Awake Spinal Fusion Is Associated with Reduced Length of Stay, Opioid Use, and Time to Ambulation Compared to General Anesthesia: A Matched Cohort Study

David A.W. Sykes[1], Troy Q. Tabarestani[1], Nauman S. Chaudhry[1], David S. Salven[1], Christopher I. Shaffrey[1], W. Michael Bullock[2], Nicole R. Guinn[2], Jeffrey Gadsden[2], Miles Berger[2], Muhammad M. Abd-El-Barr[1]

■ OBJECTIVE: **There is increasing interest in performing awake spinal fusion under spinal anesthesia (SA). Evidence supporting SA has been positive, albeit limited. The authors set out to investigate the effects of SA versus general anesthesia (GA) for spinal fusion procedures on length of stay (LOS), opioid use, time to ambulation (TTA), and procedure duration.**

■ METHODS: **The authors performed a retrospective review of a single surgeon's patients who underwent lumbar fusions under SA versus GA from June of 2020 to June of 2022. SA patients were compared to demographically matched GA counterparts undergoing comparable procedures. Analyzed outcomes include operative time, opioid usage in morphine milligram equivalents, TTA, and LOS.**

■ RESULTS: **Ten SA patients were matched to 10 GA counterparts. The cohort had a mean age of 66.77, a mean body mass index of 27.73 kg/m^2, and a median American Society of Anesthesiologists Physical Status Score of 3.00. LOS was lower in SA versus GA patients (12.87 vs. 50.79 hours, $P = 0.001$). Opioid utilization was reduced in SA versus GA patients (10.76 vs. 31.43 morphine milligram equivalents, $P = 0.006$). TTA was reduced in SA versus GA patients (7.22 vs. 29.87 hours, $P = 0.022$). Procedure duration was not significantly reduced in SA patients compared to GA patients (139.3 vs. 188.2 minutes, $P = 0.089$).**

■ CONCLUSIONS: **These preliminary retrospective results suggest the use of SA rather than GA for lumbar fusions is associated with reduced hospital LOS, reduced opioid utilization, and reduced TTA. Future randomized prospective studies are warranted to determine if SA usage truly leads to these beneficial outcomes.**

INTRODUCTION

There has been a marked rise in the volume of lumbar spine surgery for the treatment of lumbar degenerative disease, with incidence rising from 60.4 per 100,000 to 79.8 per 100,000 between 2004 and 2015 alone.[1-5] As the incidence of lumbar spine surgery has increased, so too has the sophistication of surgical techniques, as many surgeons now consider more minimally invasive approaches due to improved patient outcomes.[6-10] Evolution in surgical technique, though, is not the only way in which spine surgery has grown.

In recent years, there has been an increasing, albeit limited, evidence to suggest that spine surgery under awake spinal anesthesia (SA), rather than general anesthesia (GA), may improve outcomes for patients undergoing lumbar spine surgery for degenerative disease.[11,12] Settings in which SA's use in spine surgery has been studied include but are not limited to decompressive laminectomy and discectomy as well as spinal fusion.[13-16] Meta-analysis reveals that the majority of prior

Key words
- Length of stay
- Lumbar fusion
- Opioids
- Spinal anesthesia
- Spine surgery

Abbreviations and Acronyms
ASA-PS: American Society of Anesthesiologists Physical Status
BMI: Body Mass Index
DSD: Degenerative Spine Disease
ESP: Erector spinae plane
GA: General Anesthesia
LOS: Length of stay
MIS TLIF: Minimally Invasive Transforaminal Lumbar Interbody Fusion
MME: Morphine milligram equivalents
PACU: Postanesthesia care unit
percLIF: Percutaneous Lumbar Interbody Fusion
SA: Spinal Anesthesia

From the Departments of [1]Neurosurgery, and [2]Anesthesiology, Duke University Medical Center, Durham, North Carolina, USA

To whom correspondence should be addressed: David A.W. Sykes, A.B. [E-mail: david.sykes@duke.edu]

Citation: World Neurosurg. (2023). https://doi.org/10.1016/j.wneu.2023.05.001

*Journal homepage: **www.journals.elsevier.com/world-neurosurgery***

*Available online: **www.sciencedirect.com***

studies investigating the efficacy of SA have involved patients receiving decompressions, leaving a relative dearth of information on the use of SA for spinal fusions.[1]

While there have been studies investigating the relative efficacies of SA and GA, these trials have yielded mixed results and frequently suffered from bias due to deviation from intended intervention as well as incomplete outcome data.[17] Furthermore, many of these studies compared the anesthetic modalities with respect to operative metrics such as intraoperative hemodynamics or estimated blood loss, rather than patient outcomes such as opioid utilization or time to ambulation.[18]

Despite SA's promise, and perhaps due to the sparsity of data surrounding its use, most clinicians consider GA the standard of care for the surgical management of lumbar degenerative disease. To better understand the relative advantages and disadvantages of SA in comparison to GA, we present a single-surgeon, retrospective, matched cohort study of patients receiving spinal and GA for comparable spinal fusion procedures to compare outcomes. The primary studied outcome is hospital length of stay (LOS), while secondary outcomes include opioid utilization, time to ambulation, and procedure duration.

METHODS

All patients were seen by the anesthesia preoperative team prior to surgery, and informed consent was obtained before every procedure. Institutional review board approval was submitted to our ethics review committee and approved. Patient permission to publish deidentified data were not necessary, as this matched cohort study fell under the university's institutional review board's guide-lines for "exempt" patient research. Individual patient identifiers were removed from case examples and associated imaging.

Cohort Creation

The authors performed a single-center, single-surgeon, retrospective review of a prospectively collected database of patients undergoing lumbar spinal fusion for degenerative spinal disease under awake SA at a major academic research institution. Patients who received surgery between June of 2020 and June of 2022 were considered for inclusion. For each of these patients, a comparable patient that had received surgery under GA was sought out. A comparable patient was defined as having a similar age, similar body mass index (BMI), and receiving the same procedure at an identical or adjacent spinal level, using the same technique such as percutaneous versus minimally invasive fusion. While there were no hard cutoffs for differences in age between matched patients, the average discrepancy was 4.9 years. Similarly, there were no hard cutoffs for BMI difference in matched patients; the average discrepancy was 2.75 kg/m^2. Fusion techniques included percutaneous lumbar interbody fusion (percLIF) as well as minimally invasive transforaminal lumbar interbody fusion (MIS TLIF). Each patient was carefully matched in terms of which operative technique was used. Patient matching was performed prior to any statistical analysis, and investigators were blind to patient outcomes throughout the matching process. There was no difference in admission and discharge pathways between the SA and GA cohorts. Patients all received identical truncal blocks, as described below, and all patients received local lidocaine prior to incision. The same expandable cage was used in all patients, and all patients received the same extent of facetectomy. All patients received appropriate preoperative counseling on the relative risks associated with surgery and respective anesthesia modality.

