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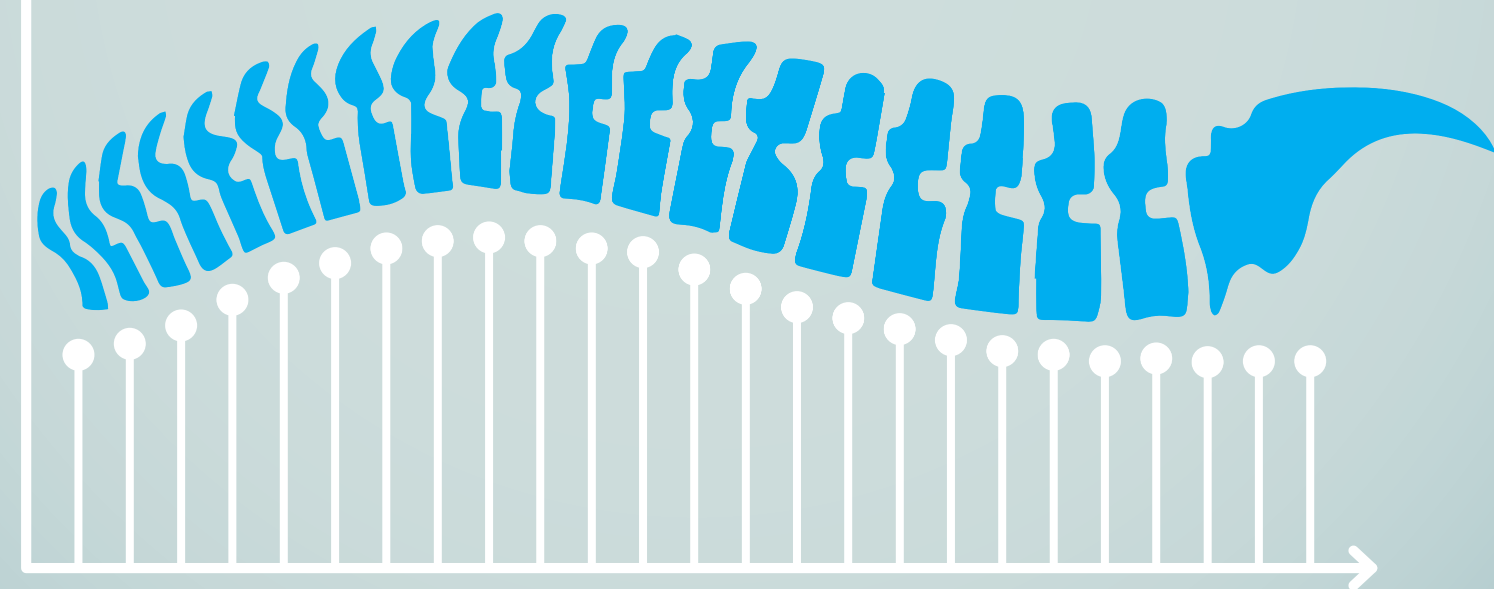
FALL 2020

FLATTENING THE MIS **LEARNING CURVE**



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This publication is available digitally at www.isass.org/news/vertebral-columns-fall-2020

Flattening the MIS Learning Curve


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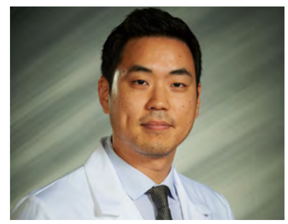
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Since the introduction of minimally invasive surgery (MIS), the way in which spine surgeons perform procedures has changed drastically. As a growing body of evidence has demonstrated, use of MIS techniques and specialized technology can lead to shorter operative times and reduced soft tissue trauma, which in turn can result in fewer complications and improved postoperative outcomes.[1,2] Within the past decade, MIS has become more the rule rather than the exception for many spine surgeons, and it is projected that nearly half of all spine procedures in 2020 will involve these techniques.[3] The appeal of MIS is rooted in potential benefits not only to the patient, but also to the surgeon and team. Such benefits include smaller incisions, avoidance of crushing injury to soft tissue through the use of tubular dilators, and preservation of spine stabilizing muscles.[4] Additionally, for spine surgeons, MIS techniques result in increased operative efficiency, reduced operative times, and decreased blood loss, all of which can translate to reduced cost and improved outcomes for the patient.[5-7] However, achieving proficiency in MIS techniques requires a substantial leap in both surgical and team management skills, resulting in what some have described as a daunting learning curve.

Characterized as the progression of results as a new skill improves over time, the concept of the learning curve was first introduced into surgery by the Bristol Royal Infirmary, which aimed to reduce mortality in infants undergoing procedures for congenital heart disease.[8] Since its inception, surgeons have typically assessed progress along the learning curve in terms of reductions in operative time, blood loss, and rates of complications. While all surgeons aim to become proficient early in their careers, studies suggest the time to proficiency may differ based on the type of spine procedure.[9-11] This raises two questions: (1) What aspect(s) of MIS contribute to the curve? and (2) What are the best ways to shorten time to proficiency?

Challenges of MIS

While mastery of some surgical techniques can be acquired quite rapidly, significantly more experience may be required to achieve optimal results for MIS procedures. A case series of the senior author's first 65 primary MIS transforaminal lumbar interbody fusions (TLIF) illustrates this point nicely: procedures in the latter half of this series demonstrated significantly better outcomes in terms of surgical and anesthesia duration, estimated blood loss, and administration of intraoperative fluids.[12] Similar trends in

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operative proficiency were also detailed over the course of our practice's experience with MIS lumbar decompression[11] and anterior cervical discectomy and fusion, where a 90% proficiency was reached by case 57.[13]

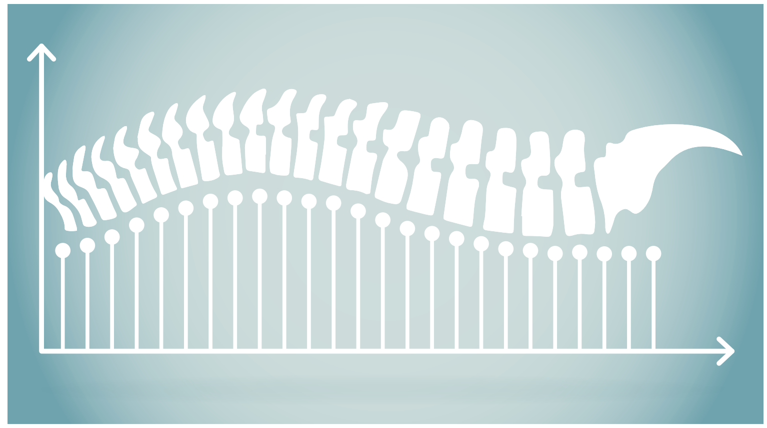
The steep initial curve associated with MIS TLIF reflects a period of substantial learning and acquisition of pertinent techniques and "tricks" that facilitate a more efficient procedure. However, during this time, patients may be exposed to a greater risk of complications. A systematic review of early complications associated with the learning curve in MIS spine surgery detailed that specific types of procedures may be linked with lower or higher rates of complications, with lumbar decompressions having the lowest rate and MIS TLIF having the highest, with an overall rate of 20%.[14] To further complicate the matter is the potential for a "second wave" of the learning curve as attendings take on more challenging cases once they have established a level of comfort with the procedure. This presents an early challenge for surgeons aiming to improve their technique as they strive to "do no harm" to their patients while simultaneously taking full advantage of every opportunity to better themselves as MIS spine surgeons.

