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Technical notes & surgical techniques

Awake percutaneous transforaminal lumbar interbody fusion with expandable cage and robotic-assisted navigation and instrumentation: Case report and review of literature

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ABSTRACT

Awake surgeries are commonly performed in many specialties through the use of local or regional anesthesia. These methods avoid the risks associated with general endotracheal anesthesia and allow faster recovery times. In neurosurgery, awake surgeries are typically reserved for craniotomies involving tumor or lesion resection near eloquent tissue. Only recently has awake spine fusion surgery been performed, and only in very limited capacity. Here, we describe the first reported case of awake percutaneous transforaminal lumbar interbody fusion with robotic navigation and instrumentation under spinal anesthesia.

1. Introduction

Awake surgery is performed across multiple disciplines including obstetrics, orthopedics, and even cardiothoracic surgery [3,4,10,15,21]. Awake surgery is a staple within neurosurgery as well, although mainly limited to craniotomies for lesions in speech- or motor-eloquent areas [7,11]. Until recently, there has been no utilization of awake surgery for spine fusion surgery, mainly due to prolonged prone positioning, significant use of intraoperative cautery, and need for invasive cardiorespiratory monitoring. With the development of more minimally invasive techniques, however, patients can now undergo the same surgical procedures as in years past but with less blood loss, less tissue trauma, and less postoperative pain. This has opened the possibility of awake spine fusion surgery.

The percutaneous transforaminal lumbar interbody fusion (percLIF) using the Optimesh (Spineology Inc, St. Paul, MN, USA) implant and local anesthesia is one spinal fusion surgery that has recently been performed without general endotracheal anesthesia [13,23]. There are only a handful of other established case series or reviews of awake spine surgery, and to the authors' best knowledge, there is only a select few groups that have attempted this form of lumbar fusion in an awake patient [22,25]. Because of this, variations in operative and anesthetic techniques required for awake spine surgery are almost completely lacking.

Here, we review the available literature on awake spine surgery, and describe a case report of the first awake percutaneous transforaminal lumbar interbody fusion with an expandable cage using robotic navigation and instrumentation performed under spinal anesthesia.

2. Case presentation

A 64-year-old male with no significant past medical history except for a previous left hip replacement presented to our institution's neurosurgery spine clinic with bilateral lower extremity radicular pain in the L5 distribution. Besides radicular pain, his neurological exam was otherwise unremarkable. A magnetic resonance image (MRI) and computed tomography (CT) scan of his lumbar spine demonstrated grade 2 anterolisthesis of L5 on S1 with associated bilateral pars defects and vacuum disc phenomenon that had slight reduction between supine and upright positioning (Figs. 1, 2). A subsequent electromyography (EMG) study confirmed right greater than left radiculopathies involving the L4 and L5 nerve roots. Over the course of the next year, he tried multiple conservative measures including transforaminal injections and physical therapy, but his pain had become refractory to these treatments, and thus a transforaminal lumbar interbody fusion was offered for therapeutic relief.

Abbreviations: percLIF, Percutaneous transformaminal lumbar interbody fusion; CT, Computed tomography; EMG, Electromyography; BMP, Bone morphogenic protein; MRI, Magnetic resonance imaging

