Current Trends of Artificial Intelligence Assisted Spine Surgery: A Systematic Review

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Study design: Systematic review.

Purpose: This systematic review aims to summarize the existing evidence and outline the stated benefits of artificial intelligence-assisted spine surgery.

Overview of literature: The popularity of artificial intelligence has grown significantly, demonstrating its benefits in computer-assisted surgery and advancements in the area of spinal treatment.

Methods: This research adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), a set of reporting guidelines specifically designed for systematic reviews and meta-analyses. The search strategy with MeSH terms was “MeSH (Artificial intelligence), “Spine” AND “Spinal” Filters: in the last 10 years, English—from January 1, 2013, to October 31, 2023. A total of 442 articles fulfilled the first screening criteria. A detailed analysis of those articles identified 220 that matched the criteria, of which 11 were considered appropriate for this analysis after applying the complete inclusion and exclusion criteria.

Results: A total of 11 studies met the eligibility criteria. Analysis of those studies found that all types of artificial intelligence-assisted spine surgery. There was no evidence to suggest the superiority of with or without artificial intelligence-assisted spine surgery in terms of outcomes. In terms of feasible, accurate and safe, and facilitating lower patient radiation exposure compared to standard fluoroscopic guidance, this artificial intelligence-assisted spine surgery produced satisfactory and superior outcomes.

Conclusions: The incorporation of artificial intelligence with augmented reality and virtual reality appears promising, holding the potential to elevate surgeon proficiency and enhance overall surgical safety.

Keywords: Artificial intelligence; AI; Spine surgery; Virtual reality; Augmented reality

Introduction

The healthcare sector has experienced a significant impact from the field of artificial intelligence (AI) [1,2]. The contemporary definition of AI emphasizes the application of algorithms, enabling machines to address problems that traditionally necessitated human intelligence [3]. AI, in general, is designed to recognize patterns through algorithms capable of self-correction and continuous improvement. AI is proficient in performing human cognitive functions, including image, word, and pattern recognition, as well as decision-making with integrated
learning and improvement [4]. Moreover, AI algorithms excel in identifying correlations among numerous variables, establishing relationships that might escape human comprehension [1].

Currently, the use of artificial intelligence in spine surgery is in its early developmental phase, encountering several obstacles such as fragmented data, insufficient integration, and limited clinical implementation [5]. However, as AI is being applied across the entire medical field, research based on AI in challenging and high-risk spinal surgeries continues to be conducted. The relative complexity and higher surgical risks in spinal surgeries make them a focal point for ongoing studies in this area [6].

This is the systematic review of current trends of AI in the field of spine surgery to offer a comprehensive overview of the most clinically relevant applications of AI in the field of spine surgery. Aim of this study to focus more on reviewing how AI can be applied in the surgical process. Prior to the review, a brief overview of the types of AI commonly used in spine surgery is presented below for a comprehensive understanding of the content. This systematic review to summarize the existing evidence and outlines the stated benefits and types of AI in spine surgery.

Methods

This study has been waived ethical approved for this review article by the ethical committees in accordance with the declaration of Helsinki.

1. Literature search strategy

In this study, an extensive literature search was performed on the PubMed and Scopus databases to examine existing research on the application of AI in spine surgery. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria (Fig. 1) were followed in conducting this systematic review. A literature search was performed using the search engine to collect articles published in PubMed and Scopus between January 1, 2013, to October 31, 2023, using the MeSH terms. The search included the keywords "artificial intelligence", "spine" and "spinal" in the title or abstract. Additional manual checks of the reference lists were also accomplished. Only articles written in English were considered for inclusion.

2. Inclusion and exclusion criteria

This systematic review included all randomized controlled trials (RCTs) and observational cohort studies. There were no limitations on the research design, such as retrospective or prospective. Exclusion criteria involved filtering out research from other domains, case reports, reviews, or meta-analyses, as well as studies lacking available abstracts or full texts. Two independent reviewers conducted the literature collection, resolving any discrepancies through consensus.

3. Data extraction

The following data on the studies were recorded: (1) author and year of publication, (2) type of study design (3) the country in which the AI was conducted, (4) type of AI technique or algorithm technique, (5) Method of AI, (6) Main objectives, (7) Objective of findings and (8) Other detail of study.

