

Current Concepts

Artificial Intelligence in Orthopedic Surgery: A Practical Overview of Current Applications and Trends

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Keywords: Machine Learning, Orthopedic Surgery, Artificial Intelligence

<https://doi.org/10.58616/001c.137606>

SurgiColl

Vol. 3, Issue 3, 2025

Artificial intelligence (AI) is transforming orthopedic surgery through diagnostics, treatment planning, and postoperative care advancements. This review introduces AI's current applications, including convolutional neural networks (CNN) for imaging analysis and machine learning (ML) models for predictive assessments. By introducing specific emerging AI technologies and offering insight into their functionality in clinical settings, the review aims to give orthopaedic surgeons an idea of how such tools could enhance their practice. Additionally, the review analyzes the challenges hindering broader AI adoption, including concerns over data privacy, algorithmic bias, and integration into existing clinical workflows. By providing an overview of AI's practical applications and potential barriers, the review equips orthopedic surgeons with a foundational understanding of the technology's role and its implications for future practice.

INTRODUCTION

Artificial intelligence (AI) is steadily gaining traction in healthcare, offering new tools for improving diagnostics, predictive modeling, and patient care management. However, its adoption across different medical specialties, including orthopedics, is still in its initial stages. For orthopedic surgeons, the potential of AI to assist in clinical decision-making, surgical planning, and post-operative care is promising but not without challenges. This review aims to provide an overview of the current and potential applications of AI in orthopedic surgery, as well as highlight the practical barriers to its implementation in everyday practice.

APPLICATIONS IN ORTHOPEDIC SURGERY

DIAGNOSTIC TOOLS

Recent investigations have elucidated the capacity of CNNs to enhance the interpretive accuracy of radiological examinations, especially for fracture diagnosis in radiographs. The commercial product BoneViewTM (Paris, France) has shown strong diagnostic ability in both pediatric and adult populations. In a prospective study, Boginskis et al. showed a 2-3 times reduction in diagnostic errors.¹ It also shows

promise as an assistive tool for radiology residents. Meetschen et al. found improved accuracy in reading 200 adult and pediatric trauma radiographs from 58% without AI to 79% with AI while also decreasing the interpretation time by 2.6 seconds on average.² In urgent situations or trauma settings where a radiologist may not be immediately available, AI can help them make faster, more accurate decisions about surgical intervention. This allows surgeons to efficiently validate diagnoses and focus on treatment planning without waiting for additional input.

Beyond bone injury diagnosis, ML applications have demonstrated promising results in identifying muscle pathologies, such as rotator cuff tears. A novel automated detection system developed in 2024 employed deep learning algorithms to accurately classify rotator cuff tears from plain shoulder radiographs, signifying a substantial advancement in diagnostic capabilities.³ Due to the high sensitivity of 92% of the model, it could be used as a screening method to rule out shoulder pathology if weakly suspected by the clinician. For a more specific and accurate diagnosis, researchers have also shown AI's ability to specifically diagnose rotator cuff tears on MRI with an overall accuracy of 95%.⁴ In emergent situations, these technologies could reduce the workload on surgeons by providing referring physicians with a preliminary AI-generated assessment, allowing for quicker triaging and more efficient use of spe-

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cialist consultation time. Another advantage of AI diagnostic tools is their potential deployment in resource-limited countries where orthopedic expertise is scarce, enabling local clinicians to make more accurate preliminary assessments without immediate specialist involvement.⁵

RISK ASSESSMENT AND SURGICAL OUTCOME PREDICTION

The widespread adoption of Electronic Health Records (EHRs) has brought about a positive consequence: it has generated substantial data that can aid surgeons in making decisions grounded in evidence. One effective approach to leverage this data is by training ML models on it. These models analyze information from a patient's chart to gauge the suitability of a particular intervention or forecast its potential outcomes.⁶

Risk assessment calculators represent one of the most prevalent applications of ML in surgery. These calculators aid in clinical decision-making by utilizing patient characteristics, such as pertinent disease status, to forecast the risk associated with variables like the length of hospital stay. They are developed by training ML models on retrospective data extracted from patient charts and corresponding outcomes. The American College of Surgeons National Surgical Quality Improvement Program (NSQIP) risk calculator is a prominent example. It harnesses patient and surgical outcome data gathered from over five million operations to predict the risk of postoperative complications. Validation studies have demonstrated the calculator's acceptable accuracy, including in orthopedic settings.^{7,8} When evaluating a patient's candidacy for surgery, a patient's details can be plugged into this online risk calculator, providing an additional data point for the surgeon's decision-making. This could be especially advantageous in a field like spine surgery as it could make outcomes more predictable.⁹ Furthermore, insurance providers increasingly leverage these risk calculators as part of their preauthorization processes, using predictive outcome data to determine coverage eligibility for orthopedic procedures such as elective joint replacements and complex spine surgeries. These data-driven approaches also inform broader healthcare policy planning, helping payers develop evidence-based reimbursement models and cost-containment strategies that balance appropriate resource allocation with quality patient care.¹⁰

