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Research Article

Overview of Robotic Spine Surgery

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Abstract

Background and objective: Robotic spine surgery represents an advanced evolution of neuroimaging in spine surgeries. It assists and augments human actions, particularly in precision-demanding surgical fields, such as spine surgeries.

Methods: A comprehensive literature review was conducted using electronic databases, including Science Direct, PubMed, Scopus, Web of Science, ResearchGate, and Keywords included "robotic spine surgery," "computer-assisted neurosurgery," "image-guided spine surgery, and robotic spine fixation. A total of 80 studies were screened, with 60 full-text articles reviewed in-depth.

Conclusion: Overall, current evidence suggests that robot-assisted spine surgery offers promising clinical benefits and a positive and promising experience, enhancing both the effectiveness and safety of patient care. Its implementation requires close collaboration with biomedical engineers and structured training for the surgical team. The key elements for successful outcomes include meticulous preoperative planning and the high precision of the robotic system. Continuous improvements in algorithmic performance open the door to major innovations such as intraoperative customization of rods and real-time decision-support tools for spinal alignment correction.

Keywords: Computer-assisted spine surgery, Image-guided spine surgery, Spine-robotics, Advanced technology in spine surgery, Robot-assisted spine surgery, Learning curve, Innovation

Introduction

The term “robot” was formally defined for the first time in 1979 by the Robot Institute of America (RIA) as “a reprogrammable, multifunctional manipulator designed to move material, parts, tools, or special devices through variable programmed motions for the performance of a variety of tasks” [1] Since 1985 robotics surgery has rapidly developed, allowing neurosurgeons to expand their dexterity in spinal instrumentation [2]. It represents a significant technological development over the past decade, to promote superior screw placement accuracy, reduce radiation exposure, and improve surgical efficiency [3]. There are different methods of screw implantation, the most notable being: 1) “free hand “technique based on anatomical references; 2) implantation guided by intraoperative 2D

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fluoroscopy; 3) implantation guided by 3D navigation with various modalities; and more recently, 4) implantation assisted by a robotic system. [4] The number of neurosurgeons using robots has recently increased due to the emergence of new devices such as ROSA (Zimmer Biomet, Warsaw, ID), Pathfinder (Prosurgics, High Wycombe, United Kingdom), neuroArm (IMRIS, Minnetonka, MN), and SpineAssist (Medtronic, Minneapolis, MN). [5] In 2004, the Mazor Spine Assist gained FDA approval for navigated placement of thoracolumbar pedicle screws, thus becoming the first robotic system dedicated to increasing the accuracy of spinal instrumentation [6]. Since then, there have been multiple other robotic platforms that have gained FDA approval as navigational surgical adjuncts. Current industry leaders include the Excelsius GPS (Globus Medical, Audobon, PA), ROSA Spine (MedTech, Montpeller, France), and the Mazor products, including Renaissance and X-Stealth Edition (Mazor/Medtronic, Dublin, Ireland). Sustained medical innovation requires a wide range of skills and is leading to the emergence of new collaborations. The cooperation between the industrial partner's engineers, and the surgical team is the key point in the learning curve for robot-assisted surgery. Numerous articles have been published regarding the accuracy of robotic-assisted screw placement for spine surgery through better selection of entry points, screw trajectories, and better screw holding. [7] The accuracy of spinal robotic systems before 2017 was about 85% [8]. A meta-analysis reported in 2022 found that pedicle screw placement accuracy rates with new-generation robotics platforms were 99% [9]. At present, all commercially available systems – Excelsius GPS, Mazor X Stealth, and ROSA One employ fiducial markers to map the position of the robot to the patient within 3-dimensional space [10].

Methods

A targeted literature review was performed using key databases with terms related to robotic spine surgery. The inclusion criteria focused on full-text articles that discussed clinical applications, technical innovations, and outcomes associated with robotic systems in spine surgery. To determine what is currently known about robotic spine surgery. 80 articles published on electronic databases, including Science Direct, PubMed, Scopus, Web of Science, and Research Gate, were reviewed. Several terms and words, such as "robotic spine surgery," "robotic spine," "advanced technology in spine surgery," and "history of robotic spine surgery," were used to search the main text, abstracts, and keywords of the databases. It should be mentioned that my search considered the 60 papers for which full texts were available.