Baseline demographic information was collected. This included information such as age, sex, BMI, and medical comorbidities as well as American Society of Anesthesiologists Physical Status (ASA-PS). Perioperative, intraoperative, and postoperative data were collected. This included operative time, time to ambulation, opioid utilization, and LOS. Operative time was determined on the basis of incision and closure and did not include factors such as induction of anesthesia. Time to ambulation was defined as the time between the patient's arrival in the postanesthesia care unit (PACU) to their earliest recorded ambulation. LOS was defined as the time between the patient's arrivals in PACU to their time of discharge. This was done to control for variability in time between admission and procedure start. Opioid utilization was determined by consulting the medication administration records for 6 hours following arrival in the PACU. Six hours was chosen over 12 or 24 hours because many patients receiving SA were discharged in under 12 hours, while only 1 patient was discharged in under 6 hours. Opioid usage was standardized into morphine milligram equivalents (MME). Patients all received multimodal pain management.

Erector Spinae Plane Block Technique

Erector spinae plane (ESP) block was performed preoperatively in the sitting position at the L4 spinal level. A curvilinear transducer was placed in a sagittal orientation over the spinous process and translated laterally until the transverse process was visible. A 21g Stimuplex (B-Braun, Bethlehem, *Pennsylvania, USA*) or SonoPlex II Facet (Pajunk, Alpharetta, *Georgia*, USA) needle was then introduced in-plane from a cranial to caudal direction until the needle tip contacts the target transverse process at either its cranial or caudal border. Hydrodissection and separation using normal saline was performed to confirm the proper injection plane below erector spinae and above the transverse process. Once the correct plane was identified, 10mL of liposomal bupivacaine (Exparel, Pacira Biosciences, Tampa, Florida, USA) admixed with 20mL 0.25% bupivacaine HCl (for a total of 30mL) was injected in the ipsilateral ESP. The needle was then removed, and the same process repeated on the contralateral side. Every included patient received bilateral ESP blocks.

SA Technique

SA was performed in the sitting position with the patient's spine flexed and legs hanging from the side of the bed. Next, the correct spinal level (generally L3–L4 bilaterally) and access site were identified via palpation. The patient was appropriately draped and the space between the spinal levels was cleaned with ChloraPrep. For the midline approach used in these cases, the approach to the intrathecal space was midline with a straight-line single shot. After infiltration, the spinal needle (*Quincke* 25-gauge 90 mm) was introduced into the skin angled cephalically. The needle passed through the superficial skin and subcutaneous fat. Once passed through the supraspinous, interspinous ligaments, and ligamentum flavum, the needle entered the epidural space. Usually, a

"pop" is felt upon passing through the ligamentum flavum. For SA, the needle continued deeper until penetration of the dura-subarachnoid membranes. Once free-flowing cerebrospinal fluid was seen, 10–15 mg 0.5% of isobaric bupivacaine was injected to achieve the anesthesia.

MIS TLIF versus percLIF

In this study, included patients received their lumbar interbody fusion via one of 2 possible surgical techniques, the MIS TLIF or the ultraminimally invasive percLIF. These posterolateral techniques have similarities, though percLIF takes the MIS TLIF 1 step further by avoiding laminectomy or facetectomy, allowing an expandable cage to be inserted into the disc space via Kambin's triangle without disruption of bony anatomy.[19-22] All patients were matched on the basis of the operative technique received.

Outcome Measurements and Statistical Analysis

Patient demographics, age, BMI, and ASA-PS were treated as continuous variables. As not all demographic variables were found to be normally distributed per the Shapiro-Wilk test, demographics were compared with the nonparametric Wilcoxon rank-sum test. Cohort gender composition was analyzed by Fisher exact test. For measured outcomes, operative time, TTA, opioid utilization, and LOS were treated as continuous variables. Not all outcome variables were found to be normally distrusted per the Shapiro-Wilk test; outcomes were therefore analyzed by the nonparametric Wilcoxon rank-sum test. LOS was also analyzed via contingency testing for discharge occurring in greater than or less than 24 hours. In select circumstances, statistical outliers were removed. Criteria for outlier status was defined as being greater than 2 standard deviations above the group mean. One GA and 1 SA patient were removed from LOS calculations for their uncharacteristically high LOS. One GA patient was removed from TTA and opioid use calculations for uncharacteristically high TTA and opioid use. It is worth noting that all statistically significant findings would still retain statistical significance with inclusion of these outliers.

RESULTS

Cohort Matching and Demographics

The single surgeon performed 46 elective posterior approach lumbar interbody fusions (1–2 levels) for degenerative spine disease (DSD) in the study period. Thirteen (17%) of these patients received their surgeries under SA. Of the 13 patients receiving awake spinal fusion, 3 patients could not be matched to a GA counterpart due to extreme demographic features, such as morbid obesity or octogenarian status, or medical comorbidities that were relative contraindications to GA such as severe cardiopulmonary disease. The remaining 10 patients that underwent lumbar spinal fusion for DSD under SA were successfully matched to GA patients receiving fusion with the same operative technique (MIS TLIF or percLIF) at an adjacent or identical level. Cohort construction is summarized in Figure 1. The cohort had a mean age of 66.77 years, a mean BMI of 27.73 kg/m^2, and a median ASA-PS of 3.00; the groups had no statistically significant differences in demographic features. Cohort characteristics are summarized in Table 1. Standardized mean difference (d) and P values are shown.

Case Presentation: Spinal Fusion Under GA

A 68-year-old woman with a BMI of 21.62 kg/m^2 and a past medical history of intermittent asthma and depression (ASA-PS = 3) presented with chief complaints of lower back pain and bilateral radiculopathy refractory to conservative management. Imaging revealed spondylolisthesis at the level of L4–L5 with severe spinal stenosis (Figure 2). The patient elected to undergo L4–L5 MIS TLIF under GA.

The patient was brought into the operating theater. General endotracheal anesthesia was obtained. An ultraminimally invasive, percLIF was performed, and good correction of spondylolisthesis was observed. There were no intraoperative complications.