Researchers have also used ML to predict whether an intervention is required directly from an image. Using CNN, a model was developed to predict total hip replacement necessity from pelvic radiographs.¹¹ While radiographic findings are not enough to indicate the need for a total hip replacement, a tool like this could assist clinicians in incorporating radiographic findings into treatment planning in an evidence-based way.

ML's application in assessing body composition to predict outcomes in patients undergoing surgery for spinal metastases introduces a novel approach to preoperative evaluation. By analyzing muscle and adiposity characteristics through ML-derived body composition analysis, researchers have identified correlations between body com-

position and postoperative outcomes, including mortality and hospital stay duration.¹² This approach not only provides a deeper understanding of the physiological factors influencing surgical outcomes but also highlights the value of personalized patient assessments in improving care strategies.

There are still limitations to the current predictive models and work to be done. For example, a thumb carpometacarpal osteoarthritis surgery study demonstrated an ML model that attempts to predict functional improvement. However, it struggles to reliably predict postoperative pain, showing that ML still has some ways to go.¹³

INTRAOPERATIVE GUIDANCE AND FEEDBACK

While diagnosis and risk modeling can be done ahead of time, there is potential for ML systems to aid in optimizing a surgical intervention through intraoperative guidance and feedback, for instance, to analyze and improve surgical technique. Researchers developed a CNN that analyzes intraoperative video frames to facilitate the detailed analysis of hand movements during surgery. The system can take detailed measurements of hand position, which could be used to automatically assess how far trainees are away from ideal hand motions in surgery.¹⁴

Of particular interest to orthopedic surgery is automating pre-procedure planning. One application of this is an autonomous X-ray image acquisition and interpretation system for assisting percutaneous pelvic fracture fixation.¹⁵ The CNN-based model exemplifies the integration of AI in optimizing surgical workflows. By automating the acquisition of X-ray images and interpreting them to guide fracture fixation, this system illustrates how AI can streamline procedures, reduce radiation exposure, and improve accuracy. A research study also showed machine learning can predict total knee replacement implant size within one size at an accuracy of 90.0%, using preoperative features such as age and body mass index (BMI).¹⁶ Such an application aligns with the broader objectives of utilizing AI to enhance surgical precision and efficiency, underscoring the transformative potential of AI and ML in orthopedic surgery.

POSTOPERATIVE CARE: AI-DRIVEN TOOLS FOR PERSONALIZED CARE PLANS

One notable innovation is using virtual reality (VR) as both an evaluative and therapeutic tool following traumatic hand surgery.¹⁷ VR platforms powered by AI algorithms can simulate real-world tasks and environments, providing patients with a safe and engaging space for rehabilitation. These systems assess the patient's performance and progress in real-time, enabling therapists to tailor rehabilitation exercises to the individual's specific needs and recovery pace.

Another pioneering application of AI in postoperative care is the development of predictive models to improve gait training with robotic ankle exoskeletons.¹⁸ These models use ML to analyze patients' neuromuscular engagement during rehabilitation sessions, optimizing the exoskeleton's assistance to complement the patient's efforts and

predict the optimal level of support required at each stage of recovery.¹⁹

Risk assessment can enhance postoperative care as well. An excellent example is the use of ML to identify patients at risk of persistent opioid use after surgery, which signifies a proactive approach to managing postoperative pain and preventing opioid dependency.⁹ Having access to an accurate model that can predict opioid dependence would allow surgeons to better personalize a patient's postoperative treatment plan.

Furthermore, AI-powered monitoring systems play a crucial role in postoperative care by continuously assessing patients' vital signs, pain levels, and other relevant parameters. These systems utilize ML algorithms to identify early signs of complications, enabling healthcare providers to intervene promptly and adjust care plans as needed.²⁰ For example, researchers built a predictive model to identify risks such as deep vein thrombosis in rehabilitation inpatients.²¹ The study compared multiple models, including ANN-based models, and reported a very strong area under the receiver operating curve (AUROC) of 0.97. This proactive approach to postoperative care improves patient outcomes and enhances the healthcare system's overall efficiency by reducing the need for readmissions and prolonged hospital stays.