Discussion

Robotic assistance in spine surgery is currently most commonly utilized for the placement of cervical, thoracic, and/or lumbar pedicle screws. [11]

It has been the subject of scientific research due to its ability to improve the precision of transpedicular screw implantation. This technology focuses on two main concepts: the prevention of human error and the improvement of surgical planning. [12]

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Robotic spine surgery possesses remarkably high geometric accuracy without biohazards or hostile environments. It can extend the visual and manual dexterity of neurosurgeons beyond their current limitations by passing through both long and extremely tight surgical corridors.

When considering the evolving relationship between the robot and the surgeon in spine surgery, three main possibilities emerge:

Co-working model: In this scenario, the surgeon remains fully in charge of the procedure, with the robot serving as a tool. The robot, however, lacks any degree of autonomy and functions purely as an assistant, executing tasks such as trajectory guidance or holding instruments under the direct control of the surgeon [13].

Tele-manipulation model: In this type, the surgeon operates remotely from a console, while the robot reproduces and refines the surgeon's maneuvers at the surgical site. This model is already employed in some robotic-assisted systems, where the robot can improve the precision and stability of the surgeon's movements. Typically, a second human surgeon is present in the operating room to assist with tasks beyond the robot's capabilities [14].

Full automation model: In this future possibility, the surgeon's role is planning and supervising only. The robot takes full control of the surgical execution, carrying out tasks autonomously based on a preoperative plan, with the surgeon overseeing the process to intervene if necessary (Figure 1).

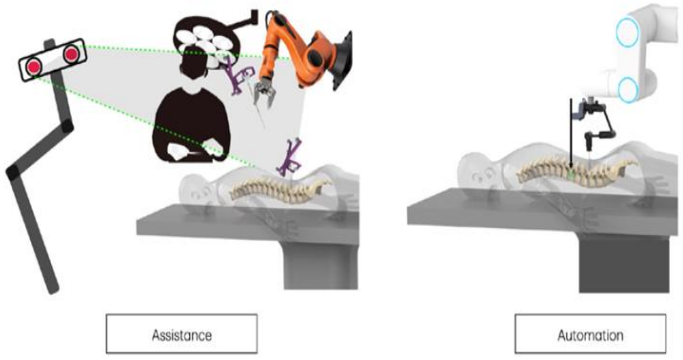


Figure 1. Full Automation Model

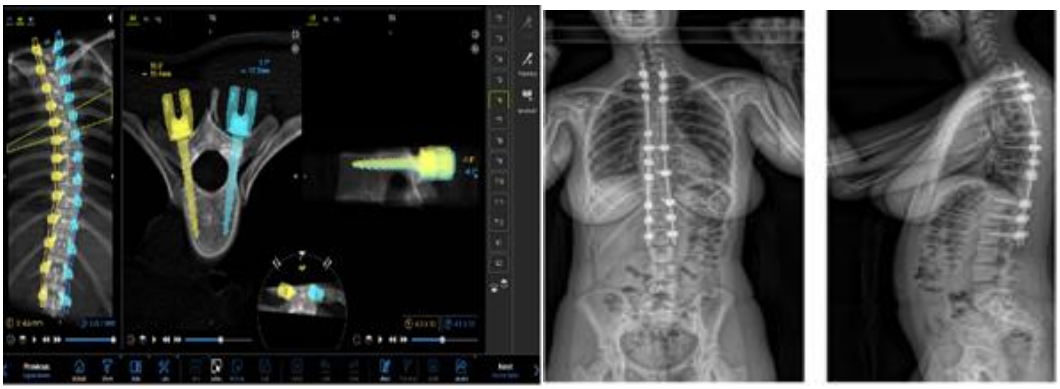


Figure 2A. Schematic representation of image-guided robotic systems utilizing optical tracking (left) compared to mechanical tracking (right). The mechanical tracking system is specifically engineered to support the progression toward full automation in surgery.

Figure 2B. shows the screws insertion and its trajectory before and after surgery.

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Several robotic systems have been developed for spinal surgery. Advances in intraoperative image-guiding systems enhance these devices [15].

