The Resident's Guide to Spine Surgery

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ISBN 978-3-030-20846-2 ISBN 978-3-030-20847-9 (eBook)
https://doi.org/10.1007/978-3-030-20847-9

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Preface

Spine surgery in 2019 is more advanced than ever. As a multidisciplinary field, it draws from the expertise of orthopaedic surgeons and neurosurgeons. Additionally, the advances in minimally invasive techniques have added a layer of complexity.

For residents in either specialty, it can be a daunting task to learn all of the procedures in a short period of time. This book has been assembled by a group of experts with a long tradition of educating residents. The overarching goal has been to create a concise guide to each procedure and make it "learnable". For both orthopaedic and neurological resident surgeons, this book will be a guide to acquire the requisite skills in spine surgery.

Bethesda, MD, USA
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Acknowledgments

I would like to acknowledge my co-editors and Claire van Ekdom for their work over the last 2 years in preparing this text book. In particular, Claire has been instrumental in organizing the entire textbook. Without their collective effort, this book would not have been possible. I would also like to thank my family (Janet, Brad and Alex) for their love and support while I focused on this project.

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Chapter 1
Anterior Cervical Discectomy and Fusion

Crystal Adams, Fadi Sweiss, Michelle Feinberg, and Jonathan H. Sherman

Indications and Patient Selection

The anterior cervical discectomy and fusion for single-level disc disease was first described by Smith, Cloward, and Robinson in 1958 and the use of anterior cervical plates was introduced in the 1960s [8]. Since that time, the anterior cervical discectomy and fusion (ACDF) procedure has become a mainstay in spinal surgery and its indications have expanded. Overall, the primary goal of the procedure is to relieve mechanical pressure on the spinal cord and/or spinal nerve roots associated with the patients' presenting symptomatology. Surgical intervention becomes necessary when patients' symptoms are refractory to nonsurgical treatment. Typical symptoms can include radicular pain, weakness, numbness, as well as difficulty walking. Some patients may also experience bowel or bladder incontinence [18].

There are several key indications for the use of the ACDF procedure and appropriate patient selection is of the utmost importance to ensure the best patient outcomes. In particular, it is helpful in patients presenting with either cervical radiculopathy or myelopathy secondary to disc herniation, anterior osteophyte complexes, or bony spurs which cause spinal canal narrowing and spinal cord compression or nerve root impingement [5]. Additionally, this procedure may be helpful in patients presenting with spondylitic radiculopathy. It may be successfully utilized in patients presenting with both single-level and multilevel cervical disease [5].

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_1

As with any procedure, there are some contraindications for utilizing an ACDF procedure. Patients whose cervical pathology is mostly posterior are not appropriate candidates for this procedure as a posterior approach would more adequately address the likely cause of their symptoms. Additionally, as will be discussed later, there are some risks associated with an anterior approach to the cervical spine such as impaired vocal cord function which some patients may be unwilling to risk. Finally, there are patients who may be poor surgical candidates in general due to significant medical comorbidities.

There are several key advantages to the ACDF. The primary advantage is that it allows the surgeon to address anterior pathology under direct vision. Second, the procedure involves a complete discectomy which promotes an overall better rate of fusion. An additional advantage is that it avoids the need for patients to be placed in prone position, particularly in elderly patients who may have multiple cardiopulmonary comorbidities.

Alternatives to ACDF include anterior cervical discectomy without fusion, cervical total disc replacement, cervical laminoplasty, posterior cervical foraminotomy, and cervical laminectomy with or without fusion.

Preoperative Planning

Patients should have appropriate preoperative imaging and exams prior to the procedure. A preoperative cervical spine MRI provides the best assessment of the spinal canal and more specifically the spinal cord. Patients may also have a cervical CT scan and/or flexion-extension x-rays to assess for evidence of any motion abnormalities suggesting instability. Patients who are unable to undergo an MRI due to presence of metal implants may have a CT myelogram. A thorough understanding of the patients' vertebral arterial anatomy is imperative to decrease the risk of inadvertent vertebral artery injury during the case. Preoperative imaging should also be used to assess anticipated dimensions of the plate and screws to be used. Given the associated risk of vocal cord dysfunction postoperatively, patients who have had a prior anterior cervical approach surgery may need to undergo a preoperative ENT evaluation with laryngoscopy to assess for preoperative vocal cord function. In one study, they found that 17.3% of patients had abnormal findings on laryngoscopic exam which affected decisions regarding approach for revision ACDF [9]. Patients with significant cardiopulmonary comorbidities should obtain necessary medical clearance prior to undergoing surgery. In addition, knowledge of patients' medical comorbidities and social history is important for assessing risk of fusion failure as well as for appropriate intraoperative and postoperative management.

Anesthetic Considerations and Preoperative Medications

In patients with cervical myelopathy or evidence of cervical instability, awake fiberoptic intubation may be performed to help minimize the potential for inadvertent neurologic trauma. The use of SSEPs during surgery requires that the anesthetic cocktail utilized be one that preserves these signals. This is typically one that utilizes a moderate dose narcotic-based regimen supplemented by an inhalation agent [12]. Preoperative antibiotics are typically given by anesthesia [7]. Some surgeons may also opt to give preoperative DVT prophylaxis with subcutaneous heparin. Additionally, preoperative steroids may be given to the patient to help decrease the risk of edema [13]. Of note, during the procedure the endotracheal cuff should be intermittently deflated to decrease risk of injury to the recurrent laryngeal nerve.

Neuromonitoring

Intraoperative neuromonitoring is an adjunct when performing an ACDF, the use of which is depending on surgeon's preference. Typically, EMG, SSEPs, and MEPs are utilized during the procedure. Preoperative baselines are performed prior to the start of the procedure, and surgeons are alerted to any signal changes during the procedure [12].

Positioning

The patient is placed in supine position with the head of the bed towards the anesthesia team. The bed can be raised in reverse Trendelenburg to facilitate venous drainage. The arms are tucked at the side. A radiolucent bed is used to facilitate intraoperative fluoroscopy. The neck is then placed in slight extension [7]. A shoulder roll is placed under the scapulae. Some surgeons place this roll vertically between the scapulae while other surgeons orient the roll horizontally. In addition to a shoulder roll, some surgeons utilize Gardner-Wells tongs with 5 to 10 pounds of traction to assist with visualization and to assist with keeping the neck in neutral rotation as well as to provide additional cervical lordosis. The shoulders are then taped down to allow for better visualization of the lower cervical spine. As an alternative to taping the shoulders, soft straps can be placed around the wrists and pulled down. Several landmarks can be used to denote certain cervical levels. The angle of the mandible can be used to approximate the C2 vertebral body. The hyoid bone is located at the C2-C3 interspace [16]. The thyroid cartilage is typically at the C4-C5 disc interspace. The cricoid cartilage typically overlies the C6 level [3, 16]. Prior to incision, a metal object, such as a towel clamp, is used in association with fluoroscopy to identify the surgical levels to ensure the positioning allows for adequate exposure. Adjustments can be made based on these preoperative fluoroscopic images.

Approach

The anterior cervical spine may be approached from either the left or the right side. The side a surgeon chooses for the approach is often dictated by surgeon preference. However, there are certain circumstances where other factors must be taken into account. For example, if a patient has had a prior anterior cervical surgery, the surgeon will often use the prior incision. In patients who have vocal cord paralysis, the cervical spine is approached from the side with the paralysis. Additionally, surgical anatomy varies to some degree between right- and left-sided approaches. In particular, the recurrent laryngeal nerve on the right has a more variable course and tends to lie more anterolateral thus putting it in a more vulnerable position for injury during approach particularly at lower cervical levels. The thoracic duct is visible on the left side at the C7-T1 level and must be protected during a left-sided approach at this level.

In most cases, a transverse incision is used along a natural skin fold. This spans from the midline to the anterior border of the sternocleidomastoid. However, for access to greater than 3 levels, a longitudinal incision along the medial sternocleidomastoid muscle may be necessary [7]. A longitudinal incision may also be necessary in extremely obese patients.

After the skin incision is performed, the platysma is sharply incised and elevated at both ends of the incision. This can be done using either Metzenbaum scissors or bovie cautery. Blunt dissection is then employed below the platysma muscle. The degree of necessary subplatysmal dissection is dictated by the number of levels to be addressed. In continuing with dissection, the cervical fascia is then opened anterior to the sternocleidomastoid muscle and dissection is proceeded along the medial border of the sternocleidomastoid muscle. The plane between the sternocleidomastoid muscle and the strap muscles is identified and both blunt and sharp dissection is used to exploit this plane [3, 10]. Special attention must be paid to the location of several key structures during this dissection to avoid inadvertent injury. In particular, the superior and inferior thyroid arteries extend from carotid towards midline through the pretrachial fascia at the C3–4 and C6–7 levels respectively. In continuing with the dissection, the carotid sheath is retracted laterally and the trachea and esophagus are retracted medially with handheld retractors. The prevertebral fascia is then excised in the midline and the vertebral bodies and disc spaces become palpable. It is important that the midline be maintained during the entire procedure. The appropriate level is identified and a spinal needle is inserted and the level is confirmed with lateral fluoroscopy. The longus colli muscles are then stripped laterally. This can be done with or without bovie cautery. A self-retaining retractor system is then utilized to retract the longus colli muscles. One should keep in mind that the cervical sympathetic plexus lies along the longus colli muscle and are at risk for injury with significant dissection along the longus colli muscles. The anterior longitudinal ligament is then dissected off the anterior vertebral bodies [3, 10].

Depending on surgeon preference, a microscope may or may not be used for the decompression portion of the procedure. While some surgeons argue that that microscope allows for enhanced visualization for the entire surgical team other surgeons prefer to use only surgical magnifying loupes. In either case, the next step in the procedure is the discectomy. At this point, a pin retractor system is utilized to create disc space distraction. A small window is made in the disc space with an 11-blade. The superficial disc material is removed using a combination of curettes and pituitary rongeurs. A Leksell rongeur may also be used to remove anterior disc osteophytes prior to the discectomy. For the deeper portion, a high-speed carbide or diamond burr drill can be used to remove all bony disc osteophyte material while preserving the posterior longitudinal ligament [13, 18]. The key in this portion of the procedure is to try to remove all bony disc material without injuring the vertebral artery. Typically, an adequate decompression is considered to have been obtained if the posterior osteophytes have been addressed, the neural foramina have been decompressed, and a 3 mm area of bone remains on each side to protect the vertebral artery. In addition to removing the bony disc material, the entire posterior longitudinal ligament is removed in a chevron fashion across the entire interspace utilizing Kerrison rongeurs. Right-angled nerve hooks are used to explore the neural foramen on each side to ensure adequate decompression. Kerrison rongeurs can be utilized to provide further decompression if necessary.

The next portion of the procedure is the fusion. The bony endplates are drilled to promote fusion. An interbody spacer sizer is used to measure the size of the disc space. An appropriate-sized structural bone graft or cage packed with autograft or allograft is then inserted into the disc space using a mallet [3, 11]. Intraoperative fluoroscopy is then used to confirm adequate placement.

A titanium cervical plate of appropriate length to span the fusion levels is chosen. Preoperative imaging can be used to measure anticipated plate length. The plate is temporarily fixed with pins and appropriate position verified by fluoroscopy prior to placement of screws. Screw holes are then made using a manual drill. The upper screws are angled rostrally and the lower screws are angled caudally at each level to be divergent to the disc space. Screws are typically between 12 and 16 mm. The screws are then tightened and locked in place. The final position is then verified by fluoroscopy.

After final confirmation of position, the self-retaining retractor system is removed. The superficial and deeper portions of the incision are then inspected and adequate hemostasis is obtained using bipolar cautery. The wound is irrigated with bacitracin irrigation. In multilevel ACFDs, a drain may be left in place. For closure, the platysma is re-approximated using 3–0 vicryl interrupted sutures. The skin is then approximated with buried 3–0 vicryl interrupted sutures and dermabond is placed over the skin incision. Alternatively, a running subcuticular 4–0 monocryl can be used to close the skin incision [3].

Postoperative Course

Patients are typically admitted to the surgical floor overnight for monitoring. Immediate postoperative AP and lateral x-rays are often obtained. However, some surgeons prefer to obtain standing AP and lateral cervical spine x-rays prior to discharge. Depending on bone quality, surgeons may opt to have some patients wear a cervical collar until follow-up in clinic [13]. Patients are usually encouraged to ambulate early once they have recovered from anesthesia. Patients are typically evaluated by physical therapy and occupational therapy on postoperative day 1.

