Recent Advances in Spine Surgery- Pros and Cons.

Arvind JanardhanVatkar[1], Sumedha Shinde[2], Sachin Kale[3], Pramod Bhor[4]

Abstract

Recent innovations in spine surgery, such as minimally invasive spine surgery, endoscopic spine surgery, robotic spine surgery, virtual reality, artificial intelligence, and biomaterials, have resulted in significant gains, although more work need to be done. Minimally invasive and endoscopic spine operations provide the advantages of minimum tissue stress and early recovery, but they have a high learning curve. Robotic spine surgery and virtual reality can improve precision and planning, although they are expensive and may be restricted in availability. Artificial intelligence and biomaterials show promise for personalised therapy, but their long-term implications are still being investigated. To make educated judgments for their patients, surgeons must consider the benefits and drawbacks of various technologies.

Keywords: minimally invasive spine surgery, artificial intelligence, robotic spine surgery, endoscopic spine surgery, virtual reality, biomaterials

Introduction

The discipline of spine surgery has greatly benefited from technological advancements that enhanced surgical procedures and patient outcomes. These developments have completely changed the field of spine surgery, from the creation of minimally invasive techniques to the application of image-guided robots and augmented reality (AR). For example, the application of robot-assisted surgery and image-guided navigation with AR has demonstrated enhanced surgical results by increasing precision in pedicle screw placement [1].

Artificial intelligence (AI) has the potential to drastically alter medicine and facilitate the shift from traditional health care to precision medicine style, owing to its apparent benefits in processing huge data and picture information [2].

These developments have put spine surgery at the forefront of medical innovation and are essential to improving surgical results and patient care. It is crucial for clinicians to keep up to date as the field continues to change.

We will go over the fundamentals, benefits, and drawbacks of four main technology revolutions that have a major impact on spine surgery: Minimally invasive spine surgery (MISS) which includes endoscopic spine surgery (**ESS**) and robotic spine surgery (**RSS**), virtual reality (VR), AI, and biomaterials.

Minimally Invasive Spine Surgery MISS

MISS has been recognized as a significant innovation in the area of orthopedic spine surgery, giving various advantages over standard open surgery. This approach involves tiny stab incisions, less tissue damage, faster recuperation, and shorter hospital stays, all of which contribute to better patient outcomes [3]. The underlying premise of MISS is to achieve the same surgical aims as open surgery while avoiding approach-related harm caused by conventional open surgery [4,5]. This is accomplished by employing specialized instruments, modern imaging methods, and surgical expertise [3].

The progression of intervertebral discectomy and decompression began with microdiscectomy and progressed to the use of tubular retractors and, eventually, ESS [6].

ESS using high-definition cameras aids in distinguishing between normal and diseased tissues and blood vessels [7-9]. The use of multiple angled endoscopes allows for the viewing of almost 360° of area, which was not achievable with traditional approaches [9]. Endoscopic access using the dorsolateral route removes the need for extensive bone

[1]Consultant Orthopedic Spine Surgeon, Fortis Hiranandani Hospital, Vashi, Navi Mumbai- 400703, India,
[2]Assistant Professor, Sir JJ Blood Center, Byculla, Mumbai, Maharashtra 400008, India,
[3]Department of Orthopedics, D Y Patil Hospital and medical college, Ayyappa Temple Road, Dr D Y Patil Vidyanagar, Sector 5, Nerul, Navi Mumbai, Maharashtra 400706, India,
[4]Director of Department of Orthopaedics, Fortis Hiranandani Hospital, Vashi, Navi Mumbai- 400703, India.

Address of Correspondence
Dr. Vatkar Arvind Janardhan,
Department of Orthopaedics, Fortis Hiranandani hospital, Juhu Nagar, Sector 10A, Vashi, Navi Mumbai, Maharashtra 400703, India.
E-mail: vatkararvind@gmail.com

Submitted Date: 30/09/2023, Review Date: 05-10-2023, Accepted Date: 04-12-2023 & Published Date: 30-12-2023

© Authors | Journal of Clinical Orthopaedics | Available on www.jcorth.com | Publisher Orthopaedic Research Group | DOI:10.13107/jcorth.2023.v08i02.596
This is an open access journal, and articles are distributed under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike 4.0 License (https://creativecommons.org/licenses/by-nc-sa/4.0/), which allows others to remix, tweak, and build upon the work non-commercially, as long as appropriate credit is given and the new creations are licensed under the identical terms.

resection and is accomplished directly through the intervertebral foramen window (transforaminal approach), especially in thoracic regions [10].