As residents, fellows, and new attendings navigate through their training, there are several aspects of MIS to consider that contribute to the learning curve. First, the challenge itself is multifactorial, and addressing one particular aspect does not result in a cure-all effect. Second, exposure to MIS techniques during a surgeon's training may be minimal until he or she begins a spine fellowship. Limited exposure diminishes familiarity with the challenges posed by MIS and limits opportunities to learn from those who have mastered these techniques. Third, a surgeon's training is predicated on visual and tactile training in the operating room; however, MIS drastically reduces not only the visibility window but also the ability to identify key anatomical landmarks vital to accurate placement of implants, screws, and use of specific surgical instruments. Finally, one aspect that adds to the challenge of MIS that may not be inherently obvious is the concept of teamwork. The largest benefit to the technique is its ability to drastically reduce operative time and the associated risks; however, this benefit can only be realized with team-wide efficiency. Given this reality, surgeons must not only navigate the duress involved with applying MIS techniques and avoiding lengthened procedures, but they must also coordinate the surgical team to maintain optimal efficiency. If this dynamic is not appreciated, then the key benefit of MIS spine procedures may be lost. Although some may suggest a steep learning curve is unavoidable, we highlight several tactics, in the context of MIS TLIF, that may be used to "flatten" the curve.

Flattening the Curve

Perhaps the most straightforward way for junior surgeons to improve operative outcomes for their MIS TLIF procedures is to simply perform more of them, as it has been well established that outcomes are more favorable after surgeons have a considerable number of TLIF procedures under their belt. Silva et al[9] demonstrated a 50% improvement in surgeons' proficiency by their 12th MIS TLIF procedure; by their 39th case, they had achieved a 90% "learning milestone." They were also able to demonstrate a considerable reduction in their rate of complications over this series of procedures. The obvious downside of learning through experience is that it necessitates that some outcomes will inherently be less than optimal for the earlier procedures toward the "left end" of the learning curve. Although this has been the traditional model for learning surgery and most aspects of medical practice, it may not be agreeable to those patients who are among a surgeon's first few patients as an independent practitioner. With this in mind, it is important to consider ways to maximize a surgeon's proficiency with MIS procedures from day one.

Before the proficiency of the surgeons themselves is addressed, one should consider that the surgical team is one of the most important factors for a successful procedure. For any procedure to be performed in a safe, efficient manner, the performance of the surgical team must be optimized. For MIS procedures, it is especially important that the team is highly familiar with the steps of the operation, the necessary preparation, and the use of intraoperative instruments and technology. Smaller approach windows place increased reliance on a team's ability to track the procedure's stage without direct visualization and coordinate with the surgeon to effectively perform their roles. To this end, standardization of every possible part of the process is key. From instrument trays to team positioning to the procedural steps themselves, the more consistency and predictability that is incorporated, the better the surgeon and team can be prepared for success.



As a newer surgeon seeks to begin his or her practice of MIS, the guidance and mentorship of a more senior surgeon who has mastered the MIS technique can be invaluable for appreciating the subtleties of the craft and avoiding crucial errors. The model of apprenticeship is quite standard to medical practice, with residents and fellows learning under the guidance of experienced attending physicians. However, for specialized spine procedures such as the MIS TLIF, residents and fellows may receive relatively little exposure during their regular training. As the role of MIS TLIF continues to expand in spine surgery, it will become important to increase the opportunities available to trainees to gain experience in such techniques while under the mentorship of an expert. Since many MIS procedures are performed in the setting of ambulatory surgical centers, exposure for residents and fellows who primarily rotate in hospital settings may be further limited. Therefore, it will be important for training programs to consider how to incorporate procedures performed in ambulatory settings more thoroughly in their curriculum.

While mentorship from those who have mastered the technique is assuredly invaluable, junior surgeons must be able to practice "hands on" in order to become proficient. Augmented reality (AR) and virtual reality (VR) technologies can offer an excellent opportunity for trainees to obtain this experience without compromising the safety of patients. Simulated surgical procedures using VR technology have allowed trainees to practice and receive feedback, resulting in significant improvements in performance of techniques such as lateral mass screw placement.[15] Additionally, a VR-based training model for pedicle screw placement that utilized haptic feedback and realistic visual tracking was tested with 51 fellows at the American Association of Neurological Surgeons annual meeting and demonstrated substantial benefits in terms of learning retention and accuracy improvement.[16]

While VR has been helpful for "preoperative" training, which is fully removed from actual patient care, AR technology has implications for "real life" surgical settings to improve the safety of procedures and allow senior surgeons to provide more direct guidance and feedback. In one study, AR technology known as the VIPAR system allowed surgeons in Birmingham, Alabama, to provide real-time input and guidance for neurosurgery procedures performed in Ho Chi Minh City, Vietnam.[17] In addition to allowing audio and visual correspondence with minimal (approximately a 237 millisecond) delay, this system allowed the surgeons in Vietnam to receive direct video overlay of hand movements and gestures made by their collaborators in Alabama. The applications of such technology for resident/fellow training are numerous. Especially for procedures such as the MIS TLIF, where direct visualization and operative space are extremely limited, such a visual overlay and "virtual" gesturing could be invaluable to allow senior surgeons to monitor and instruct their trainees while still allowing the junior surgeons to get direct, hands-on surgical experience.

Implementation of robotic surgery in the operating room continues to expand as technology advances and its use becomes more accepted. For highly demanding spine procedures such as the MIS TLIF, robotics can provide increased precision and facilitate more predictable, calculated intraoperative movements. For example, robotic surgery can remove human error to a certain degree and use native image mapping to plan trajectories for demanding operations such as pedicle screw placement.[18] However, use of robotic surgery may result in slower procedures and increased operative duration compared to more traditional operations.[19]

The precise role that robotic surgery will play in the reduction of the MIS curve is currently unclear, and increased familiarity and development will be required to fully appreciate the advantages it offers to spine surgeons.

How to Improve?

