NARRATIVE REVIEW

Clinical applications of AI-prediction tools in spine surgery: a narrative review

Mohammad Hamza Bajwa, Areeba Ahmed Samejo, Akbar Jaleel Zubairi

Abstract

Spine surgery has grown into a wide, complex field encompassing trauma surgery to deformity to tumours. Artificial intelligence (AI) based technology has been particularly useful in improving imaging-reporting and detection of predictive patterns. The purpose of this narrative review is to present practical approaches towards implementing upcoming AI spine research for clinicians to help improve practices, clinical throughput, and surgical decision-making.

Keywords: Artificial Intelligence, Acute Care Surgery, Neoplasms, spine deformity, scoliosis, prediction

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Introduction

Complex surgical specialties, such as spine surgery, require developing protocols and decision-enhancing tools based on large datasets. Particularly in spinal surgery, the influx of new technologies, advanced imaging, robotic-assisted surgery, and augmented-reality adjuncts, surgeons are likely to offer personalized options to a wide array of patients. Artificial intelligence (AI) can help improve spine surgery heuristics especially considering imaging characteristics and pattern recognition. Avoiding risk and complications, choosing optimal surgical corridors, and adjusting treatment modalities for patient-specific comorbidities are currently subjective assessments made by surgeons – an AI prediction model could help formalize many of these intuitive processes as well as protect against cognitive biases.[1] The second aim is for AI to improve surgical productivity and act as expert advisors to surgeons. Machine learning (ML)is based on multiple mathematical and computer applications, for example natural language processing (NLP), ML-derived clinical decision support, deep learning (DL)-based computer vision and ML-derived clinical decision support. Machine learning and predictive analysis use algorithms to analyse large amounts of data to generate probable estimation for outcomes. In the following review, the authors briefly discuss clinical applications of current image-based learning AI models in spine surgical practice.

Department of Surgery, Aga Khan University Hospital, Karachi, Pakistan.
Correspondence: Akbar Jaleel Zubairi **Email:** akbar.jaleel@aku.edu
ORCID ID. 0000-0002-0236-4700

Current Status of AI in Spine

Recent systematic reviews show distinct themes in the current literature, namely: diagnostic tools, clinical outcome prediction, image-based automation, and decision-support. These tools are often combinations of national datasets with imaging features, and report accuracy, sensitivity, and specificity given after applying the tool in either other datasets or prospective analysis.[2] The process remains iterative; the more a model is run through, improved, and more data points are added, the more confidence clinicians gain in its ability. Pattern recognition, particularly with imaging features, plays a role in preoperative as well as intraoperative decision-making in the spine. Varghese et al developed a ML-derived decision tree to support surgeons when assessing pedicle-screw pullout strength and holding power. The data given to a meta-model can help define the decision-making process and help determine new cases where a fusion construct may be assessed through pullout strength. As a clinical tool, this decision-making support can incorporate preoperative X-ray, CT, MRI, and DEXA scan features to determine patient-specific factors influencing the surgical decision as well.[3] This presents a unique opportunity for clinicians to help train models for various populations, and thereby develop tools based on local data. Another unique approach is using ML-models in detection of implanted hardware when considering revision surgery. A report from 2019 showcased a computer vision algorithm capable of differentiating between 9 different types of anterior cervical discectomy fusion (ACDF) systems, regardless of implant variation or size, with a high reported accuracy.[4] This assists revision surgery in the preoperative planning phase and determining optimal approaches to a previously operated spine.

An upcoming theme in AI-prediction in spine is cost-utilization and selecting candidates for outpatient spine surgery. Outpatient candidacy is predicated on various factors including patient-specific risk factors, indications for surgery, and postoperative complications. Accurate patient selection in these circumstances may help reduce inpatient burden, improve patient care, and improve surgical efficiency by selecting optimal candidates.[5] Predicting complications after index surgery may also help determine high-risk candidates requiring further intervention in the future; clinical tools developed to determine adjacent segment disease after ACDF based on paraspinal neck muscle morphology on imaging show strong prediction for early-onset ASD. This bears great implications on patient counselling, close follow-up, and perhaps further surgical interventions where warranted.[6]