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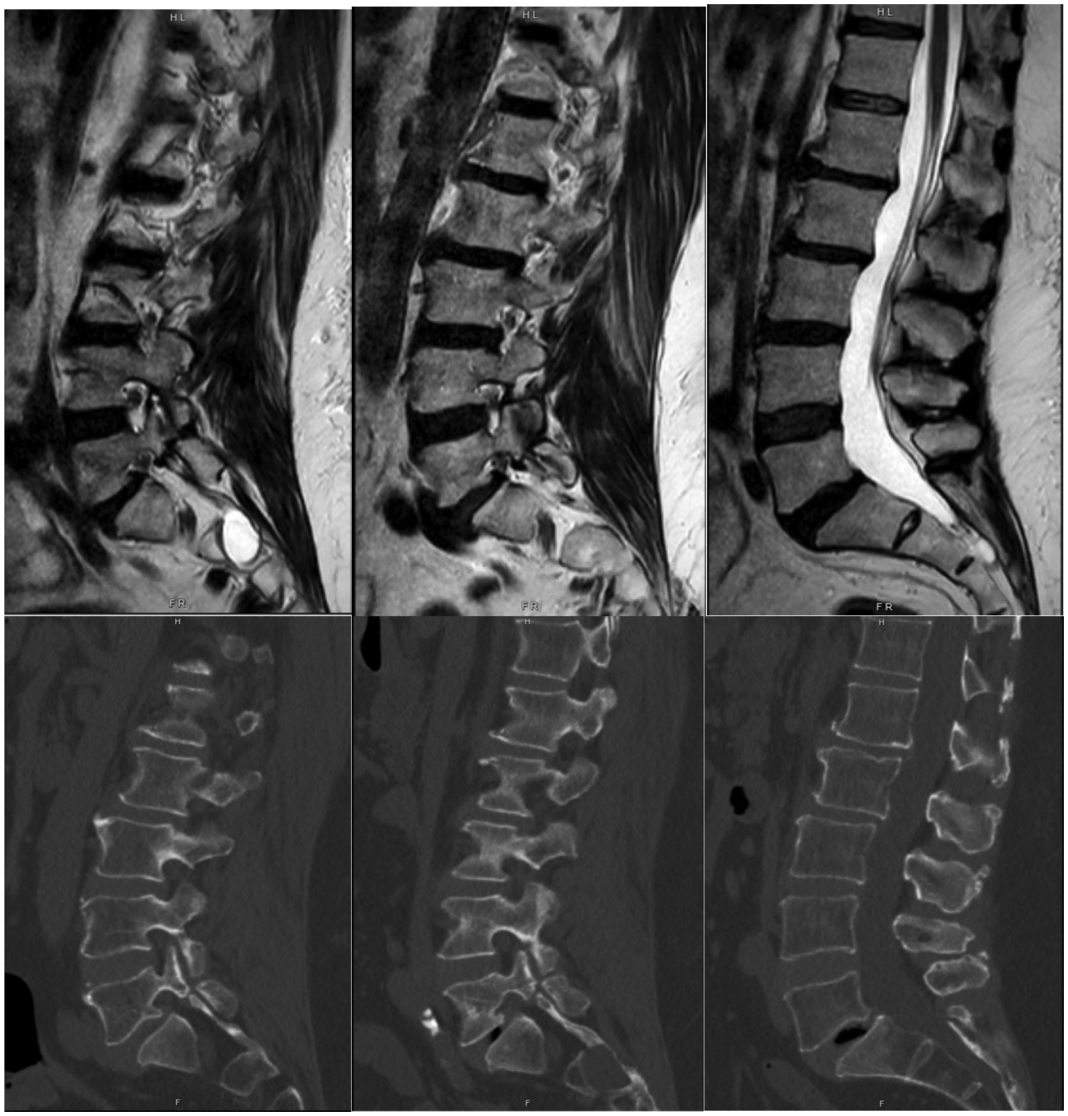

Fig. 1. *Top left:* T2 sagittal noncontrasted MRI showing left-sided L5 neuroforaminal stenosis; *Top middle:* T2 sagittal noncontrasted MRI showing right-sided L5 neuroforaminal stenosis; *Top right:* T2 sagittal noncontrasted MRI showing no appreciable central canal stenosis. *Bottom left:* CT without contrast demonstrating left pars defect at L5-S1; *Bottom middle:* CT without contrast demonstrating right pars defect at L5-S1; *Bottom right:* CT without contrast demonstrating vacuum disc phenomenon.