Many challenges young attendings will face during the refinement of their operative techniques are unavoidable; however, integration of both early exposure for trainees and use of innovative technology to facilitate early hands-on experience will represent a substantial force to help flatten the MIS learning curve. Although not every physician will have access to cutting-edge technology such as AR and VR, the use of MIS techniques in spine surgery as well as other surgical domains will continue to grow. With increasing popularity and benefits to the patient, surgical training programs may begin to expand the integration of MIS techniques in their curriculum to help trainees and young attendings flatten the MIS learning curve. ■

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Impact of COVID-19 on Finances and Growth Plans of Orthopedic Practices in the United States


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In December 2019, a novel coronavirus, severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) or coronavirus-19 (COVID-19), was discovered in the People's Republic of China[1] and quickly evolved into a global pandemic. As of October 2, 2020, the virus has infected 188 countries/regions, resulting in 34,353,480 confirmed infections and 1,023,983 deaths.[2] Estimates project that COVID-19 will be one of the top three cause of death in the United States in 2020.[3] Aside from the substantial morbidity and mortality due to the viral infection, attempts to control the virus have resulted in global economic instability and significant changes to societal norms. Businesses have been forced to rapidly adapt to stay-at-home orders and social distancing precautions while attempting to remain financially solvent. Hospital systems and medical practices are no exception. In this review, we discuss specifically how orthopedic practices have been financially affected in the early stages of the pandemic, the near-term projected healthcare outlook, and how this outlook may impact the growth plans of orthopedic practices in the United States.

Immediate Financial Impact of COVID-19 on Orthopedic Practices

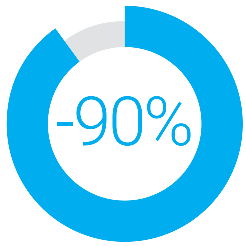
In February and March 2020, COVID-19 cases continued to increase throughout the United States, raising concerns about the availability of protective personal equipment (PPE) and the prospect of healthcare rationing as hospitals reached surge capacity. In response to this growing concern, on March 18, 2020, the Centers for Medicare and Medicaid Services (CMS) mandated that all elective surgeries be delayed in an attempt to preserve PPE, inpatient hospital beds, and ventilators. Additionally, healthcare providers were instructed to encourage patients to remain at home, barring an emergency, to limit the populace's exposure to the virus and best comply with local stay-at-home orders.

The moratorium on elective procedures, which lasted several months in some regions, and the concomitant reduction in clinic volume had a significant impact

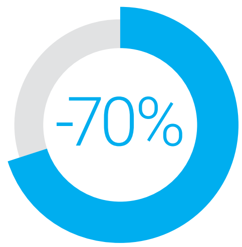
on the revenue flow of many orthopedic practices. Some studies estimate that orthopedic surgical volume decreased by approximately 90% and clinic volume decreased by approximately 70% during this period.[4,5] This abrupt and substantial decrease in patient care jeopardized the financial integrity of many orthopedic practices, which rely on these sources of revenue to pay for office overhead, other fixed costs, and ongoing capital expenditures.[6] It was projected by some surveys that one third of multispecialty physician groups would run out of cash-on-hand within weeks if clinical and surgical volume continued to remain low.[7]

In an attempt to combat the stark imbalance between incoming revenue and outgoing expenditures, large healthcare systems throughout the country made substantial changes to their payroll structure by furloughing employees, reducing salaries for administrative staff, and withholding pay from orthopedic surgeons.[4,8] As a case in point, the Mayo Clinic has been projected to lose $900 million in 2020 revenue, despite furloughing workers and decreasing physician pay.[9] University Hospitals in Cleveland is facing a similar financial problem and has temporarily decreased physician pay by 7% to 10%.[10] Even well-regarded orthopedic groups such as the Rothman Institute face financial adversity, with a projected $120 million revenue loss, and therefore temporarily closed offices, reduced the effective number of full-time employees

Approximate decrease in orthopedic surgical volume



Approximate decrease in clinic volume



by 50%, instituted structured salary reductions for management staff, and eliminated salaries for full shareholders in the month of April.[4] Significant salary reductions and decreased clinical operations also took place at Midwest Orthopaedics at Rush, OrthoCarolina, New England Orthopedic Surgeons, and other private orthopedic groups throughout the United States.[4,11,12]

In May 2020, CMS released guidelines for the controlled resumption of elective procedures based on local and state guidelines and hospital discretion.[13] Many orthopedic practices felt a substantial economic imperative to rapidly increase clinical and surgical volume to compensate for months of revenue loss. However, many of these practices encountered significant logistical challenges in the clinic and operating room. Practices had to shift responsibilities to facilitate some staff to work from home. Additionally, clinics had to be reorganized to allow for adequate social distancing of office staff, healthcare providers, and patients. Some practices invested in the infrastructure to support care via telemedicine, which can be costly.[14] From a surgical standpoint, many practices began to test their patients preoperatively for COVID-19 and provide additional PPE to minimize the risk of nosocomial transmission of COVID-19. With each subsequent challenge, costs increased while the efficiency of providing orthopedic care decreased after the release of the moratorium on elective cases.

As practices adapted to providing care in this new healthcare reality, predicting the expected clinical volume remained difficult. One study reported that nearly 90% of patients planned to reschedule their orthopaedic care as soon as possible,[5] while other clinicians reported that, even after an initial rebound, clinic volume remained 40% lower than before the pandemic.[15] Anecdotally, we noted an initial surge in scheduled surgeries throughout July 2020, primarily stemming from patients whose elective surgeries had been deferred, as opposed to new patients. In August 2020, clinic and operative volume slightly tapered and remained below pre-pandemic numbers.

Healthcare Outlook

Before the COVID-19 pandemic, the orthopedic industry was experiencing strong growth, with 3.5% and 3.8% year-over-year expansion in 2018 and 2019, respectively.[16] Some subspecialties within orthopedics demonstrated even higher year-over-year growth ranging from 5% to 6% in 2018 and

2019.[16] However, the onset of the pandemic abruptly reversed these steady growth trends and brought about widespread uncertainty regarding the economic outlook for the healthcare industry. Although the immediate short-term impact of the ongoing pandemic is difficult to gauge, if one uses medical device sales as a possible surrogate, volume has decreased 30% to 47% in the second quarter of 2020.[17,18]

The recovery of the healthcare sector, and in particular elective orthopedic surgery, is incredibly difficult to predict due to the uncertainty regarding a possible second wave of viral spread, potential anxiety of the general populace when entering healthcare facilities, decreased activity due to social distancing (thereby possibly decreasing orthopedic injuries), and the uncertainty about the timing and efficacy of a future vaccine. Given the unprecedented nature of this pandemic in the modern era, many have turned to the Great Recession of 2008 for insight. During an economic recession, the volume of most elective procedures is expected to decrease, in part due to changes in insurance coverage and increasing unemployment.[19] In the first year after the Great Recession of 2008, a survey conducted by the American Association of Hip and Knee Surgeons (AAHKS) found that both surgical and clinic volume decreased approximately 30%.[20] Given that unemployment rates are currently two to three times higher than they were during the Great Recession of 2008, it is not unreasonable to predict an even greater decrease in volume in 2020 and 2021.[21,22]

