Minimally Invasive Surgical Techniques for Intradural Extramedullary Lesions of the Thoracic Spine

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For spine surgeons who embrace minimally invasive surgery (MIS), MIS approaches represent a surgical philosophy rather than a surgical indication. MIS has certain inherent benefits, which can make it useful for treating numerous spinal pathologies. For these benefits to be realized, the spinal pathology in question must be thoroughly evaluated to determine if the patient's outcome would be improved through the use of MIS techniques. At the same time, the inherent limitations of the MIS technique must be evaluated, especially within the anatomy of the thoracic spine, to determine whether the pathology can be safely treated in a manner that provides both short- and long-term outcomes that are at least equivalent to those of traditional open surgical procedures. With the use of advanced intraoperative diagnostic techniques, such as diagnostic angiography and indocyanine green injections, complex intradural pathologies can be safely and effectively treated using MIS techniques. As these techniques gain popularity and surgeons' experience increases, there is no doubt that patients with thoracic spine disorders will be able to realize the benefits of MIS techniques that so many patients who have been treated for degenerative disc disease already know.

Key Words: dural arteriovenous fistula, ependymoma, intradural, meningioma, minimally invasive surgery, schwannoma

Abbreviations Used: CSF, cerebrospinal fluid; MR, magnetic resonance; MIS, minimally invasive surgery

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Intradural extramedullary lesions, especially those in the thoracic spine, create an additional level of complexity for spine surgeons. The exposure of the neural elements, as well as the inability to retract these elements, increases the risk of injury for the patient. Care must be taken to remove a lesion and close the dura in a way that avoids the formation of adhesions or tethering at a later date. The dural closure must be meticulous to prevent cerebrospinal fluid (CSF) leakage and infections. Nevertheless, with careful planning and specialized instruments, all of these goals can be accomplished using minimally invasive surgery (MIS).

Preoperative Planning

Addressing intradural lesions requires a preoperative assessment of the space required to remove the lesion. The patient's magnetic resonance (MR) images must be closely scrutinized, in order to determine whether a lesion can be removed using MIS techniques. The MR images must also be evaluated to see whether the lesion is eccentric to one side or the other. Intradural extramedullary lesions that compress the spinal cord from either the left or the right lend themselves well to being resected via an MIS approach (Fig. 1). Furthermore, it is possible to achieve ample visualization across the midline through a tube or an expandable retractor. However, lesions that are located on the ventral aspect of the spine and compress the spinal cord posteriorly are not amenable to MIS techniques, as they require a large dural opening to cut

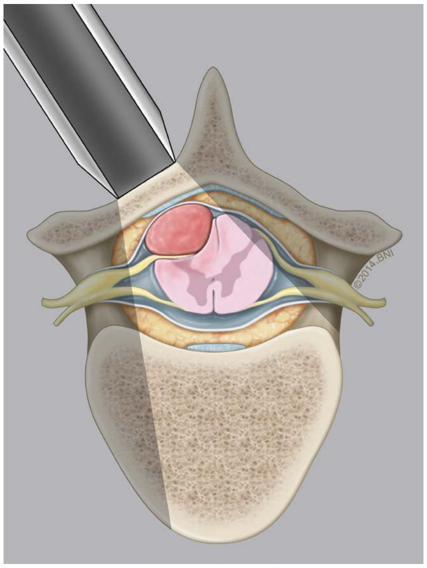


Figure 1. Axial view of docking site of expandable minimally invasive retractor, and access to intradural lesions afforded by retractor with angulation.

the dentate ligaments and mobilize the spinal cord so the tumor can be safely removed.

Both fixed tubes and expandable retractors can be used. Large intradural lesions, even up to 4 cm, can be removed with expandable minimally invasive retractors. Vascular lesions such as dural arteriovenous fistulas do not require a large exposure, but do require extensive preoperative review of the diagnostic images to identify the correct level on which to dock the MIS retractor system. Treatment of vascular lesions also requires other intraoperative diagnostic modalities, such as proper optical filters on the operative microscope to allow the surgeon to visualize indocyanine green injections, as well as the potential use of intraoperative diagnostic angiograms.