The patient utilized 19 MME for pain control in the operative and postoperative days. The patient was able to ambulate 5.07 hours after arrival in the PACU; she was discharged 53.23 hours after arrival in the PACU for a total hospital LOS of 59.61 hours. Postoperative changes are shown (Figure 3).

Case Presentation: Spinal Fusion Under SA

A 67-year-old woman with a BMI of 23.58 kg/m^2 and past medical history of osteoporosis and renal cell carcinoma (ASA-PS = 3) presented with chief complaints of lower back pain and bilateral radiculopathy refractory to conservative management. Imaging revealed spondylolisthesis at the level of L4–L5 with instability with extension (Figure 4). The patient elected to undergo L4–L5 MIS TLIF under SA.

The patient was brought into the operating theater. General endotracheal anesthesia was not obtained, as the patient remained conscious with spontaneous respiration throughout the operation. SA was obtained with 0.5% isobaric bupivacaine. An ultraminimally invasive, percLIF was performed, and good correction of spondylolisthesis was observed. There were no intraoperative complications.

The patient utilized 10.7 MME for pain control in the operative and postoperative days. The patient was able to ambulate 4.37 hours after arrival in the PACU; she was discharged 8.68 hours after arrival in the PACU for a total hospital LOS of 14.25 hours. Postoperative changes are shown (Figure 5).

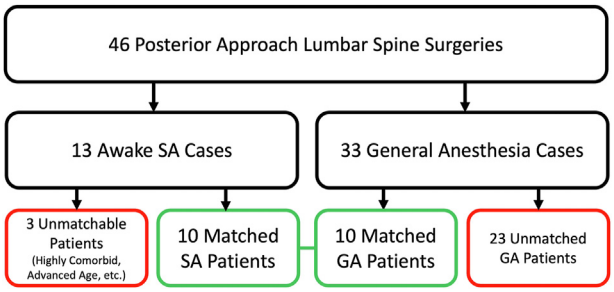

Figure 1. Patient selection resulting 10 total matched pairs.

Table 1. GA and SA Cohort Descriptive Statistics

Metric	GA Mean (95% CI)	SA Mean (95% CI)	*P* Value	d Value
Sex (% Female)	40%	50%	>0.999	-
Age (Years)	67.53 (62.16, 72.91)	66.01 (61.36, 70.65)	0.633	0.217
BMI (kg/m^2)	28.54 (24.96, 32.11)	26.91 (23.89, 29.93)	0.443	0.352
Physical status (ASA-PS)	2.80 (2.50, 3.10)	3.00 (2.25, 3.00)*	0.628	0.221
% Percutaneous	90%	90%	-	-
Number of levels treated	1.1 (0.87, 1.33)	1.2 (0.90, 1.50)	0.557	0.268

GA, general anesthesia; SA, spinal anesthesia; BMI, body mass index; ASA-PS, American Society of Anesthesiologists Physical Status.
*Median (IQR).

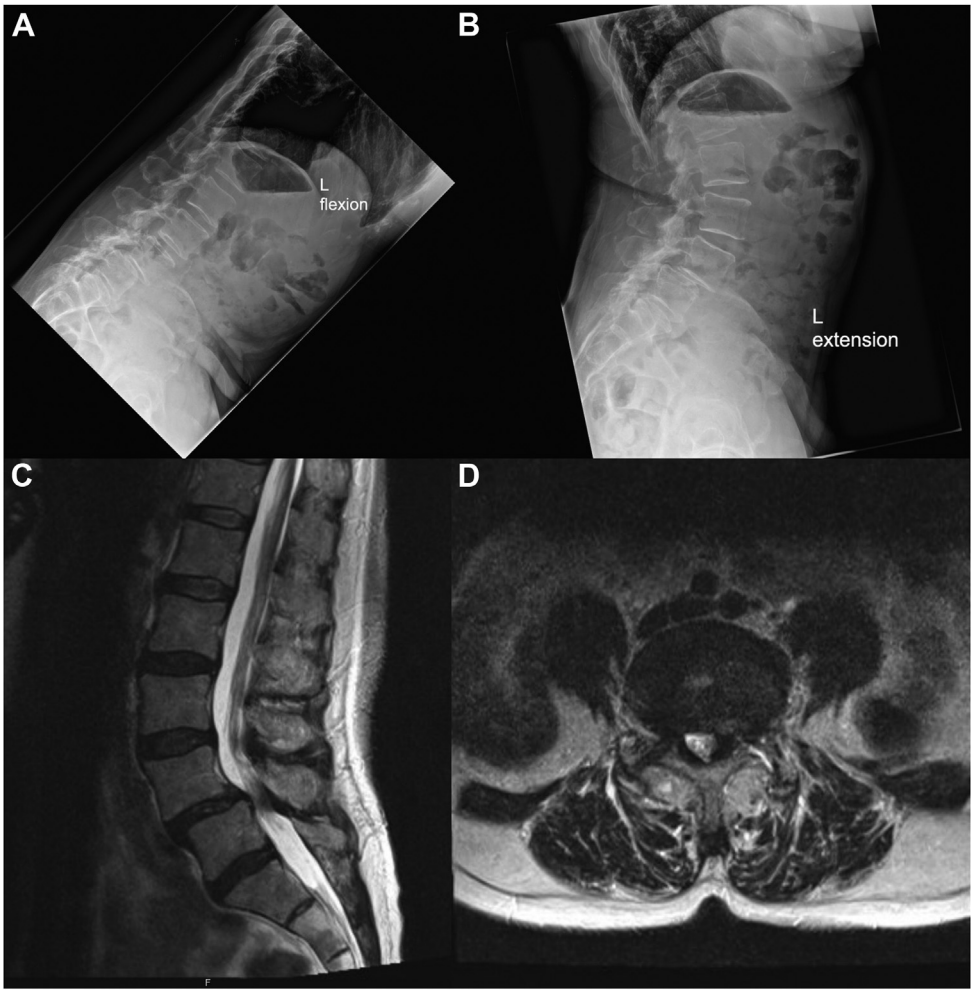

Figure 2. GA patient preoperative imaging (**A**). Flexion X-Ray, (**B**). Extension X-Ray, (**C**). T2 weighted sagittal magnetic resonance imaging [MRI], (**D**). T2 weighted axial MRI). GA, general anesthesia.