Although it is difficult to predict when surgical volume will return to pre-pandemic numbers, 28% of orthopedic surgeons believe this will not occur until the second half of 2021.[23] Optimistically, one study estimated that orthopedic surgery volume may reach 90% of pre-pandemic volume in early 2021, but, in a pessimistic scenario, others predict that volume may not normalize until late 2021,[24] while still others expect the effects of the pandemic to last beyond 2022.[16]

Impact on Growth Plans

In the setting of this uncertainty, healthcare providers and organizations will attempt to limit variable costs, decrease fixed costs, consider consolidation, and limit or suspend previously planned growth and capital investments. Consolidation of healthcare practices may allow for the sharing of fixed cost, thereby decreasing overhead, but it may limit the autonomy of orthopedic providers and decrease surgeon choice for patients. Additional strategies to control costs may involve the suspension of ongoing construction, such as a $120 million spine tower or a $10 million sports medicine center.[25,26]

Perhaps the greatest aspect of orthopedic growth to be impacted by the COVID-19 pandemic will be the hiring of new orthopedic surgeons. The recruitment of new orthopedic surgeons into existing practices will likely be tempered for the next few years until surgical volume increases and original workforces are restored to pre-pandemic levels. In the current pandemic, one study reported that 50% of orthopedic surgeons sustained a decrease in compensation,[27] further providing impetus to limit new hiring until revenue for currently employed orthopedic surgeons returns to normal. Lastly, in prior recessions, some orthopedic surgeons reported a 30% loss of retirement savings, prompting surgeons to delay retirement and in turn constricting opportunities for new hires to enter existing practices.[20]

Limited recruitment of new orthopedic surgeons will have the greatest impact on trainees finishing residency or fellowship and seeking first-time employment. Some orthopedic groups have already withdrawn employment offers to residents/fellows as a result of the COVID-19 pandemic.[27] Unfortunately, this unfavorable job environment for residents and fellows entering the workforce in 2020 and 2021 may necessitate choosing a position in locations that are sub-optimal for a given trainee but have a greater demand for orthopedic care. Additionally, trainees may consider locums work, allowing for flexibility should the job market improve in a desired geographic area. Those trainees who do find

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jobs may seek to sign contracts with more guaranteed income in lieu of contracts with performance incentives, whereas those groups hiring new trainees may seek to offer contracts of the opposite structure, thereby hedging their risk if a new hire's practice does not generate significant revenue in part due to the pandemic.

Conclusion

Ultimately, much remains to be seen regarding the impact of COVID-19 on the growth plans of orthopedic practices in the United States. The immediate impact of the virus has resulted in a marked decrease in orthopedic clinical and surgical volume, economically straining orthopedic practices and necessitating temporary decreases in staff and compensation. When clinical volume will return to near pre-pandemic levels is unknown. A rapid turnaround may occur if an effective vaccine is developed with lasting immunity, but even in that scenario, it may take several years for orthopedic practices to fully recover financially and resume previous plans for growth and expansion. ■

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Robot-Assisted Single-Position Surgery: The Perfect Application for Robotics?

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Over the past 5 years, it seems nearly every implant company has introduced or plans to introduce a robotics-based platform for spinal instrumentation. Someone with a cynical perspective on this new technology might argue that the growth in robotics is driven purely by a business model. Just like iPhone users must rely on the App Store for apps, hospital systems that have absorbed the substantial capital expense of a robot are tightly tied to the same company's implants to maximize efficiency and compatibility.

There is, however, a reasonably strong clinical case to be made for robotics. For instance, in a study comparing robotic-assisted placement to fluoroscopic-guided freehand placement of 2,937 lumbar pedicle screws in 597 patients and 12 cadavers, a significant increase in "perfect" and "clinically acceptable" placement was demonstrated using robotic-assisted technology.[1] Similarly, Han et al[2] conducted a randomized controlled trial of 1,116 pedicles in 234 patients and found no screw repositions were required in the robot cohort, whereas 2 were required in the freehand group despite using less radiation per case in the robot group. These findings demonstrate that robotic screw placement is at least as accurate as freehand and fluoroscopically guided techniques and are an important proof of concept for this new technology.

However, such findings are not without a caveat, as fewer studies have been performed comparing robotics to computer-based navigation. This is an important comparison to make, as navigation is less expensive and serves as an "open" platform that is typically interoperable with multiple implant systems.

Robotic-assisted spine surgery is, however, arriving at an opportune time given recent developments in surgical technique. As spine surgeons have adopted more minimally invasive surgery (MIS) techniques, we have moved toward more lateral- and anterior-based approaches to treat degenerative pathology and spinal deformity. MIS approaches have lower rates of intraoperative complications compared to open and hybrid approaches. Additionally, MIS may enable shorter constructs in deformity surgery without compromising outcomes. Furthermore, lateral and anterior approaches to the spine allow for placement of large interbody implants that limit subsidence and maximize the available surface area for fusion, alignment correction, and indirect decompression. These advantages have led several investigators to attempt lateral interbody fusion with percutaneous screws placed in the lateral position (single-position surgery).

Although experience with this technique is limited, preliminary results have shown that single-position surgery demonstrates no difference in any outcome measure (including alignment correction and indirect decompression), but it saves 30 to 60 minutes of operating room time when compared to lateral-then-prone surgery.[6,7] However, single position surgery is technically challenging: it requires surgeons to place pedicle screws in an unfamiliar orientation, is not conducive to most available navigation techniques, and (in its current state) requires significant amounts of fluoroscopy and radiation exposure.

Robotic-assisted single-position (RASP) surgery circumvents many of these limitations and may represent an ideal platform to demonstrate the added value of robotics. Our early experience with RASP has been largely positive. In our first 10 cases, more than 98% of screws were placed without the need for repositioning (**Figure 1**), and the safety profile was acceptable, with no intraoperative complications and no substantial radiation. The use of robotics allows us to place the "down" sided pedicle screws with

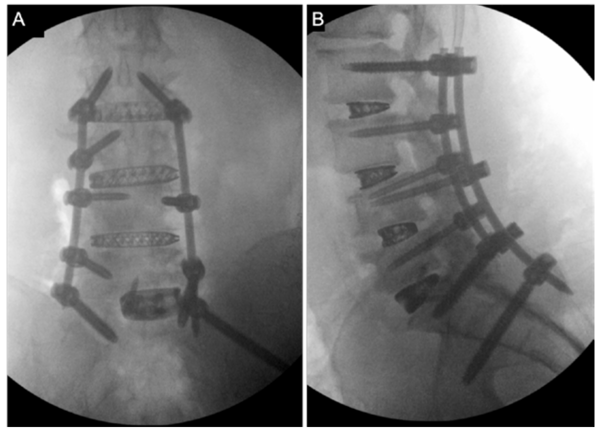

Figure 1. Screw placement using robotic-assisted single-position surgery.

