervertebral disc degeneration histopathological scoring system	Artificial neural networks and multilayer perceptron	Basic science
Zhu, et al.[28]	Develop a predictive model for postoperative osteonecrosis of the femoral head	MATLAB convolutional neural network	Basic AI education outcomes assessment
Maki, et al.[35]	Develop a predictive model for surgical outcomes in patients with cervical ossification of the posterior longitudinal ligament	Machine learning, LightGBM, deep learning, RadImagenet	Spine-oriented surgery Radiographic assessment
Patel, et al.[36]	Develop and evaluate a model for identifying orthopedic implants using radiographs	Seven convolutional neural networks U-Net segmentation network	Basic AI education Radiographic assessment
Shen, et al.[37]	Developed an MRI-based system to detect early osteonecrosis of the femoral head	Convolutional neural network	Radiographic assessment
Guy, et al.[38]	Make the diagnosis of proximal femur fracture on radiographs	Deep learning algorithm (TensorFlow)	Radiographic assessment
Guo, et al.[39]	Developed a model for diagnosing supraspinatus tears shoulder MRI	Convolutional neural networks (Xception)	Radiographic assessment
Yi, et al.[40]	Identification, classification and differentiation for knee arthroplasty implants	Deep convolutional neural network	Radiographic assessment
Klempt, et al.[41]	Develop and validate a model for identification of hip and knee joint arthroplasty designs from plain radiographs	Convolutional neural network	Radiographic assessment
Merkely, et al.[42]	Identify cartilage defects when applied to the interpretation of knee MRI	Three convolutional neural networks	Radiographic assessment
Yamamoto, et al.[43]	Statistically evaluate the osteoporosis identification ability	ResNet convolutional neural network	Radiographic assessment
Tiwari, et al.[44]	Identify the most appropriate -based model for the detecting grade of knee osteoarthritis	Eight machine learning models (DenseNet)	Radiographic assessment Basic AI education
Leung, et al.[45]	Develop a prediction model for risk of knee osteoarthritis progression	Transfer learning approach (ResNet34)	Radiographic assessment
Borjali, et al.[46]	Develop a model for efficient and accurate hip dislocation detection following primary total hip replacement from medical narratives	Convolutional neural network natural language processing models	Basic AI education
Eweje, et al.[47]	Develop an algorithm that can differentiate benign and malignant bone lesions using routine MRI	EfficientNet-B0 architecture and a logistic regression model	Radiographic assessment
Ashkani, et al.[48]	Assess the performance of two different networks in detecting ankle fractures using radiographs	Deep convolutional neural networks Inception V3 and ResNet50	Radiographic assessment

Continuous Table 1: Summary of deep learning techniques applied to orthopedic literature.

Study	Aims	Deep learning method	Application
Li, et al.[49]	Improve the diagnostic accuracy and efficiency for diagnosing meniscal tear using MRI	Mask regional convolutional neural network. ResNet50	Radiographic assessment
Magneli, et al.[50]	Train and evaluate a model for AO/OTA classification of shoulder fractures	A modified CNN of the ResNet architecture	Radiographic assessment
Shen, et al.[51]	Exploratory investigation for the classification and prediction of mechanical states of cortical and trabecular bone tissue	Convolutional neural networks. ResNet with transfer learning	Basic science Basic AI education
Lau, et al.[52]	Build an image-based machine-learning model for detecting TKA loosening	Random forest classifier Xception Model, ImageNet and TensorFlow	Radiographic assessment Basic AI education
Kim, et al.[53]	To automatically select and position THA components that are most suitable for the patient’s bone anatomy	Convolutional neural network	Basic AI education
Recht, et al.[54]	Accelerate MRI to allow a 5-minute comprehensive examination of the knee	Variational network U-Net	Basic science Basic AI education
Borjali, et al.[55]	Increase accuracy, accelerate analysis time, and reduce interobserver bias by automating 3D volume assessment of syndesmosis anatomy	Three deep learning models	Radiographic assessment Basic AI education
Yang, et al.[56]	To assess the severity of knee osteoarthritis in portable devices	RefineDet Deep learning-based diagnostic model	Basic AI education Radiographic assessment
Hernigou, et al.[57]	Provide an overview of the possibility to predict dislocation with a calculator according to the type of implant for THA	Supervised learning model Artificial neural network	Basic AI education Outcomes assessment
Rahman, et al.[58]	To detect loosening of the hip implant using X-Ray images	Deep Convolutional Neural Networks based novel stacking approach (HipXNet)	Basic AI education Radiographic assessment
Wang, et al.[59]	Develop a recovery and nursing system after total hip arthroplasty and to conduct clinical trials	Deep neural network based on Mask R-CNN	Basic AI education Outcomes assessment
Kinugasa, et al.[60]	Evaluate the accuracy of diagnoses made by AI on ultrasound images of developmental dysplasia of the hip	MATLAB deep learning toolbox	Basic AI education Radiographic assessment
Sharifi, et al.[61]	Identify spatiotemporal gait parameters, gait patterns, activity types, and changes in mobility after total knee arthroplasty	Six contemporary multivariate time series neural network architectures	Basic AI education Outcomes assessment
Li, et al.[62]	Evaluate the performance of DL in differentiation of benign and malignant vertebral fracture on CT	ResNet50 network	Radiographic assessment
Rouzrokh, et al.[63]	Identify all pelvic and hip radiographs with appropriate annotation of laterality and presence or absence of implants	Two deep-learning algorithms EfficientNetB3 classifier YOLOv5 object detector	Basic AI education Radiographic assessment
Huang, et al.[64]	Automated segmentation and quantification of the vertebrae and intervertebral discs on lumbar spine MRIs	Deep learning-based program (Spine Explorer)	Radiographic assessment Spine-oriented surgery
Kong, et al.[65]	Develop an X-Ray-based fracture prediction model using deep learning with longitudinal data	Convolutional neural network. DeepSurv	Radiographic assessment Spine-oriented surgery
Zhao, et al.[66]	Create a reliable learning-based approach that provides consistent and highly accurate measurements of the Cobb angle	Convolutional neural network Deep learning SpineHRformer	Radiographic assessment
Wang, et al.[67]	Analytic function for the correlation between lumbar disc herniation and angle and irregular variation of joint of lumbar facet-joint	Convolutional neural network-Based MRI image recognition algorithm	Radiographic assessment Spine-oriented surgery
Broida, et al.[68]	To more accurately screen surgical candidates seen in a spine clinic.	Transformer-based machine learning architecture	Spine-oriented surgery Basic AI education