4. Assessment of risk of bias of this systematic review

The risk of bias for individual RCTs was assessed and the examination included many types of biases, including se-
lection bias, performance bias, attrition bias, bias in detection, and bias in reporting. Each prejudice was categorized as either high risk, low risk, or unknown risk. Prior to comparing their findings, two investigators independently assessed the degrees of bias in the studies that were included. When there were disagreements, judgments were taken based on consensus, and if needed, the opinion of a third author was sought. Furthermore, a third reviewer successfully addressed any lingering discrepancies pertaining to the assessment of the obtained data.

**Results**

A total of 442 articles that met the first screening criteria were identified in the PubMed and Scopus databases. An extensive examination revealed 220 papers that met the specified criteria, out of which 11 were deemed suitable for inclusion in this analysis after the application of comprehensive inclusion and exclusion criteria. The study focused on the purpose of AI and the kind of study, considering the nationality of the participants. The research conducted by the author in the published year analyzed demographic data (Table 1).

**1. Study design and publication information**

In this review, we found prospective studies and retrospective studies. Three studies were prospective studies by Bissonnette et al. [7], Mirchi et al. [8] and Jecklin et al. [9]. Two studies were retrospective studies, including studies by Hanna et al. [10] and Scherer et al. [11]. Two of experimental studies were identified by Wei et al. [12] and Huang et al. [13]. Two of cadaveric studies were identified by Siemionow et al. [14]. Only two of randomized Controlled Trials (RCT) were found in this review by Auloge et al. [15] and Bhogal et al. [16].

**2. Nationality**

The number of publications on AI-assisted surgery increased between January 1, 2013 and October 31, 2023 as the trend toward this AI technique grew. The studies included three articles from the United States, two articles each from Canada and China, and one article each from France, Germany, Belgium, and Switzerland.

**3. Risk of bias analysis**

A summary of the study’s risk of Non-Randomized Controlled Trial (Non-RCT) bias is shown in Table 2 and Randomized Controlled Trial (RCT) bias in this systematic review in Table 3. The risk of bias in non-RCT studies was assessed using the ROBINS-I tool and is presented in Fig. 2 [17]. For RCT studies, the risk of bias was evaluated using the Cochrane Risk of Bias Assessment Tool and is depicted in Fig. 3 [18]. The non-RCT’s studies found that three studies had a low risk of bias, five had a moderate risk of bias and only one study had a serious risk of bias (Table 2). All RCT’s studies had a low risk of performance bias for blindness of outcome assessment, incomplete outcome data, and selection outcome reporting (Table 3).
### Table 2. Risk of Non-randomized controlled trial (Non-RCT) bias in this systematic review.

<table>
<thead>
<tr>
<th>Study</th>
<th>Confounding</th>
<th>Selection of participants</th>
<th>Classification of intervention</th>
<th>Deviations from intended interventions</th>
<th>Missing data</th>
<th>Measurement of the outcome</th>
<th>Selection of the reported results</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auloge et al.[15]</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Bhogal et al.[16]</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Siemionow et al.[14]</td>
<td>Low</td>
<td>Low</td>
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<td>Moderate</td>
<td>Moderate</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>Hanna et al.[10]</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Serious</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
<td>Serious</td>
</tr>
<tr>
<td>Scherer et al.[11]</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>Wei et al.[12]</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
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<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Jecklin et al.[9]</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>Huang et al.[13]</td>
<td>Moderate</td>
<td>Low</td>
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<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
</tr>
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</table>

### Table 3. The Randomized Controlled Trial (RCT) risk of bias in this systematic review.

<table>
<thead>
<tr>
<th>Study</th>
<th>Randomization</th>
<th>Deviation from the intended intervention</th>
<th>Missing outcome data</th>
<th>Measurement of the outcome</th>
<th>Selection of the reported results</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auloge et al.[15]</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Bhogal et al.[16]</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
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</table>

**Fig. 2.** Risk of bias summary for non-randomized controlled trials, assessed using The Risk of Bias in non-randomized studies of interventions ROBINS-I tool.
4. Types of AI commonly used in spine surgery