Robotic spine surgery relies on several key components: a robotic arm, an optical tracking system, and a surgical navigation system. These elements collaborate to establish a detailed surgical plan with precise trajectories for the pedicle screws, allowing real-time monitoring during the procedure [16]. Previous studies reported higher accuracy in some procedures in brain and spinal surgeries, such as improved screw accuracy. However, robotic surgery has several limitations, such as registration failure, soft-tissue hindrance, higher procedure time, higher costs, and a lateral drill guide[17]. Minimally invasive spine surgery (MISS) may be beneficial for patients with spine pathology. As a means to improve surgical outcomes, integration of robotics into MISS has been an important part of the evolution of MISS techniques [18]. Furthermore, intra-operative radiosurgery can be assumed as one of the common spine robotic surgery methods; however, it is not a real surgery technique and can be used as an adjuvant or alternative method for surgery [19] (Figure 2A,2B).

Robotic systems include

- Mazor X (MAZOR Robotics Inc, Orlando, Florida)/ Mazor X Stealth Edition (Medtronic, Denver, Colorado)
- ROSA spine (Medtech S.A., Montpellier, France)
-ExcelsiusGPS (Globus Medical, Audobon, Pennsylvania)
- SpineAssist/Renaissance (MAZOR robotics Inc, Orlando, Florida) (Table 1)

Spine Assist works in five steps: preoperative planning, bony anatomy attachment, image acquisition and registration, robot assembly and motion, and manual execution. In the preoperative planning phase, the surgeon chooses the implants and plans the route of entry utilizing sagittal, axial, and coronal reformats reconstructed from a preoperative CT scan. [20]

Mazor subsequently released the Mazor X Stealth Edition following its acquisition by Medtronic in 2016. [21] It contained major structural and technical upgrades, including a serial robotic arm. This maximizes the machine's work volume while minimizing reliance on manual surgical tools, so it reduces human error. The robot also incorporates a linear optic three-dimensional (3D) camera that provides a volumetric assessment of the patient in real-time to avoid potential collisions with the patient and other objects within the surgical field. [22] The surgeon, during spinal fixation using this system, has two options: intraoperative ''scan-and-plan" or traditional preoperative CT scan.

ROSA spine (Medtech S.A., montpellier, France Originally conceived for cranial operations in 2012, the ROSA robot was subsequently adapted for use in spinal operations in 2016. A major advantage of ROSA Spine is the intraoperative navigation camera that allows the robot to adjust to the patient's movements via percutaneous tracking pins placed on the patient's bony anatomy and tracking spheres fixed to the robot itself [23].

Globus Medical, Inc, Audubon, PA, USA approved in 2017 by the FDA. This is a "shared control system" device, in which the surgeon and robot work simultaneously (the surgeon plans and both execute jointly). It is also a portable

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system with an independent foot ("floor-mounted robotic system"), which does not require Kirschner wires for the implantation of transpedicular screws ("K-wireless screw placement") [24].

Features	Mazor	ROSA	Excelsius GPS
Mount	Bed, bone	Floor	Floor
Need for intraoperative scan		Yes	
Reference frame		Spine	
Need for fixing the robotic arm to the patient	Yes	No	No
Navigation tracking Camera		Yes	
Preoperative trajectory planning on CT spine	Yes	No	Yes

Table1. shows the key features of different robotic systems

A. Mazor. B. Excelsius GPS. C. Rosa Evidence is beginning to emerge that shows the utility of robotic surgery for neural decompression surgeries such as laminectomy and interbody fusion [25].

Robotic applications have expanded, sometimes off- label, to assist with interbody placement and cervical instrumentation. Recent advancement involves a robotic system that utilizes electromagnetic (EM) navigation, which has not been used in spine surgery before. EM technology works by producing a low- intensity, controlled EM field that can locate small sensor coils inserted in tools, as well as on the patient, from reference points. This allows the robotic system to understand the exact positioning of the instruments in relation to the patient with no line-of-sight barriers [26]. This has become possible by the continued advancement of technologies, which now allows posterior elements of the spine to be better represented on intraoperative imaging. Robotic endoscopic techniques are also beginning to gain evidence, frequently being applied to decrease the burden of the most technically demanding aspects of surgery [27].

Advantages of robotic systems in spine surgery

- High geometric accuracy without error, and it can work through very narrow and long surgical corridors
- Remote control of the surgical procedure, with higher quality, more accurate visualization of the surgical field, and a greater degree of freedom.
- Hold the tools for prolonged periods without tremor, even against externally imposed forces.
- Good localization and positioning of the surgical instrumentation with a superior three-dimensional view.
- One of the potential advantages of robotic surgery is minimizing the reliance on intraoperative fluoroscopy and radiation exposure [28].