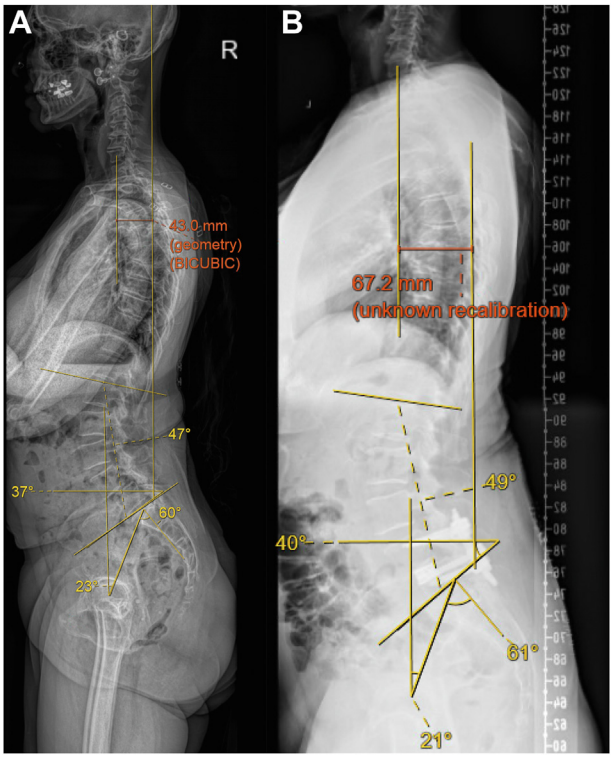

Figure 3. GA Patient Whole Spine X-Rays with Spinopelvic Parameters (**A**). Preoperative, (**B**). Postoperative). Preoperative: PI = 60, PT = 23, SS = 37, LL = 47, SVA = +43. Postoperative: PI = 61, PT = 21, SS = 40, LL = 49, SVA = +67.2. GA, general anesthesia; LL, lumbar lordosis; PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; SVA, sagittal vertical axis.

Patient Outcomes

When compared to their GA counterparts, SA patients had a reduced hospital LOS (12.87 vs. 50.79 hours, $P = 0.001$) (Figure 6A and B). SA patients also required fewer opioids than their GA counterparts (10.76 vs. 31.43 MME, $P = 0.006$) (Figure 6C). TTA was reduced in SA patients compared to GA patients (7.22 vs. 29.87 hours, $P = 0.022$) (Figure 6D). Procedure duration was not statistically significantly reduced in SA patients compared to GA patients (139.3 vs. 188.2 minutes, $P = 0.089$) (Figure 6E). No patients in the SA cohort had any 90-day readmissions. One patient in the GA cohort had multiple readmissions due to bradycardia and syncope in the 90-day postoperative period. Results are summarized in Table 2 and Figure 6.

DISCUSSION

Advances in the Field of Awake Spine Surgery

There has been significant increase in the occurrence of awake spinal surgery over the past years.[1] Many factors have led to this increase, yet it is largely due to changes in route of administration of anesthesia as well as advances in surgical technique. Despite these advancements, GA is still the most prevalent anesthetic technique, with up to 98% of cases occurring under GA.[23] GA is not without drawbacks, however. GA, while generally safe, is associated with a significant increase in postoperative nausea and vomiting (at least when performed with inhaled anesthetics) and may be associated with other, more serious, complications as well.[24] To decrease complication rates, protocols utilizing regional anesthetic techniques, such as the ESP block and thoracolumbar interfascial plane (TLIP) blocks, have been implemented.[14-16] Spine surgeries performed under SA have been found, by meta-analysis, to be associated with reduced incidence of postoperative nausea and vomiting, shorter LOS, and lower intraoperative blood loss.[11,12,25] While a recent, noteworthy study by Neuman et al. found SA to be nonsuperior to GA, this study was conducted in older adults undergoing hip surgery.[26] This population faced significantly greater morbidity than routine spine surgery patients, as nearly 1 in 5 included patients reached a composite outcome of immobility or death within a 60-day period. These findings, therefore, should not be extrapolated to suggest that SA provides no benefit in spine surgery patients.

While SA is what ultim ately allows patients to receive surgery while awake, the development of minimally invasive spine surgery has also been a critical component in enabling the development of awake spine surgery. Minimally invasive spine surgery not only facilitates awake spine surgery through reducing the psychological burden on the patient, but also is associated with reduced blood loss, reduced LOS, less postoperative disability, and fewer complications such as dural injury or wound infection.[12,25,27,28]

Awake spine surgery has been used for a wide variety of spinal procedures, and commonly performed awake spinal surgeries include, but are not limited to laminectomy, discectomy, anterior cervical discectomy and fusion, lumbar fusion, and dorsal column stimulator placement.[29]

Preliminary work on the use of SA for surgical management of DSD has been tentatively promising; previous studies have shown that with SA, there is improved postoperative analgesia, decreased intraoperative complications, reduced economic costs, and improved perioperative outcomes.[11,23,29-39] Although there is growing evidence favoring the use of SA over GA, the relative strengths of each have not yet been consistently identified. Additionally, the current literature may not accurately assess the relative strengths of SA over GA. For instance, meta-analysis has shown that many studies are troubled by bias, and not all studies compare SA and GA patients with equivalent baseline demographics.[17,40] The authors hypothesize this results from the fact that awake surgery is disproportionately offered to patients with multiple medical comorbidities, as awake spine surgery may facilitate operative management of DSD in traditionally poor surgical candidates.[41] In this sense, the current literature may actually underestimate the relative benefits of awake spine surgery under SA, as its recipients are more often predisposed to more challenging postoperative courses independent of their anesthetic modality. With this in mind, the authors set out to perform a retrospective matched cohort study to help determine the relative strengths and weaknesses of SA and GA in patients of comparable baseline demographics with comparable medical comorbidity burdens. Importantly, all patients were also matched in terms of operative management (MIS TLIF vs. percLIF) and regional anesthesia (ESP blocks).