Some patients may require speech therapy evaluation due to dysphagia or swallowing difficulty due to manipulation during surgery. In cases where a drain was left in place, it can usually be removed on postoperative day 1 if output is relatively low. Many patients are able to be discharged home on postoperative day 1. Some patients may require a slightly prolonged hospital stay.

Of note, there are some institutions which have started to perform single and two level ACDFs on an outpatient basis at ambulatory surgery centers. A retrospective study conducted by Adamson et al. compared 1000 consecutive patients undergoing ACDFs performed at an ambulatory surgery center with 484 consecutive patients undergoing ACDFs performed at the associated hospital. Their study showed similar complication rates in both groups with serious complications such a postoperative hematoma or vascular injury were last than 0.5% in both groups. The overall conclusion was that ACDFs can be performed safely in the ambulatory surgery center setting. However, they emphasized that not all patients are appropriate for surgery in this setting which underscores the need to have a good understanding of each patient's underlying medical comorbidities prior to surgery [1].

Potential Complications

There are several well-defined potentially serious complications which can occur with the procedure. A cerebrospinal fluid leak may occur and, if possible, should be repaired primarily. Dural substitutes or fibrin glue may also be used. Patients should be kept upright after the procedure in the case of a cervical spinal fluid leak. A lumbar drain may need to be placed if the leak does not resolve [3]. There is also risk of vertebral artery injury during the procedure particularly if the exposure is too lateral. In one study looking at 992 ACDF procedures, vertebral artery injury occurred in 0.3% of the cases during foraminal decompression. This point reinforces the need to have a good understanding of the patient's vertebral artery course on preoperative imaging. Should a vertebral artery injury occur, it is important to try and obtain sufficient hemostasis as quickly as possible with hemostatic packing such as gelfoam [15]. Better exposure of the vertebral artery may be required to identify the site of bleeding [3]. Should adequate hemostasis not be able to be obtained, the involved vertebral artery segment may need to be IR intervention [15]. Another potential complication is hematoma formation requiring evacuation. For this reason, patients are watched closely for evidence of airway compromise in the postoperative period.

Other potential complications include recurrent laryngeal nerve injury, tracheal or esophageal injury, graft or screw migration, pseudoarthrosis, and future adjacent segment disease [3, 4, 6]. Rates of adjacent segment disease after ACDF vary greatly in the literature from 25% to 92% [2]. In a systematic review performed by Lawrence et al., they estimated the risk of symptomatic adjacent segment disease as anywhere between 1.6% and 4.2% per year [14]. In the immediate postoperative period, some patients experience dysphagia and/or difficulty swallowing requiring speech therapy evaluation and diet adjustment. In some cases, patients may require temporary alternative means of nutrition such as a dobhoff tube or PEG tube in more severe cases. In a retrospective study performed by Wang et al., they found that increased operative time was a factor that significantly increased immediate postoperative dysphagia. Additionally, smoking and diabetes were the patient factors that most significantly affected rate of recovery from postoperative dysphagia [17]. Some patients also experience hoarseness in the immediate postoperative period which typically improves over several days. In some cases, patients may benefit from a short course of postoperative steroids to decrease perioperative edema. In a double-blinded randomized controlled trial performed by Jeyamohan et al., patients received either preoperative IV dexamethasone or placebo and then received postoperative IV dexamethasone every 6 h for the first 24 h after surgery or placebo. Their results showed that patients receiving the steroids had significantly lower rates of dysphagia and trend in decreased number of airway issues and need for intubation trended towards significance in the steroids group. Of note, their study did reveal that rate of fusion was significantly lower in the steroids group at 6 months but that there was no significant difference in fusion rate between groups at 12 months' follow-up [13].

References

1. Adamson T, Godil SS, Mehrlich M, Mendenhall S, Asher AL, McGirt MJ. Anterior cervical discectomy and fusion in the outpatient ambulatory surgery setting compared with the inpatient hospital setting: analysis of 1000 consecutive cases. J Neurosurg Spine. 2016;24(6):878–84.
2. Ahn SS, So WS, Ku MG, Kim SH, Kim DW, Lee BH. Radiologic findings and risk factors of adjacent segment degeneration after anterior cervical discectomy and fusion: a retrospective matched cohort study with 3-year follow-up using MRI. J Korean Neurosurg Soc. 2016;59(2):129–36.
3. Albasheer M, AlFawareh M, AlMusrea K, Attia W. Anterior cervical diskectomy and fusion. In: Neurosurgery tricks of the trade, spine and peripheral nerves. 1st ed. New York: Thieme Medical Publishers; 2014.
4. Basques BA, Ondeck NT, Geiger EJ, Samuel AM, Lukasiewicz AM, Webb ML, et al. Differences in short-term outcomes between primary and revision anterior cervical discectomy and fusion. Spine. 2017;42(4):253–60.
5. Bohlman HH, Emery SE, Goodfellow DB, Jones PK. Robinson anterior cervical discectomy and arthrodesis for cervical radiculopathy. Long-term follow-up of one hundred and twenty-two patients. JBJS 10993. 75(9):1298–307.
6. Cauthen JC, Kinard RE, Vogler JB, Jackson DE, DePaz OB, Hunter OL, et al. Outcome analysis of noninstrumented anterior cervical discectomy and interbody fusion in 348 patients. Spine. 1998;23(2):188–92.
7. Choudri TF, McCormick P. Anterior cervical approach. In: Fundamentals of operative techniques in neurosurgery. (2nd. New York: Thieme Medical Publishers; 2010.
8. Cloward RB. The anterior approach for removal of ruptured cervical disks. J Neurosurg. 1958;15(6):602–17.
9. Curry AL, Young WF. Preoperative laryngoscopic examination in patients undergoing repeat anterior cervical discectomy and fusion. Int J Spine Surg. 2013;7(1):e81–3.
10. Dillin W. Anterior cervical disc surgery: technical challenges. In: Surgical Techniques for the Spine. 1st ed. New York: Thieme Medical Publishers; 2003.

11. Floyd T. A meta-analysis of autograft versus allograft in anterior cervical fusion. Eur Spine J. 2000;9(5):398–403.
12. Hammerberg K. Anesthesia. In: Spinal Deformities. 1st ed. New York: Thieme Medical Publishers; 2003.
13. Jeyamohan SB, Kenning TJ, Petronis KA, Feustel PJ, Drazin D, DiRisio DJ. Effect of steroid use in anterior cervical discectomy and fusion: a randomized controlled trial. J Neurosurg Spine. 2015;23(2):137–43.
14. Lawrence BD, Hilibrand AS, Brodt ED, Dettori JR, Brodke DS. Predicting the risk of adjacent segment pathology in the cervical spine: a systematic review. Spine. 2012;37:S52–64.
15. Obermüller T, Wostrack M, Shiban E, Pape H, Harmening K, Friedrich B, et al. Vertebral artery injury during foraminal decompression in “low-risk” cervical spine surgery: incidence and management. Acta Neurochir. 2015;157(11):1941–5.
16. Shen XH, Xue HD, Chen Y, Wang M, Mirjalili SA, Zhang ZH, Ma C. A reassessment of cervical surface anatomy via CT scan in an adult population. Clin Anat. 2017;30(3):330–5.
17. Wang T, Ma L, Yang DL, Wang H, Bai ZL, Zhang J, Ding WY. Factors predicting dysphagia after anterior cervical surgery: a multicenter retrospective study for 2 years of follow-up. Medicine. 2017;96(34)
18. Zheng B, Hao D, Guo H, He B. ACDF vs TDR for patients with cervical spondylosis–an 8 year follow up study. BMC Surg. 2017;17(1):113.

Chapter 2
Cervical Corpectomy

Gregory Callanan, Ra' Kerry Rahman, and Kris Radcliff

Introduction

Anterior cervical corpectomy and fusion (ACCF) is a surgical technique utilized to treat patients when a more generous decompression is required than capable with discectomy alone. By far, the most common condition treated with this technique is cervical spondylotic myelopathy (CSM). It is also utilized to remove vertebrae that have been damaged or otherwise deformed from trauma or neoplasms of the cervical spine. It is performed by removal of the affected vertebral body and associated intervertebral discs to allow for decompression of the cervical cord. A strut graft or cage construct is then placed into the void to stabilize the anterior column. Anterior plating can be used to provide stability and support during the fusion process. Segmental anterior plating is especially recommended when performing multilevel corpectomies due to the high incidence of early instrument failure [8, 17]. Furthermore, posterior instrumentation may be necessary to support multilevel corpectomies [18]. This chapter will discuss the application of ACCF in the clinical setting as well as technical aspects of the procedure.

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_2

Indications for Cervical Corpectomy

The presence of retrovertebral disease is the primary indicator for use of the corpectomy procedure. ACCF has been shown to be an effective procedure for decompressing the anterior spinal cord. Multilevel discectomies should be performed when feasible over corpectomy procedures. When retrovertebral disease is present and multilevel surgery is required, a hybrid discectomy/corpectomy procedure is a viable option [15, 16]. Cervical corpectomy has several advantages/disadvantages that a surgeon should consider when contemplating this technique for patients. Corpectomy is generally favored over multilevel anterior discectomy in cases of long segment ossification of the posterior longitudinal ligament (OPLL), traumatic disruption of the vertebral body, osteomyelitis, and neoplasms [3]. Essentially, all of these conditions require either expanded decompression in order to attain the desired clinical result or removal of the vertebral body to accomplish the clinical goal. This removal is necessary to provide space for appropriate anterior column support and/or is part of a treatment plan for proper resection. Corpectomy has the ability to provide a more complete decompression, especially when there is significant stenosis behind the vertebral body. Corpectomy also has the advantage of improved visualization, fewer bone-graft interfaces to heal and a greater surface area to help facilitate fusion [8]. Hence, the theoretical risk of pseudarthrosis is less with ACCF compared to multilevel ACDF. Fraser et al. performed a meta-analysis investigating the fusion rates between ACDF with plating and ACCF. The authors reported no significant difference between ACDF with plating and ACCF when investigating two level disease; for three level disease however, the authors reported that ACCF was associated with higher fusion rates than ACDF [5].

The disadvantages include greater approach morbidity per level, more technically demanding than discectomy only procedure, greater risk of vertebral artery injury, more bleeding, more exposure of the spinal cord with resultant risk of iatrogenic injury, higher implant and graft complication profile, subsidence, and risk of suboptimal postoperative sagittal alignment [13, 14].

Surgical Approach

The patient is positioned supine on the operating table after induction and intubation. A longitudinal bump is placed between the patient scapulae with a small pillow beneath the patient's head in order to place the cervical spine into slight extension. Extreme caution must be taken when positioning the patient cervical spine and intubation to avoid neurological deterioration secondary to hyperextension of the stenotic canal in those patients with significant myelopathy. The patient's arms are tucked at the side with shoulders taped caudally to help with proper visualization during exposure and lateral radiographs. Care should be taken to prevent excessive traction of the patient shoulders that may result in a brachial plexus injury. Pay careful attention to upper extremity neuromonitoring baseline potentials obtained before taping for comparison. It is helpful to take a fluoroscopic image before prepping in order to refine positioning. A decision should be made in regard to need for Mayfield tongs or Gardner-Wells (GW) tongs. The author prefers 15–20lbs of Gardner-Wells traction in addition to the use of vertebral distraction pins to obtain desired postop lordosis. This requires GW tong placement slightly anterior to the cervical axis of rotation.

The anterior cervical spine can be accessed from the right or left side depending on surgeon preference. A transverse incision is utilized for procedures involving one to two levels. For procedures involving three or more disc levels, a longitudinal or oblique incision may be used. The vertebral segments involved determine the location of the incision. There are palpable landmarks of the anterior neck that will help guide the surgeon to the appropriate location for the incision. The angle of the mandible demarcates the C2–3 interspace. The hyoid bone typically lies anterior to C3 level. The superior portion of the thyroid cartilage marks C4–5 interspace. The location of C6 can be determined via palpation of the cricoid cartilage or by palpation of the carotid tubercle which projects anteriorly from the transverse process. Intraoperative fluoroscopy can also be utilized to localize the operative level.