It is of the utmost importance that the surgeon be able to visualize the entirety of the tumor through the retractor system, as well as the normal neural elements that are rostral and caudal to the tumor. An exposure that does not allow full visualization may lead to unnecessary manipulation of the tumor, nerve roots, or spinal cord. Inability to properly visualize the plane of the tumor may cause unnecessary piecemeal resection, which can be inefficient and may result in residual tumor being left behind. Inadequate visualization may also lead the surgeon to reposition the tube, which can increase the risk of damage to the neural elements. Repositioning the tube often causes blood to drain into the subarachnoid space. Thus, an expandable retractor system can assist the MIS surgeon in properly treating patients with these difficult lesions.

The size of retractor needed is determined preoperatively by measuring the size of the lesion in the sagittal plane. We usually choose either a tube or an expandable retractor that is 5 to 10 mm larger than the planned length of the dural incision; the incision length is usually planned to be 5 to 10 mm larger than the length of the intradural pathology. The retractor must provide an exposure that gives the surgeon enough space to perform a tight dural closure. For intradural lesions, expandable retractors are used more often than fixed tubes because expandable tubes cause minimal trauma to the tissue while providing adequate working space. Expandable retractors have more freedom in angulation so that one can accommodate the dural opening and any tenting sutures. Expandable retractors also allow greater ability to reposition the retractor blades intraoperatively. This ability can be helpful when dealing with tumors of the cauda equina, which can migrate slightly due to body position. Intraoperative localization of these intradural lesions based on the preoperative MR image may be more challenging than other spinal lesions, and having additional angulation is invaluable.

Technique

After appropriate preoperative planning has occurred, fluoroscopy and a small Tuohy needle are used to determine if the surgeon is at the planned entry point. It is our preference to use a Jackson table with standard chest, hip, and thigh pads, as all are radiolucent. Because localization in the thoracic spine can be particularly difficult, all patients have standard radiographs of the lumbar spine taken, and we confirm that the patient has 5 non-rib vertebrae in the lumbar spine on the anteroposterior radiograph. These radiographs serve as a valuable reference in the operating room when looking at the fluoroscopic images. For localization in the thoracic spine, multiple spinal needles are placed at regular intervals, starting at the L4 pedicle and proceeding into the thoracic spine. Lateral and anteroposterior images are taken and the levels of the spinal needles are confirmed. The ideal strategy is to have the tip of the spinal needle pointing directly to the thoracic pedicle of the pathology to be treated, as this minimizes any confusion on anteroposterior and lateral images.

Use of an expandable retractor to dilate through the muscle to access the pathology prevents painful recovery for the patient, which often occurs after traditional open procedures that require stripping the muscle away from the midline structures for access to the lamina and facets.[3,4,9,10] In the thoracic spine, the transverse process becomes the initial docking point in minimally invasive procedures. The transverse process projects more posteriorly than laterally, as opposed to the lumbar spine. It may be readily palpated and used to guide the dilators onto the lamina. The thoracic lamina tends to be steeper than the lumbar lamina as it joins the spinous process, which makes the working corridor slightly narrower, constraining intradural work. However, this narrower lamina allows a trajectory to readily undercut the spinous process and expose the midline of the thecal sac. For lesions in the thoracic spine, an incision that is 2 to 2.5 cm lateral to midline allows for appropriate docking onto the transverse process. An incision too medial will prevent angulation of the tube, therefore preventing adequate midline and pedicle exposure.