Complicating his clinical picture, however, was an adverse clinical event associated with general anesthesia and possibly vancomycin administration during his previous left hip replacement. While the exact details of this complication were unclear, he stated that this surgery resulted in bilateral leg shaking and uncontrollable jerking, and he was particularly hesitant to undergo any surgical intervention involving general anesthesia. Thus, with the assistance of our institution's neuroanesthesia team, it was determined that he would be a candidate for awake spinal surgery with a spinal anesthetic. To decrease the total amount of tissue trauma and blood loss associated with his planned fusion, it was determined that we would perform his transforaminal lumbar interbody fusion via a percutaneous technique with minimally invasive navigated robotic screw instrumentation and navigated placement of percutaneous cage.

Some aspects of this case have been discussed before, but as far as the authors can tell, this is the first account of using all these technologies and surgical techniques in one case. We have recently been placing an expandable titanium expandable graft, which we feel has more structural integrity compared to the porous allograft-containing mesh. We elected to use robotic instrument navigation for both the placement of the pedicle screws and to navigate into Kambin's triangle as we felt that this would decrease tissue manipulation and patient discomfort.

3. Surgical technique

The patient was brought to the operating room after having been *nil per os* since midnight on the night before surgery. Intravenous access was established per anesthesia, and the patient was placed leaning forward in the seated position at the side of the operative bed in order to facilitate the access to the intrathecal space. 3% chlorhexidine was applied across the thoracolumbar region of the back and given 3 min to dry. A sterile drape with a circular cutout was applied. At the L3-4 level, a 20-gauge 1.25 in. introducer needle was placed and then a 25-gauge Quincke needle was inserted between the L3 and L4 spinous processes and advanced into the interspinous ligament and then advanced through the Quincke needle until a loss of resistance was felt. A flash of cerebrospinal fluid was seen, and 15 mg of isobaric preservative-free bupivacaine and 20mcg of fentanyl were injected into the thecal space. This produced a dense T4 spinal block resulting in complete sensory loss and paresis below this level. The patient was then laid supine

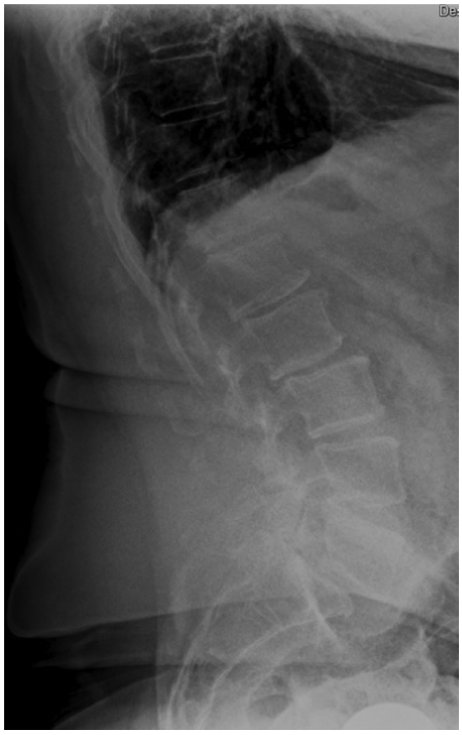

Fig. 2. Preoperative standing radiograph demonstrating Grade 2 anterolisthesis of L5 on S1.

where a Foley catheter was placed, and then the patient was placed prone onto a Jackson table with arms bent 90 degrees and aimed forward in the "Superman" position. The patient's face was placed in a foam pillow and all pressure points were adequately padded. The patient was then prepped and draped in usual fashion with chlorhexidine gluconate and alcohol and universal drapes. Two stab incisions were made over the left and right posterior superior iliac spine, into which a 4- and 1-point reference frame were placed. C-arm fluoroscopy was then prepped and draped with the Globus fluoroscopic reference arrays and brought into the operative field and true anterior-posterior (AP) and lateral images at L5 and S1 were obtained. The Globus ExcelsiusGPS Robot (Globus Medical Inc, Audobon, PA, USA) was draped and then brought into the surgical field and the fluoroscopic images were then registered to a preoperative CT scan. Previously planned screw trajectories were then confirmed (Fig. 3). Stab incisions were made overlying the screw entry sites and serial pilot holes, taps, and Globus Creo pedicle screws were then placed into the bilateral L5 (6.5x45mm) and S1 (7.5x45mm) pedicles. Fluoroscopy was used to make sure the screws appeared appropriate. Given the spinal block, neuromonitoring was not applicable to this case.