Continuous Table 1: Summary of deep learning techniques applied to orthopedic literature.

Study	Aims	Deep learning method	Application
Ito, et al.[69]	Predict postoperative complications in patients with cervical ossification of the posterior longitudinal ligament	Deep learning was used to create two predictive models	Spine-oriented surgery Outcomes assessment
Etzel, et al.[70]	Predict and classify whether a patient will experience a short or long hospital LOS after lumbar fusion surgery with a high degree of accuracy	Six machine learning algorithmic analyses	Spine-oriented surgery Outcomes assessment
Maras, et al.[71]	Differentiate normal cervical graphs and graphs of diseases that cause mechanical neck pain	Convolutional neural networks VGG-16, VGG-19, Resnet-101, and DenseNet-201 networks	Radiographic assessment
Campagner, et al.[72]	Define an invasiveness score for LBP procedures based on biological markers and inflammatory profiles	Supervised machine learning	Spine-oriented surgery Outcomes assessment
Liu, et al.[73]	Diagnosis of benign and malignant spinal tumors based on magnetic resonance imaging	Multimodel weighted fusion framework	Radiographic assessment
Müller, et al.[74]	Predict the multidimensional outcome of patients undergoing surgery for degenerative pathologies of the thoracic, lumbar or cervical spine	Convolutional neural network	Spine-oriented surgery Outcomes assessment
Mandel, et al.[75]	Forecasting the outcome of vertebral body growth modulation from skeletally immature patients	Spatial-temporal corrective networks	Spine-oriented surgery Outcomes assessment
Fan, et al.[76]	Simulated foraminoplasty of percutaneous endoscopic transforaminal discectomy	Deep learning-derived 3D (DL-3D) models	Spine-oriented surgery
Chen, et al.[77]	Analyze perioperative factors and predict the occurrence of surgical site infection following posterior lumbar spinal surgery	LASSO regression analysis, support vector machine, and random forest	Spine-oriented surgery Outcomes assessment
Mu, et al.[78]	Application value of magnetic resonance spectroscopy and computed tomography in the treatment of lumbar degenerative disease and osteoporosis	Deep convolutional neural network image segmentation processing technology	Spine-oriented surgery Basic AI education
Cho, et al.[79]	Automatically detect the tip of the instrument, localize a point, and evaluate the detection accuracy in biportal endoscopic spine surgery	RetinaNet and YOLOv2	Spine-oriented surgery Basic AI education
Silva, et al.[80]	Predict spine surgery outcome	Boosted decision tree classifier (SpineCloud)	Spine-oriented surgery
Kuris, et al.[81]	Determine whether it could predict readmission after 3 lumbar fusion procedures	Neural network, a supervised machine learning technique	Spine-oriented surgery Outcomes assessment
von Atzingen, et al.[82]	Marker-less surgical navigation proof-of-concept to bending rod implants	Augmented reality with on-device machine learning	Spine-oriented surgery Basic AI education
Tran, et al.[83]	Semantic segmentation on X-Ray images	Multipath convolutional neural network, BiLuNet	Basic AI education Radiographic assessment
Chen, et al.[84]	Identify the possibility of THR in three months of hip joints by plain pelvic radiography	Sequential two-stage deep learning algorithm HipRD and SurgHipNet	Basic AI education Radiographic assessment
Niculescu, et al.[85]	Comparative study of the biomechanical behavior of commonly used orthopedic implants for tibial plateau fractures	Artificial Neural Network model	Basic science Basic AI education
Bonnheim, et al.[86]	Calculating biomarkers of cartilage endplate health using MRI images	Four independent convolutional neural networks	Basic science Radiographic assessment
Kasa, et al.[87]	Assess surgical performance with comparable performance to the expert human raters	Multimodal deep learning model	Basic AI education Outcomes assessment
Loftus, et al.[88]	Reproducibility of an automated postoperative triage classification system	Deep convolutional neural network	Basic AI education