After appropriate localization, incision, and docking, the main approach for accessing the spinal cord using an

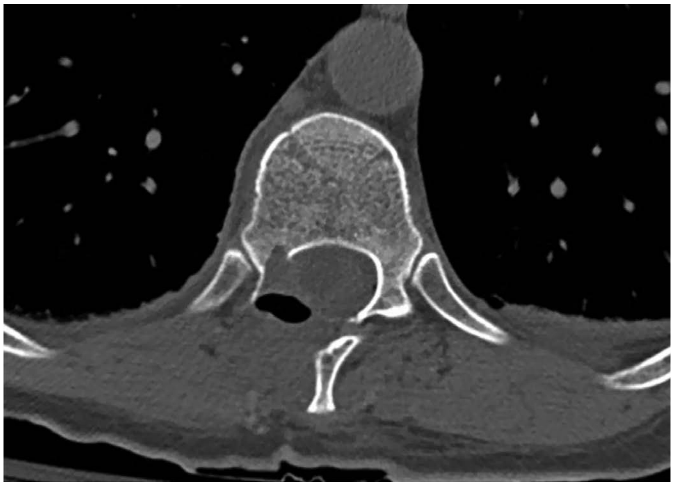


Figure 2. Axial postoperative computed tomography scan demonstrates the amount of bone typically removed in a minimally invasive procedure to access intradural lesions.

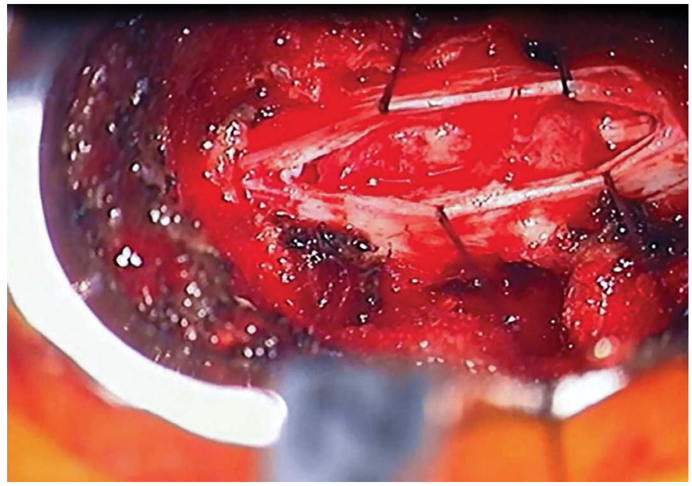
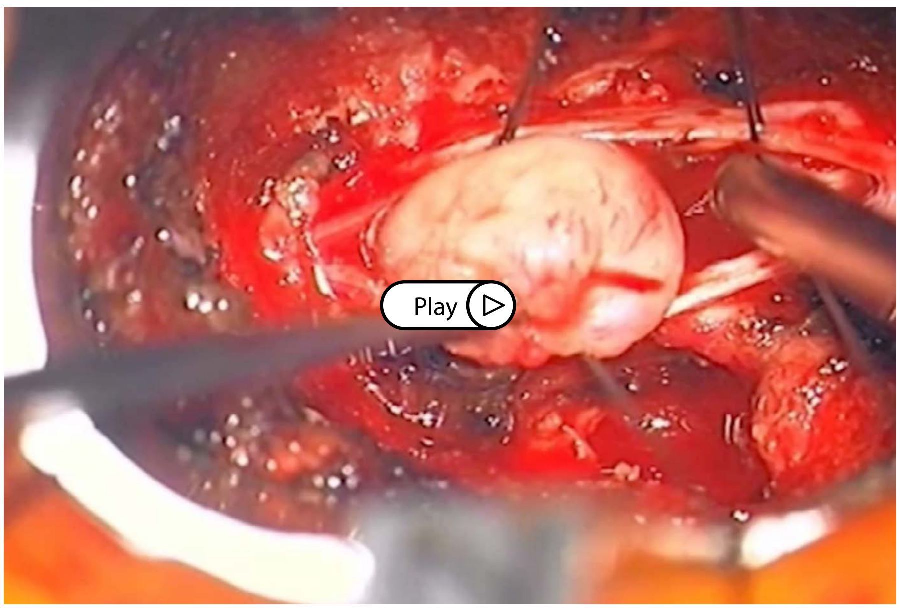


Figure 3. Complete exposure of a meningioma in the thoracic spine before removal.