The cohorts were constructed of SA patients who had well controlled GA counterparts, as is seen by their equivalent baseline demographics, particularly ASA-PS. Although 10 patients from each

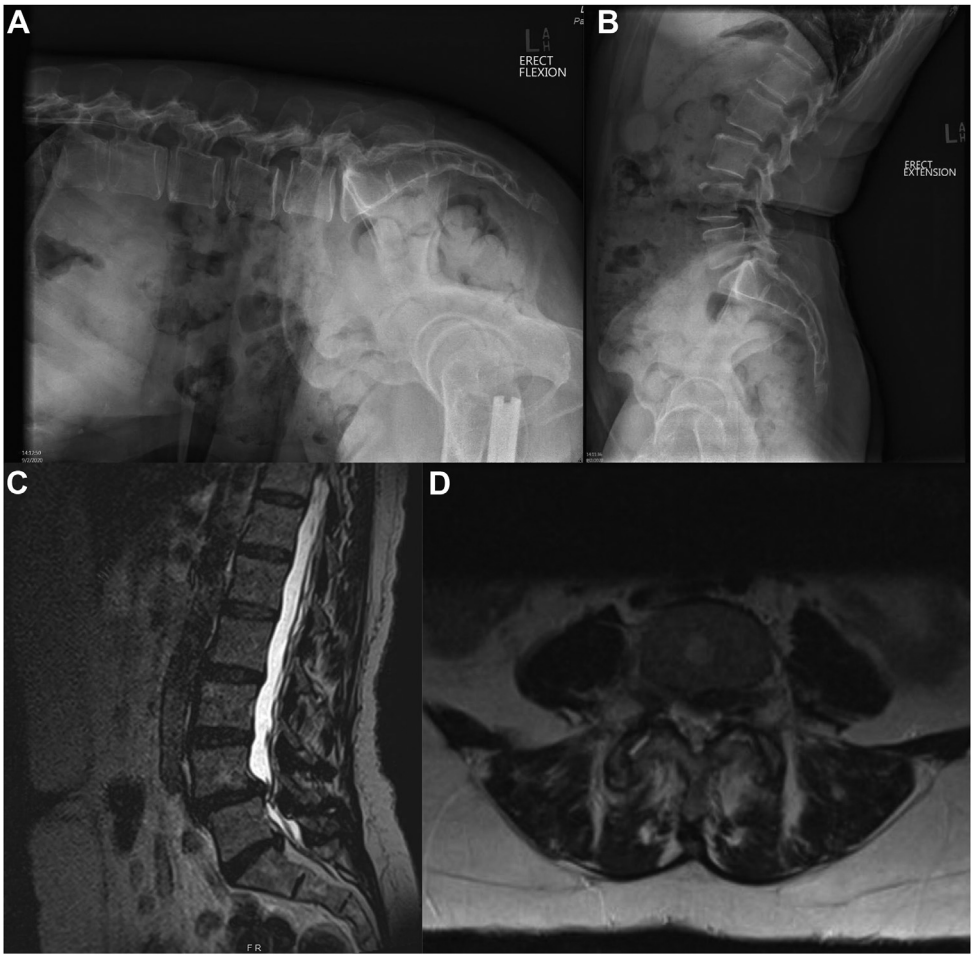

Figure 4. SA Patient Preoperative Imaging (**A**). Flexion X-Ray, (**B**). Extension X-Ray, (**C**). T2 weighted sagittal magnetic resonance imaging [MRI], (**D**). T2 weighted axial MRI). SA, Spinal anesthesia.

cohort were analyzed, it is worth noting that more than 10 patients underwent SA during the study period. It was impossible, however, to match 3 of these patients from the larger SA group to a comparable GA patient. This is because the SA patients disproportionately carried medical comorbidities that put them at increased risk for GA's potential cardiopulmonary or cognitive complications, thereby making SA the safest choice for this population.[24,25,42,43] Examples of such patients include octogenarians as well as patients with severe cardiovascular disease and BMIs greater than 40 kg/m^2. Within the matchable cohort, however, SA appears to demonstrate the capacity to improve some patient outcomes.

Study Results

Some of the most noteworthy findings of this study surround our primary objective, SA's impact on hospital LOS when compared to GA. Our study demonstrated that SA may reduce hospital LOS and may increase the likelihood of being discharged within 24 hours of arrival in the PACU. This is particularly meaningful in the context of the current healthcare landscape in the wake of COVID-19, where healthcare worker shortages make it challenging to maintain prior operative volume.[44,45] In this sense, SA's capacity to increase same-day discharges make it a powerful tool in a congested healthcare system. Our study additionally suggested that SA is associated with decreased TTA, which likely helps contribute to this decreased discharge time. This finding is consistent with prior literature.[46,47]

Another significant finding of our study was SA patient's reduced opioid utilization. It is perhaps worth noting, that neither the SA nor the GA cohorts used a tremendous quantity of opioids compared to what is often seen following lumbar fusion.[48] One factor that likely led to minimal opioid utilization in both the SA and GA cohorts is the fact that all patients studied received an ESP block and 9 out of 10 matched pairs underwent a newer ultraminimally invasive technique called the percLIF. Previous studies have illustrated the ESP's ability to reduce opioid utilization, with 1 notable study of nearly 700 patients which revealed a significant decrease in morphine utilization in patients

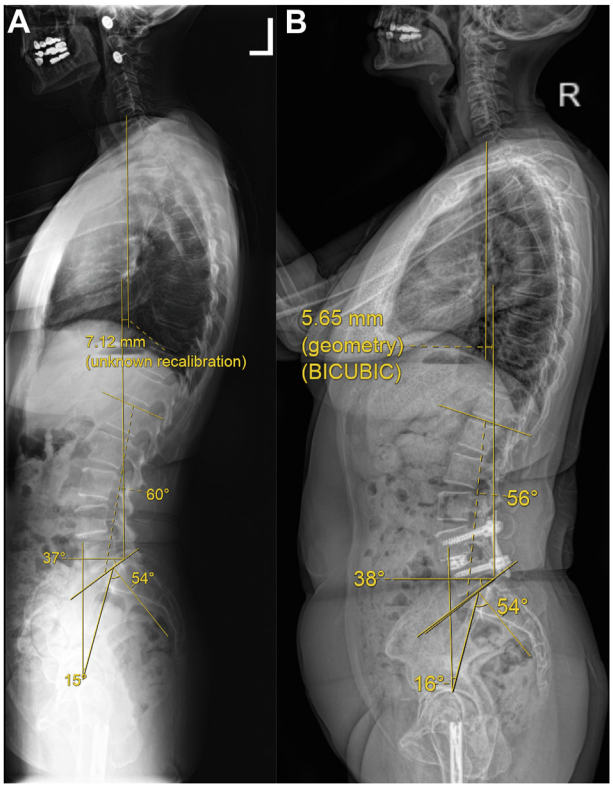

Figure 5. SA Patient Whole Spine X-Rays with Spinopelvic Parameters (**A**). Preoperative, (**B**). Postoperative). Preoperative: PI = 54, PT = 15, SS = 37, LL = 60, SVA = -7.12. Postoperative: PI = 54, PT = 16, SS = 38, LL = 56, SVA = +5.65. SA, Spinal anesthesia; LL, lumbar lordosis; PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; SVA, sagittal vertical axis.