However, complete adoption of DL in spine-related orthopedic practices remains a challenging task. Despite the considerable progress, issues such as data privacy, algorithmic transparency, and the need for interdisciplinary collaboration between data scientists and clinicians need to be adequately addressed. As the potential of DL continues to be explored, more comprehensive guidelines governing its application in spinal surgeries have yet to be established to leverage its benefits effectively.

Application 3: Basic science (biomechanics/pathogenesis)

In the realm of basic science in orthopedics, the incorporation of DL has amplified the possibility of understanding intricate details and processes at the molecular, cellular, and tissue levels. The established DL algorithms can supplement traditional research methods by analyzing complex patterns and interrelationships among numerous biological variables. They can handle vast multidimensional datasets, aiding in biomarker discovery, modeling disease progression, and identifying potential therapeutic targets.[22]

DL can aid genomic research in orthopedics, where it could be used to understand patterns of gene expression pertaining to bone growth, determine the underlying genetic causes behind orthopedic diseases, or predict patient responses to treatments at the genetic level. Similarly, at the tissue level, DL-powered image analysis can provide a more in-depth analysis of histopathological samples, potentially enabling early detection of degenerative diseases and comprehensive assessment of cellular responses to different interventions.[25]

Moreover, DL can complement biomechanical studies by facilitating the analysis of complex motion patterns and forces, providing deeper insights into the effects of various physical activities on the musculoskeletal system.[26]

Application 4: outcomes assessment

DL has proven to be a critical tool in orthopedics for assessing patient outcomes. By analyzing vast sets of patient data, DL models can predict patient-specific outcomes following various interventions, thereby enabling a more personalized approach to patient care. Moreover, this approach can help identify factors contributing to optimal and suboptimal outcomes, facilitating improvements in therapeutic strategies.[27,28] DL algorithms can be used to mine data to uncover complex, non intuitive correlations between patient characteristics, intervention details, and postoperative outcomes. Such correlations could be used to predict future patient recovery patterns, incidence of complications, or even the likelihood of rehospitalization, allowing clinicians to effectively plan and adjust treatments and follow-up schedules.[29]

Furthermore, DL can be used to analyze real-time patient data collected through wearable technology to provide a comprehensive understanding of patient function and recovery in real-world settings. By mining these rich data sources, DL can potentially uncover nontraditional metrics of orthopedic outcomes, which may prove relevant in achieving patient-centered care.[29,30] DL can decipher patterns in movement data to accurately assess rehabilitation progress following joint replacement or reconstructive surgeries. Likewise, this study can provide insights into the adherence of patients to prescribed rehabilitation protocols and enable tailored interventions for improving patient compliance.[31,32]

While this fusion of DL and wearable technology opens a new dimension in outcome research in orthopedics, key issues, including patient acceptance, data privacy, and data validity, need careful deliberation. Nonetheless, with continuous refinement and stringent validation practices, the integration of DL can undoubtedly drive a paradigm shift in outcome assessment, taking orthopedic care a step closer to the aim of optimized, patient-centered care. As we move forward, the effective application of DLs can significantly enhance the quality and efficacy of orthopedic care by ensuring that interventions align with individuals' expectations and desired outcomes.

Application 5: fundamental AI education for orthopedic surgeons

DL, as a subset of AI, has been progressively weaving its way into medical education, including orthopedics. With its capacity to process vast and complex datasets, DL can contribute significantly to bolstering both theoretical knowledge and practical skills among medical students and professionals in the orthopedic field. For example, DL algorithms can assist in creating immersive, personalized learning experiences by identifying individual learning patterns and offering tailored educational content.[33]

Beyond direct educational functions, DL can serve as an integral tool in fostering research literacy among medical students and professionals in orthopedics. With increasing focus on evidence-based practice in the current healthcare landscape, having skills to conceive, conduct, and interpret research is now considered equally important as clinical skills. DL can equip learners to handle big data analytic tasks, analyze complex research data, and more accurately interpret the findings of a study.[34] Additionally, DL can be used as a pedagogical tool to teach foundational concepts of bioinformatics relevant to orthopedics, such as genomic studies in osteoarthritis or proteomic data analysis in bone healing.