Once the incision has been made through the skin and subcutaneous tissue, the platysma is divided in line with the skin. Any superficial veins encountered must be protected or ligated if they cross the planes of dissection. The vein pattern encountered is most often a single vertical vein. However, infrequently a Y-shaped bifurcation is encountered and at other times two bifurcations may be seen. Be prepared to ligate the veins if bleeding is uncontrollable. Dissection is continued through the superficial layers of the investing deep cervical fascia between the sternocleidomastoid and the medial visceral muscle column. Next, the carotid sheath must be palpated. Blunt dissection is performed through the middle layer of deep cervical fascia between the esophagus and carotid sheath. The author prefers to use a Peanut sponge to sweep the fascia laterally while protecting the carotid sheath. This provides medial lateral dimension for the work necessary. The prevertebral fascia will then be visualized anterior to the vertebral column. This fascia is subsequently incised and dissected off the vertebral bodies. The medial borders of the longus colli muscles are now identified off of the midline. The midline can be marked at this point to reference for decompression and graft alignment later in the procedure. The operative level is marked and lateral fluoroscopy confirms the level.

Following the confirmation of the operative level, the longus colli is elevated using mono or bipolar cautery. The author prefers bipolar cautery as the bleeding of the dorsal or undersurface of the longus colli is better controlled with bipolar. It also helps the surgeon delineate when the mid-body bleeding is the result of a bone tributary versus muscle vein. Proceeding with the dissection, the longus is elevated from the level of the mid-vertebral body above and below the body of interest. Care must be taken to avoid dissection on the ventral surface of the longus colli muscles that may result in injury of the sympathetic chain causing Horner syndrome. Next, place retractors under the longus colli bilaterally.

Discectomies are subsequently performed both at the levels above and below the vertebral body(ies) planned for corpectomy(ies). The disc is removed to the level of the posterior longitudinal ligament (PLL). The next anatomic landmark that must be identified is the lateral cortical wall of the vertebral body. A Penfield 2 or 4 can help accomplish this task. This is the junction of the transverse process and vertebral body. Identifying the lateral cortical wall allows for the establishment of a symmetrical and central trough while avoiding injury to the vertebral artery which lies just lateral to this wall. A secondary landmark of reference is the uncovertebral joint on either side. This generally demarcates the lateral cortical wall of the vertebral body.

The most ventral portion of the corpectomy trough is created with a ronguer. This resected bone should be saved for autogenous bone graft. With the anterior cortex removed, a bur is utilized to expand the trough. Alternatively, the author prefers to use the Misonix Bone Scalpel® to osteotomize the body with 3 cuts. These chunks are then removed en bloc. At this juncture, the surgeon can overlay the graft to judge trough width and centrality. Resection is continued until the posterior cortex of the vertebral bodies is visualized. The cortical bone is less porous and less vascular than cancellous bone of the body. The posterior cortex can be removed with small angled curets by pulling the bone away from the PLL and dura or authors preferred method of using high-speed drill to cut longitudinal osteotomies creating a floating island of posterior cortex. This island is dissected free from PLL and removed. The PLL can be carefully removed via nerve hook and ronguer. Care must be taken in cases of ossification of the posterior longitudinal ligament (OPLL) as this ligament may be incorporated into the dura [9]. Removal of the ligament should not be attempted as this may cause a tear in the dura; it may be necessary to leave islands of ossification to avoid an anterior dural leak. It has been demonstrated that a safe and sufficient decompression requires approximately a 15 to 19 mm-wide trough [10, 11].

After adequate neural decompression has been achieved, the end plates are then prepared for insertion of the graft. The high-speed drill is used to remove endplate cartilage until fresh bleeding edges are visible. Take care to avoid endplate disruption. With adequate tension traction being applied to the head and/or distraction pins, the properly contoured graft or synthetic cage is gently placed. Assessment of graft stability is assessed with release of traction followed by manual flexion and rotation of the head by the anesthesiologist. Decorticate the uncinates and place autogenous bone graft in each exposed uncinate gutter. Segmental anterior plating is then performed.

A postoperative cervical collar is often placed on patients to provide additional immobilization [6].

Alternative Methods for Multilevel Corpectomy

As stated previously, ACCF has been shown to be an effective procedure for one- to two-level disease, but there is a higher rate of failure for three- and four-level cervical-plated corpectomy. Early construct failure is of particular concern in ACCF and that risk increases with constructs of three or more levels. Vaccaro et al. treated 45 CSM patients with two-level or three-level corpectomies with anterior plating in the absence of posterior instrumentation. The authors reported 9% dislodgement in the two-level group and a 50% dislodgement rate in the three-level group with migration of the graft occurring in over 80% of the three-level corpectomy even with the use of a halo [12]. A number of additional studies have also reported similar high rates of construct failure after multilevel corpectomy as well [7]. Without the addition of posterior instrumentation, the long lever arm created in anterior-only constructs creates instability which leads to graft migration and dislodgement [8]. The addition of posterior instrumentation is recommended to supplement multilevel ACCF to decrease the incidence of graft migration and dislodgement.

Another option for cervical disc degenerative disease affecting two or more adjacent levels includes a partial corpectomy which involves discectomies at the affected levels with removal of the anterior portions of the involved vertebrae leaving approximately one half to one third of the posterior portion of the body behind, strut graft, and anterior plating. Groff et al. conducted a retrospective study over a 9-year period investigating this technique with positive results. Some authors reported a fusion rate of 95.8% independent of the numbers fused. The authors asserted that their high fusion rate was due to improved stability with additional fusion surface area from the remaining vertebral body [4].

Cervical skip corpectomy is another method that can be used for compressions from C3–4 to C6–7. Skip corpectomy involves corpectomy at C4 and C6 with preservation of the C5 vertebral body as an intermediate point of fixation thus avoiding the use of a long strut graft. This technique also has the advantage of four healing surfaces as opposed to the eight surfaces associated with an equivalent ACDF. Ashkenazi et al. investigated skip corpectomy in 13 patients with CSM. The authors reported a 100% fusion rate and one case of mechanical failure (4%) [1]. Dalbayrak et al. also reported high fusion rates (100%) and low graft hardware-related complication rate utilizing this technique [2].

Technical Pearls

- Measure the planned corpectomy width on the preoperative CT scan.
- Identify the vertebral artery location on the preoperative CT and carefully scrutinize for aberrant vertebral artery anatomy.
- Typically, 16 mm is a standard corpectomy width.
- A large Leksell rongeur is usually 8 mm wide. Therefore, two rongeur bites side by side will be 16 mm.
- Cut a paper ruler to the planned corpectomy width (16 mm). Throughout the case, the surgeon can bring that paper ruler into the operative field to ensure proper width.
- The vertebral arteries are located at the mid-vertebral level. Therefore, at the posterior third of the vertebral body, more width can be accomplished if necessary.

- Carefully identify the uncovertebral joints at the adjacent disc levels prior to the performance of a corpectomy. The standard corpectomy should move from Uncus to Uncus.
- Advanced bone cutting tools, such as a bone scalpel or a Sonopet, may be useful for reducing the risk of vascular injury and for reduction of bleeding.
- Take down the PLL at the disc levels prior to performing the corpectomy so that a clear plane is visible.
- Carefully apply bone wax to the corpectomy walls to reduce bleeding.
- Carefully measure the size of the planned graft on a preoperative CT scan (usually 25 mm).
- Do not overdistract corpectomies or there is a substantial risk of graft subsidence and failure.
- Test the corpectomy graft with a Kocher clamp (pulling anteriorly) to ensure that it does not displace with minimal force.
- If necessary, omnipaque can be applied to the anterior epidural space in an angiocatheter to visualize the back of the corpectomy graft (if a tricortical ilium strip is used).

References

1. Ashkenazi E, Smorgick Y, Rand N, et al. Anterior decompression combined with corpectomies and discectomies in the management of multilevel cervical myelopathy: a hybrid decompression and fixation technique. J Neurosurg Spine. 2005;3(3):205–9. https://doi.org/10.3171/spi.2005.3.3.0205.
2. Dalbayrak S, Yilmaz M, Naderi S. "Skip" corpectomy in the treatment of multilevel cervical spondylotic myelopathy and ossified posterior longitudinal ligament: technical note. J Neurosurg Spine. 2010;12(1):33–8. https://doi.org/10.3171/2009.7.SPINE08965.
3. Gillis CC, O'Toole J, Traynelis VC. Cervical interbody strut techniques. In: Benzels spine surgery: techniques, complication avoidance, and management. Philadelphia: Elsevier; 2017. p. 532–9.
4. Groff MW, Sriharan S, Lee SM, et al. Partial corpectomy for cervical spondylosis. Spine (Phila Pa 1976). 2003;28(1):14–20. https://doi.org/10.1097/00007632-200301010-00005.
5. Fraser JF, Hartl R. Anterior approaches to fusion of the cervical spine: a metaanalysis of fusion rates. J Neurosurg Spine. 2007;6(4):298–303. https://doi.org/10.3171/spi.2007.6.4.2.
6. Herkowitz H, Luszczyk M. Cervical spondylotic myelopathy. In: Rothman-Simeone the spine. Philadelphia: Elsevier; 2011. p. 762–90.
7. Naderi S, Dalbayrak S, Yilmaz M. Cervical skip Corpectomy. In: Benzels spine surgery: techniques, complication avoidance, and management. Philadelphia: Elsevier; 2017. p. 540–2.
8. Quinn JC, Kiely PD, Lebl DR, Hughes AP. Anterior surgical treatment of cervical Spondylotic myelopathy: review article. HSS J. 2015;11(1):15–25. https://doi.org/10.1007/s11420-014-9408-6.
9. Smith MD, Bolesta MJ, Leventhal M, et al. Postoperative cerebrospinal-fluid fistula associated with erosion of the dura: findings after anterior resection of ossification of the posterior longitudinal ligament in the cervical spine. J Bone Joint Surg Am. 1992;74:270–7.
10. Smith MD, Emery SE, Dudley A, et al. Vertebral artery injury during anterior decompression of the cervical spine: a retrospective review of ten patients. J Bone Joint Surg Br. 1993;75:410–5.

11. Vaccaro AR, Ring D, Scuderi G, et al. Vertebral artery location in relation to the vertebral body as determined by two dimensional computed tomography evaluation. Spine (Phila Pa 1976). 1994;19:2637–41.
12. Vaccaro AR, Falatyn SP, Scuderi GJ, et al. Early failure of long segment anterior cervical plate fixation. J Spinal Disord. 1998;11(5):410–5.
13. Liu J, Chen X, Long X, et al. Anterior cervical discectomy and fusion versus corpectomy and fusion in treating two-level adjacent cervical spondylotic myelopathy: a minimum 5-year follow-up study. Arch Orthop Trauma Surg. 2015;135(2):149–53.
14. Hartmann S, Tschugg A, Obernauer J, et al. Cervical Corpectomies: results of survey and review of the literature on diagnosis, indications, and surgical technique. Acta Neurochir. 2016;158(10):1859–67.
15. Shamji MF, Massicotte EM, Traynelis VC, et al. Comparison of anterior surgical options for the treatment of multilevel cervical spondylotic myelopathy: a systematic review. Spine. 2013;38(22. Suppl 1):S195.
16. Li Z, Huang J, Zhang Z, et al. A comparison of multilevel anterior cervical discectomy and Corpectomy in patients with 4-level cervical Spondylotic myelopathy: a minimum 2-year follow-up: multilevel anterior cervical discectomy. Clin Spine Surg. 2017;30(5):E540.
17. Singh K, Vaccaro AR, Lorenz EP, et al. Enhancement of stability floowoing anterior cervical corpectomy: a biomechanical study. Spine. 2004;29(8):845.
18. Setzer M, Eleraky M, Johnson WM, et al. Biomechanical comparison of anterior cervical spine instrumentation techniques with and without supplemental posterior fusion after different corpectomy and discectomy combinations: laboratory investigation. J Neurosurg Spine. 2012;16(6):579.

Chapter 3
Cervical Disc Arthroplasty

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Introduction

The seven cervical vertebrae are separated by intervertebral discs that have dual purpose in both load bearing and motion transfer. Disc degeneration, facet arthropathy, ligamentum flavum hypertrophy, and foraminal narrowing is the natural progression from degenerative disc disease to cervical spondylosis. Anterior cervical discectomy and fusion (ACDF) is a proven modality of treatment for patients with cervical radiculopathy and myelopathy. Neurological dysfunction is consistently improved, which makes ACDF a standard against which many spine surgeries are compared. Plating has eliminated the need for postoperative immobilization [1]. Because of concern for kinematic and biomechanical issues inherent to fusion of the cervical motion segment, investigators have developed surgical alternatives.