RSS - Robotic spine systems recognize predefined standard points of reference using a spinous process clamp or pelvic pin and employ an intraoperative navigation system and a robotic arm to implant vertebral pedicle screws. This RSS enables treatments to be performed more quickly, precisely, and accurately [11,12]. According to a meta-analysis of 19 trials, patients in the RSS group had greater accuracy, 92% lower rate of cranial facet joint violations, and 69% less total complications. They did, however, need more intraoperative time than typical fluoroscopy-assisted screw insertion [13]. Studies show that robots significantly reduce radiation exposure to patients and surgical teams, and as surgeons become more proficient, operative time decreases [14,15].

While the benefits of MISS are obvious in terms of less tissue damage and faster recuperation, it is crucial to examine the risks. Although the clinical results of MISS are equivalent to open surgery [16], understanding the specialized techniques and equipment used in minimally invasive treatments may require a steep learning curve. Furthermore, not all spinal diseases are appropriate for MISS, and the indications for these treatments have been broadening as medical equipment and technology have advanced [3].

The robot technology provides high-definition three-dimensional pictures and outperforms human hand limits for accurate motions, free of fatigue and error. Future integration of robotics and intelligent navigation in endoscopic spinal surgery might result in revolutionary developments, showcasing the field's sophisticated technology's promise [17].

VR and AR in Spine Surgery

VR and AR have become popular as potential spine surgical tools. VR and AR technologies offer a three-dimensional perspective of the operating area, allowing doctors to more correctly visualize the anatomy and plan the procedure. AR may also be utilized to superimpose photos of the patient's anatomy in the surgical area, allowing for real-time guidance throughout the process. These technologies have the ability to increase surgical precision, decrease complications, and cut recovery periods [1].

For surgery residents, VR technology can generate precise, engaging simulations, giving a realistic teaching experience outside of the operating room. It enables complex analytics and algorithms to be used to examine performance metrics. The immersive experience, which is augmented by head-mounted screens and tactile feedback, enables trainees to hone their surgical abilities in a flexible and safe atmosphere [18]. According to research, VR improves surgical precision by giving real-time visual cues and feedback to surgeons, reducing errors in pedicle screw insertion by up to 53.7% [19]. VR and AR technology are rapidly being employed in spine surgery for treatments such as decompression, tumor removal, and deformity correction also. AR aids in the visualization of tumor location and connections during tumor excision, decreasing the learning curve. AR assists in pre-operative planning in spinal deformity correction procedures, resulting in improved patient results and fewer problems [19,20].

The immense expense of VR and AR technology, including hardware, software, and maintenance, is a significant barrier to wider adoption. This is seen in programs such as Augmedics Xvision, which intends to offer the device to health-care facilities for between $200,000 and $300,000 USD [18]. However, the long-term benefits of these technologies, such as shorter operating times and less surgical stress, can more than compensate for the upfront expenses [19]. Despite the incorporation of VR into residency training programs, only 9.8% of trainees have used it in arthroscopy with a mix of excitement and skepticism. Currently, no major orthopedic specialty organizations have supported standardized curriculum for VR/AR surgical instruments [21]. The global inequality in access to new medical technology such as VR and AR, particularly in low-income countries, further impedes their general adoption [22].

AI in spine surgery

Precision medicine, which tailors treatment to specific patients, will benefit from data and expert opinion. Unique patient and pathological features are deconstructed into variables as datasets grow, offering significant insights for optimizing patient care. AI and machine learning advancements will enable comparative analysis of a single patient's data throughout the treatment continuum to diagnose problems, personalize methods, and forecast treatment outcomes [23].

In the pre-operative scenario, recent research has used AI and machine learning to automate the computation of patient-specific imaging metrics such as Cobb angles, sagittal balance, and bone density in spine surgery, therefore enhancing therapy selection and surgical planning [24-26]. Intraoperatively, AI can enhance navigation and robotics in intraoperative surgery by guiding alignment and construct placement and providing real-time finite element modeling [27]. This allows surgeons to optimize results and reduce stress, leading to better patient outcomes. Cases with optimal outcomes will be captured, while suboptimal ones will be analyzed for best practices [26]. In the post-operative phase, it enables objective recording of outcome metrics and physical features of patients, as well as prediction of recovery and problems.

Digital phenotypes are being created for patient monitoring through early warning systems and mobile phone sensors. This data improves early management decisions by refining algorithms [28-31].