Disadvantages of robotic spine surgery

- The robotic equipment occupies a large space and has poor flexibility and mobility.
- Long registration time
- Possibility of relative displacement

The greatest disadvantage of robotic surgeries is the lack of sensory feedback, such as sensing the lesion, position, velocity, or acceleration of the instruments.

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Conclusion

Overall, current evidence suggests that robot-assisted spine surgery offers promising clinical benefits and a positive and promising experience, enhancing both the effectiveness and safety of patient care. Its implementation requires close collaboration with biomedical engineers and structured training for the surgical team. The key elements for successful outcomes include meticulous preoperative planning and the high precision of the robotic system. Continuous improvements in algorithmic performance open the door to major innovations such as intraoperative customization of rods and real-time decision-support tools for spinal alignment correction.

Limitations

As all the studies included were retrospective, the findings are susceptible to unmeasured confounding and may overestimate the efficacy of robot-assisted surgery. Therefore, results necessitate confirmation in randomized trials.

List of Abbreviations

RIA= Robot Institute of America, MISS= Minimally Invasive Spine Surgery, EM= Electromagnetic, FAD= The Food and Drug Administration, CT= Computerized Tomography, 3D= Three-Dimensional

Declarations

Ethics approval and consent to participate: This study was exempt from IRB approval due to the public nature of its data source, and not involving human, or animal participant

Consent for publication: not applicable

Availability of data and materials: Data, material, or code availability Data used in this study is publicly available articles.

Competing Interests: The author has no relevant financial or non-financial interests to show

Conflict of Interest: there is no conflict of interest.

Author contribution: the only author no other authors

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References

1. Robotics today, robotics institute of America (ria) news, no date.
2. Mallela, A. N., Beiriger, J., Gersey, Z. C., Shariff, R. K., Gonzalez, S. M., Agarwal, N., ... & Abou-Al-Shaar, H. (2022). Targeting the future: developing a training curriculum for robotic assisted neurosurgery. *World neurosurgery*, *167*, e770-e777.