We then used the ExcelsiusGPS Robot to help design a trajectory to Kambin's Triangle (Fig. 4). To do this, we eliminated the screw trajectory for L5 and created a new "screw" trajectory into the disc space that on the lateral view was farthest caudal from the L5 pedicle to ensure that we were as far as possible from the exiting nerve root (L5). On the AP view, this entrance into the disc space was at the mid-pedicle point so as to enter Kambin's triangle in the largest part of the 'safe zone'. A lateral stab incision approximately 6 cm to the left of midline was made [6]. The proprietary (Spineology) dilator was used to pierce through the subcutaneous soft tissue and fascia and was docked on the annulus of the L5-S1 disc. A kirschner wire was placed down the dilator to pierce the annulus at L5-S1 and enter the actual disc space. The ExcelsiusGPS robot cannula and arm were then removed from the operative field, and serial dilation with progressively larger dilators was then done over the kirschner wire until we were able to dock an 8 mm portal on the skin and inside the L5-S1 disc space. The kirschner wire was removed, and

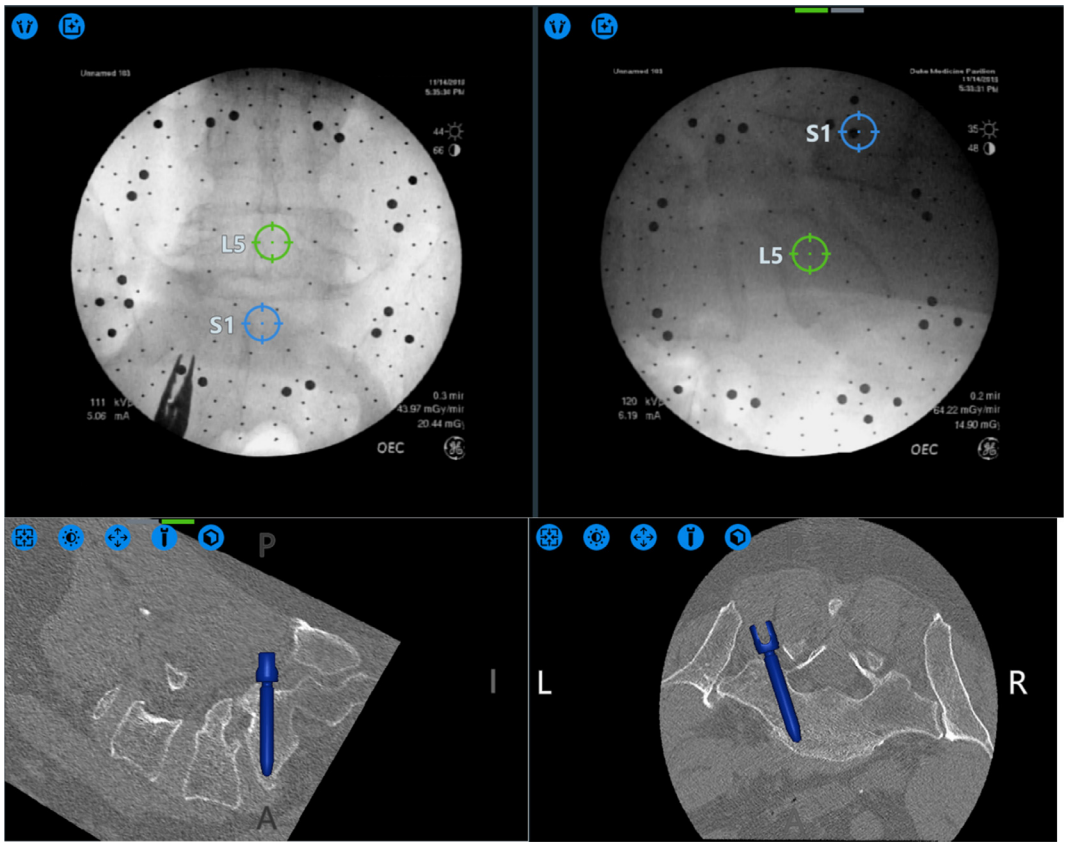

Fig. 3. *Top:* AP and lateral registration images using AP and lateral fluoroscopy. *Bottom:* representative image of the left S1 screw trajectory.

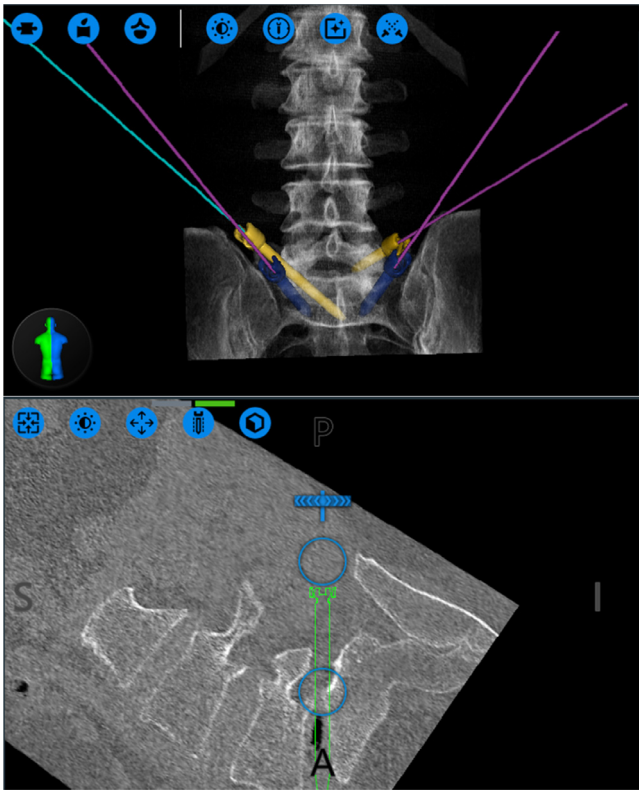

Fig. 4. *Top:* 3D rendition of the right L5 screw, left and right S1 screws, and trajectory for cage placement through Kambin's triangle. The left L5 screw trajectory was eliminated after the screw was placed so as to accommodate a new trajectory for cage placement. *Bottom:* lateral CT projection of cage trajectory.

our attention was turned to the discectomy. Discectomy was done using a combination of articulating curettes, pituitary rongeurs, and drill brushes. At the conclusion of the discectomy, a balloon with radiopaque contrast was inserted down the working channel and inflated, and subsequent C-arm images showed that the radiopaque balloon filled and pressed along the edges of both the superior and inferior endplates; thus indicating a thorough discectomy and adequate endplate preparation. One-half of a small kit of bone morphogenic protein (BMP) was then placed into the disc space. This was pushed anteriorly. A kirschner wire was then placed back into the working channel to maintain access to the disc space, and the 8 mm portal was removed. The expandable cage obturator was then put in over the kirschner wire and malleted into the disc space. The kirschner wire was then removed and an 8 mm expandable Spineology ELITE cage packed with allograft was then malleted into the disc space and expanded to 13 mm. The obturator was then removed. Final intraoperative fluoroscopic films demonstrated full expansion of the cage with good bony contact on both the L5 and S1 endplates.