AI analysis needs a massive amount of data. This therapeutically relevant dataset for AI in surgery necessitates fundamental investments in electronic medical record systems from physicians, hospitals, and the health-care ecosystem. To enable data use across hospitals and geographical boundaries, data privacy and security standards must be modified. To fully realize the benefits of AI in surgery, cultural problems, litigation concerns, and discoverable information from operations must be addressed. Lifelong learning and adaptability to new technologies are critical for this field's progress, which necessitates spine surgeons pulling up their socks and learning to integrate new technology [23].

Biomaterials in Spine Surgery

Many novel biomaterials have been investigated in the field of spine surgery in recent years. Among the innovative biomaterials are tantalum, nitinol (50% titanium + 50% nickel), polyetheretherketone (PEEK) with carbon fiber, PEEK doped with titanium, and recombinant bone morphogenetic protein 2 (BMP2) and bioglass.

Tantalum has improved pullout strength and osteoblast proliferation induction than titanium. Tantalum-coated pedicle screws hence showed enhanced bone integration [32]. Nitinol is a notch-sensitive metal with shape memory elastic properties making it apt as a material for rods in scoliosis surgery. Reinforcing PEEK with carbon fiber (CFR-PEEK) or doping with titanium (TiPEEK) allows for a mixing of attributes to suit unique purposes. CFR-PEEK has shown potential in the field of spinal tumors, with excellent radiographic characteristics and no noted differences in outcomes or complications from traditional titanium or PEEK [33]. When PEEK is doped with Ti, it may show improved subsidence rates [34,35]. HA-coated pedicle screws have increased pullout force and bone-to-implant contact, making them often indicated in patients with low bone mineral density. RhBMP2 is an alternative to iliac crest bone graft to avoid donor site morbidity and increased wound-related complications [36]. It has superior spinal fusion rates and may improve PROMs in anterior cervical discectomy and fusion but may cause potentially life-threatening prevertebral edema [37].

Ceramics such as tricalcium phosphate is an osteoinductive ceramic bone graft alternative with high lumbar interbody union percentages. The radiographic fusion efficiency of silicon-substituted calcium phosphate is 93%, which is comparable to rhBMP2-impregnated graft [38-40]. In lumbar interbody surgeries, stromal vascular fraction (SVF) is utilized in combination with ceramics. At 6 months, a case series revealed a statistically significant rise in fusion grade with SVF [41]. Bioactive glass, a semi-crystalline gel substance with antibacterial and osteoinductive qualities, acts equivalent to iliac crest autograft in fusion, although there is not enough clinical research on it [39,42].

Conclusion

Emerging technology in spine surgery has revolutionized how surgeons practice, and the future appears limitless. Improvements enable superior pre-operative decision-making, better outcomes for patients, and better intraoperative execution. Minimally invasive approaches aid in increasing exposure and access while causing the least amount of tissue harm. Subsidence, loss of alignment and deformity correction, and the need for reoperation are all reduced when implant materials and device alternatives improve. As the profession evolves, it is critical that practitioners should be informed of these developments to deliver the most effective therapy possible.

References

1. Móga K, Ferencz A, Haidegger T. What is next in computer-assisted spine surgery? Advances in image-guided robotics and extended reality. Robotics 2022;12:1.
2. Zhou S, Zhou F, Sun Y, Chen X, Diao Y, Zhao Y, et al. The application of artificial intelligence in spine surgery. Front Surg 2022;9:885599.
3. Choi JY, Park SM, Kim HJ, Yeom JS. Recent updates on minimally invasive spine surgery: Techniques, technologies, and indications. Asian Spine J 2022;16:1013-21.
4. Sharma A, Shakya A, Singh V, Deepak P, Mangale N, Jaiswal A, et al. Incidence of dural tears in open versus minimally invasive spine surgery: A Single-center prospective study. Asian Spine J 2022;16:463-70.
5. Wang X, Borgman B, Vertuani S, Nilsson J. A systematic literature review of time to return to work and narcotic use after lumbar spinal fusion using minimal invasive and open surgery techniques. BMC Health Serv Res 2017;17:446.
6. Thongtrangan I, Le H, Park J, Kim DH. Minimally invasive spinal surgery: A historical perspective. Neurosurg Focus 2004;16:E13.
7. Tieber F, Lewandrowski KU. Technology advancements in spinal endoscopy for staged management of painful spine conditions. J Spine Surg 2020;6:S19-28.
8. Park SM, Park J, Jang HS, Heo YW, Han H, Kim HJ, et al. Biportal endoscopic versus microscopic lumbar decompressive laminectomy in patients with spinal stenosis: A randomized controlled trial. Spine J 2020;20:156-65.
9. Kang MS, You KH, Han SY, Park SM, Choi JY, Park HJ. Percutaneous full-endoscopic versus biportal endoscopic posterior cervical foraminotomy for unilateral cervical foraminal disc disease. Clin Orthop Surg 2022;14:539-47.

