Recent Advances in Spine Surgery: Pros and Cons.

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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 personalized 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), endoscopic spine surgery (ESS), robotic spine surgery (RSS), and 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 tube 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

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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 compared to 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 discectomies 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.

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