The foremost concern with ACDF is adjacent segment degeneration, which is degeneration of a level adjacent to a fused level. With long-term follow-up of 5–10 years, adjacent segment degeneration has been found radiographically in 81.3–92.1% of patients [2–4]. The cause of adjacent segment degeneration is debated, with the frontrunners being related to postsurgical biomechanics and aging. However, adjacent segment degeneration and adjacent segment disease should be contrasted, with the latter having both evidence of radiographic degeneration and clinical symptoms, such as pain or neurological dysfunction [5]. Adjacent segment disease has been reported to occur at a rate of 2.9% per year and in 25.6% of patients within 10 years of ACDF [5]. Biomechanical studies have demonstrated segments adjacent to fusion constructs have increased range of motion and intradiscal

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_3

pressures as compared to the native state [6, 7]. These changes are likely related to compensation of loss of motion in the fused segments.

Currently, ACDF is performed with various grafts, including allograft and iliac crest autograft. Complications such as meralgia paresthetica, fracture, chronic pain, and infection have been reported altogether at an incidence as high as 25% [8–10]. Pseudoarthrosis is another concern with ACDF, which becomes more prevalent as the number of segments fused increases. There has been a reported 97% fusion rate with single-level fusion, but this decreases to 83% with three-level fusions [11]. Pseudoarthrosis has been reported in 11% with single-level fusions and in 27% with multilevel fusions [12].

Because of these concerns as well as the desire to preserve motion and return patients to routine activities, cervical disc arthroplasty was developed. Following discectomy, restoration of disc height and segmental motion should allow for preservation of normal motion at adjacent levels. With cervical disc arthroplasty, autograft is unnecessary and its potential complications are avoided. Additionally, pseudoarthrosis is avoided, as well as other problems inherent to anterior cervical plating and immobilization. However, patients must have pathology primarily limited to the cervical disc, with relative sparing of the facet joints.

History

The first artificial cervical disc replacement, the Bristol/Cummins device [13], was developed and tested through the late 1980s to early 1990s. This original ball and socket design was composed of 316 L stainless steel. Technological advancements and design innovations led to the development of the currently FDA-approved devices, listed Table 3.1.

Materials, Biomechanics, and Wear

The main metal alloys used in devices are titanium, cobalt chromium, and stainless steel [14]. There are also a number of bearing interfaces: metal-on-metal, metal-on-polymer (polyurethane), ceramic-on-ceramic and ceramic-on-polymer. The material selection and device design should be optimized so as to preserve motion, reduce friction, and improve durability. Maintenance of the normal kinematics of the spine is one of the primary goals in disc arthroplasty. The cervical spine is inherently dynamic, with flexion, extension, and lateral bending in addition to anterior and posterior translation. One example of how cervical disc arthroplasty attempts to mirror the natural motion of the cervical spine is demonstrated in Fig. 3.1. Rousseau et al. [15] examined the intervertebral kinematics after use of a ball and socket device (either the Prestige LP or Prodisc-C) and concluded this design did not fully preserve natural range of motion or center of motion between flexion and extension. This may be attributed to the absence of translation when using a constrained

Table 3.1 Currently FDA-approved devices

	Manufacturer	Materials	Design	Articulating Method	Primary Fixation	Secondary Fixation	Modular
Bryan cervical disc	Medtronic Sofamor Danek USA Inc.	Titanium, polymer	Constrained bearing	Bi-	Milled vertebral endplates	Endplate on-growth	No
Mobi-C cervical disc	Zimmer Biomet Inc.	CoCrMo, UHMWPE	Superior endplate with ball and socket motion, inferior endplate with sliding constraint	Bi-	Lateral self-retaining teeth	Endplate on-growth	Yes
PCM	NuVasive Inc.	CoCrMo, UHMWPE	Upper endplate translation on fixed UHMWPE	Uni-	Ridged metallic endplates	Endplate on-growth	No
Prestige ST	Medtronic Sofamor Danek USA Inc.	316 L stainless steel	Ball and trough	Uni-	Vertebral body screws	–	No
Prestige LP	Medtronic Sofamor Danek USA Inc.	Titanium ceramic composite	Ball and trough	Uni-	Dual rails	Endplate on-growth	No
ProDisc-C	Synthes Spine	CoCrMo, UHMWPE	Ball and socket	Uni-	Central keel	Endplate on-growth	No
Secure-C	Globus Medical Inc.	CoCrMo, UHMWPE	Metal on polyethylene	Bi-	Ridged central keel	Endplate on-growth	Yes

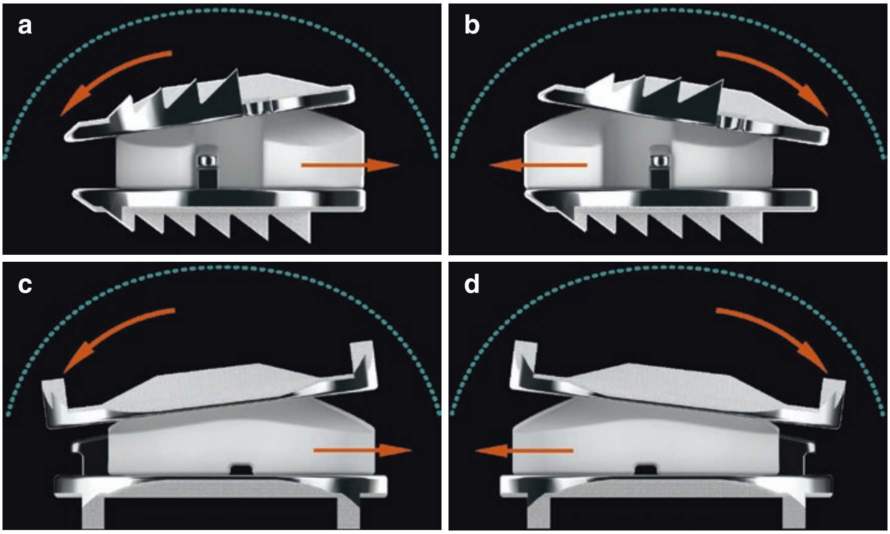

Fig. 3.1 A-1D demonstrate the Mobi-C (Zimmer Biomet, Warsaw, IN) cervical disc replacement. The Mobi-C incorporates superior and inferior cobalt chromium molybdenum alloy endplates coated with a plasma sprayed titanium and hydroxyapatite coating and a polyethylene mobile bearing insert. The mobile bearing translates up to 1 mm on the inferior endplate, allowing flexion (**a**), extension (**b**), and lateral bending (**c** and **d**)

prosthesis [16]. Additionally, a comparison of constrained devices featuring a fixed core (Prodisc-C) and mobile core (Mobi-C) evaluated stress on the polyethylene core, pressure on the facet joint, and biomechanical impact; the fixed core device exhibited less pressure on the facet joint, more pressure on the core, and a more severe biomechanical impact if the device is not centered, while the opposite was seen in devices with a mobile core [17]. A major cause of failure of cervical disc replacement is wear debris, which can trigger an inflammatory reaction leading to osteomyelitis, pain, and loosening of the device [18]. Veruva et al. [19] conducted a systematic review to determine any adverse effects from the materials used in the different devices. It was reported that metal-on-polymer replacements could lead to polymer wear debris, thus stimulating an innate response. Metal-on-metal devices could generate metallic wear debris causing activation of the adaptive immune system and subsequent tissue reactions.

Indications and Contraindications

According to FDA guidelines, cervical disc arthroplasty is indicated following discectomy for intractable symptomatic cervical disc disease, and intractable radiculopathy and/or myelopathy. Contraindications vary between devices and include infection, osteoporosis, allergy to materials, severe spondylosis, compromised vertebral bodies attributed to disease or trauma, severe facet joint degeneration, cervical instability observed on imaging, and axial neck pain. Some authors have recommended a disc height of >3 mm for adequate disc space access and removal [20]. Placing an oversized implant into a collapsed disc space can potentially place excessive forces through the facet joints and lead to worsening of axial neck pain. While there are no strict criteria for degree of facet degeneration in patients being indicated for cervical disc arthroplasty, proposed criteria include developed arthritis of the zygapophyseal articular facets of the level to be operated and marked asymmetry of the articular facets, or a history of laminarthrectomy [21]. Computed tomography (CT) and magnetic resonance imaging (MRI) scans are useful to assess for the presence and degree of facet arthropathy. Facet blocks with combinations of local anesthetic and corticosteroid may also be employed to evaluate for facet arthropathy. Additionally, patients with a kyphotic deformity of over 15° should be carefully considered for this operation, as this deformity is usually seen in conjunction with a posterior spinal pathology. Lastly, anterior soft tissue abnormalities or anomalies including tracheal or esophageal abnormalities or history of radiation may be a general contraindication to any anteriorly based cervical spine procedure [22].

Currently, there are 7 total cervical disc replacement devices approved by the FDA for single-level disc arthroplasty [23–29]. These include the Bryan cervical disc (Medtronic Sofamor Danek USA Inc.), Mobi-C cervical disc (Zimmer Biomet Inc.), PCM cervical disc (NuVasive Inc.), Prestige LP and Prestige ST cervical discs (Medtronic Sofamor Danek), ProDisc-C total disc replacement device (Synthes Spine), and Secure-C cervical artificial disc (Globus Medical Inc.) Among these, only Prestige LP and Mobi-C have approval for two-level disc arthroplasty.

Surgical Management

Preoperative Evaluation and Imaging

Preoperative imaging for cervical disc arthroplasty involves plain radiographs and more advanced imaging techniques. Anteroposterior, odontoid, neutral lateral, and flexion-extension lateral radiographic views should be obtained. The flexion-extension lateral views can be used to assess the preoperative mobility of the cervical spine. MRI or CT scans offer a more comprehensive evaluation of the index surgical level, particularly regarding the presence of conditions such as spondylosis, neurologic compression, and pre-existing facet arthropathy. Myelography can be incorporated to gain additional information. These imaging studies could also reveal contraindications for this procedure.

Technique

The anterior cervical spine is approached as discussed in Chap. 1. A nasogastric tube can be placed for easier identification and protection of the esophagus. The neutral to slightly lordotic position is preferred, which can be created with the use of a small towel bump under the neck rather than between the shoulders or under the thoracic spine, which can cause a hyperlordotic position. A donut pillow is placed under the head to prevent it from rolling. Taping of the shoulders can additionally stabilize the operative field and may be utilized in order to obtain light traction. A right or left Smith-Robinson approach is used to expose the levels of interest and adequate decompression is completed. Of note, in comparison to an anterior cervical discectomy and fusion, a more rigorous decompression is often necessary with cervical disc replacement. The posterior longitudinal ligament should always be removed to maximize the biomechanics of the device. A wide foraminotomy should also be performed as the level will continue to remove and any foraminal stenosis can lead to recurrent radicular symptoms. Meticulous hemostasis should be maintained in an effort to keep a clear operative field and minimize the risk of heterotopic ossification.

Prior to endplate preparation, exact sagittal position of the vertebrae should be confirmed with lateral fluoroscopic imaging. Anteroposterior views should place spinous processes at the target level centered between pedicles to ensure coronal plane alignment. Next, sizing of the device should be assessed. The largest diameter disc possible for the prepared space should be utilized. This can be accomplished with preoperative templates, radiographs, and CT. Intraoperatively, trials along with fluoroscopy confirm or allow for adjustment of the final device implanted. Endplate preparation is generally implant-specific. Milling of the endplate is required for the Bryan system and creating a bony trough is required for the Prodisc-C’s endplate keel. Regardless of manufacturer-specific endplate preparation, subchondral bone should be preserved as much as possible to prevent subsidence. After the endplate is prepared, centering and neurologic decompression should again be checked.

The artificial disc device is then implanted, with the appropriate depth based on implant design. Fluoroscopic imaging ensures appropriate coronal and sagittal plane positioning. The prosthesis should cover the endplates on both fluoroscopic views [30]. Lastly, implants are fixed with any implant-specific instrumentation and final imaging is performed. Wound closure should proceed with meticulous hemostasis to prevent postoperative wound complications and heterotopic ossification.