who underwent ESP in the first 24 hours following surgery compared to a control group.[49] Our findings show, however, that even in the presence of an ESP block, surgery under SA is associated with reduced postoperative opioid utilization. Other findings of this study include SA's capacity to reduce hospital LOS, which is supported by current literature.[11]

Other findings of SA patients reduced procedure duration did not meet criteria for statistical significance. Nevertheless, it is the author's belief that these findings warrant further study. For example, while not previously shown through a matched cohort construct, SA's capacity to reduce operative time has been demonstrated by meta-analysis.[11,36] It is possible that reduced operative time is a result of increased surgeon focus in the setting of an awake patient. There are several other, well documented phenomena that may also contribute to this finding, and they are described well in meta-analysis by Urick et. al.[11]

Our study additionally adds to the sparse body of evidence supporting the use of SA for spinal fusions, as the majority of literature surrounding SA investigates is utility in decompressions.[11]

Limitations

The most significant limitation of this study was the small size of the cohort, featuring only 10 matched pairs for a total of 20 studied patients. Despite this, SA did demonstrate statistically significant effects in reducing LOS, opioid utilization, and time to ambulation.

Another important limitation was the fact that opioid utilization was only studied in the immediate, six-hour postoperative setting due to the brief hospital stays of many patients. Future work must seek to investigate at home opioid utilization following discharge. Long-term clinical status was not investigated due to the recency of surgery in many of the included patients.

Lastly, a significant limitation of this study is its retrospective nature, which introduces a possible selection bias. To reduce this bias as much as possible, a matched-cohort design was chosen in order to best control for demographic factors, such as age, BMI, and ASA-PS, as well as surgical factors such as surgical technique and level of fusion. Another rationale behind the matched-cohort construct was to address the fact that highly comorbid patients may be more frequently offered awake surgery. This concern is supported by the fact that 3 of the 13 identified awake fusion patients were unable to be matched to a GA counterpart. It was, however, the authors' belief that a carefully constructed matched-cohort construct may eliminate an unaddressed indication bias in existing retrospective studies that do not account for patient baselines. Still, this study's retrospective nature cannot be entirely void of indication bias. A prospective randomized control trial, therefore, is necessary to achieve optimum scientific rigor.

CONCLUSION

Although the study was performed retrospectively in a small cohort, we demonstrate that SA is a safe, effective anesthetic technique for lumbar spinal fusion. Furthermore, these preliminary retrospective results suggest the use of SA rather than GA for lumbar fusions is associated with shorter hospital LOS, reduced opioid utilization, and reduced time to ambulation compared to a matched cohort. Future randomized prospective studies are warranted to determine if SA usage truly leads to these beneficial patient outcomes.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

David A.W. Sykes: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing — original draft, Writing — review & editing, Visualization. **Troy Q. Tabarestani:** Writing — review & editing. **Nauman S. Chaudhry:** Methodology, Writing — review & editing. **David S. Salven:** Writing — review & editing. **Christopher I. Shaffrey:** Supervision, Project administration. **W. Michael Bullock:** Supervision, Project administration. **Nicole R. Guinn:** Formal analysis, Writing — review & editing. **Jeffrey Gadsden:** Writing — review & editing, Supervision. **Miles Berger:** Writing — review & editing, Supervision. **Muhammad M. Abd-El-Barr:** Conceptualization, Methodology, Writing — review & editing, Supervision, Project administration.

ACKNOWLEDGMENTS

Thank you to the Duke departments of neurosurgery, orthopedic surgery, and anesthesia. Miles Berger acknowledges support from the NIH grant K76-AG057022-05S1.

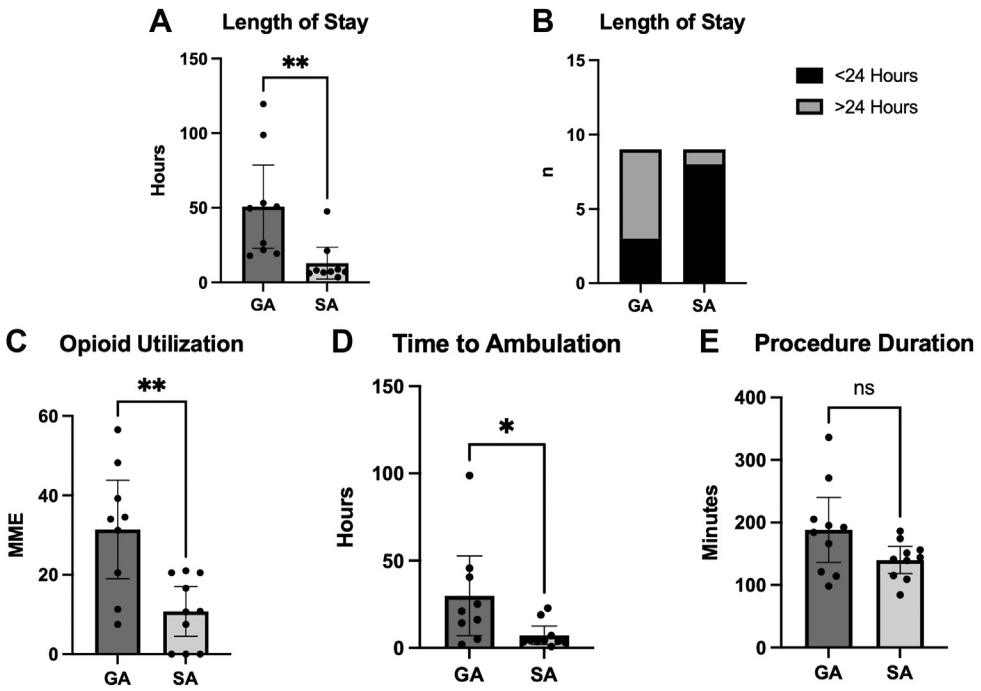

Figure 6. Summary of patient outcomes (**A**). Length of Stay, (**B**). 24 Hour Discharge, (**C**). Opioid Use, (**D**). Time to Ambulation, (**E**). Procedure Duration). Length of stay was statistically significantly reduced in Spinal Anesthesia (SA) patients (50.79 vs. 12.87 hours, $P = 0.010$). SA patients are statistically significantly more likely to be discharged within 24 hours of PACU arrival ($P = 0.050$). Postoperative opioid utilization is statistically significantly reduced in SA patients (31.42 vs. 10.76 MME, $P = 0.003$). Time to ambulation is statistically significantly reduced in SA patients (29.87 vs. 7.22 hours, $P = 0.032$). Procedure duration is nonstatistically significantly reduced in SA patients (188.2 vs. 139.9 minutes, $P = 0.069$). PACU, postanesthesia care unit.