A 60 mm and 65 mm rod were then guided onto the screw heads on the left and right side, respectively. Set screws were placed and tightened, and final tightening with counter torque confirmed adequate securement. Biplanar fluoroscopy showed good placement of the screws and the rods and significant reduction of his preoperative spondylolisthesis. An intraoperative CT scan was then performed, which demonstrated appropriate placement of all screws and cage. The incisions were irrigated with bacitracin-impregnated lactated ringer solution and 1-gram topical vancomycin powder was placed in the wound. The wound was closed in layers, with 0-vicryl sutures used to close fascia, 2–0 sutures for the dermis and staples for skin closure. Total skin-to-skin operative time was 163 min. The patient was then turned supine and brought to the perioperative anesthesia recovery unit for recovery. The patient remained fully awake during the entire procedure and throughout the course of the procedure endorsed complete anesthesia and distal to the navel. By the time he arrived at the recovery unit, he had full strength and sensation in his bilateral lower extremities. The total length of spinal anesthesia spanned 4.5 h. He was brought to our neuroscience stepdown unit where his Foley was subsequently removed. Postoperative spinal films were obtained (Fig. 5), which demonstrated appropriate hardware placement and alignment, and he cleared physical therapy for return home on postoperative day 1. The patient did not have any evidence of a new radiculopathy, pain syndrome or motor weakness. He was subsequently discharged and has

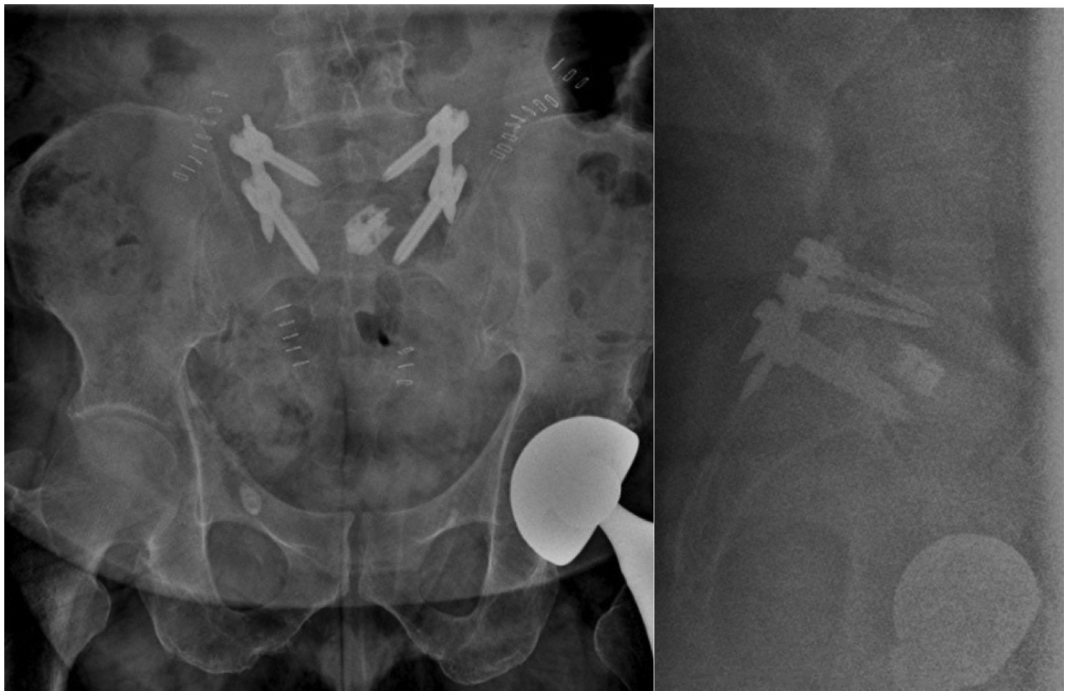

Fig. 5. Postoperative AP and lateral intraoperative fluoroscopy demonstrating left sided TLIF cage placement and satisfactory position of 4 pedicle screws.

been doing well, since.