Figure 2. Patient positioning and draping for robotic-assisted single-position surgery.

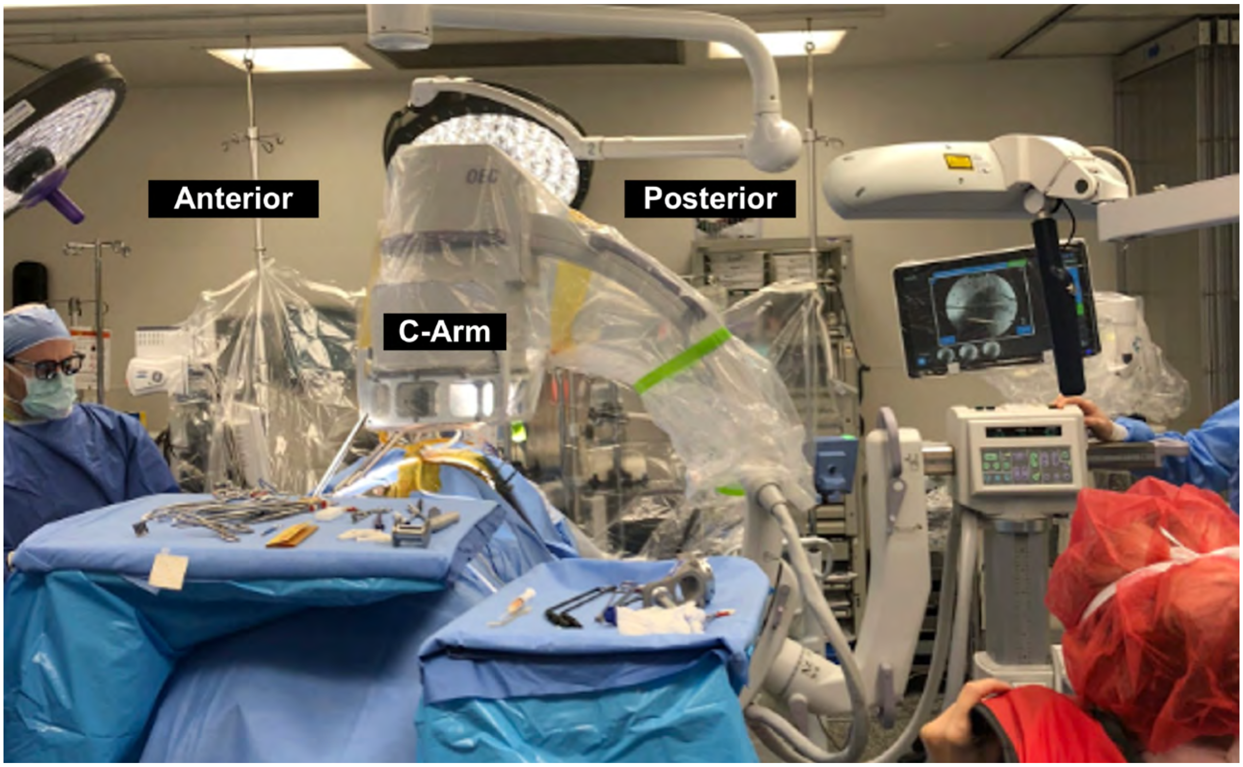

Figure 3. C-arm positioning for robotic-assisted single-position surgery.

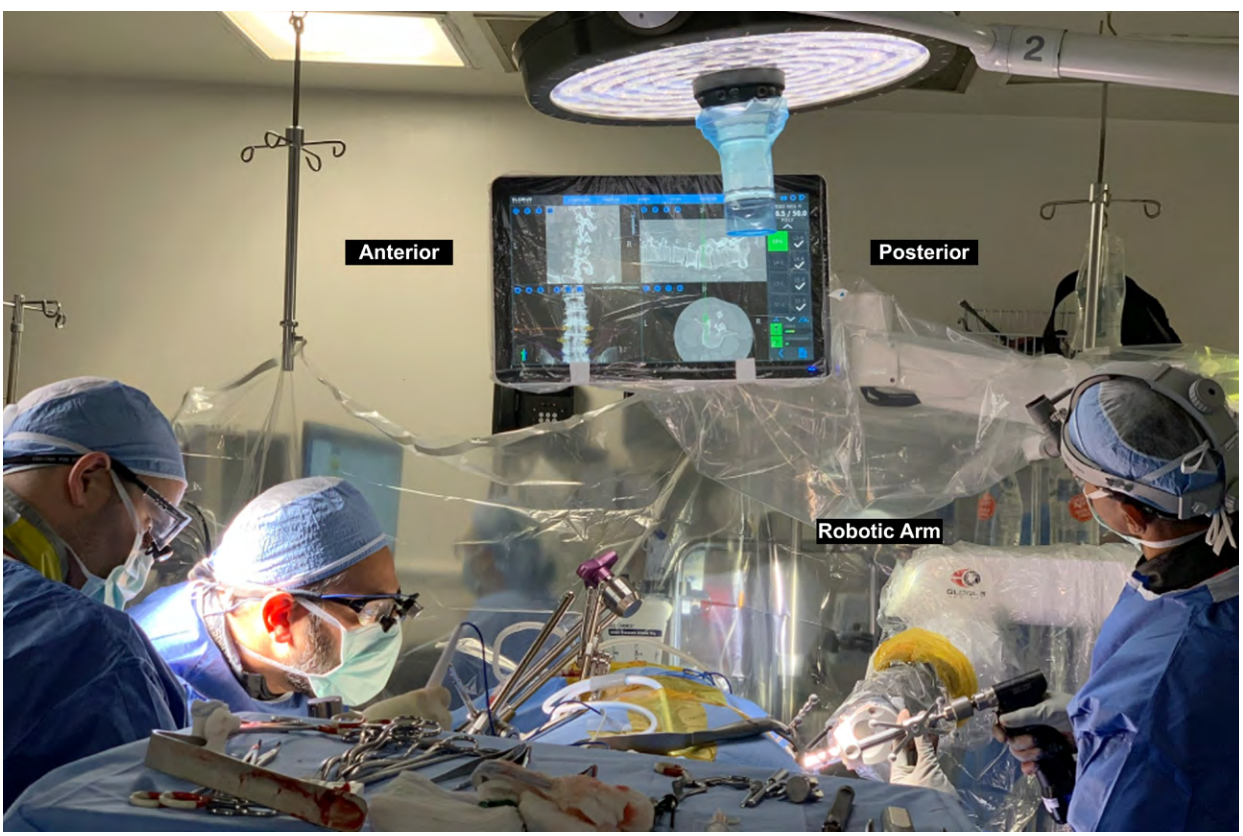

Figure 4. Robotic arm positioning for robotic-assisted single-position surgery.

relatively little difficulty and minimizes the need for fluoroscopy compared to free-hand techniques.