Table 2. GA and SA Patient Outcomes

Metric	GA Mean (95% CI)	SA Mean (95% CI)	*P* Value
Hospital length of stay (Hours)	50.79 (33.86, 78.73)	12.87 (2.16, 23.58)	0.001
Postoperative opioid use (MME)	31.43 (19.03, 43.84)	10.76 (4.51, 17.01)	0.006
Time to ambulation (Hours)	29.87 (7.047, 52.69)	7.22 (1.93, 12.51)	0.022
Procedure duration (Minutes)	188.2 (136.1, 240.3)	139.3 (118.1, 161.7)	0.089

GA, general anesthesia; SA, Spinal anesthesia; MME, Morphine milligram equivalents.

REFERENCES

1. Deyo RA, Mirza SK. Trends and variations in the use of spine surgery. *Clin Orthop Relat Res*. 2006; 443:139-146.

2. Beschloss A, Ishmael T, Dicindio C, et al. The expanding Frontier of outpatient spine surgery. *Int J Spine Surg*. 2021;15:266-273.

3. Beschloss A, Dicindio C, Lombardi J, et al. Marked increase in spinal deformity surgery throughout the United States. *Spine*. 2021;46: 1402-1408.

4. Grotle M, Småstuen MC, Fjeld O, et al. Lumbar spine surgery across 15 years: trends, complications and reoperations in a longitudinal observational study from Norway. *BMJ Open*. 2019;9: e028743.

5. Martin BI, Mirza SK, Spina N, Spiker WR, Lawrence B, Brodke DS. Trends in lumbar fusion procedure rates and associated hospital costs for degenerative spinal diseases in the United States, 2004 to 2015. *Spine (Phila Pa 1976*. 2019;44:369-376.

6. Hathi K, Bigney E, Richardson E, et al. Minimally invasive vs. Open surgery for lumbar spinal stenosis in patients with diabetes - a Canadian spine outcomes and research Network study. *Global Spine J*. 2021, 21925682211042576.

7. Lu VM, Kerezoudis P, Gilder HE, McCutcheon BA, Phan K, Bydon M. Minimally invasive surgery versus open surgery spinal fusion for spondylolisthesis: a systematic review and meta-analysis. *Spine*. 2017;42:E177-E185.

8. McClelland S 3rd, Goldstein JA. Minimally invasive versus open spine surgery: what does the best evidence tell us? *J Neurosci Rural Pract*. 2017;8:194-198.

9. Kim CH, Easley K, Lee JS, et al. Comparison of minimally invasive versus open transforaminal interbody lumbar fusion. *Global Spine J*. 2020;10(2 Suppl):143s-150s.

10. Miller LE, Bhattacharyya S, Pracyk J. Minimally invasive versus open transforaminal lumbar interbody fusion for single-level degenerative disease: a systematic review and meta-analysis of randomized controlled trials. *World Neurosurg*. 2020;133:358-365.e4.

11. Urick D, Sciavolino B, Wang TY, Gupta DK, Sharan A, Abd-El-Barr MM. Perioperative outcomes of general versus spinal anesthesia in the lumbar spine surgery population: a systematic review and meta-analysis of data from 2005 through 2021. *J Clin Orthop Trauma*. 2022;30, 101923.

12. Garg B, Ahuja K, Mehta N, Sharan AD. Awake spinal fusion. *JBJS Rev*. 2021;9.

13. Kai-Hong Chan A, Choy W, Miller CA, Robinson LC, Mummaneni PV. A novel technique for awake, minimally invasive transforaminal lumbar interbody fusion: technical note. *Neurosurg Focus*. 2019;46:E16.

14. Kolcun JPG, Brusko GD, Basil GW, Epstein R, Wang MY. Endoscopic transforaminal lumbar interbody fusion without general anesthesia: operative and clinical outcomes in 100 consecutive patients with a minimum 1-year follow-up. *Neurosurg Focus*. 2019;46:E14.

15. Wang MY, Grossman J. Endoscopic minimally invasive transforaminal interbody fusion without general anesthesia: initial clinical experience with 1-year follow-up. *Neurosurg Focus*. 2016;40:E13.

16. Khattab MFM, Sykes DAW, Abd-El-Barr MM, et al. Spine surgery under awake spinal anesthesia: an Egyptian experience during the COVID-19 pandemic. *Neurosurg Focus*. 2021;51:E6.

17. De Cassai A, Geraldini F, Boscolo A, et al. General anesthesia compared to spinal anesthesia for patients undergoing lumbar Vertebral surgery: a meta-analysis of randomized controlled trials. *J Clin Med*. 2020;10:102.

18. McLain RF, Kalfas I, Bell GR, Tetzlaff JE, Yoon HJ, Rana M. Comparison of spinal and general anesthesia in lumbar laminectomy surgery: a case-controlled analysis of 400 patients. *J Neurosurg Spine*. 2005;2:17-22.

19. Hamouda F, Wang TY, Gabr M, et al. A prospective comparison of the effects of instrument tracking on time and radiation during minimally invasive lumbar interbody fusion. *World Neurosurg*. 2021;152:e101-e111.

20. Syed H, Voyadzis JM. True percutaneous transforaminal lumbar interbody fusion: case illustrations, surgical technique, and limitations. *J Neurol Surg Cent Eur Neurosurg*. 2016;77:344-353.

21. Wang TY, Mehta VA, Gabr M, et al. Percutaneous lumbar interbody fusion with an expandable titanium cage through Kambin's triangle: a case series with initial clinical and radiographic results. *Int J Spine Surg*. 2021;15:1133-1141.

22. Dalton T, Sykes D, Wang TY, et al. Robotic-assisted trajectory into Kambin's triangle during percutaneous transforaminal lumbar interbody fusion-initial case series investigating safety and efficacy. *Oper Neurosurg (Hagerstown)*. 2021;21:400-408.

23. Azad TD, Alomari S, Khalifeh JM, et al. Adoption of awake spine surgery - trends from a national registry over 14 years. *Spine J*. 2022;22:1601-1609.