Postoperative Care

Postoperative immobilization is not required. Plain films may be obtained in the PACU and typically consist of anteroposterior and lateral views but upright flexion-extension views may also be obtained for comparison to follow-up films. Imaging studies obtained postoperatively provide an opportunity to evaluate the device placement and motion. Plain radiographs, specifically lateral bending and flexion-extension views, are relatively easy to obtain, reduce radiation exposure compared to CT or CT myelography, and allow for motion of the spine to be analyzed. MRI is an alternative imaging technique to CT myelography that can be used to assess post-operative neurologic status. A comparison of several devices regarding image artifact and visualization of neural elements at index and adjacent sites suggested that this modality is particularly useful in devices containing titanium alloy [31]. Fayyazi et al. observed that the amount of artifact was similar when any of four titanium devices (ProDisc-C Ti, Prestige LP, Discover, and Bryan) were used and increased significantly following implantation of the Prestige-ST, a stainless steel device. Visualization of the index and adjacent levels was easily performed with the titanium devices. The ProDisc-C Cobalt Chrome implant produced an image where only the index level was obscured by the artifact, while visualization could not be performed at the index and adjacent levels following implantation of the Prestige-ST. These differences necessitate that preoperative selection of a device considers the imaging studies that might be completed postoperatively.

Outcomes and Complications

Recent studies have assessed the long term results of total disc arthroplasty (TDA) using a specific device, analyzed the outcomes of ACDF versus TDA, and described differences between cervical arthroplasty devices. One meta-analysis examined surgical parameters, functional indicators, and the need for secondary surgery in patients with cervical degenerative disc disease undergoing TDA using the Prestige, Bryan, Kineflex C, Mobi-C, and ProDisc-C devices compared to recipients of ACDF [32]. ACDF was significantly associated with reduced operation time and decreased blood loss compared to any of the TDA procedures. TDA using the Bryan and Prestige discs demonstrated improved neurological success compared to ACDF, with the Bryan disc also resulting in better neck disability index (NDI) scores. ACDF had a higher rate of reoperation and secondary surgery at the adjacent and index levels than TDA using the Mobi-C disc. Patient satisfaction was not significantly different between ACDF and TDA.

A second meta-analysis compared the clinical outcomes 24 months postoperatively of TDA using the Bryan, Prestige, ProDisc-C, and PCM devices to those for patients undergoing ACDF [33]. Metrics including neurological success, survivorship, and overall success revealed a statistically significant difference in patient outcomes, suggesting that TDA is superior to ACDF. While the four devices differed in how they scored in these categories, conclusions on this data could not be drawn as no statistical analysis was undertaken to compare the devices.

Prestige

Burkus et al. [34] reported the 7-year postoperative clinical outcomes of ACDF compared to those for patients receiving TDA with the Prestige Cervical Disc. Neurological status was improved or maintained in 88.2% TDA patients and 79.7% ACDF patients. Rates of additional surgical procedures was also reduced in patients undergoing TDA versus ACDF at 4.6% and 11.9%, respectively. NDI scores, success, work status, rate of adverse events, and adjacent segment motion were similar between both groups.

Peng et al. [35] completed a prospective study looking at clinical and radiographic outcomes for patients that underwent ACDF and TDA with the Prestige LP Cervical Disc. Follow-up time was an average of 2.9 years with a minimum of 2 years. Significant improvement in metrics for neck and limb pain, neurogenic symptoms, myelopathy, and quality of life was observed for all patients, although no statistically significant difference was noted between patients in the ACDF and TDA groups. Physiologic motion was maintained at the surgical level for TDA and no significant difference in motion was exhibited at the adjacent segments. This finding contrasted ACDF which resulted in increased motion at adjacent levels; these changes in motion patterns have been implicated in adjacent level degeneration.

PCM Disc Prosthesis

Phillips et al. [36] conducted a study to assess the 5-year postoperative outcomes of ACDF versus TDA with the PCM disc. Scores for NDI, neck and arm pain, patient satisfaction, rates of dysphagia, and a general health summary for patients receiving TDA were significantly superior to those with ACDF. Radiological findings mirrored these results, as degeneration at the superior disc level was seen in 33.1% of the TDA patients compared to 50.9% ACDF patients. People in the TDA group also had fewer secondary surgeries and maintained range of motion at the 5-year follow-up with an average flexion-extension value of 5.2°.

ProDisc-C

Zigler et al. [37] compared the 5-year postoperative clinical outcomes of ACDF and a cervical total disc replacement using ProDisc-C. Neurological status, patient satisfaction, and number of adverse events were not significantly different between these two groups. However, patients who underwent TDA reported less neck pain intensity and frequency and had lower rates of secondary surgery (2.9% for TDA patients and 11.3% for ACDF patients). Range of motion was also maintained in the ProDisc-C patients at the 5-year follow-up.

Adjacent segment motion was evaluated by Kelly et al. [38] following ACDF versus TDA using the ProDisc-C prosthesis. Flexion-extension films were obtained of the 199 patients to assess range of motion 2 years following surgery. Both cranial and caudal adjacent segments demonstrated a statistically significant increase in motion for the ACDF patients, although there was no difference observed between the ACDF and TDA groups.

Mobi-C

Radcliff et al. [39] recently reported on the long-term outcomes of a multicenter randomized clinical trial with 7-year follow-up comparing ACDF to TDA. Interestingly, this analysis demonstrated clinical superiority of two-level TDA over two-level ACDF and non-inferiority of single-level TDA versus single-level ACDF. The overall success rates of two-level TDA and two-level ACDF patients were 60.8% and 34.2%, respectively. Success rates of single-level TDA and single-level ACDF were similar between cohorts. Both the single- and two-level TDA and ACDF groups showed significant improvement in NDI scores, pain scores, and SF-12 MCS/PCS scores. In the single-level cohort, there was an increased percentage of TDA patients who reported themselves as "very satisfied" (90.9% vs. 77.8%). There was a lower rate of adjacent level secondary surgery in the single-level TDA patients (3.7%) versus the ACDF patients (13.6%). In the two-level TDA group, the NDI success rate was significantly greater (79% vs. 58%), as was the rate of patients who were "very satisfied" with treatment (85.9% vs. 73.9%). The rate of subsequent surgery at the index level was significantly lower in the two-level TDA group compared to the ACDF group (4.4% vs. 16.2%). The rate of adjacent level secondary surgery was significantly lower in the two-level TDA (4.4%) patients compared to the ACDF (11.3%) patients.

An assessment of the occurrence of heterotopic ossification (HO) in patients presenting with extremity radiculopathy receiving TDA using the Mobi-C was completed by Park et al. [40]. Mean follow-up time was 40 months for the 75 patients. NDI scores and neck and arm pain levels all improved significantly between preoperative and postoperative evaluation. HO occurred in 67 levels at 12 months, and then at 80 levels by 24 months following the procedure, out of a total of 85 surgical levels. A univariate and multivariate logistic regression indicated that anterior HO was significantly associated with surgical technique, although the study was limited by follow-up time and number of patients enrolled.

Bryan Cervical Disc

Quan et al. [41] analyzed the clinical and radiological outcomes of a Bryan cervical disc arthroplasty at 8 years postoperative. None of the 21 patients required revision surgery and 19 reported an ability to perform daily activities without limitations. Motion was maintained to an average range of 10.6 +/− 4.5 degrees in 78% of the cases. Evidence of HO was seen in nearly half of the patients, many presenting with grades 3 and 4 HO. Four patients developed adjacent segment degeneration, although this only occurred in patients who exhibited signs of degenerative disc changes prior to their operation.

In a similar study, Dejaegher et al. [42] provided a 10-year follow-up to TDA with the Bryan prosthesis. Neurological success was achieved in 89% of the 72 patients, and over 80% of the prostheses had mobility of at least 2 degrees. Adverse events, specifically cases of radiculopathy and myelopathy, were reported by 24% of the patients, of which 8% required additional surgery to address new or recurrent symptoms. In an FDA IDE trial, Sasso et al. [43] conducted a prospective, randomized controlled trial of the Bryan cervical disc arthroplasty compared to ACDF and followed patients for 10 years. At this time point, arthroplasty demonstrated a significantly improved NDI (8 vs. 16) and a lower reoperation rate (9% vs. 32%).

Secure-C

Vaccaro et al. [29] compared the 2-year patient outcomes of using TDA with the Secure-C to ACDF. A total of 380 patients were included in this study. Mean surgery time was significantly shorter with ACDF. NDI reduction and improvement in neck and arm pain were seen at a higher rate in TDA patients; patient satisfaction and neurologic status were also better for this group. Radiological assessments indicated that 84.6% of TDA patients were range of motion successes at 24 months, with mean flexion-extension of 9.7°. It was also observed that 89.1% of patients who received ACDF had successful fusion at 24 months.

Pearls and Pitfalls

- Cervical TDA is a viable FDA-approved tool in the armamentarium of the spine surgeon, but indications and contraindications should be seriously considered after obtaining patient history and preoperative diagnostics.
- Patients with single-level and two-level cervical disease should be assessed for infection, osteoporosis, allergies, severe spondylosis or instability, facet arthropathy, and axial neck pain prior to considering TDA since these are all contraindications to the procedure.
- Although there are no gold-standard diagnostics to assess facet arthropathy, consider CT, MRI, and facet blocks to aid in diagnosis.
- Generally speaking, patients with less than 3 mm of disc space or greater than 15° of kyphotic deformity are poor candidates for cervical TDA.

Summary

Cervical disc arthroplasty is becoming more popular as a motion-preserving technique for patients with degenerative conditions of the cervical spine largely limited to the disc and relative sparing of the facet joints. This has been thought to decrease the incidence of adjacent segment degeneration and pseudoarthrosis as compared to ACDF. However, it is not the only motion-preserving option; cervical laminoplasty and foraminotomy should also be considered in patients who desire retaining neck motion. Biomechanical studies have supported the belief that arthroplasty leads to less adjacent level strain than fusion [6, 7]. Superior outcomes have been demonstrated in a few randomized controlled trials and cohort studies comparing ACDF and arthroplasty as far out as 10 years [34, 36, 39, 43].

References

1. Campbell MJ, Carreon LY, Traynelis V, Anderson PA. Use of cervical collar after single-level anterior cervical fusion with plate: is it necessary? Spine. 2009;34(1):43–8.
2. Goffin J, Geusens E, Vantomme N, Quintens E, Waerzeggers Y, Depreitere B, et al. Long-term follow-up after interbody fusion of the cervical spine. J Spinal Disord. 2004;17(2):79–85.
3. Litrico S, Lonjon N, Riouallon G, Cogniet A, Launay O, Beaurain J, et al. Adjacent segment disease after anterior cervical interbody fusion: a multicenter retrospective study of 288 patients with long-term follow-up. Orthop Traumatol Surg Res. 2014;100(6. Suppl):S305–9.
4. Chung J-Y, Kim S-K, Jung S-T, Lee K-B. Clinical adjacent-segment pathology after anterior cervical discectomy and fusion: results after a minimum of 10-year follow-up. Spine J. 2014;14(10):2290–8.
5. Hilibrand AS, Carlson GD, Palumbo MA, Jones PK, Bohlman HH. Radiculopathy and myelopathy at segments adjacent to the site of a previous anterior cervical arthrodesis. J Bone Joint Surg Am. 1999;81(4):519–28.
6. Eck JC, Humphreys SC, Lim T-H, Jeong ST, Kim JG, Hodges SD, et al. Biomechanical study on the effect of cervical spine fusion on adjacent-level intradiscal pressure and segmental motion. Spine. 2002;27(22):2431–4.
7. Fuller DA, Kirkpatrick JS, Emery SE, Geoffrey Wilber R, Davy DT. A kinematic study of the cervical spine before and after segmental arthrodesis. Spine. 1998;23(15):1649–56.
8. Sandhu HS, Grewal HS, Parvataneni H. Bone grafting for spinal fusion. Orthop Clin North Am. 1999;30(4):685–98.
9. Brown CA, Eismont FJ. Complications in spinal fusion. Orthop Clin North Am. 1998;29(4):679–99.
10. Summers BN, Eisenstein SM. Donor site pain from the ilium. A complication of lumbar spine fusion. J Bone Joint Surg Br. 1989;71(4):677–80.
11. Brodke DS, Zdeblick TA. Modified smith-Robinson procedure for anterior cervical discectomy and fusion. Spine. 1992;17(10 Suppl):S427–30.
12. Bohlman HH, Emery SE, Goodfellow DB, Jones PK. Robinson anterior cervical discectomy and arthrodesis for cervical radiculopathy. Long-term follow-up of one hundred and twenty-two patients. J Bone Joint Surg Am. 1993;75(9):1298–307.
13. Cummins BH, Robertson JT, Gill SS. Surgical experience with an implanted artificial cervical joint. J Neurosurg. 1998;88(6):943–8.
14. Stanton P, Eck JC. Materials and design characteristics of cervical arthroplasty devices. Tech Orthop. 2010;25(2):93–6.
15. Rousseau M-A, Cottin P, Levante S, Nogier A, Alexis N, Lazennec J-Y, et al. In vivo kinematics of two types of ball-and-socket cervical disc replacements in the sagittal plane: cranial versus caudal geometric center. Spine. 2008;33(1):E6–9.
16. Barrey C, Mosnier T, Jund J, Perrin G, Skalli W. In vitro evaluation of a ball-and-socket cervical disc prosthesis with cranial geometric center. J Neurosurg Spine. 2009;11(5):538–46.
17. Lee S-H, Im Y-J, Kim K-T, Kim Y-H, Park W-M, Kim K. Comparison of cervical spine biomechanics after fixed- and mobile-core artificial disc replacement: a finite element analysis. Spine. 2011;36(9):700–8.
18. Moatz B, Tortolani PJ. Cervical disc arthroplasty: pros and cons. Surg Neurol Int. 2012;3(Suppl 3):S216–24.

