SPINE RESEARCH

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The next decade in spine surgery

Opportunities, challenges, and global synergy

Henry Avetisian[a], William Karakash[a], Jeffrey C. Wang[a,*]

Spine surgery has undergone profound evolution over the past several decades, driven by rapid innovations in surgical technique, perioperative technology, and global collaboration. International organizations such as AO Spine have played a pivotal role in facilitating these advancements by connecting spine surgeons worldwide through shared education, research, and advocacy. Yet, as the field progresses toward more data-integrated care, it also becomes increasingly important to address persistent disparities in access to spine care globally. The next decade presents an opportunity not only to celebrate the remarkable strides made but also to embrace the responsibility of shaping a more equitable and innovative future for all.

Among the most promising technological advances in spine surgery are robotics, navigation systems, and minimally invasive (MIS) techniques. These tools are redefining precision and improving patient outcomes.

Robotics and navigation systems have seen a significant rise in adoption within spine surgery, driven by their potential to improve instrumentation accuracy and enhance clinical outcomes. The initial robotic spine system to gain US Food and Drug Administration approval was Spine Assist in 2004.[1] Since then, several platforms—including ROSA ONE Spine, ExcelsiusGPS, CUVIS, and Cirq—have gained approval and widespread clinical use.[1] Utilization trends reflect this growing interest: robotic assistance in spinal fusion procedures increased from 6.3% in 2007 to 23.1% in 2015.[2] By 2019, patients undergoing spinal fusion were 4 times more likely to receive robotic-assisted surgery compared with 2016.[3]

Navigation systems have followed a similar trajectory. Their use in spinal fusion increased from just 0.04% in 2004 to 3.3% in 2014, with continued growth through 2018.[4,5] A 2025 global survey further revealed that nearly 50% of spine surgeons are now utilizing navigation systems in their practice.[6] A robust body of literature supports the clinical benefits of both of these technologies, including improved pedicle screw placement accuracy, reduced complication rates, shorter hospital stays, diminished radiation exposure due to less reliance on fluoroscopy, and faster postoperative recovery.[1,2,7,8] Despite these advantages, several barriers limit widespread adoption. Robotic and navigation systems come with high acquisition and maintenance costs, and their implementation requires a steep learning curve that can extend operative times during early use.[9] Nonetheless, the outlook remains highly optimistic. As robotic systems become more affordable, modular, and seamlessly integrated with digital health records and intraoperative imaging, their utility and accessibility are expected to expand. Looking ahead, we anticipate broader applications in complex procedures such as cervical instrumentation, spinal deformity correction, and revision surgeries—making robotics and navigation integral components in the future of spine surgery.[1]

MIS techniques—including both endoscopic and microscopic techniques—represent one of the most significant advancements in modern spine surgery. These methods have particularly transformed decompression procedures, offering clear clinical advantages over traditional open techniques. Numerous studies have demonstrated that MIS decompression is associated with reduced postoperative pain, less soft tissue disruption, lower opioid requirements, decreased complication rates, shorter hospital stays, and a lower risk of iatrogenic spinal instability.[10–13] Owing to its favorable safety profile, MIS decompression has become widely adopted in the outpatient management of common degenerative conditions such as spinal canal stenosis, foraminal stenosis, and disc herniations—disorders that affect millions of patients globally. In addition to these clinical advantages, MIS carries significant public health implications.

With an aging global population, the demand for spine surgery is projected to rise among older patients with higher comorbidity burdens. This population may be less suited for open surgical approaches, making MIS a vital solution for delivering safe, effective care in this

[a] Department of Orthopaedic Surgery, Keck School of Medicine of the University of Southern California, Los Angeles, California.

* Correspondence: Jeffrey C. Wang, Department of Orthopaedic Surgery, Keck School of Medicine of the University of Southern California, 1975 Zonal Ave, Los Angeles, CA 90033 (e-mail: jcwspine@gmail.com).

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expanding demographic. Unsurprisingly, the utilization of MIS has steadily increased in recent years, reflecting both their clinical efficacy and growing surgeon familiarity.[14] While challenges such as a learning curve and limited anatomic visualization exist, these are increasingly being addressed through advanced training programs and evolving technology. Interestingly, the global adoption of MIS varies considerably. A recent study found that 70.2% of surgeons in Asian countries reported using MIS techniques, compared with only 55.2% of those practicing outside of Asia.[15] This discrepancy may be due to differences in training exposures, as well as financial barriers such as limited reimbursement and high equipment costs, which can restrict feasibility in some regions. Nonetheless, the future of MIS remains highly promising. As adoption grows, surgical programs are increasingly incorporating these techniques into their curricula. Furthermore, as device manufacturing becomes more cost-effective and technology continues to improve, broader accessibility is likely. These innovations are poised to make MIS a central pillar in the future of spine care—offering safer, patient-centered solutions with lower perioperative risk and faster recovery.

To ensure the widespread adoption of emerging technologies, I do believe that international academic societies—including AO Spine and the North American Spine Society—play a crucial role. These organizations are uniquely positioned to disseminate the evidence and research, which validate new technologies, standardize education, and promote best practices across diverse health systems. This would include peer-reviewed research presentations, educational events, and publications in journals such as the *Global Spine Journal*, and other academic society-affiliated journals. Guidelines can also be developed based on the literature to ensure the proper implementation of new devices and technologies. Rigorous patient follow-up and outcomes assessment will be essential to determine the true clinical benefit of these innovations. Additionally, cost analyses and scientific evaluations of societal impact should be conducted to ensure that the technologies are both effective and economically sustainable. Professional societies will play a critical role in overseeing these processes and ensuring that results are disseminated in a standardized and impactful manner.