AI is a broad generic term. It encompasses various forms of automated decision-making [19]. Embedded within the realm of AI exists a hierarchical structure of processes, each exhibiting escalating levels of sophistication. Various AI types fall into the categories of either narrow or general, depending on their capacity to replicate human functions [1]. Artificial Intelligence, Machine Learning, and Deep Learning have emerged as highly discussed topics in the field of spine surgery. Artificial Intelligence refers to the development of intelligent machines with advanced cognitive abilities. Machine Learning is a branch of artificial intelligence that enables the development of applications powered by AI. Deep Learning is a kind of machine learning that employs large amounts of data and intricate algorithms to train a model [1,20]. The AI fundamental differences and relationships and examples are shown in Fig. 4. AI in spine surgery includes; Basic spinal research, preoperative planning, Decision making, post-operative outcome predictions, intraoperative navigation assisted surgery and selected patients of spinal surgery (Fig. 5) [5,21-26].

1) Machine learning (ML)

Machine learning, a subset of AI, involves training models to make predictions based on known datasets, allowing the machine to "learn" from the data [21,27]. Supervised machine learning models utilize labeled input data to establish relationships with output training data, commonly employed for data classification or prediction tasks [21,28,29]. In contrast, unsupervised machine learning
models operate on unlabeled raw training data, identifying relationships and patterns within the dataset and uncovering inherent trends [29]. Unsupervised models serve primarily as efficient representations of the initial dataset, utilizing statistical properties like densities, distances, or clustering to enhance comprehension of relationships or patterns within the data [21,30]. The supervised machine learning models was shown in Fig. 6.

2) Deep learning (DL)
Deep learning (DL) represents a higher level of abstraction in comparison to unsupervised machine learning, as it operates without the labelling of either input or output variables [1]. This approach involves emulating the neural connections found in the human brain. DL encompasses a collection of machine learning methods and leverages techniques such as Artificial Neural Networks (ANN) and Convolutional Neural Networks (CNN) [6,22,25,26].

3) Natural Language Processing (NLP)
Natural Language Processing (NLP) stands as a dedicated discipline within AI, centering its focus on the comprehension of human language [31]. In the context of extensive, plain-text analysis of Electronic Medical Records (EMR), NLP plays a pivotal role. It takes unstructured data and goes beyond mere word recognition, incorporating syntax and semantics to extract meaning and sentiment [1]. NLP finds utility in diverse applications, including the generation of medical records from speech, summarizing historical clinical notes, handling billing processes, scheduling surgeries, and facilitating triage, among various other functions [1,32-34].

4) Computer vision
Computer vision is the most well-known application of deep learning and commonly utilizes CNN for pattern recognition [1,35]. CNNs are predominantly used within healthcare for image-based diagnosis. CNN consists of nodes, each assigned specific weights. However, the connections between layers are more constrained. This convolution process enables computers to interpret images in a manner analogous to the human brain. We summarized computer vision for assisted navigation surgery for intraoperative application (Fig. 7).

**Discussion**

Artificial intelligence applied in spinal surgery is evolving towards the ultimate integration with augmented reality and virtual reality. This development involves the direct application of AI in surgery, starting from preoperative learning and evaluating the surgeon’s capabilities, aiming to assist in surgery under navigation for enhanced safety, precision, and speed. In recent years, various AI instruments, including surgical robots, navigation systems, and computer-assisted surgical systems, have experienced
rapid development within the field of orthopedic surgery [36].

Virtual reality surgical simulators create a secure setting for trainees to engage in targeted surgical scenarios, fostering self-guided learning [37]. The utilization of AI technology, including ANN, holds the promise of processing extensive datasets from simulators. This enables a deeper understanding of the significance of specific performance metrics during simulated operative tasks. Bissonnette et al. [7] investigated the use of machine learning to evaluate surgical expertise in a virtual reality spine procedure, specifically focusing on virtual reality hemilaminectomy. They processed raw data from the virtual reality hemilaminectomy process through metric extraction, normalization, and selection before conducting machine learning analysis. Upon identifying the optimal algorithm and parameters, they trained a unified model using all available data, subjecting it to generalizability testing on new subjects. Through this approach, they assessed the safety, efficiency, tool motion, and coordination of the procedure. In conclusion, they determined that AI could play a role in the assessment of surgical competence. Additionally, there is a study that evaluated the performance of anterior cervical disectomy and fusion (ACDF) using the concept of artificial neural networks [8]. ACDF has historically been widely used and has proven to be safe and effective [38]. Considering the complications that may arise from surgery, it is undoubtedly a challenging procedure for novice surgeons. However, understanding the areas where one lacks proficiency in the surgical process before the operation can be of great assistance in preparing for the surgery. Mirchi et al. [8] analyzed a total of 369 metrics in four areas (safety, efficiency, motion, and cognition) obtained from 21 participants who performed anterior cervical disectomy using virtual reality. They employed ANN for the analysis. Among these metrics, those related to safety were identified as the most crucial aspect in areas demonstrating surgical competence. The importance of both these studies lies in the potential synergy of integrating virtual reality simulation and artificial intelligence. This combination offers the prospect of safer training and objective assessment of surgical skills, ultimately contributing to enhanced patient care.