19. Veruva SY, Steinbeck MJ, Toth J, Alexander DD, Kurtz SM. Which design and biomaterial factors affect clinical wear performance of total disc replacements? A systematic review. Clin Orthop Relat Res. 2014;472(12):3759–69.
20. Ding D, Shaffrey ME. Cervical disk arthroplasty: patient selection. Clin Neurosurg. 2012;59:91–7.
21. Amoretti N, Iannessi A, Lesbats V, Marcy P-Y, Hovorka E, Bronsard N, et al. Imaging of intervertebral disc prostheses. Diagn Interv Imaging. 2012;93(1):10–21.
22. Leven D, Meaike J, Radcliff K, Qureshi S. Cervical disc replacement surgery: indications, technique, and technical pearls. Curr Rev Musculoskelet Med. 2017;10(2):160–9.
23. Gornet MF, Burkus JK, Shaffrey ME, Argires PJ, Nian H, Harrell FE Jr. Cervical disc arthroplasty with PRESTIGE LP disc versus anterior cervical discectomy and fusion: a prospective, multicenter investigational device exemption study. J Neurosurg Spine. 2015:1–16.
24. Heller JG, Sasso RC, Papadopoulos SM, Anderson PA, Fessler RG, Hacker RJ, et al. Comparison of BRYAN cervical disc arthroplasty with anterior cervical decompression and fusion: clinical and radiographic results of a randomized, controlled, clinical trial. Spine. 2009;34(2):101–7.
25. Hisey MS, Bae HW, Davis R, Gaede S, Hoffman G, Kim K, et al. Multi-center, prospective, randomized, controlled investigational device exemption clinical trial comparing Mobi-C cervical artificial disc to anterior discectomy and fusion in the treatment of symptomatic degenerative disc disease in the cervical spine. Int J Spine Surg [Internet]. 2014;8. Available from https://doi.org/10.14444/1007.
26. Mummaneni PV, Kenneth Burkus J, Haid RW, Traynelis VC, Zdeblick TA. Clinical and radiographic analysis of cervical disc arthroplasty compared with allograft fusion: a randomized controlled clinical trial. J Neurosurg Spine. 2007;6(3):198–209.
27. Murrey D, Janssen M, Delamarter R, Goldstein J, Zigler J, Tay B, et al. Results of the prospective, randomized, controlled multicenter Food and Drug Administration investigational device exemption study of the ProDisc-C total disc replacement versus anterior discectomy and fusion for the treatment of 1-level symptomatic cervical disc disease. Spine J. 2009;9(4):275–86.
28. Phillips FM, Lee JYB, Geisler FH, Cappuccino A, Chaput CD, DeVine JG, et al. A prospective, randomized, controlled clinical investigation comparing PCM cervical disc arthroplasty with anterior cervical discectomy and fusion. 2-year results from the US FDA IDE clinical trial. Spine. 2013;38(15):E907–18.
29. Vaccaro A, Beutler W, Peppelman W, Marzluff JM, Highsmith J, Mugglin A, et al. Clinical outcomes with selectively constrained SECURE-C cervical disc arthroplasty: two-year results from a prospective, randomized, controlled, multicenter investigational device exemption study. Spine. 2013;38(26):2227–39.
30. Anderson PA, Sasso RC, Riew KD. Update on cervical artificial disk replacement. Instr Course Lect. 2007;56:237–45.
31. Fayyazi AH, Taormina J, Svach D, Stein J, Ordway NR. Assessment of magnetic resonance imaging artifact following cervical Total disc arthroplasty. Int J Spine Surg. 2015;9:30.
32. Xu B, Ma J-X, Tian J-H, Ge L, Ma X-L. Indirect meta-analysis comparing clinical outcomes of total cervical disc replacements with fusions for cervical degenerative disc disease. Sci Rep. 2017;7(1):1740.
33. McAfee PC, Reah C, Gilder K, Eisermann L, Cunningham B. A meta-analysis of comparative outcomes following cervical arthroplasty or anterior cervical fusion. Spine. 2012;37(11):943–52.
34. Burkus JK, Traynelis VC, Haid RW Jr, Mummaneni PV. Clinical and radiographic analysis of an artificial cervical disc: 7-year follow-up from the Prestige prospective randomized controlled clinical trial: clinical article. J Neurosurg Spine. 2014;21(4):516–28.
35. Peng CWB, Yue WM, Basit A, Guo CM, Tow BPB, Chen JLT, et al. Intermediate results of the Prestige LP cervical disc replacement. Spine. 2011;36(2):E105–11.

36. Phillips FM, Geisler FH, Gilder KM, Reah C, Howell KM, McAfee PC. Long-term outcomes of the US FDA IDE prospective, randomized controlled clinical trial comparing PCM cervical disc arthroplasty with anterior cervical discectomy and fusion. Spine. 2015;40(10):674–83.
37. Zigler JE, Delamarter R, Murrey D, Spivak J, Janssen M. ProDisc-C and anterior cervical discectomy and fusion as surgical treatment for single-level cervical symptomatic degenerative disc disease: five-year results of a Food and Drug Administration study. Spine. 2013;38(3):203–9.
38. Kelly MP, Mok JM, Frisch RF, Tay BK. Adjacent segment motion after anterior cervical discectomy and fusion versus ProDisc-C cervical Total disk arthroplasty. Spine. 2011;36(15):1171–9.
39. Radcliff K, Davis RJ, Hisey MS, Nunley PD, Hoffman GA, Jackson RJ, et al. Long-term evaluation of cervical disc arthroplasty with the Mobi-C© cervical disc: a randomized, prospective, multicenter clinical trial with seven-year follow-up. Int J Spine Surg. 2017;11:31.
40. Park JH, Rhim SC, Roh SW. Mid-term follow-up of clinical and radiologic outcomes in cervical Total disk replacement (Mobi-C). J Spinal Disord Tech. 2013;26(3):141–5.
41. Quan GMY, Vital J-M, Hansen S, Pointillart V. Eight-year clinical and radiological follow-up of the Bryan cervical disc arthroplasty. Spine. 2011;36(8):639–46.
42. Dejaegher J, Walraevens J, van Loon J, Van Calenbergh F, Demaerel P, Goffin J. 10-year follow-up after implantation of the Bryan cervical disc prosthesis. Eur Spine J. 2017;26(4):1191–8.
43. Sasso WR, Smucker JD, Sasso MP, Sasso RC. Long-term clinical outcomes of cervical disc arthroplasty: a prospective, randomized, controlled trial. Spine. 2017;42(4):209–16.

Chapter 4
Posterior Cervical Positioning

Joseph Rabe

Introduction

Surgical positioning of patients who are to undergo posterior cervical surgery is complicated and needs to be performed correctly to achieve successful surgical outcomes and avoid intraoperative and postoperative complications. There are a variety of indications for posterior cervical surgery including posterior cervical decompression via laminoplasty or laminectomy, nerve root decompression through foraminotomies, and various instrumented fusions including occipitocervical, atlantoaxial, and/or subaxial fusion. During these cervical operations, the patients are placed in nonphysiologic conditions for extended periods of time that would not be tolerated by an awake individual. In order to achieve the best postoperative outcomes, it is vital to understand potential pitfalls, mechanisms, and etiologies of the various complications. While the overall risk of complication is low, the morbidities and possible mortality can be potentially devastating.

Initial Evaluation

A thorough preoperative evaluation needs to be performed by both the surgeon and anesthesia team to ensure safety during intubation and positioning. Preoperative safe ranges of cervical motion that do not produce or reproduce symptoms need to be determined, especially in myelopathic patients. In cases of severe myelopathy, the anesthesia team may need to consider awake fiber-optic intubation [1]. It is also important in patients with spinal cord injury or myelopathy to ensure hypotensive anesthesia is avoided. Anesthesia should maintain the mean arterial pressure (MAP)

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_4

at 80 mm Hg to ensure adequate spinal cord blood flow during surgery. In these patients, arterial lines should be placed in order to better monitor and control the MAP. The position of the neck during the surgery is determined by the operation being performed. Patients undergoing both occiput-C2 and subaxial procedures need the chin to be flexed in order to allow adequate visualization of the occipito-cervical junction and reduce the overlap of the facets and laminae inferiorly to facilitate decompression [1]. In the case of fusion, the patient's neck should be placed in neutral to slight extension to create the desired post-fusion lordosis [1]. Any protracted placement of the cervical spine in hyperflexion or hyperextension can contribute to underlying spinal cord injury. In myelopathic patients, neuromonitoring sensory evoked and motor evoked potentials are frequently used. Pre-positioning signals can be obtained and repeated post-positioning to assure no neurologic injury with neck manipulation or hyperextension.

Room Setup and Equipment (Fig. 4.1)

Basic room setup:

- Radiolucent bed with a sheet folded placed on top
- Gel rolls x2

Fig. 4.1 Room setup and equipment

- Mayfield head rest and pins with betadine ointment
- A 4-inch cloth tape
- Pillow case
- Towel clips
- Small foam donuts x4
- Gray foam pad x2
- Large C-arm machine
- Long back table
- Bovie and bipolar machines

Positioning

The patient is initially brought into the room, and the anesthesia team will intubate on the bed while taking care not to excessively mobilize the cervical spine. The neuromonitoring technician will insert leads throughout the body to allow for perioperative monitoring. The Mayfield retractor is attached to the head. When selecting the pin entry points, it is important to ensure the Mayfield clamp can be freely rotated over the nose once the patient is placed into the prone position. The desired position for the retractor is to place the single skull pin as close as possible to the centerline of the patient's head while the two rocker pins at equal distance on the opposite side of the patient's head from the single skull pin. The placement of both sides of the retractor should be above the ear, specifically above the temporal line [2]. Retractor placement inferiorly into the temporalis muscle should be avoided to decrease pin slippage due to decreased bone purchase and to decrease bleeding after removal [2]. The single pin should be placed just above the pinna and again superior to the temporal line and slightly anterior to help control flexion of the neck and the angle of the pins as close as possible to 90 degrees (perpendicular) to the patient's skull [2]. It is important to avoid placing the pins over uneven or fragile bone such as the frontal sinuses, abnormally thin bone, near the orbit, or temporal fossa [2]. If the pin is placed too high, again it will lose purchase within the skull secondary to the overall curvature [2].

The patient is then carefully flipped and rested on the two gel rolls, wrapped within pillowcases that are taped down to the bed, and positioned underneath the patient's chest. The surgeon should control the head during the flip with at least three assistants supporting the torso, pelvis, and legs. It is important to allow the abdomen to hang free to increase venous return to the heart and decrease pressure applied to the lungs during inhalation [1]. The Mayfield retractor is then connected to the bed with the neck in the optimal degree of flexion to extension based on the procedure being performed. The patient's knees are placed onto two 7-inch foam donuts, and two or three pillows are placed underneath the legs and feet to decrease the stretch on the sciatic nerve. Sequential compression devices are placed and connected on bilateral legs. The bed controls are then used to place the patient in reverse Trendelenburg position to help reduce intraoperative bleeding secondary to decreased pressure in the epidural venous plexus [1]. The bed is then flexed at the knees to prevent the patient from sliding when in reverse Trendelenburg. The elbows (to protect the ulnar nerve) and wrist are then well padded with gray foam pads, and the arms are tucked at the patient's side. The white sheet beneath the bed is then brought up and around the patient. Each end is rolled up and secured to the opposite side of the sheet by two towel clamps being careful not to grab the skin. The arms are then secured with 4-inch cloth tape starting above the patient's shoulders and unrolled over the patient's back and fastened to the distal end of the bed. The tape allows increased visualization of the cervical spine with radiographs, but increased traction will increase the risk for iatrogenic brachial plexus injury [1]. All bony prominences and peripheral nerves are double checked to be well padded to ensure protection against intraoperative skin breakdown and neuropraxia. At this stage, anesthesia should confirm that all IV and arterial access lines are functioning normally. Radiographs are then obtained to ensure adequate visualization after positioning has finished. The surgical site is then shaved superiorly to the occiput and four 10–10 drapes are placed. The patient is then prepped and draped in the normal sterile fashion (Fig. 4.2).