The introduction of AI-driven research concepts in medical education faces several hurdles, including the need for curricular adaptations, lack of skilled educators, and the risk of overreliance on algorithms at the expense of contextual decision-making. Despite these challenges, the incorporation of DL in medical education is a necessary advancement that can mold a generation of medical professionals competent in both clinical and research domains of orthopedics.

Importantly, familiarizing future orthopedic practitioners with AI concepts and their uses also becomes fundamental to nurturing a workforce that is adept at leveraging DL in clinical problem solving.

Limitations and challenges

Certain challenges surfaced in the literature under review include the 'black box' nature of neural network models, which makes it difficult for users and orthopedic surgeons to comprehend and explain the basis of the outcomes produced. Moreover, there are hindrances to the applicability and implementation of these models across various healthcare institutions due to variations in standardization, procedures, and dataset parameter availability. Even when dataset parameters are available, their values may differ because of varying demographics and geographical locations. These limitations may influence the overall accuracy and predictive potency of the artificial intelligence model and could pose a risk to patients if implemented indiscriminately. Thus, further investigations and trials are indispensable for confirming the efficacy of the developed model.

Despite its impressive potential, it is crucial to note that the success of DL applications relies primarily on the quality, size, and diversity of the data used for model training. The full integration of DL into surgery, therefore, requires additional studies, robust data handling techniques, and stringent validation measures to ensure accurate and reliable utilization in clinical practice.

Future considerations

The integration of advanced technologies such as DL and AI into orthopedics marks a significant shift toward more precise, personalized, and efficient care in the field. Currently, these technologies are being applied to improve diagnostic processes, such as interpreting X-Rays and MRI scans with remarkable accuracy and modeling and simulating surgical planning. In the future, orthopedics could be profoundly impacted by further advancements in DL and AI. These technologies hold the promise of enhancing diagnostic accuracy, streamlining treatment planning, optimizing surgical interventions through robotic assistance, and tailoring patient care to individual needs with unprecedented precision. Furthermore, AI-driven predictive models could pave the way for proactive management of orthopedic conditions, potentially improving long-term outcomes.

The field of radiology research has widely embraced deep learning, a testament to the potential of this technology to revolutionize medical imaging analysis. A noticeable trend in the plethora of medical literature is the frequent use of deep learning models applied through different conception methodologies. The replication observed in radiology studies emblematic of the community's determination to fine-tune the accuracy of these models, emphasizing the importance of deriving diverse methodologies tailored to distinct datasets and clinical scenarios, despite the commonality of the underlying algorithms. While the repetitive use of similar models facilitates a deeper understanding of their capabilities and limitations, it also poses the challenge of potentially stalling innovation by focusing on incremental improvements rather than groundbreaking discoveries.

However, this approach has undeniably propelled radiology forward, improving image analysis, helping early and accurate diagnoses, and initiating a continual dialog on best practices. In sum, although the repetitive nature prevails in radiological deep learning research, its presence is pivotal both for incremental progress and for highlighting areas where novel contributions are crucial for further advancements in the field, urging researchers to persistently seek innovative solutions.

The widespread adoption of AI in orthopedic practice must carefully address potential challenges, including data privacy concerns, the need for substantial training datasets, and ensuring equitable access to AI-driven care. Ethical considerations around patient autonomy and the role of AI in clinical decision-making also require thoughtful addressing.

Conclusion

Advancements in deep learning offer immeasurable opportunities in orthopedic surgery, from aiding in diagnosing complex conditions to performing surgical procedures with greater precision than ever before. However, integrating deep learning algorithms into orthopedics is associated with numerous challenges, including ethical concerns about data privacy and regulating the use of AI in clinical environments. More research is needed to validate and refine these tools and strategies so they can be safely and effectively incorporated into practice.

Heterogeneity was high between studies, and extensive variation in methodology, terminology and outcome measures was noted. This can lead to an overestimation of the diagnostic accuracy of DL algorithms for medical imaging. There is an immediate need for the development of artificial intelligence-specific guidelines to provide guidance around key issues in this field.

DL is a burgeoning field with immense potential across all areas of healthcare, particularly radiology. The present systematic review and meta-analysis scrutinized the quality of the literature and summarized the diagnostic accuracy of DL techniques. Despite the high diagnostic accuracy of DL currently available, interpreting these findings is vital considering the poor design, conduct, and reporting of studies, which could result in bias and overestimation of the power of these algorithms. Improving DL application requires standardized instructions related to study design and reporting, which can further clarify its clinical utility.

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