Video 1. Minimally invasive resection of spinal meningioma. https://www.barrowneuro.org/Intradural1

MIS approach is via a hemilaminectomy. Drilling proceeds on the underside of the spinous process (Fig. 2). To determine if visualization is sufficient across the midline, the surgeon can feel for the foramen on the other side using a blunt nerve hook. This approach allows the surgeon to access pathology on both the ipsilateral and contralateral sides of the approach. While providing adequate visualization, the hemilaminectomy also maintains the integrity of the spinous processes and posterior tension bands. As a result, much of the patient's spinal stability is retained postoperatively. Visualization through the tube is maximized by using the operative microscope. A combination of a curette, Kerrison rongeurs, and a bayonetted drill can be used to create a hemilaminectomy. This hemilaminectomy can be continued to the level above or below the lesion, depending on its size. Identifying and detaching the ligamentum flavum from the lamina using a curette will allow the surgeon to angle the tube more medially and to drill more medially while still protecting the dura.

Once proper visualization across the midline, as well as cranially and caudally, has been achieved, the fibers of the ligamentum flavum can be carefully separated in a cranial-caudal direction by using a No. 4 Penfield dissector. When the plane between the ligamentum flavum and the dura has been identified, an angled curette or a ball-tipped probe can be used to detach and pull away the ligamentum flavum from the dura. With the space created, 1- or 2-mm Kerrison rongeurs can further remove the ligamentum flavum. When the dura is fully exposed, a No. 11 blade is used to incise the dura. Then 4-0 Nurolon sutures (Ethicon US, LLC, Somerville, NJ) are tacked on either side of the dura and clamped with a hemostat outside the tube to create the desired tension on the dura. At this point, standard microsurgical techniques are used to remove the lesion. Microscissors and Rhoton dissectors are used to create a plane around the lesion, and small Cottonoids are used to maintain the plane. This type of dissection is predominantly used in meningioma removal (Fig. 3, Video 1). An ultrasonic aspirator can be used to debulk tumors. Although piecemeal tumor removal can be inefficient and may lead to residual tumor, it is occasionally required to avoid cord injury. One can achieve adequate space within an expandable tube to properly identify lesions, such as in dural arterio-

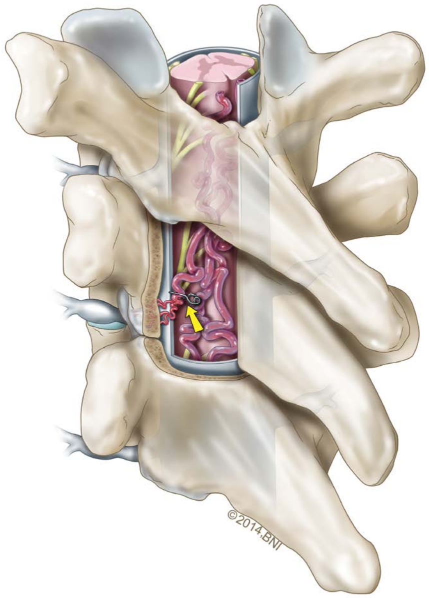


Figure 4. Illustration of amount of bone removed to visualize a dural arteriovenous fistula (*arrow*) through an expandable retractor.

venous fistulas when the fistulous point may lie more laterally than midline (Fig. 4). For vascular lesions, such as dural arteriovenous fistulas and arteriovenous malformations, indocyanine green angiography can be performed intraoperatively to visualize feeders before placing an aneurysm clip or performing bipolar cauterization (Fig. 5 and 6, Video 2). Many types of lesions can be treated using this approach.

Once the lesion is treated, hemostasis is achieved and the surgical site is irrigated with antibiotic solution. The dura can be closed with 4-0 Nurolon or 5-0 Prolene (Ethicon US, LLC), according to surgeon preference (Fig. 7). A knot pusher in combination with a Castro-viejo needle holder can help speed this process. A Valsalva maneuver is performed to ensure a watertight closure, and surgical glue, such as the hydrogel sealant DuraSeal (Confluent Surgical, Inc.; Integra LifeSciences Holdings Corp., Plainsboro, NJ) or the fibrin sealant Tisseel (Baxter Healthcare Corp., Westlake Village, CA), is placed over the dural incision. Dural closure can consistently be performed safely