4. Discussion

Awake surgery for a multitude of specialties has been well described in the literature. It is most commonly used in the field of obstetrics (cesarian section) [2,9,21] and orthopedic surgery (hand, foot/ankle, knee) [1,18], but has recently been applied to even cardiothoracic surgery [17,20,24]. Within neurosurgery however, awake surgeries have typically been confined to intracranial cases involving eloquent motor or speech cortex. These neurosurgical techniques have been refined for many decades, and awake craniotomies are now commonly performed at many if not all neurosurgical tertiary care centers [7]. The success of awake intracranial surgery is aided by the lack of pain nocioceptors in brain parenchyma, and thus the patient can remain comfortable with only topical anesthetic applied to the skin and muscle around the incision and at the cranial fixation pin sites.

For spinal fusion surgery however, the usage of electrocautery combined with muscle dissection and drill work require that deeper anesthesia be attained. This necessitates general endotracheal anesthesia which is currently the gold standard for anesthesia utilized for all types of spine surgery. Within the past several years, however, newer advances in minimally invasive, minimally traumatic spine surgery, and regional and spinal anesthesia have now made it possible to consider performing spine surgery under awake conditions.

One operative example is the development of the minimally invasive percutaneous transforaminal lumbar interbody fusion (percLIF). As described above, discectomy and cage placement in a percLIF are performed through a 1 cm stab incision. Sequential dilators are then placed into the disc space through the natural anatomic corridor provided by Kambin's triangle. These dilators separate tissue fibers rather than coagulate them, and thus one can reach the disc space without more trauma than a skin and fascial stab incision. Percutaneous pedicle screws and rods can be placed via stab incisions as well. In this approach, there is no need for any drilling or significant electrocautery, and many patients are discharged within 24–48 h of surgery [16]. Due to the reduction in trauma associated with this approach, it was theorized that this procedure could be done without the need for general anesthesia, and in 2014, the University of Miami became the first institution to perform percLIF in an awake patient using only local liposomal bupivacaine and moderate/high doses of propofol and ketamine. In their case series published in 2019, Kolcun et al described operative outcomes for 100 patients undergoing the percLIF with minimum of 1-year follow-up. In their series, average operative time was 84.5 min for 1-level fusions and 128.1 min for 2-level fusions, with an average length-of-stay of 1.4 days. Only four cases had to be converted to general endotracheal anesthesia due to epistaxis, anxiety, and emesis. It should be noted that in these cases, a porous allograft-containing mesh was used as the interbody device and back-filled with allograft.

This was followed by another case report by Chan et al of two patients undergoing nonpercutaneous minimally invasive transforaminal lumbar interbody fusion with conscious sedation [12]. Liposomal bupivacaine was also used for these patients, and both were instrumented using the O-Arm CT guidance and StealthStation Surgical Navigation System (Medtronic, Inc., Minneapolis, MN, USA). Operative time was 2.5 h for both cases, and neither patient experienced perioperative complications. Both were discharged home on postoperative day 1.

The case report described in this manuscript differs from these previous subjects in several ways. Firstly, the anesthetic of choice in the other cases was liposomal bupivacaine, which required adjunctive intravenous moderate/high dose propofol and low-dose intravenous ketamine. While a local field block can be effectively attained when liposomal bupivacaine is co-administered with bupivacaine, any changes in screw trajectory or positioning and any use of electrocautery would theoretically cause significant discomfort to the patient if outside the area of local anesthetic infiltration and diffusion. Any bony-work and disc preparation would also be accomplished without the benefit of local anesthetic, as liposomal bupivacaine can only be delivered via a standard hypodermic needle that is unable to accurately anesthetize deeper structures around the spine. Additionally, this method would not prevent discomfort during nerve irritation that may occur during cage placement.