After the procedure, the patient is unhooked from the Mayfield clamp on the operating room bed and flipped onto the hospital bed with the Mayfield retractor in

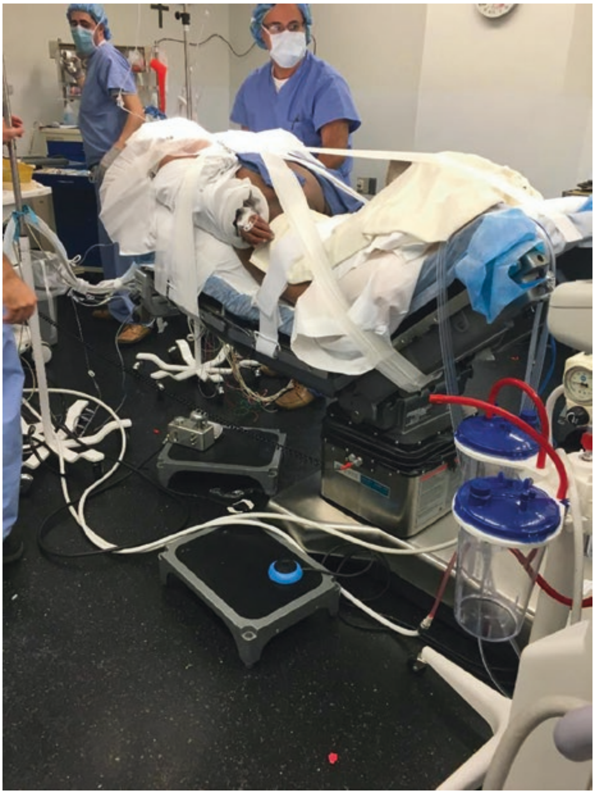

Fig. 4.2 Patient preparation and positioning

place. It is important that the surgeon is at the head of the bed and cognizant of moving the retractor at the same rate as the body while the patient is flipped. The Mayfield retractor is then unscrewed and the prongs removed from the patient's scalp. It is not uncommon to encounter brisk venous scalp bleeding. It can be helpful to have 4 × 4's in reach during removal to be able to hold pressure until the venous ooze has stopped which may take upwards of 5 min.

Other potential complications that are less common include [3, 4]:

- Pressure necrosis at the pin sites requiring local wound care
- Scalp or eye laceration secondary to slipping of the pins requiring pressure dressing, suture closure, or ophthalmology consultation
- Middle meningeal artery laceration leading to epidural hematoma or AV fistula formation requiring neurosurgical consultation
- Skull fracture
- Air embolism or CSF leak requiring neurosurgical consultation

References

1. Wiesel SW. Operative techniques in orthopaedic surgery: Lippincott Williams & Wilkins; 2012.
2. Cohen-Gadol A. Skull clamp placement: introduction. YouTube. 2014:7. www.youtube.com/watch?v=EUevdYSc4ik.
3. Lee MJ, Lin EL. The use of the three-pronged Mayfield head clamp resulting in an intracranial epidural hematoma in an adult patient. Eur Spine J. 2010;19(2):187–9.
4. Mesfin A, Gjolaj J, Lemma MA. A method for intraoperative repositioning of the cervical spine during posterior cervical surgery. Orthopedics. 2011;34:597–9. https://doi.org/10.3928/01477447-20110627-19.

Chapter 5
Posterior Cervical Fusion Surgery: Occiput to C2

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Overview

Occipitocervical fusion (OCF) with instrumentation is used to treat congenital, traumatic, and acquired pathologies of the craniovertebral junction that lead to spinal instability and neural compression. Patients with minor occipitocervical instability can be asymptomatic. As instability and, in turn, neural compression progress, symptoms including occipital headaches, neck pain, lower cranial nerve dysfunction, gait instability, and even autonomic dysfunction can present.

Foerester first described reconstruction of the occipitocervical junction with the use of fibular strut grafts in 1927 [5]. In the next few decades that followed, various wiring techniques were described to stabilize and enhance arthrodesis of the posterior elements. The last few decades have seen the advent of polyaxial screws, occipital plating systems, and cranial bolt techniques that are now used routinely for OCF.

Indications

The craniocervical junction can be affected by congenital, acquired, and traumatic etiologies. Several developmental abnormalities affecting the craniovertebral junction will be mentioned in this section, but the details of embryology and developmental errors leading to these conditions are outside the scope of this chapter.

Craniocervical instability is seen in 14 to 24% of Down syndrome patients. However, the incidence of symptomatic instability is less than 1% [11]. Grisel's syndrome is an inflammatory and spontaneous subluxation that affects the

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_5

craniovertebral junction following parapharyngeal infection. Occipitocervical fusion is rarely indicated as immobilization with a sterno-occipital mandibular immobilizer is often sufficient. Atlas assimilation is a result of failure of segmentation between the fourth occipital sclerotome and first cervical sclerotome resulting in secondary basilar invagination. This places an abnormal axial load on the cervical motion segments and can lead to craniocervical instability. Initially, this instability is reducible. Overtime a panus begins to form around the dens. The basilar invagination remains reducible until the age of 15. However, after mid-adolescence this instability becomes irreducible.

Primary basilar invagination is a defect that implies prolapse of the vertebral column into the foramen magnum. In ventral basilar invagination, the clivus is short and horizontally oriented. This shortens the basiocciput and displaces the plane of the foramen magnum in an upward direction relative to the spinal column. In paramesial basilar invagination, condylar hypoplasia dorsally displaces the clivus into the posterior fossa. The resultant clivoaxial angle produces deformation of the craniomedullary neuroaxis. Chiari malformation is associated with basilar invagination in about 25 to 30% of individuals.

Acquired abnormalities of the craniocervical junction can be classified as rheumatoid and nonrheumatoid entities. The synovial lining of the craniocervical joints is affected early in patients with rheumatoid disease. AOD and basilar invagination occur, respectively, in approximately 39% and 11% of patients with rheumatoid arthritis [18]. These patients experience neck pain and myelopathy from instability and spinal cord compression. Untreated patients with myelopathy have a grim prognosis due to progressive neurologic decline and immobility. The primary treatment goals for patients with rheumatoid arthritis at the craniocervical junction are relief of compression on the neuroaxis and stabilization. Achieving these goals is dependent on the location of compressive pathology. Treatment of reducible lesions in which relief of compression can be obtained by restoring alignment of the craniocervical junction can be accomplished by positioning and occipital cervical instrumented stabilization. If there is any irreducible pathology, such as a panus, causing ventral compression, then this must be first addressed prior to posterior instrumented stabilization.

Nonrheumatoid-acquired causes of craniocervical junction are rare but include ankylosing spondylitis, Reiter's syndrome, forms of psoriatic arthritis, and infectious etiologies, among others. Evaluation of craniocervical joint and treatment using posterior occipital cervical instrumentation is similar to that in rheumatoid patients.

Contraindications

The major contraindication for OC instrumentation and fusion is irreducible anterior compression of the cervicomedullary junction. Performing OC instrumentation without decompressing any anterior pathology will propagate progressive neurologic decline of the patient. OCF using occipital keel screws and plates is not feasible in patients who are undergoing or have already been treated with a suboccipital craniectomy. Instrumentation of the C1 lateral mass or C2 pars or pedicle with polyaxial screws is contraindicated in patients with bony destruction. Pars or pedicle screws of C2 may be contraindicated in specific cases of aberrant vertebral artery.

Relevant Surgical Anatomy

A dorsal approach to the occipitocervical region requires dissection through several muscular layers. The trapezius is the most superficial muscle, and it arises from the external occipital protuberance (EOP), the ligamentum nuchae, and the spinous processes of the seventh cervical and all thoracic vertebrae. The second layer of muscles include the levator scapulae and splenius cervicalis laterally and the splenius capitis and semispinalis capitis medially. Underlying the splenius capitis are the erector spinae muscles including the iliocostalis, longissimus, and spinalis.

The vertebral artery (VA) is, arguably, the structure to be most cognizant of when performing surgery in the OC region. Injury to the VA can result in irreversible and catastrophic outcomes. The third segment of the VA emerges from the vertebral foramen of C1, turns dorsomedially, and travels around the lateral mass of C1 in a groove on the posterior ring called the sulcus arteriosus. In approximately 8% to 15% of the population, calcification of the posterior atlanto-occipital membrane can form a bony covering over the VA as it runs in the sulcus arteriosus [23]. This anatomical variant is called the *arcuate foramen* or *ponticulus posticus*, and it should be recognized prior to surgery to prevent catastrophic placement of C1 lateral mass instrumentation through the VA. The vertebral artery then ascends toward the foramen magnum in the midline and pierces the dura to become intradural. It is important to recognize the vertebral venous plexus that surrounds the vertebral artery. Bleeding from this plexus can occur during dissection around the atlanto-axial joint and should not be confused for vertebral artery bleeding. The C2 nerve root is also encountered during dissection around the inferior lateral mass of C1, and dissection should carefully proceed around the nerve root and its dorsal root ganglion (DRG).

The craniocervical junction is also an intricate osseous and ligamentous complex. The dens of C2 articulates with the dorsal surface of the anterior ring of C1 by the transverse ligament. This ligament essentially straps the dens against the anterior ring of C1 and allows C2 to pivot with respect to C1. The axis and the occiput share four attachments: the alar ligament courses obliquely from the posterior lateral surface of the dens to the anterior medial surface of the occipital condyles; the apical ligament courses from the medial aspect of the foramen magnum to the tip of the dens; the tectorial membrane, which is an extension of the posterior longitudinal ligament; the ascending and descending bands of the cruciate ligament that course from the anterior rim of the foramen magnum to C2.

The occipitoatlantal and atlanto-axial joints account for approximately 25% of flexion and extension movement of the neck. The atlanto-axial joint is responsible for 40 to 50% of rotational movement. The cruciate ligament prevents the dens of C2 from drifting away from the anterior arch of C1 by more than 3 mm in adults during flexion.

Radiographic Assessment

Several parameters and reference lines can be used to evaluate stability and pathology of the craniocervical junction. Basilar invagination is an abnormality where the tip of the dens projects above the foramen magnum and can result in brainstem compression. McRae's line is drawn on a lateral skull radiograph or sagittal CT to join the basion and opisthion. The tip of the dens should be 5 mm below McRae's line, and migration of the dens above this line indicates the presence of basilar invagination. Chamberlain's line joins the posterior hard palate with the opisthion on a lateral view of the craniocervical junction. Basilar invagination is considered to be present if the tip of the dens is >3 mm above this line. McGregor's line is a modification to Chamberlain's line for radiographs in which the opisthion cannot be identified – a line is drawn connecting the posterior hard palate to the most caudal point of the occipital curve. The tip of the dens should not lie more than 4.5 mm above this line.

Atlanto-occipital dissociation can be assessed by several radiographic parameters as well. Powers Ratio is best used to assess for type I AOD – anterior subluxation of the occiput in relation to the atlas. Line AB is drawn from the basion to the posterior arch of C1, and line CD is drawn from the opisthion to the anterior arch of C1. If the ratio of AB/CD is >1, then anterior AOD should be suspected. The basion-axial interval (BAI) is the horizontal distance between the basion and a line extending superiorly from the posterior cortex of C2. A BAI > 12 mm is also suggestive of type I AOD. The basion-dens interval (BDI) is the distance between the most inferior portion of the basion and the most superior part of the dens. A BDI >12 mm on plain radiograph is concerning for type II AOD – longitudinal distraction of the occiput. The condyle-C1 interval (CCI) is measured on lateral CT. It measures the distance between the inferior most point of the occipital condyle and the superior lateral mass of C1. A CCI > 2 mm is almost 100% sensitive for AOD.