IMPROVING PATIENT FACING CARE

Improving patient-facing care through the integration of AI has shown promising results, particularly in enhancing the comprehensibility and accessibility of medical information for patients. Studies utilizing AI, specifically large language models (LLMs) like ChatGPT, have demonstrated significant improvements in making complex medical reports and surgical information more understandable to non-medical audiences. For example, in the realm of radiology, an AI-LLM was employed to translate foot and ankle radiology reports into layperson's terms, resulting in higher readability scores and better comprehension by patients.²²

In orthopedic surgery, AI's potential to inform and educate patients has been further explored, with studies focusing on common surgeries such as rotator cuff repair and anterior cruciate ligament reconstruction. These studies assessed the quality and reliability of AI-generated responses to patient queries, finding that while AI can offer high-quality information, challenges remain in terms of readability and the absence of source citations.²³

Moreover, studies have explored AI's role in pre-surgical counseling, such as one that built an educational chatbot for total knee replacement. However, caution is advised due to AI's tendency to generate non-existing references, highlighting the importance of verification and oversight by medical professionals.²⁴

CHALLENGES AND CONSIDERATIONS

The integration of AI and ML in orthopedic surgery, while promising, presents several challenges and considerations that must be addressed to ensure their effective and ethical

application. The performance of AI and ML models is heavily dependent on the quantity, quality, and diversity of the data on which they are trained.²⁵ In orthopedic surgery, this means accessing comprehensive datasets that include a wide range of patient demographics, medical histories, imaging data, and outcomes. However, the availability of such datasets can be limited due to data privacy regulations, the siloed nature of healthcare data repositories, and the variability in data collection and annotation standards across different institutions.²⁶ Ensuring data quality and representativeness is crucial to developing accurate and generalizable models for diverse patient populations.

Ethical and privacy concerns are also paramount when considering the implementation of AI and ML in healthcare. Using patient data to train AI models raises questions about consent, data security, and the potential for unintended bias.²⁷ Bias in AI models can lead to disparities in diagnosis, treatment recommendations, and outcomes for specific patient groups, exacerbating existing healthcare inequalities. Addressing these concerns requires stringent data protection measures, transparent model development processes, and the incorporation of ethical considerations from the outset of AI project design.²⁸

Integrating AI and ML technologies into existing medical practices poses another significant challenge. The healthcare industry is characterized by complex workflows, regulatory requirements, and a need for high levels of accuracy and reliability. Integrating AI tools into this environment requires careful consideration of how these technologies will fit into existing clinical workflows, the impact on healthcare professionals' roles and responsibilities, and the potential need for changes to regulatory frameworks.²⁹ Moreover, the reliability and accuracy of AI models in clinical settings must be rigorously validated to gain the trust of healthcare providers and patients alike. This involves not only technical validation but also clinical trials to demonstrate the efficacy and safety of AI-assisted interventions.³⁰

Finally, the successful adoption of AI and ML in orthopedic surgery will necessitate substantial training and education for surgeons and other healthcare professionals. Many practitioners may not have a background in data science or AI. This education should not only focus on the technical aspects of AI but also the ethical considerations, potential biases, and limitations of AI models.³¹

CONCLUSION

Integrating AI and ML offers practical tools for orthopedic practice, from improving fracture detection and predicting surgical outcomes to enhancing intraoperative guidance and postoperative care. While promising, implementation requires addressing data quality issues, privacy concerns, and workflow integration challenges. For these technologies to be clinically valuable, orthopedic surgeons need a basic understanding of AI methods and should collaborate with data scientists to ensure tools meet real clinical needs. With proper validation and ongoing education, AI can serve as an adjunct to clinical judgment, potentially improving

efficiency and patient outcomes without replacing the expertise of the treating surgeon.

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DECLARATION OF CONFLICT OF INTEREST

The authors do NOT have any potential conflicts of interest related to the content presented in this manuscript.

DECLARATION OF FUNDING

The authors received NO financial support for the preparation, research, authorship, and publication of this manuscript.

DECLARATION OF ETHICAL APPROVAL

Institutional Review Board approval was not required to produce this manuscript.

DECLARATION OF INFORMED CONSENT

There is no information (names, initials, hospital identification numbers, or photographs/images) in the submitted manuscript that can be used to identify any patients.

Submitted: May 29, 2024 EDT. Accepted: May 03, 2025 EDT.

Published: September 22, 2025 EDT.



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