The authors of this manuscript thus utilized complete spinal anesthesia via a spinal block as a solution to the drawbacks of the aforementioned challenges. In a spinal block, a local anesthetic (i.e. lidocaine, ropivacaine, prilocaine, bupivacaine) can be injected into the thecal space near the affected level to provide anesthesia (i.e., sensory block and paresis) [5]. The baricity, concentration, volume, and dose of the local anesthetic administered determines the number of dermatomes covered. The addition of a short duration opioid (i.e., fentanyl) or a long duration opioid (i.e., morphine) can increase the quality and duration of the analgesia. The main advantages of using spinal anesthesia rather than a field infiltration of local anesthetic include complete motor and sensory anesthesia, thus allowing surgeons the ability to retract the nerve roots and thecal sac and use unlimited electrocautery, if necessary. Redosage of anesthetic, if needed, can be accomplished by simply re-accessing the intrathecal space with a spinal needle and administering additional anesthetic. This method of anesthesia has been shown in small series to be efficacious for non-fusion spine surgery, such as lumbar laminectomies or microdiscectomies [14]. One downside to spinal anesthesia is that it completely blocks all spinal function thereby eliminating the possibility of using somatic sensory (SSEP) or motor evoked potentials (MEP). In the case of percLIF, the initial dilator must be navigated into the disc space through Kambin's triangle, a small space defined by the exiting nerve root laterally and superiorly, superior endplate of the caudal vertebral body inferiorly, and thecal sac medially (or in some cases, the superior articulating facet) that can vary between 60 square millimeters to 100 square millimeters depending on the lumbar level and patient-specific anatomy [6,8]. In an asleep percLIF, the initial dilator is attached to an electromyography (EMG) stimulator, and continuous neuromonitoring can inform the surgeon when the dilator is placed too close to the exiting nerve root or thecal sac. Theoretically, intraoperative evoked EMG to determine pedicle screw placement is possible under spinal anesthesia because even though it prevents afferent sensory inputs from being transmitted at the spinal cord level, the spinal anesthetic does not inhibit the peripheral nerve function. However, this has not been described in awake patients, and the amount of motor movement elicited is unclear. Because movement of the patient could interfere with the accuracy of surgical navigation, we did not use intraoperative evoked EMG in this case. The consequences of incorrectly placed dilators in percLIF are grave and include dural tears, nerve root irritation, or even nerve root avulsion and thus should be avoided at all costs [19].

To navigate around this, we applied instrument navigation of the ExcelsiusGPS surgical robot. Using preoperative MRI and CT images, a percutaneous lateral trajectory could be planned, thus providing the surgeon with a dilator trajectory that placed the tip of the instrument underneath the exiting nerve root and lateral to the thecal sac. This is the first reported adaptation of a spine robot to aid in instrument navigation for instruments other than pedicle screws. As we become more adept in robotic technology, more applications will be forthcoming.

5. Conclusions

Our case demonstrates that for the appropriately selected patient, the combination of spinal anesthesia, robotic instrumentation, instrument navigation, and expandable interbody cages can be utilized to safely perform lumbar fusion. This is the first case of awake percutaneous transforaminal lumbar interbody fusion with an expandable cage using robotic navigation and instrumentation under spinal anesthesia. As awake spine surgery becomes more commonly utilized, larger case series and prospective data will be required to fully assess the efficacy

and safety of these techniques across a broader patient population. A multidisciplinary effort between neuroanesthesia and neurosurgery is paramount to the success of such operations.

Disclosures

Muhammad Abd-El-Barr serves as a consultant to Spineology, Inc. The remaining authors report no relevant disclosures.

CRediT authorship contribution statement

Timothy Y. Wang: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing - original draft. **Vikram A. Mehta:** Validation, Formal analysis, Investigation, Data curation, Writing - original draft. **Eric Sankey:** Validation, Formal analysis, Investigation, Writing - original draft. **Khoi D. Than:** Conceptualization, Investigation, Data curation, Writing - review & editing, Supervision. **C. Rory Goodwin:** . **Isaac O. Karikari:** Investigation, Data curation, Writing - review & editing, Supervision. **Dhanesh K. Gupta:** . **Muhammad M. Abd-El-Barr:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing - review & editing, Supervision, Project administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.inat.2020.100685.

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