24. Berthoud MC, Reilly CS. Adverse effects of general anaesthetics. *Drug Saf*. 1992;7:434-459.

25. Xie Q, Zhang J, Lu F, Wu H, Chen Z, Jian F. Minimally invasive versus open Transforaminal lumbar Interbody fusion in obese patients: a meta-analysis. *BMC Musculoskelet Disord*. 2018;19:15.

26. Neuman MD, Feng R, Carson JL, et al. Spinal anesthesia or general anesthesia for hip surgery in older adults. *N Engl J Med*. 2021;385:2025-2035.

27. Patel AA, Zfass-Mendez M, Lebwohl NH, et al. Minimally invasive versus open lumbar fusion: a comparison of blood loss, surgical complications, and hospital course. *Iowa Orthop J*. 2015;35:130-134.

28. Starkweather AR, Witek-Janusek L, Nockels RP, Peterson J, Mathews HL. The multiple benefits of minimally invasive spinal surgery: results comparing transforaminal lumbar interbody fusion and posterior lumbar fusion. *J Neurosci Nurs*. 2008;40:32-39.

29. Fiani B, Reardon T, Selvage J, et al. Awake spine surgery: an eye-opening movement. *Surg Neurol Int*. 2021;12:222.

30. Jellish WS, Thalji Z, Stevenson K, Shea J. A prospective randomized study comparing short- and intermediate-term perioperative outcome variables after spinal or general anesthesia for lumbar disk and laminectomy surgery. *Anesth Analg*. 1996;83:559-564.

31. Griffin J, Nicholls B. Ultrasound in regional anaesthesia. *Anaesthesia*. 2010;65(Suppl 1):1-12.

32. Garg B, Ahuja K, Sharan AD. Regional anesthesia for spine surgery. *J Am Acad Orthop Surg*. 2022;30:809-819.

33. De Biase G, Chen S, Akinduro O, Quinones-Hinojosa A, Abode-Iyamah K. Awake robotic minimally invasive L4-5 transforaminal lumbar interbody fusion. *World Neurosurg*. 2021;148:93.

34. Letchuman V, Agarwal N, Mummaneni VP, et al. Pearls and Pitfalls of awake spine surgery: a simplified patient-selection algorithm. *World Neurosurg*. 2022;161:154-155.

35. West JL, De Biase G, Bydon M, et al. What is the learning curve for lumbar spine surgery under spinal anesthesia? *World Neurosurg*. 2022;158:e310-e316.

36. Perez-Roman RJ, Govindarajan V, Bryant JP, Wang MY. Spinal anesthesia in awake surgical procedures of the lumbar spine: a systematic review and meta-analysis of 3709 patients. *Neurosurg Focus*. 2021;51:E7.

37. Basil GW, Wang MY. Trends in outpatient minimally invasive spine surgery. *J Spine Surg*. 2019;5(Suppl 1):S108-S114.

38. Telfeian AE, Sastry R, Oyelese A, et al. Awake, transforaminal endoscopic lumbar spine surgery in octogenarians: case series. *Pain Physician*. 2022;25:E255-E262.

39. Lu VM, Brusko GD, Urakov TM. Defining the time benefit of awake versus general anesthesia for single-level lumbar spine surgery. *World Neurosurg*. 2022;158:e793-e798.

40. Olmos M, Hernandez NS, Kanter M, Liu P, Riesenburger RI, Kryzanski J. Periprocedural polypharmacy in lumbar fusions performed under spinal anesthesia compared with general anesthesia. *Neurosurgery*. 2023;92:632-638.

41. Sykes DAW, Tabarestani TQ, Salven DS, et al. Awake spinal anesthesia facilitates spine surgery in poor surgical candidates: a case series. *Neurochirurgie*. 2023;69:101444.

42. Smith G, D'Cruz JR, Rondeau B, Goldman J. General Anesthesia for Surgeons. In: *StatPearls*. Treasure Island, FL: StatPearls Publishing; 2023.

43. Zorrilla-Vaca A, Healy RJ, Mirski MA. A comparison of regional versus general anesthesia for lumbar spine surgery: a meta-analysis of randomized studies. *J Neurosurg Anesthesiol*. 2017;29:415-425.

44. Prasad NK, Englum BR, Turner DJ, et al. A Nationwide review of elective surgery and COVID-surge capacity. *J Surg Res*. 2021;267:211-216.

45. Haddad LM, Annamaraju P, Toney-Butler TJ. Nursing shortage. In: *StatPearls*. Treasure Island, FL: StatPearls Publishing; 2023.

46. De Biase G, Gruenbaum SE, West JL, et al. Spinal versus general anesthesia for minimally invasive transforaminal lumbar interbody fusion: implications on operating room time, pain, and ambulation. *Neurosurg Focus*. 2021;51:E3.

47. Capdevila X, Aveline C, Delaunay L, et al. Factors determining the choice of spinal versus general anesthesia in patients undergoing ambulatory surgery: results of a multicenter observational study. *Adv Ther*. 2020;37:527-540.

48. Ge DH, Hockley A, Vasquez-Montes D, et al. Total inpatient morphine milligram equivalents can Predict long-term opioid use after transforaminal lumbar interbody fusion. *Spine*. 2019;44:1465-1470.

49. Kendall MC, Alves L, Traill LL, De Oliveira GS. The effect of ultrasound-guided erector spinae plane block on postsurgical pain: a meta-analysis of randomized controlled trials. *BMC Anesthesiol*. 2020;20:99.

Conflict of interest statement: Christopher I. Shaffrey MD: Receives support from, holds shares/stock in, and consults for NuVaisive. Recieves support from and consults for Medtronic. Holds shares/stock in Proprio. W. Michael Bullock

MD: Consultant and Speakers Bureau Member for Pacira Biosciences, Inc. Jeffrey Gadsden MD MBA: Consultant for Pacira Biosciences, Inc. Miles Berger MD PhD: has received material support (i.e., EEG monitor loan) for a postoperative recovery study in older adults from Masimo and has received private legal consulting fees related to perioperative neurocognitive disorders. Muhammad M. Abd-El-Barr MD PhD: Consultant for Spineology, Depuy Synthes, TrackX, and Spinal Elements. Receives research support from the NIH, Abbvie, and the Dana and Christopher Reeve Foundation.

Received 8 January 2023; accepted 1 May 2023

Citation: World Neurosurg. (2023). https://doi.org/10.1016/j.wneu.2023.05.001

*Journal homepage: **www.journals.elsevier.com/world-neurosurgery***

*Available online: **www.sciencedirect.com***