Spinal surgeries pose significant challenges due to their technical intricacy and proximity to critical organs such as the spinal cord, nerves, and the aorta [9,39,40]. Previous literature has identified various surgeon- and patient-specific factors as potential causes for postoperative complications in these interventions, ranging from pedicle screw malplacement to cage malpositioning [41-44]. To address these challenges, computer-assisted surgical (CAS) navigation techniques have been introduced [9]. These techniques aim to facilitate and standardize spinal procedures by offering 3D intraoperative spatial guidance. Research has demonstrated that CAS navigation leads to substantially higher accuracy in pedicle screw insertion compared to free-hand and conventional 2D fluoroscopy-guided methods [42,45,46]. Moreover, CAS technologies have been employed for cage insertion, resulting in improved performance [47,48]. This integration of CAS navigation holds promise for enhancing the precision and safety of spinal interventions [49]. Particularly, in the current prevalence of Minimally Invasive Spine Surgery (MISS), utilizing navigation provides an advantage by en-
hancing the visibility of the intricate anatomical structures of the challenging spine. This makes surgery more comfortable, given the complexities involved in MIS procedures. Especially in critical surgeries where the trajectory, such as pedicle screw insertion or vertebroplasty, holds significance, there are studies utilizing AI to automatically predict the trajectory [11,12,15].