In addition to promoting the educational use of these technologies, it is vital to address nationwide disparities in patient access to spine care. Technological innovation has reshaped the standard of spine care in high-income countries (HICs) through major advances such as MIS surgery, navigation systems, and biologic therapies.

However, these breakthroughs have not translated into equitable global access. In low- and middle-income countries (LMICs), even basic spinal procedures remain inaccessible, underscoring a stark disparity where complex surgeries are routine in HICs while essential, life-saving interventions are often unavailable elsewhere.[16] With an estimated 5 billion people lacking access to safe surgical care and spinal disorders contributing substantially to global disability-adjusted life years, the burden of unmet spine care is profound.[17] Nearly half of patients with severe spinal injuries remain untreated, contributing to a backlog of 5 million essential neurosurgical cases, most of which are in LMICs.[18] Traumatic spinal cord injury (SCI) occurs at rates up to 8 times higher in these regions, where limited acute care and rehabilitation services lead to preventable disability and mortality.[19]

Central to this disparity is a critical shortage in the surgical workforce. Despite comprising nearly half the world's population, LMICs maintain a surgeon density 10 times lower than that of HICs, with only 5.5 surgeons per 100,000 inhabitants.[20] The shortage is particularly acute in neurosurgery and orthopedic spine surgery, where over 23,000 additional specialists are needed to meet baseline operative demand.[18] Addressing this gap, global initiatives have emphasized workforce development through structured "train-the-trainer" programs that empower LMIC surgeons with advanced skills and promote regional self-sufficiency.[21] Programs led by the World Federation of Neurosurgical Societies and AO Spine illustrate the value of targeted education, mentorship, and continuous professional development in fostering sustainable improvements in spine care delivery.

However, surgical expertise alone cannot overcome the systemic barriers posed by inadequate infrastructure. Across LMIC healthcare settings, limitations in diagnostic imaging, surgical instrumentation, and implant availability are widespread.[22,23] One-third of physicians report lacking access to magnetic resonance imaging for spinal trauma evaluation, while perioperative care is further compromised by unreliable electricity, sterilization challenges, and staff shortages.[24] Financial constraints often compel deviation from evidence-based standards due to unaffordable implant costs. In response, strategies such as local manufacturing, pooled procurement, and procedural simplification have been introduced to help mitigate these constraints.[25] Additionally, context-specific adaptations such as orthotic bracing and the use of regional anesthesia demonstrate how care can be extended within resource-limited environments.[26]

Postoperative rehabilitation, which is essential for functional recovery in spine surgery and SCI care, remains underdeveloped in LMICs. In-hospital mortality rates are nearly 3 times higher than those in HICs, reflecting compounded barriers such as minimal rehabilitation infrastructure and poor access to assistive devices.[27] For example, wheelchair availability in LMICs ranges from just 5% to 35% for those in need.[28] Although the World Health Organization's "Rehabilitation 2030" initiative has drawn global attention to this issue, substantial progress will require investment in the rehabilitation workforce, integration of community-based models, and improved access to low-cost assistive technologies.[29]

Digital health has emerged as a powerful adjunct to traditional care models. Telemedicine, rapidly accelerated by the COVID-19 pandemic, now enables remote consultations, diagnostic evaluations, and intraoperative

mentorship across geographic boundaries. Teleradiology and telemonitoring have proven effective in optimizing spine trauma management, minimizing unnecessary transfers, and enhancing surgical education in LMICs.[30] As digital infrastructure expands, telehealth will continue to play a key role in decentralizing expertise and mitigating specialist shortages.

Progress in global spine care is increasingly driven by coordinated international collaboration. Initiatives such as the Global Spine Care Initiative and SPINE20 unite multidisciplinary stakeholders to establish evidence-based, resource-appropriate guidelines and advocate for the integration of spine care into global health agendas.[31,32] Sustained outreach programs rather than short-term mission trips, such as World Spine Care and the Scoliosis Research Society's global initiatives, demonstrate the value of longitudinal engagement that combines clinical service, education, and system-level capacity building.[33,34]

Incorporating spine care into national policy frameworks represents a critical step toward systemic change. As LMICs implement National Surgical, Obstetric, and Anesthesia Plans aligned with global surgical goals, it is essential that spine surgery, SCI care, and rehabilitation services are explicitly included, supported by public financing and insurance coverage.[35] Concurrently, prevention must be prioritized. Road traffic injuries falls, and occupational hazards, which are leading causes of spinal trauma, can be mitigated through legislative reform, public health initiatives, and community education.[36,37]

Achieving equity in global spine care demands a comprehensive, multipronged strategy. This includes investment in workforce development, infrastructure expansion, innovative care delivery models, rehabilitation services, telehealth integration, international collaboration, and strong policy advocacy. Preventive efforts must remain central to reduce the incidence of spinal pathology. While the challenges are complex, ongoing global efforts provide a strong foundation upon which equitable, high-quality spine care can be realized, ensuring that access to treatment is determined by need rather than geography or economic status.

Looking to the future, it is essential that the next generation of spine surgeons not only master advanced surgical techniques but also develop leadership and business acumen. Many young surgeons today finish training with minimal exposure to essential skills such as practice management, coding, and navigating the complex landscape of healthcare finance. Formal education in these domains is critical to long-term success in clinical practice. Equally important is the cultivation of leadership. The ability to lead a surgical team, manage institutional relationships, and contribute meaningfully to professional societies is a "superpower" that enables career advancement and lasting impact. I have personally benefited from leadership training and dedicated study of human behavior and organizational dynamics. These tools have helped me not only lead my practice and team effectively but also contribute to academic and global initiatives in spine surgery. I strongly encourage all young surgeons to actively pursue leadership development alongside their technical training.

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