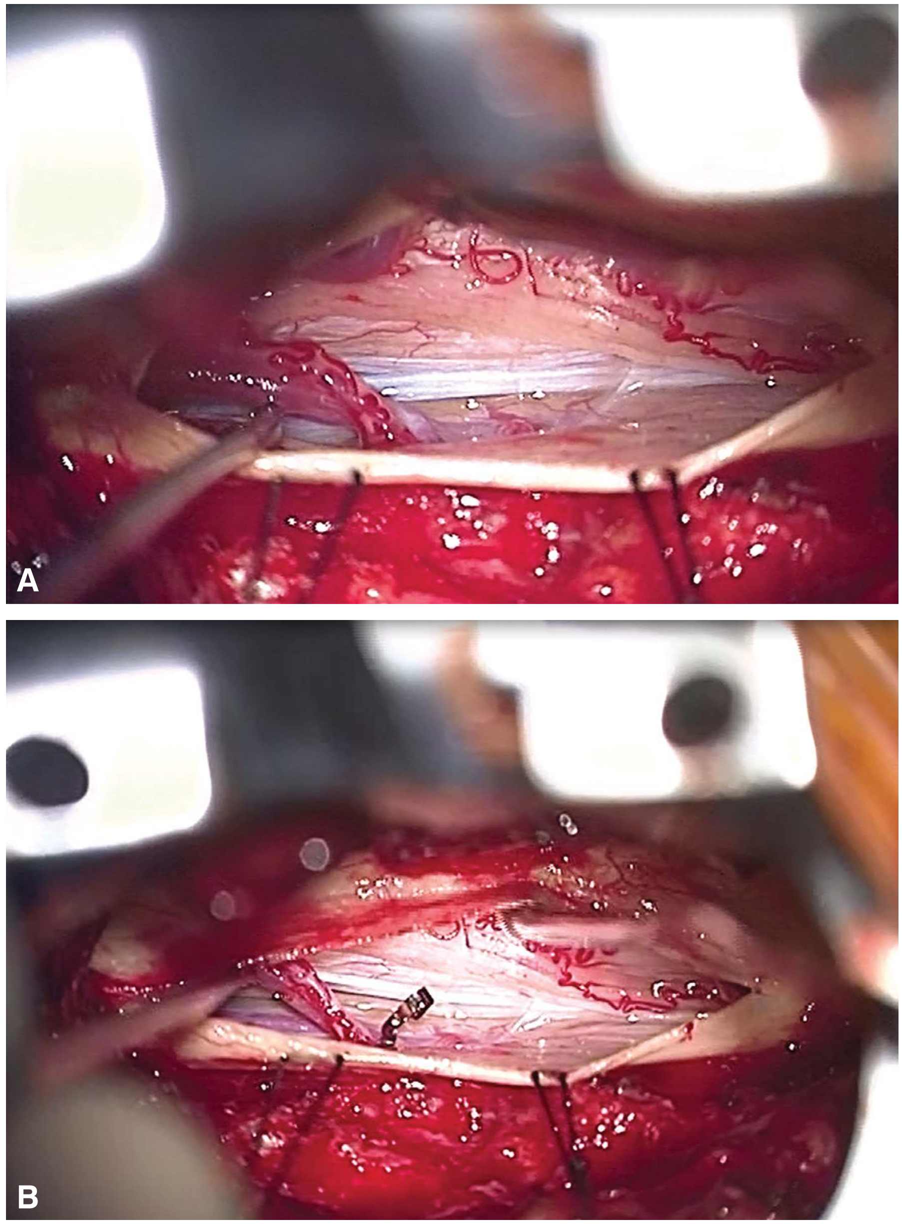


Figure 5. A dural arteriovenous fistula at T9 (A) before and (B) after clipping.