The most prevalent CAS systems still depend on operative 3D imaging and preoperative planning [9,50]. This process enables the creation of patient-specific models, often referred to as biomechanical digital twins, which serve as the foundation for computer simulations [9]. These simulations aid in determining and optimizing surgical plans. However, the registration of preoperative data to the actual anatomy remains a challenging and occasionally error-prone task, often requiring meticulous manual input [51,52]. The need for a registration process between preoperative and intraoperative data remains a significant challenge.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Based of application</th>
<th>Algorithms and methods of study</th>
<th>Outcome and summary</th>
<th>Title of Journal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auloge et al.[15]</td>
<td>Artificial intelligence</td>
<td>To assess technical feasibility, accuracy, safety and patient radiation exposure of a novel navigational tool integrating augmented reality (AR) and AI, during percutaneous vertebroplasty</td>
<td>AR/Al-guided percutaneous vertebroplasty appears feasible, accurate and safe, and facilitates lower patient radiation exposure compared to standard fluoroscopic guidance</td>
<td>Eur Spine J.</td>
</tr>
<tr>
<td>Mirchi et al.[8]</td>
<td>Artificial neural network</td>
<td>To distinguish performance in a virtual reality-simulated anterior cervical discectomy scenario</td>
<td>Artificial neural networks classified 3 groups of participants based on expertise allowing insight into the relative importance of specific metrics of performance</td>
<td>Oper Neurosurg (Hagerstown).</td>
</tr>
<tr>
<td>Siemionow et al.[14]</td>
<td>Convolutional neural network</td>
<td>Assess the accuracy of an autonomous convolutional neural network in measuring vertebral body anatomy utilizing clinical lumbar computed tomography scans and automatically segment vertebral body anatomy.</td>
<td>The CNN algorithm tested in this study provides an accurate means to automatically identify the vertebral body anatomy and provide measurements for implants and placement trajectories.</td>
<td>J Craniovertebr Junction Spine.</td>
</tr>
<tr>
<td>Siemionow et al.[17]</td>
<td>Artificial intelligence</td>
<td>Develop a technique and assess the accuracy and feasibility of lumbar vertebrae pedicle instrumentation using augmented reality-assisted surgical navigation.</td>
<td>The ARAI surgical navigation system correctly and accurately identified the starting points at all the attempted levels.</td>
<td>J Craniovertebr Junction Spine.</td>
</tr>
<tr>
<td>Hanna et al.[10]</td>
<td>Artificial intelligence</td>
<td>Describe the evolution of thoracoscopic spine surgery from basic endoscopic procedures using fluoroscopy and anatomical localization through developmental iterations to the current technology use</td>
<td>With the exponential growth of artificial intelligence, there may be further refinements of video-assisted thoracoscopic image-guided spine surgery on the horizon.</td>
<td>Neurosurg Focus.</td>
</tr>
<tr>
<td>Scherer et al.[11]</td>
<td>Convolutional neural network</td>
<td>To develop and validate an automated planning tool for lumbosacral pedicle screw placement using a convolutional neural network to facilitate the planning process.</td>
<td>This study derived and validated a fully automated planning tool for lumbosacral pedicle screws using a convolutional neural network.</td>
<td>Spine J.</td>
</tr>
<tr>
<td>Wei et al.[12]</td>
<td>Artificial intelligence</td>
<td>Evaluate the clinical effectiveness and safety of robotic-assisted pedicle screw placement.</td>
<td>Only Renaissance and Robotic-assisted techniques hold great promise in spinal surgery due to their safety and effectiveness.</td>
<td>eClinicalMedicine.</td>
</tr>
<tr>
<td>Bhogal et al.[16]</td>
<td>Artificial intelligence</td>
<td>This study compared intra-operative radiation dose using posterior internal fixation using impedance-guided pedicle positioning by the Pediguard system versus standard free-hand sighting when surgery was performed with a trainee or expert surgeon.</td>
<td>The overall time was longer for the novice surgeon with the Pediguard system, but allowed to decrease by 50% the fluoroscopy time.</td>
<td>Int Orthop.</td>
</tr>
<tr>
<td>Jecklin et al.[9]</td>
<td>Deep learning</td>
<td>Proposes a novel deep learning-based method to intraoperatively estimate the 3D shape of patients’ lumbar vertebrae directly from sparse, multi-view X-ray data.</td>
<td>This increase in accuracy opens new possibilities for surgical navigation and intraoperative decision-making solely based on intraoperative data, especially in surgical applications where the acquisition of 3D image data is not part of the standard clinical workflow.</td>
<td>J Imaging.</td>
</tr>
<tr>
<td>Huang et al.[13]</td>
<td>Artificial intelligence</td>
<td>In minimally invasive spine surgery (MISS), where the surgeon cannot directly see the patient’s internal anatomical structure, the implementation of augmented reality (AR) technology may solve this problem.</td>
<td>AR-MISS system is accurate and applicable.</td>
<td>Bioengineering (Basel).</td>
</tr>
</tbody>
</table>
bottleneck in the widespread adoption of CAS systems [9]. To overcome these drawbacks, recent research has explored the transformation of 3D images of the spine based on X-rays captured during surgery, rather than relying solely on preoperative images [9]. Jecklin et al. [9] introduced an innovative deep learning approach designed to estimate the 3D shape of patients’ lumbar vertebrae in real-time using sparse, multi-view X-ray data during surgery. This research marks a significant advancement, offering new prospects for surgical navigation and intraoperative decision-making exclusively using real-time data. This is particularly valuable in surgical scenarios where obtaining 3D image data is not a standard part of the clinical workflow.

In MISS, where the surgeon cannot directly see the patient’s internal anatomical structure, the implementation of AR technology may solve this problem [13,53]. These days, in navigation spine surgery, there is a shift away from performing surgery on two-dimensional monitors towards the adoption of AR. Many studies in this area highlight the central role of AI in data analysis and prediction, emphasizing its significance in advancing the field [10,13,14,54]. Huang et al. [13] integrated AR, AI, and optical tracking to improve the augmented reality minimally invasive spine surgery (AR-MISS) system. The system encompasses three key functions: AR radiograph superimposition, AR real-time puncture needle tracking, and AR intraoperative navigation. Through the implementation of AR technology, the system enables the convergence of three spaces – the actual intraoperative space, the video image space, and the medical image space. This integration allows surgeons to directly access information from all three spaces simultaneously, eliminating the need to divert their gaze from the surgical site. Siemionow et al. [54] pioneered a technique and evaluated the precision and viability of lumbar vertebrae pedicle instrumentation with the assistance of augmented reality-assisted surgical navigation (ARAI). The ARAI surgical navigation system successfully and accurately identified the starting points at all attempted levels. Furthermore, the virtual anatomy image overlay precisely matched the actual anatomy in all tested scenarios.