As with most new techniques, obstacles have been revealed during the early stages of use. Given current limitations in both navigation and robotics, registration and positioning can be difficult for patients with high body mass indexes. For RASP surgery, patients are positioned laterally on their side while both the anterior or lateral, as well as the posterior, exposures are draped into the sterile field (**Figure 2**). The C-arm comes in posteriorly to the patient (**Figure 3**) with the monitor positioned within the eyeline anteriorly. The robot is positioned posteriorly as well (**Figure 4**). With the assistance of an access surgeon, the anterior exposure can happen simultaneously with the placement of posterior percutaneous screws.

As the indications for MIS approaches and RASP surgery continue to expand, a few patient-related relative contraindications have become clear. To maintain a safe corridor, it is important to be completely below the vascular bifurcation and beware of the "Mickey Mouse" psoas, in which the vessels are more lateral and the plexus more anterior. Additionally, patients with a high pelvic incidence can pose difficulties for robot access and thus require freehand placement, which can be technically difficult in the lateral position. Similarly, a narrow pelvis can make placing L5-S1 screws difficult, so pelvic orientation is of particular importance when deciding if a patient is a candidate for RASP surgery.

Overall, RASP surgery allows for safe treatment of many lumbar pathologies, significant time savings, less radiation, and likely improved screw accuracy compared to freehand or fluoroscopic techniques. The robotic arm provides guidance in a position where many surgeons do not yet have muscle memory. As such, the use of robotics in single position lumbar surgery can assist in overcoming the learning curve of using navigation in an unfamiliar position and may be the perfect application of robotics. ■

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Awake Lumbar Fusion Surgery


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Advances in perioperative protocols,[1] regional anesthesia,[2-4] and surgical techniques[5-8] have led to a recent rise in awake spine surgery. Proponents of awake spine surgery cite improved patient satisfaction, reduced costs, improved outcomes, accelerated rehabilitation, and enhanced neuromonitoring capabilities when spine surgery is performed without general endotracheal anesthesia (GETA).[9-16] However, it is important to note that the absence of GETA does not always equate to "awake" surgery—there is a continuum of sedation and patient responsiveness. Different anesthetic techniques and protocols uniquely impact consciousness, responsiveness, respiratory function, and neurological monitoring.[15,17] Given the potential benefits over traditional techniques, surgeon and patient interest in awake spine surgery has increased in recent years, particularly in regard to lumbar fusion surgery.

As with all elective spine surgery, patient selection is critical to maintaining patient safety and obtaining optimal outcomes. Typically, awake spinal fusion is reserved for patients with one-and two-level degenerative pathology refractory to conservative care. Patients with anxiety or mental health conditions may not tolerate awake surgery, and other relative contraindications include poor respiratory reserve and morbid obesity. Of note, spinal implants and anesthetics are frequently used off-label in these techniques.

In this article, we detail modern surgical and anesthetic techniques for awake lumbar fusion surgery, which builds upon a previous piece in the Spring 2020 issue of *Vertebral Columns* that reviewed related regional anesthetic techniques for lumbar spine surgery.

Awake Endoscopic Spine Fusion

Endoscopic spine surgery is generally performed using GETA or conscious sedation (CS). CS coupled with local anesthetic allows the patient to remain awake and maintains protective reflexes. Endoscopic procedures are uniquely suited for CS from a pain standpoint because they can be performed via sub-centimeter incisions with minimal soft tissue disruption to generate intraoperative pain response. Awake patients can provide immediate feedback if a neural structure is inadvertently contacted and can confirm the relief of radicular symptoms.[18] This is particularly useful for endoscopic transforaminal procedures where the exiting nerve root is often in close proximity to the working cannula. Additionally, traditional intraoperative neuromonitoring is not necessary when performing awake endoscopic surgery in this fashion.

Initial reports of awake endoscopic transforaminal lumbar interbody fusion (TLIF) were published in 2016, where Wang and Grossman[6] described their experience and 1-year outcomes for the first 10 consecutive patients whom they treated. The authors utilized propofol and ketamine to keep patients under light to moderate sedation and did not administer narcotics or spine-based regional anesthesia, but liposomal bupivacaine was injected into the percutaneous pedicle screw tracts. As such, patients were able to provide live feedback to the surgeons throughout the procedure. After preparing the disc space for fusion, they inserted 2.1 mg of recombinant human bone morphogenetic protein-2 in the disc space followed by a 22-mm or 25-mm expandable cage. All patients underwent successful surgery without complication or conversion to alternate techniques, and all but one patient were discharged on postoperative day one (the longer length of stay for that patient was a result of a lack of social support). At 1-year follow-up, patients had a significant improvement in dysfunction from lower back pain, and there were no reported cases of pseudoarthrosis. To avoid respiratory compromise, the authors limited these procedures to 120 minutes.

In an expansion of their 2016 report, Kolcun et al[8] reported 1-year clinical outcomes for awake TLIFs performed on the first 100 patients who underwent awake endoscopic TLIFs, including both one-level (n=84) and two-level (n=16) fusions. While they reported significant patient improvement as well as favorable operative times, reported blood loss, and length of stay, they also detailed some of the challenges associated with awake endoscopic TLIF surgery. In particular, the authors reported that four cases required an intraoperative conversion to GETA, albeit without complication. Reasons for conversion included emesis (n=2), epistaxis, and extreme anxiety. Furthermore, there were two cases of cage migration, one case of osteomyelitis, and one case of endplate fracture. There were no reported cases of pseudoarthrosis or hardware failure with an average radiographic follow-up of 14.6 months. The authors also commented that their growing familiarity and improved efficiency with the procedure eventually enabled multilevel cases to be performed. The authors concluded that in appropriately selected patients, awake endoscopic TLIF is a safe and efficacious procedure for lumbar fusion without the morbidity of open surgery. Since this publication, the authors continued to refine their surgical and anesthetic techniques,[7,19] and increased efficiency now allows for the performance

Awake patients can provide immediate feedback if a neural structure is inadvertently contacted and can confirm the relief of radicular symptoms.

of three-level fusions. In an effort to avoid intraoperative emesis and prevent epistaxis, the addition of preoperative glycopyrrolate and ondansetron as well as oxymetazoline spray were implemented, respectively.

Further investigation is needed to assess the ability to maintain or restore sagittal parameters with endoscopic fusion techniques, regardless of whether or not the patient is awake. While concerns do presently exist, we are optimistic that techniques and device technology will continue to improve with time.