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Research Article

3. Khan, A., Meyers, J. E., Siasios, I., & Pollina, J. (2019). Next-generation robotic spine surgery: first report on feasibility, safety, and learning curve. *Operative neurosurgery*, *17*(1), 61-69.
4. Eck, J. C., Lange, J., Street, J., Lapinsky, A., & DiPaola, C. P. (2013). Accuracy of intraoperative computed tomography–based navigation for placement of percutaneous pedicle screws. *Global spine journal*, *3*(2), 103-107.
5. Chenin, L., Peltier, J., & Lefranc, M. (2016). Minimally invasive transforaminal lumbar interbody fusion with the ROSATM Spine robot and intraoperative flat-panel CT guidance. *Acta neurochirurgica*, *158*(6), 1125-1128.
6. Staub, B. N., & Sadrameli, S. S. (2019). The use of robotics in minimally invasive spine surgery. *Journal of spine surgery*, *5*(Suppl 1), S31.
7. Kam, J. K., Gan, C., Dimou, S., Awad, M., Kavar, B., Nair, G., & Morokoff, A. (2019). Learning curve for robot-assisted percutaneous pedicle screw placement in thoracolumbar surgery. *Asian Spine Journal*, *13*(6), 920.
8. Joseph, J. R., Smith, B. W., Liu, X., & Park, P. (2017). Current applications of robotics in spine surgery: a systematic review of the literature. *Neurosurgical focus*, *42*(5), E2.
9. Ong, V., Swan, A. R., Sheppard, J. P., Ng, E., Faung, B., Diaz-Aguilar, L. D., & Pham, M. H. (2022). A comparison of spinal robotic systems and pedicle screw accuracy rates: review of literature and meta-analysis. *Asian Journal of Neurosurgery*, *17*(04), 547-556.
10. Huang, M., Tetreault, T. A., Vaishnav, A., York, P. J., & Staub, B. N. (2021). The current state of navigation in robotic spine surgery. *Annals of translational medicine*, *9*(1), 86.
11. Wang, J., Miao, J., Zhan, Y., Duan, Y., Wang, Y., Hao, D., & Wang, B. (2023). Spine surgical robotics: current status and recent clinical applications. *Neurospine*, *20*(4), 1256.
12. Al-Naseem, A. O., Al-Muhannadi, A., Ramadhan, M., Alfadhli, A., Marwan, Y., Shafafy, R., & Abd-El-Barr, M. M. (2024). Robot-assisted pedicle screw insertion versus navigation-based and freehand techniques for posterior spinal fusion in scoliosis: a systematic review and meta-analysis. *Spine Deformity*, *12*(5), 1203-1215.
13. Liounakos, J. I., Chenin, L., Theodore, N., & Wang, M. Y. (2021). Robotics in spine surgery and spine surgery training. *Operative Neurosurgery*, *21*(2), 35-40.
14. Mehrdad, S., Liu, F., Pham, M. T., Lelevé, A., & Atashzar, S. F. (2020). Review of advanced medical telerobots. *Applied Sciences*, *11*(1), 209.
15. Keric, N., Doenitz, C., Haj, A., Rachwal-Czyzewicz, I., Renovanz, M., Wesp, D. M., ... & Kantelhardt, S. R. (2017). Evaluation of robot-guided minimally invasive implantation of 2067 pedicle screws. *Neurosurgical focus*, *42*(5), E11.
16. Khan, A., Meyers, J. E., Siasios, I., & Pollina, J. (2019). Next-generation robotic spine surgery: first report on feasibility, safety, and learning curve. *Operative neurosurgery*, *17*(1), 61-69.
17. Joseph, J. R., Smith, B. W., Liu, X., & Park, P. (2017). Current applications of robotics in spine surgery: a systematic review of the literature. *Neurosurgical focus*, *42*(5), E2.
18. Komolafe, T. E., Zhou, L., Zhao, W., Guo, J., Li, Z., Fan, Z., ... & Samuel, O. W. (2024). Advancing robot-guided techniques in lumbar spine surgery: a systematic review and meta-analysis. *Expert Review of Medical Devices*, *21*(8), 765-779.
19. Adler Jr, J. R., Murphy, M. J., Chang, S. D., & Hancock, S. L. (1999). Image-guided robotic radiosurgery. *Neurosurgery*, *44*(6), 1299-1306.
20. Hu, X., Ohnmeiss, D. D., & Lieberman, I. H. (2013). Robotic-assisted pedicle screw placement: lessons learned from the first 102 patients. *European Spine Journal*, *22*(3), 661-666.
21. D'Souza, M., Gendreau, J., Feng, A., Kim, L. H., Ho, A. L., & Veeravagu, A. (2019). Robotic-assisted spine surgery: history, efficacy, cost, and future trends. *Robotic Surgery: Research and Reviews*, 9-23.
22. Khan, A., Meyers, J. E., Siasios, I., & Pollina, J. (2019). Next-generation robotic spine surgery: first report on feasibility, safety, and learning curve. *Operative neurosurgery*, *17*(1), 61-69.

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Research Article

23. Overley, S. C., Cho, S. K., Mehta, A. I., & Arnold, P. M. (2017). Navigation and robotics in spinal surgery: where are we now?. *Neurosurgery*, *80*(3S), S86-S99.
24. Shahi, P., Maayan, O., Shinn, D., Dalal, S., Song, J., Araghi, K., ... & Qureshi, S. A. (2023). Floor-mounted robotic pedicle screw placement in lumbar spine surgery: an analysis of 1,050 screws. *Neurospine*, *20*(2), 577.
25. Altorfer, F. C., Avrumova, F., & Lebl, D. R. (2024). Robotic-assisted decompression, decortication, and instrumentation for minimally invasive transforaminal lumbar interbody fusion. *JBJS Essential Surgical Techniques*, *14*(4), e23-00080.
26. Andria, G., Attivissimo, F., Di Nisio, A., Lanzolla, A. M. L., Larizza, P., & Selicato, S. (2019). Development and performance evaluation of an electromagnetic tracking system for surgery navigation. *Measurement*, *148*, 106916.
27. Park, D., Mummaneni, P. V., Mehra, R., Kwon, Y., Kim, S., Ruan, H. B., & Chou, D. (2020). Predictors of the need for laminectomy after indirect decompression via initial anterior or lateral lumbar interbody fusion. *Journal of Neurosurgery: Spine*, *32*(6), 781-787.
28. Yu, E., & Khan, S. N. (2014). Does less invasive spine surgery result in increased radiation exposure? A systematic review. *Clinical Orthopaedics and Related Research®*, *472*(6), 1738-1748.

Citation: Eldanasory O. A. (2026). Overview of Robotic Spine Surgery. *Journal of Integrated Human Health Sciences, 2*(1): 1-8.