Recently, not only through the integration of AI into navigation but also by leveraging the proprietary characteristics of bone conductivity called “Pediguard,” a tool has been developed to assess the penetration of pedicle screws without relying on fluoroscopy [16]. This device functions as a wireless perforation instrument, similar to a conventional pedicle awl, and operates based on the principle of local tissue electrical conductivity, measured through the electromagnetic field at the instrument’s tip. The sharp tip of the instrument features an electronic conductivity sensor that translates relative electronic conductivity values into an audible signal. Through machine learning, electronic conductivity analysis allows for assessing whether the pedicle has been penetrated. If there is a change in electrical conductivity at the distal part of the instrument, it alerts the surgeon through a change in sound. This detection is possible because alterations in the electromagnetic field around the instrument’s tip enable the identification of media with a consistency different from bone (Table 4). This systematic review offers

<p>| Table 5. Summary of the advancements in artificial intelligence (AI) in the field of spine surgery, which showed great potential and were continuously developing. |</p>
<table>
<thead>
<tr>
<th>Category of topic in spine surgery</th>
<th>Promising and evolving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diagnostic imaging in spinal disease</td>
<td>AI was being extensively used in interpreting diagnostic imaging such as MRI, CT scans, and X-rays to detect spinal conditions, fractures, tumors, and other anomalies. AI algorithms aided in precise and faster analysis, assisting surgeons in accurate diagnoses.</td>
</tr>
<tr>
<td>Planning and simulation of spine surgery</td>
<td>AI tools assisted in pre-operative planning by generating 3D models of the spine based on imaging data. Surgeons could simulate procedures, map out surgical strategies, and anticipate potential complications, thus enhancing surgical precision.</td>
</tr>
<tr>
<td>Robot-assisted spine surgery</td>
<td>Robotic systems equipped with AI algorithms were gaining traction in spine surgery. These systems provided enhanced dexterity, precision, and stability during procedures, allowing surgeons to perform complex operations with greater accuracy.</td>
</tr>
<tr>
<td>Patient’s outcome prediction and management</td>
<td>AI-driven predictive models helped forecast patient outcomes post-surgery. These models utilized patient data to estimate recovery trajectories, enabling personalized care plans and better patient management.</td>
</tr>
<tr>
<td>Augmented Reality (AR) and Virtual Reality (VR) assisted surgery</td>
<td>AR and VR technologies were employed to create immersive environments for surgeons, aiding in pre-operative planning and intraoperative guidance. These technologies offered real-time feedback and visualization during surgery.</td>
</tr>
<tr>
<td>Data analytics and decision system</td>
<td>AI algorithms process vast amounts of patient data to identify patterns, trends, and risk factors. This analysis supported clinicians in making informed decisions regarding treatment plans and post-operative care.</td>
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</table>
a thorough and inclusive summary of the whole field of research. The authors propose and approve the current advances of Artificial Intelligence in the area of spine surgery, as shown in Table 5.

The importance of AI in healthcare is expected to increase, contributing to personalized medicine, illness diagnosis, medication development, and therapy optimization. The use of AI-driven technology is expected to significantly transform patient care via the provision of more accurate diagnoses and personalized treatment regimens. However, the progress in AI is expected to result in the creation of increasingly advanced autonomous systems and robots. These technologies have the potential to be used in diverse sectors such as manufacturing, transportation, agriculture, and healthcare, enabling the execution of intricate tasks with less human involvement.

**Conclusions**

In complex spinal surgeries characterized by challenging anatomical structures and relatively high surgical difficulty, AI is being utilized in various ways throughout the perioperative procedures. Particularly during the intraoperative phase, its integration with AR and VR seems promising, as it has the potential to enhance the surgeon’s skills and contribute to increased surgical safety.

**Conflict of Interest**

No potential conflict of interest relevant to this article was reported.

**Author Contributions**

All authors contributed to the study’s conception and design. Material preparation, data collection, and analysis were performed by WL, PS, and STC. The first draft of the article was written by WL and STC. All authors commented on previous versions of the article. All authors read and approved the final article.

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Artificial Intelligence in Spine Surgery