Minimally invasive spine surgery is more suitable for local and regional anesthetic techniques than traditional open spine surgery.

Awake Minimally Invasive Spine Fusion

Minimally invasive spine surgery is more suitable for local and regional anesthetic techniques than traditional open spine surgery. Spine-based regional anesthesia (SBRA) and ultrasound-guided fascial plane blocks may be utilized in perioperative protocols for awake minimally invasive spine surgery.[2,15,20] Garg et al[15] recently published their perioperative protocol for awake lumbar fusions and recommended multimodal analgesia, titrated propofol sedation, and lumbar spinal and thoracolumbar interfascial plane (TLIP) block utilizing liposomal bupivacaine. Common concerns with SBRA include its finite duration of effectiveness, difficultly of establishing an emergency airway in the prone position, and the potential impact on postoperative neurological function. Contraindications to SBRA include bleeding disorders and/or severe stenosis precluding proper anesthetic permeation.

Chan et al[20] described an awake minimally invasive TLIF technique in two patients using tubular retractors, navigation, spinal anesthesia, liposomal bupivacaine, and no intraoperative neuromonitoring. The authors highlighted their ability to perform a direct decompression, unlike previously described endoscopic techniques, and reported no intraoperative complications. They concluded that their novel approach was feasible for select patients; however, larger cohorts and/or control cohorts are needed to better evaluate their techniques.

Sekerak et al[2] completed a comparative outcome analysis of SBRA for awake minimally invasive TLIFs. The authors retrospectively reviewed outcomes of 111 patients and compared outcomes of GETA to SBRA with and without TLIP block. Patients who underwent SBRA (+/- TLIP block) had significantly reduced postoperative pain scores, required fewer opioids in the postanesthesia care unit, and had reduced time in the postanesthesia care unit after surgery compared to patients who received GETA. Furthermore, the addition of a TLIP significantly reduced length of stay compared with GETA and trended toward significance when compared with SBRA alone. The authors concluded that SBRA alone and SBRA with TLIP block are viable and beneficial options to perform awake TLIFs.

Conclusion

Numerous techniques exist to perform awake minimally invasive lumbar fusion surgery. Choosing the most appropriate method to safely deliver care to patients depends on the comfort and experience of both the surgeon and anesthesiologist. The data available on this topic are currently limited and come from a handful of specialized centers that have devoted significant time and resources to advancing the field of awake lumbar spine fusion. Therefore, it remains to be seen whether these techniques and outcomes are generalizable to other practice environments. Finally, additional high-quality studies are needed to assess short- and long-term outcomes of awake lumbar fusion surgery. ■

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Update on the Use of Intrawound Vancomycin Powder

Yu-Po Lee, MD

Surgical site infection (SSI) is a potential complication after spinal surgery, with rates reported in the literature ranging from 0.7% to 11.9%, depending on the diagnosis and the complexity of the procedure.[1-3] SSIs account for enormous medical, social, and economic costs for patients as well as hospitals.[4-5] Direct costs include a longer hospital stay, additional procedures to eradicate the infection, and antibiotics. An SSI infection may also have an emotional impact on a patient's view of the overall outcomes of the procedure, despite a generally successful treatment of the infection.

The evidence suggests that systemic intravenous antibiotic prophylaxis reduces the risk of postoperative infections.[6-8] In general, cephalosporins are typically the antibiotic of choice based on their good efficacy against both staphylococcal species and uropathogens; however, vancomycin is indicated in high-risk patients carrying methicillin-resistant *Staphylococcus aureus*.[6] Additionally, patients with allergies to beta-lactam antibiotics will prompt the use of either clindamycin or vancomycin.

In an effort to reduce the incidence of SSIs, several studies have evaluated the use of vancomycin powder in the surgical site.[10,11] For example, O'Neill et al[10] performed a retrospective review of 110 patients who underwent a posterior instrumented fusion for thoracolumbar fractures. The authors reported a significant difference in infection rates, with zero infections reported in the group where intrawound vancomycin powder was applied to the wound compared with a 13% infection rate in cases where only the standard intravenous antibiotic prophylaxis was used. A similar finding was also reported by Sweet et al[11] in their retrospective review of 1,732 consecutive thoracic and lumbar posterior instrumented spinal fusions. They noted a 2.6% deep wound infection rate in patients who received standard antibiotic prophylaxis, while patients who also received 2 g of vancomycin powder had an infection rate of 0.2%.

While a number of studies report the benefits of intrawound vancomycin powder, there is a growing concern regarding the potential for negative selection of more virulent organisms. Several studies have demonstrated that the use of vancomycin powder, compared to perioperative cephalosporin prophylaxis, may select for gram-negative and polymicrobial SSIs. To highlight this point, Ghobrial et al[12] presented a single-institution experience of more than 900 contiguous cases in which vancomycin powder was routinely placed

during surgical closure. Among these cases, 66 patients (6.7%) developed postoperative SSI, with the most common organism among positive wound cultures being *S. aureus*.[6] Interestingly, the investigators also demonstrated that there was a trend toward higher incidence of polymicrobial infections (19%) in their cohort versus the historical control (15%, *P*=0.96).

In another study, Chotai et al[13] investigated the use of intrawound vancomycin powder in a cohort of 2,802 patients split into control and experimental groups. The authors demonstrated that vancomycin powder use lowered SSI rates from 2.5% to 1.6% (*P*=0.02) with a significantly lower rate of *S. aureus* SSIs in the treatment group (32% vs 65%, *P*=0.003). While no growth of vancomycin-resistant *S. aureus* was detected, there was a higher incidence of gram-negative SSIs (28% [n=7] vs 13% [n=5]) in the treatment cohort. Additionally, culture profiles were markedly different (*P*=0.003) in the vancomycin group, with a higher proportion of organisms identified as *Escherichia coli*, *Pseudomonas*, *Citrobacter*, *Klebsiella*, and *Serratia*. Furthermore, a larger number of patients with gram-negative SSIs (27%) required chronic suppressive antibiotic therapy versus those with gram-positive SSIs (12%). These findings underscore the clinically relevant adverse implication of gram-negative SSIs in the setting of routine vancomycin powder prophylaxis.