10. Fiani B, Siddiqi I, Reardon T, Sarhadi K, Newhouse A, Gilliland B, et al. Thoracic endoscopic spine surgery: A comprehensive review. Int J Spine Surg 2020;14:762-71.
11. Naros G, Machetanz K, Grimm F, Roser F, Gharabaghi A, Tatagiba M. Framed and non-framed robotics in neurosurgery: A 10-year single-center experience. Int J Med Robot 2021;17:e2282.
12. Grimm F, Naros G, Gutenberg A, Keric N, Giese A, Gharabaghi A. Blurring the boundaries between frame-based and frameless stereotaxy: Feasibility study for brain biopsies performed with the use of a head-mounted robot. J Neurosurg 2015;123:737-42.
13. Fatima N, Massaad E, Hadzipasic M, Shankar GM, Shin JH. Safety and accuracy of robot-assisted placement of pedicle screws compared to conventional free-hand technique: A systematic review and meta-analysis. Spine J 2021;21:181-92.
14. Han X, Tian W, Liu Y, Liu B, He D, Sun Y, et al. Safety and accuracy of robot-assisted versus fluoroscopy-assisted pedicle screw insertion in thoracolumbar spinal surgery: A prospective randomized controlled trial. J Neurosurg Spine 2019;2;1-8.
15. Keric N, Doenitz C, Haj A, Rachwal-Czyzewicz I, Renovanz M, Wesp DM, et al. Evaluation of robot-guided minimally invasive implantation of 2067 pedicle screws. Neurosurg Focus 2017;42:E11.
16. Park J, Ham DW, Kwon BT, Park SM, Kim HJ, Yeom JS. Minimally invasive spine surgery: Techniques, technologies, and indications. Asian Spine J 2020;14:694-701.
17. Yu Y, Li ZZ, Nishimura Y. Editorial: Endoscopic spine surgery. Front Surg 2022;9:1127851.
18. Hasan S, Miller A, Higginbotham D, Saleh ES, McCarty S. Virtual and augmented reality in spine surgery: An era of immersive healthcare. Cureus 2023;15:e43964.
19. Gasco J, Patel A, Ortega-Barnett J, Branch D, Desai S, Kuo YF, et al. Virtual reality spine surgery simulation: An empirical study of its usefulness. Neurol Res 2014;36:968-73.
20. Ma L, Fan Z, Ning G, Zhang X, Liao H. 3D Visualization and augmented reality for orthopedics. Adv Exp Med Biol 2018;1093:193-205.
21. Hasan LK, Haratian A, Kim M, Bolia IK, Weber AE, Petrigliano FA. Virtual reality in orthopedic surgery training. Adv Med Educ Pract 2021;12:1295-301.
22. Saeed SA, Masters RM. Disparities in health care and the digital divide. Curr Psychiatry Rep 2021;23:61.
23. Browd SR, Park C, Donoho DA. Potential applications of artificial intelligence and machine learning in spine surgery across the continuum of care. Int J Spine Surg 2023;17:S26-33.
24. Broida SE, Schrum ML, Yoon E, Sweeney AP, Dhruv NN, Gombolay MC, et al. Improving surgical triage in spine clinic: Predicting likelihood of surgery using machine learning. World Neurosurg 2022;163:e192-8.
25. Wilson B, Gaonkar B, Yoo B, Salehi B, Attiah M, Villaroman D, et al. Predicting spinal surgery candidacy from imaging data using machine learning. Neurosurgery 2021;89:116-21.
26. Xie N, Wilson PJ, Reddy R. Use of machine learning to model surgical decision-making in lumbar spine surgery. Eur Spine J 2022;31:2000-6.
27. Peng L, Zhang G, Zuo H, Lan L, Zhou X. Surgical design optimization of proximal junctional kyphosis. J Healthc Eng 2020;2020:8886599.
28. Garcia-Canadilla P, Isabel-Roquero A, Aurensanz-Clemente E, Valls-Esteve A, Miguel FA, Ormazabal D, et al. Machine learning-based systems for the anticipation of adverse events after pediatric cardiac surgery. Front Pediatr 2022;10:930913.