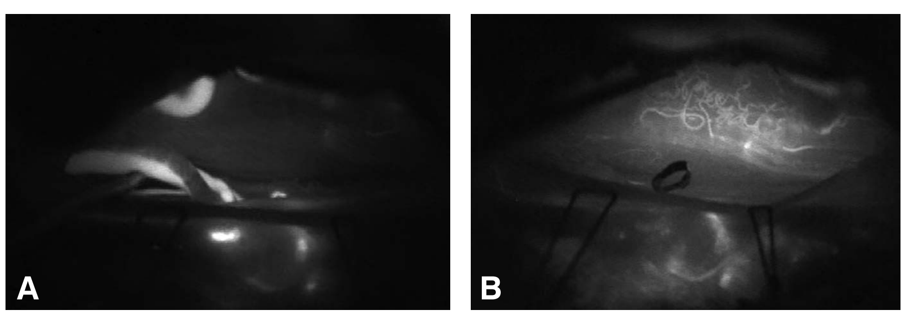
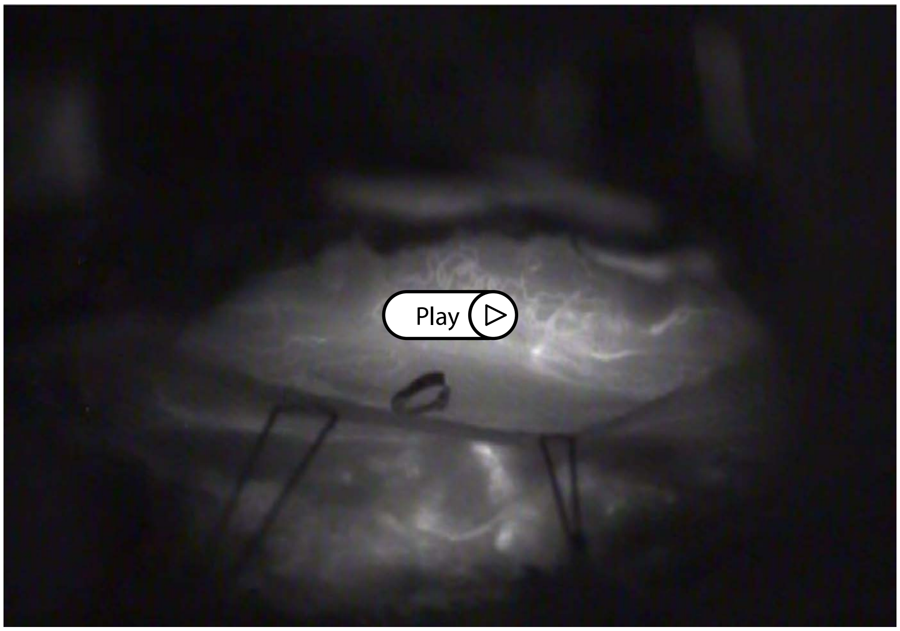


Figure 6. Indocyanine green angiography of a T9 dural arteriovenous fistula (A) before and (B) after clipping.



Video 2. Minimally invasive treatment of spinal dural arteriovenous fistula. https://www.barrowneuro.org/Intradural2