Although the benefits of using intrawound vancomycin may outweigh the risk for some patients, we must also consider its use with individuals at increased risks of SSIs. Several studies have identified a number of patient and operative characteristics, including advanced age, increased body mass index, diabetes, smoking, alcohol abuse, longer operation times, and anterior/posterior spinal fusion as potential risk factors for SSI.[14,15] Additionally, analysis of data reported to the National Healthcare Safety Network from 2006 to 2008 found that the mean SSI rate was 0.7% for spinal fusions and 0.7% to 2.3% for laminectomies depending on the National Healthcare Safety Network risk class.[4] Therefore, it may be prudent to limit the use of intrawound vancomycin to procedures and patients who are at increased risk for infection. ■

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Occupational Health Hazards in Spine Surgery

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As the average age of the population and the need for healthcare continue to rise, more is expected of practicing physicians than ever before. Spine surgery is physically and mentally demanding and continues to become more demanding as advances in the field allow for treatment of more complex pathology. Spine surgeons, like other physicians, approach their work with a "patient-first" mindset, often without consideration of the impact on their own health. But spine surgeons face numerous occupational health hazards, including radiation exposure, musculoskeletal disorders, and psychological and stress-related conditions.

Radiation Exposure

Ionizing radiation is a familiar and widely studied occupational health hazard in spine surgery.[1] The trend toward less invasive surgical techniques has increased surgeons' reliance on intraoperative imaging.[2] While use of computed tomography–based navigation and robotic guidance are on the rise, fluoroscopy continues to be a mainstay of intraoperative imaging. This trend may be concerning to spine surgeons, as multiple studies have demonstrated the increased risk of malignancy with fluoroscopy use.[3-5] More specifically, colon, lung, breast, and thyroid tissues have been identified as some of the most radiosensitive tissue types.[6] In addition to carcinogenesis, the deleterious effects of ionizing radiation include its potential for cataract formation in the lens of the eye and influence on gonadal/hematopoietic tissue.

In an effort to mitigate negative effects of radiation, the International Commission on Radiological Protection (ICRP) sets radiation safety standards and recommends a maximum occupational radiation exposure of 20 millisievert (mSv) per year to both the body and the eye.[7] Based on data from the Life-Span Study of survivors of the Hiroshima and Nagasaki atomic bombings, cumulative exposure of 1 sievert (Sv) corresponds to an absolute lifetime risk of 5% mortality from malignancy.[8] The precise exposure corresponding to increased risk of cataract formation is controversial, with most studies suggesting a threshold lifetime dose of

Ionizing radiation is a familiar and widely studied occupational health hazard in spine surgery. The trend toward less invasive surgical techniques has increased surgeons' reliance on intraoperative imaging.

0.5 Sv. Epidemiological studies of interventional cardiologists have shown increased prevalence of posterior lens opacities when compared to controls.[9]

Multiple strategies can reduce radiation exposure to spine surgeons. At a minimum, surgeons who utilize fluoroscopy during instrumentation should wear circumferential lead aprons with properly fitted thyroid shields and leaded eyewear. Folding of aprons should be avoided because that can create defects in the shielding material. Aprons should be inspected on a yearly basis at a minimum. Because ionizing radiation follows an inverse square law, surgeons should always attempt to position themselves as far from the patient as possible during fluoroscopy. In fact, standing at a distance of just 2 feet from the beam source can lower exposure by a factor of 8. Additionally, using "low dose" settings as well as pulsed rather than continuous fluoroscopy further reduces exposure. Collimation of the field of view to only the relevant anatomy is also very effective at lowering the radiation dose required for an image. Special care should also be taken during lateral fluoroscopic imaging, as the increased thickness of tissue being imaged (compared with anteroposterior images) requires the fluoroscope to use a higher current, increasing radiation exposure. Likewise, magnified images can increase radiation dose by 2-fold or more and should be used only when necessary. Dose monitoring is required by all facilities performing imaging and should be reviewed by the surgeon on a regular basis.

Musculoskeletal Disorders

The physically demanding nature of spine surgery is evident to most after a long operative day, but in comparison to radiation exposure, the musculoskeletal health of spine surgeons is under-studied and infrequently discussed. Spine procedures generally require the surgeon to stand in a kyphotic, flexed posture for extended periods of time.[10] Ironically, it is this posture that much of spine surgery aims to correct on behalf of the patient. There is a limited number of studies on the musculoskeletal health of spine surgeons.[11,12] A 2011 survey of the Scoliosis Research Society found that among 561 responding spine surgeons, the prevalence of lumbar and cervical radiculopathy was 31% and 28%, respectively—well above that of the general population.[11] Perhaps even more surprising was that 23% percent of respondents had undergone surgical intervention for lumbar disc herniation, with 11% of respondents having had surgery for a cervical disc herniation.[11] The rate of carpal tunnel release was even higher, at 40% of respondents. Thirty-two percent of respondents reported missing work related to a musculoskeletal disorder.[11]

Certain modifications to technique can mitigate the physical toll upon the spine surgeon's body. Use of an operating microscope reduces neck flexion and associated muscle strain. Pneumatically powered Kerrison rongeurs can reduce repetitive force on the hand and wrist, though with some sacrifice of tactile feedback. Surgeons performing multilevel pedicle screw insertion may choose to utilize powered drivers to limit stress on the upper extremity. When safe, delegation of manual tasks (ie, rod cutting, contouring, set screw insertion) to surgical assistants can also help preserve surgeons' joint health. As the use of robotic technology becomes more prevalent in the operating room, further ergonomic protection for the spine surgeon may be just on the horizon.

Psychological and Stress-Related Conditions

The psychological and stress-related hazards of spine surgery are perhaps even more prevalent and more harmful than the physical ones. "Burnout" is a commonly used term to refer to these hazards and comprises a syndrome of emotional exhaustion, depersonalization, and career dissatisfaction leading to decreased work performance.[13] Burnout among physicians has been linked to substance abuse, suicide, and an increased rate of medical errors. Unfortunately, the high-stakes, precise nature of spine surgery, coupled with many of the common workplace frustrations prevalent within medicine today, creates an environment ripe for burnout. A 2020 study of 701 members of the North American Spine Society found that 39% of participants experienced psychosocial debility related to their work.[12] In this survey, respondents cited job stress, poor reimbursement, lack of midlevel provider support, operating room inefficiency, and poor sleep as common causes. Burnout

Burnout among physicians has been linked to substance abuse, suicide, and an increased rate of medical errors.

was much more common in surgeons in private practice than in academic settings (55% vs 17%).

Given the prevalence of these psychosocial hazards and their downstream consequences for patient care and the field as a whole, developing strategies to combat burnout should be front of mind within the spine surgery community. Commonly cited protective factors include married status, mentorship in the workplace, exercise, and limited alcohol intake.[14] Mindfulness and meditation practices centered around gratitude have also demonstrated efficacy in combating burnout.[15] At the institutional level, initiatives to increase physician participation in decision-making and organizational leadership have also been effective at reducing the rates of burnout.

Conclusion

Occupational hazards within spine surgery are common and have the potential to limit surgeon longevity and reduce the quality of patient care. As the patient population in need of spine care continues to grow and the number of spine surgeons remains relatively unchanged, a focus on mitigating these hazards is essential. Increasing awareness of these work-related risks among surgeons is a key first step in minimizing their impact on the future of our specialty. ■

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