29. Iqbal FM, Joshi M, Fox R, Koutsoukou T, Sharma A, Wright M, et al. Outcomes of vital sign monitoring of an acute surgical cohort with wearable sensors and digital alerting systems: A pragmatically designed cohort study and propensity-matched analysis. Front Bioeng Biotechnol 2022;10:895973.
30. Boaro A, Leung J, Reeder HT, Siddi F, Mezzalira E, Liu G, et al. Smartphone GPS signatures of patients undergoing spine surgery correlate with mobility and current gold standard outcome measures. J Neurosurg Spine 2021;35:796-806.
31. Lyman S, Hidaka C, Fields K, Islam W, Mayman D. Monitoring patient recovery after THA or TKA using mobile technology. HSS J 2020;16:358-65.
32. Shi LY, Wang A, Zang FZ, Wang JX, Pan XW, Chen HJ. Tantalum-coated pedicle screws enhance implant integration. Colloids Surf B Biointerfaces 2017;160:22-32.
33. Takayanagi A, Siddiqi I, Ghanchi H, Lischalk J, Vrionis F, Ratliff J, et al. Radiolucent carbon fiber-reinforced implants for treatment of spinal tumors-clinical, radiographic, and dosimetric considerations. World Neurosurg 2021;152:61-70.
34. Lv ZT, Xu Y, Cao B, Dai J, Zhang SY, Huang JM, et al. Titanium-coated PEEK versus uncoated PEEK cages in lumbar interbody fusion: A systematic review and meta-analysis of randomized controlled trial. Clin Spine Surg 2023;36:198-209.
35. Singhatanadgige W, Tangchitcharoen N, Kerr SJ, Tanasansomboon T, Yingsakmongkol W, Kotheeranurak V, et al. A comparison of polyetheretherketone and titanium-coated polyetheretherketone in minimally invasive transforaminal lumbar interbody fusion: A randomized clinical trial. World Neurosurg 2022;168:e471-9.
36. Feng JT, Yang XG, Wang F, He X, Hu YC. Efficacy and safety of bone substitutes in lumbar spinal fusion: A systematic review and network meta-analysis of randomized controlled trials. Eur Spine J 2020;29:1261-76.
37. Iunes EA, Barletta EA, Barba Belsuzarri TA, Onishi FJ, Cavalheiro S, Joaquim AF. Correlation between different interbody grafts and pseudarthrosis after anterior cervical discectomy and fusion compared with control group: Systematic review. World Neurosurg 2020;134:272-9.
38. Ament JD, Vokshoor A, Yee R, Johnson JP. A systematic review and meta-analysis of silicon nitride and biomaterial modulus as it relates to subsidence risk in spinal fusion surgery. N Am Spine Soc J 2022;12:100168.
39. Fiani B, Jarrah R, Shields J, Sekhon M. Enhanced biomaterials: Systematic review of alternatives to supplement spine fusion including silicon nitride, bioactive glass, amino peptide bone graft, and tantalum. Neurosurg Focus 2021;50:E10.
40. Cottrill E, Premananthan C, Pennington Z, Ehresman J, Theodore N, Sciubba DM, et al. Radiographic and clinical outcomes of silicate-substituted calcium phosphate (SiCaP) bone grafts in spinal fusion: Systematic review and meta-analysis. J Clin Neurosci 2020;81:353-66.
41. Choi UY, Kim KT, Kim KG, Lim SH, Kim YJ, Sohn S, et al. Safety and tolerability of stromal vascular fraction combined with β-Tricalcium phosphate in posterior lumbar interbody fusion: Phase I clinical trial. Cells 2020;9(10):2250.
42. Kwon BT, Kim HJ, Lee S, Park SM, Ham DW, Park HJ, et al. Feasibility and safety of a CaO-SiO2-P2O5-B2O3 bioactive glass ceramic spacer in posterior lumbar interbody fusion compared with polyetheretherketone cage: A prospective randomized controlled trial. Acta Neurochir 2023;165:135-44.

Conflict of Interest: NIL
Source of Support: NIL

How to Cite this Article

Vatkar AJ, Sinde S, Kale S, Bhor P. Recent Advances in Spine Surgery- Pros and Cons. Journal of Clinical Orthopaedics July-December 2023;8(2):50-53.