Spinal Oncology

While research in radiation, surgical techniques, and instrumentation in primary and metastatic spinal tumours has increased, predicting potential benefit after intervention remains difficult particularly in terms of function and quality of life. Predictive analytics propose objective assessments to help guide these patients through a difficult period; to match outcomes with patient-specific goals. In metastatic disease, detection of lesions and differentiating from confounding pathologies can be greatly augmented by AI-algorithms, improving radiologist reading and assessment. A large part of prognosis is determining treatment response: recent studies have shown radiomic features can be used to help predict response to pain after radiation treatment for vertebral metastasis, with stronger accuracy than clinical models.[7] Predictive models are also being utilized for identifying vertebral metastases with high-risk for fracture to help facilitate early and safe intervention.[8]

In primary spine tumours as well, AI-assisted surgical tools can be employed to improve operative efficiency and decrease complications.[9] DL-approaches can differentiate spinal cord tumours from mimicking pathologies – combing radiological data with clinical and molecular datasets allows clinicians to train a model towards detecting mutations based on MR imaging alone, as shown previously in studies for H3 K27M mutations.[10] Applications of AI in spinal oncology require further expansion of existing models in neuro-oncology prediction. Deep neural network tools have been shown to help automate and improve neuro-histopathology diagnostic accuracy, even with fresh, unstained intraoperative specimens, which may provide valuable input for spine oncological surgeons.[11]

Deformity Surgery

As mentioned previously, AI tools in predicting further deterioration and deformity can help personalize approaches for certain patient populations. After correcting cervical deformity, concerns regarding construct durability remain, with revision surgery often needed for some patients. Junctional kyphosis in the cervical spine after deformity correction significantly impacts quality of life and functional outcomes. Applying image-based AI prediction in a surgical cohort, researchers were able to determine strong predictors using radiological factors with thresholds for determining risk.[12] Similarly, complex surgical decisions can be facilitated in adolescent idiopathic scoliosis with AI tools – a study based on Cobb angle measurements was able to train a model to determine optimal fusion region category, with correlations drawn with Lenke classification. The authors noted a particular benefit to the trained model in ‘grey areas’, i.e. borderline cases within the Lenke classifications, thereby helping with surgical planning in such cases.[13]

In adult deformity surgery, clinical scoring systems such as the GAP Score (Global Alignment and Proportion Score) have been developed to predict mechanical failure following surgery, such as proximal junctional kyphosis, distal junctional kyphosis, and rod failure.[14] This scoring system supports correlations of pre- and post-operative spinopelvic sagittal parameters with adjacent segment disease. AI tools can help facilitate alignment analysis in these circumstances – a hybrid AI-powered model has been validated for clinical use to help predict postoperative alignments, with radiographs.[15] Patient-specific implant devices have also been developed through preoperative planning software. This allows for patient-specific surgical correction. UNiD™ (Unique Identity) rods report higher rates of appropriate alignment and low rod fracture rates compared with conventional standards. Predictive software can help surgeons develop preoperative plans with these patient-specific constructs, and therefore accurately determine postoperative alignment through modelling algorithms. Patient-specific spine surgery allows creation of a unique surgical plan for patients ultimately improving their long-term outcomes and quality of care.[16]

Challenges

AI models are predominantly based on large datasets and registries – the quality of this data therefore determines applicability and accuracy of predictive models. Some databases, such as the NSQIP, are non-targeted datasets which only capture certain cases every month and therefore faces selection bias. Outcomes may only be assessed in limited time periods and therefore be difficult for determining long-term complications. Databases are often dependent on ICD or CPT coding and therefore may be influenced by external factors such as insurance-claims or local reimbursement policies, resulting in high variability even between databases.[17] Lastly, statistical significance does not always translate to meaningful clinical significance which tempers interpretation of prediction tools.

Developing these tools for expanded use also means including populations in low- and middle-income countries (LMICs) – registries are not always up-to-date or developed and may not reflect ground realities. AI-predictive tools trained in non-native settings may be poorly applicable, considering veracity and completeness of local data.

Future directions

With rapid technological progress in spine surgery, individualized approaches are more likely to take over, in order to maximize outcomes and reduce cost and complications. ML models are currently being implemented in real-time assessment of MRIs and diagnosis, to improve diagnostic reliability. AI tools in surgical planning and outcome visualization is another key focus, including robot-assisted spine surgeries with preoperative planning and intraoperative complication determination.

Conclusion

AI-based tools in spine surgery can facilitate precise strategies in complex cases. The presented evidence shows significant benefits in surgical efficiency and optimizing treatment strategies, with considerations for high-risk populations. Further avenues for research may include expansion of AI-based imaging and surgical tools for primary spine oncology, prediction in complications after deformity correction, and patient-specific solutions in revision or complex spine procedures.

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