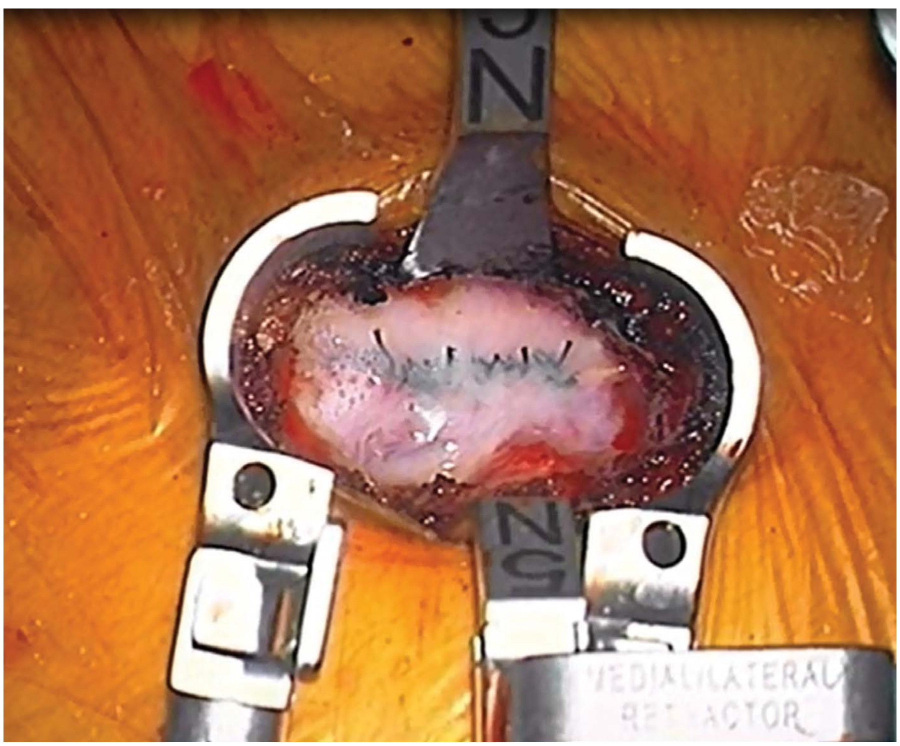


Figure 7. Dural closure with nylon sutures and a fibrin sealant.

and efficaciously without an increased likelihood of CSF leak after the procedure.[1] The retractor is removed slowly to allow any further bleeding sites to be identified. The fascia and skin are closed with buried sutures. The small incisions and decreased muscle dissection associated with these procedures allow for decreased blood loss and shorter hospital stays.[7]

As can be seen in the cases described above and in the figures, because minimally invasive resections of intradural tumors are performed unilaterally, disruption of the posterior elements is limited. Patients are therefore less susceptible to spinal instability that may require fusion. In open approaches, removing the midline support structures, such as the interspinous ligaments, midline bone, and muscle, even when a laminoplasty is performed, may predispose the patient to developing progressive kyphosis. Because the MIS approach obviates the need for a large exposure, and often prevents the surgeon from performing laminoplasty or fusion, both the duration of the procedure and the risk of infection can be decreased.[6] Smaller exposures also have less dead space because less muscle is displaced, and there is therefore a decreased risk of pseudomeningocele or reoperation for CSF leak.[8] Furthermore, unless the lesion extends to the facet and the facet is disrupted during dissection, the facet joints remain intact, preventing instability and the need for fusion at a later time.

Outcomes

In 2006, Tredway and colleagues first reported using MIS techniques to treat intradural spinal tumors.[11] Since then, several other reports have further demonstrated the safety and efficacy of MIS techniques when using expandable tubular retractors in select groups of patients with intra- or extradural spinal neoplasms. In 2013, Gandhi and German treated 14 oncological lesions via an MIS approach without CSF leak, infection, or spinal instability.[2] In 2011, Haji et al. reported treating patients with 2 cervical, 7 thoracic, and 13 lumbar neoplasms with a mean intraoperative time of 210 minutes, a mean blood loss of 428 mL, and a mean length of hospital stay of 3 days. Four patients required postoperative patient-controlled analgesia for pain control and an average of 5.8 doses of narcotic were given per patient.[5] Lu et al. examined the differences between 18 patients with MIS-treated intradural tumors and 9 with intradural tumors treated with open surgery and found no statistically significant difference in operative duration, American Spinal Injury Association impairment scale score improvement, or back pain visual analog scale score improvement between groups. However, the mini-open group demonstrated a significantly lower estimated blood loss (153 vs. 372 mL, respectively) and a significantly shorter length of hospitalization (4.9 vs. 8.2 days, respectively) compared with the open group.[6] In centers in which minimally invasive intradural spine surgery is being performed, patients have experienced reduced operative time, blood loss, length of hospital stay, and postoperative pain without an increased incidence of complications.

Conclusions

The management of intradural extramedullary lesions of the thoracic spine is not only feasible but also safe and efficacious. As spine surgery continues to evolve toward less invasive techniques, it becomes imperative for the next generation of surgeons to develop a skill set to manage such lesions.

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