The clivoaxial angle (CXA) is the angle subtended by a line drawn along the dorsal surface of the clivus and second line drawn along the dorsal surface of C2. CXA < 130 can result in a tethering phenomenon at the cervicomedullary junction, causing stretching of the medullary and upper cervical fibers [4]. As a result, neurological symptoms can develop. A decrease in CXA is often seen in patients with Chiari malformation following treatment with a suboccipital craniectomy.

The above radiographic parameters are used in context of the patient's congenital, acquired, or traumatic pathology in evaluating for craniovertebral instability and need for occipital cervical fusion.

Technique

While there are several methods to achieve occipitocervical fusion with instrumentation, recent studies have demonstrated that instrumentation with polyaxial screws and rods provides the most rigid construct, higher fusion rates, and fewer hardware failures [1, 6, 8, 14, 16, 21]. In recent years cranial fixation systems have undergone many modifications in design to improve the ease of instrumentation and lower complication rates. Modern occipital plates allow multiple screws to be placed in the midline keel of the occipital bone and achieve bicortical purchase. The saddle for the rods is located more laterally on newer occipital plates to easily accommodate the rods. The inside-outside technique utilizes lateral plating of the occiput with a cranial bolt system that connects the plate to the cervical construct with a rod [17, 18] (Fig. 5.1). This technique does not necessitate an occipital keel and

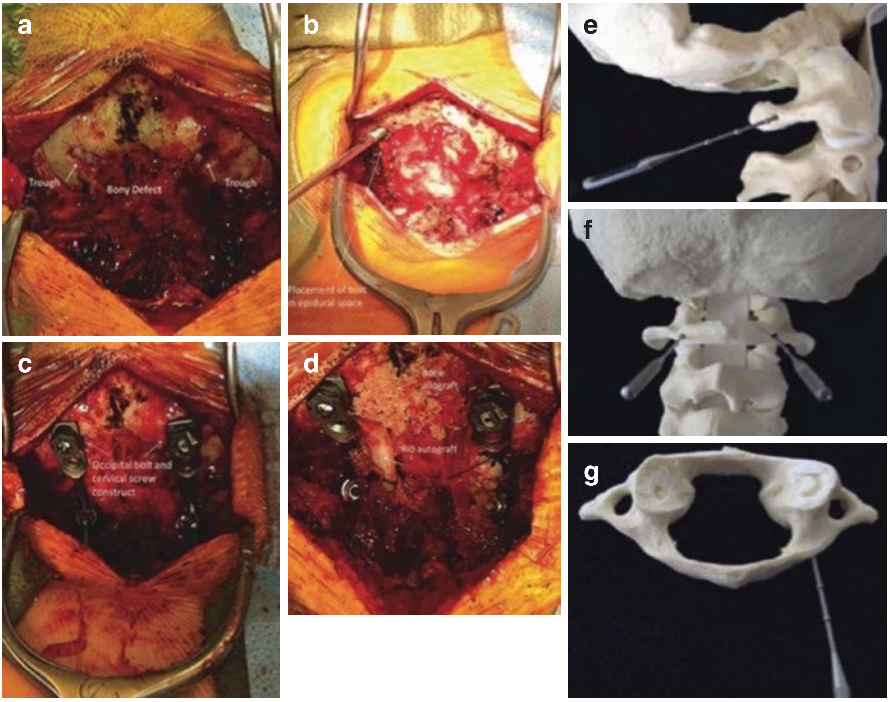

Fig. 5.1 Photographs of intraoperative occipital instrumentation using inside-outside technique and cadaveric demonstration of C1 lateral mass screws using the alternate entry point. (**a**) Troughs are created in the occipital bone with a high-speed drill in line with the cervical instrumentation. (**b**) Occipital bolt is positioned in the epidural space in line with the cervical screws. (**c**) Occipital bolt is secured to the cervical instrumentation using plates, rods, and set screws. (**d**) Final construct with autologous rib graft and bone allograft. (**e**) Superior, (**f**) lateral, and (**g**) posterior views of the trajectory of C1 lateral mass screws placed using the alternate entry point on the posterior arch

eliminates the risk of persistent cerebrospinal leak or cerebellar hematoma. Regardless of the technique and instrumentation system that is used, the surgeon should carefully examine the patient's cervical spine CT and MRI for any aberrancy or anomaly of the VA.

Preoperative Considerations

Neuromonitoring using somatosensory evoked potentials (SSEP) and motor evoked potentials (MEP) should be utilized throughout the procedure. Inhaled anesthetics should not be used if MEP are being monitored. Prepositioning and postpositioning should be considered in cases of AOD to ensure there are no changes in SSEP or MEP secondary to positioning. Steroids may be considered in setting of acute cervicomedullary compression. Preoperative antibiotics should be given prior to incision. Lastly, fiber-optic intubation should be performed in patients with AOD.

Positioning

After induction of general anesthesia and intubation, intravenous lines, intra-arterial lines, and a Foley catheter are placed. The patient is then placed in a Mayfield head holder and is secured to the operating table in prone position with the neck slightly flexed. It is important to ensure that the patient is not hyperflexed or hyperextended as these positions can cause dysphagia and “star gazing,” respectively.

Localization

The upper cervical spine down to C3 for occiput to C2 instrumentation is localized and the EOP is marked. The incision is then marked from the EOP to C3. The patient is then prepped and draped in a sterile fashion.

Exposure

A midline incision is made and dissection is carried down in an avascular plane using monopolar cautery. Recognizing the midline raphe and opening the dorsal cervical fascia in this plane can achieve exposure of the bony elements with little blood loss. The suboccipt is dissected in the subperiosteal plane. In patients who have a previous craniectomy defect, Cobb elevators and curettes can be used to safely define the edge of the cranial defect and the remaining lateral subocciput. The posterior arch of C1 and the C2 spinous process and lamina are then completely exposed. Use of monopolar cautery should be limited when exposing the lateral aspects of the posterior ring of C1 to avoid devastating injury of the VA.

C1 Instrumentation

The C1 lateral mass screw fixation was first described by Goel and then further modified and popularized by Harms [6, 8, 14, 21]. This technique requires exposure of the posterior-inferior portion of the C1 lateral mass and the C2 dorsal root ganglion (DRG). In doing so, one may encounter significant bleeding from the venous plexus surrounding the C2 nerve root and its DRG. Hemostasis can be achieved with bipolar cautery and hemostatic agents such as thrombin-soaked gelfoam. The dorsal root ganglion of C2 is retracted inferiorly to expose the midpoint of the posterior-inferior lateral mass. Management of the C2 nerve root may depend on surgeon preference. Retraction of the C2 nerve root has been associated with occipital neuralgia, and, therefore, some surgeons choose to transect the C2 nerve root. Performing this is associated with increased occipital numbness. However, this has no effect on patient-reported outcomes and quality of life [3]. Regardless of how the C2 nerve root is managed, a pilot hole is drilled at the midpoint of the posterior-inferior C1 lateral mass using a high-speed drill. The trajectory in the sagittal plane is parallel to the posterior arch of C1 and in the axial plane is straight in or slightly convergent. The pilot hole should then be palpated with a ball tip probe to rule out a breach. The hole is then tapped and an appropriately sized partially threaded polyaxial screw is inserted into the lateral mass. The superficial shaft of the screw should be smooth shanked to avoid irritation of the C2 nerve root and DRG.

The senior author performs polyaxial screw instrumentation of the C1 lateral mass using an alternate entry point that is on the lateral posterior arch of C1 [20]. After exposure of the posterior elements of the atlas and axis, the VA is dissected away from the superior surface of the posterior arch of C1 using straight and up-angled curettes. The medial border of the C1 lateral mass is palpated. The entry point is just lateral to the medial border of the C1 lateral mass. While protecting the VA with a No.4 Penfield dissector, the entry point is marked using a high-speed drill. A pilot hole is then drilled in line with the C1 posterior arch and approximately 10° of medial angulation. A power drill is used to penetrate the hard cortical bone of the C1 lateral mass. The pilot hole is then palpated to rule out a breach and tapped. A fully threaded 3.5 mm polyaxial screw is then inserted. This posterior arch technique avoids limitations and hazards of the previously described Harms technique – only a superficial exposure of the posterior aspect of C1 is required and therefore avoids extensive exposure of the C1–C2 articulation and the overlying C2 DRG. This decreases the risk of injury to the nerve root and reduces bleeding from the venous plexus.

C2 Instrumentation

C2 instrumentation can be accomplished in several ways [6, 8, 14, 15, 21]. The senior author's preference is to instrument C2 using a pars interarticularis polyaxial screw. Once the posterior elements of C2 and the C2–C3 facet joint have been exposed, a No. 4 Penfield dissector is used to define and palpate the medial border of the C2 pars interarticularis. The starting point for the C2 pars screw is approximately 3 mm rostral and 3 mm lateral to the inferomedial aspect of the C2–C3 articulation. The length of the pars and its relation to the VA should be measured and studied beforehand. The entry point is marked with a high-speed drill, and the pilot hole is made with a power drill. The sagittal trajectory of the screw parallels that of the pars as seen on intraoperative fluoroscopy. The axial trajectory is straight in or slight medial angulation.

The C2 pedicle screw is an alternate instrumentation technique. Placement of this screw requires a significantly more medial trajectory than the C2 pars screw. The entry point for the C2 pedicle screw is midway between the superior and inferior articular processes of C2. The pilot hole and screw are placed with 15° to 30° of medial angulation and 20° to 25° of cephalad angulation. Biomechanical studies have shown that the C2 pedicle screw has twice the pullout strength of the C2 pars screw [16, 19]. However, the clinical results of the two techniques are comparable [8]. Furthermore, the C2 pedicle may not be large enough to accommodate a polyaxial screw in some patients. The placement of a C2 pars screw may arguably be technically more feasible.

Lastly, C2 translaminar screws can also be placed. Wright et al. first described this technique in 2004 [22]. Screws are inserted in a crossed trajectory into the lamina of C2. One biomechanical study showed that this C2 instrumentation technique is superior to the C2 pars screw in pullout strength and insertional torque [8]. The C2 translaminar screw is technically simple and avoids placing the VA at risk. However, the screw heads are not in line with the cranial plate or the C1 lateral mass screw head. Nonetheless, C2 translaminar screws are considered to be a sufficient alternative technique in cases of failed C2 pars or pedicle screws or in cases of VA anomaly [13].

Cranial Instrumentation

Cranial fixation can be achieved through a variety of methods. If screws are the choice of instrumentation, then preoperative films should be studied to identify the proximity of dural sinuses and to measure the thickness of the occipital bone or keel. The occipital bone is thickest at the EOP measuring up to 15 mm in males and 12 mm in females. However, the risk of injuring the torcular herophili and devastating sequelae makes this technique unfavorable.

Midline occipital keel screws placed with a midline Y- or T-shaped plate are more commonly used. These screws are typically placed with bicortical purchase and have comparable pullout strength to unicortical screws placed at the EOP [2, 16, 21].

The senior author utilizes the inside-outside technique for cranial instrumentation [17, 18]. This technique utilizes a washer, bolt, and plate construct under the occipital bone in the epidural space to act as anchoring points for cranial fixation of the rostral construct. In this technique, first, a mark is placed on the occiput for location of the occipital bolts in line with the position of the C1 and C2 screw heads. A trough is then created using a high-speed drill. The occipital bolt is then placed in the epidural space and slid into its final position. Each plate is secured to the occiput with a locking nut. The inside-outside technique circumvents potential challenges and complications of occipital keel screw fixation systems. The inside-outside technique does not require an intact keel and can be used in patients with a suboccipital craniectomy. This technique involves aligning the bolts and washers with the C1 and C2 screw heads and allows for easier rod placement. Risks of CSF leak and bleeding from dural sinuses are also markedly reduced with the inside-outside technique in comparison to keel screw systems. For these reasons, the inside-outside technique is the senior author's preferred method of cranial fixation.

Transarticular O-C1 Instrumentation

The entry point for a transarticular occiput to C1 screw is similar to that for the Harms technique C1 lateral mass screw. The entry point is marked using a high-speed drill at the center of the inferior lateral mass of C1 at its junction with the C1 posterior arch. A handheld power drill is used to drill a pilot hole with a trajectory directed 10 to 20 medially and 45 superiorly. A K-wire is placed and a polyaxial screw is passed over the K-wire. The biomechanical studies show that transarticular occiputs to C1 screws are comparable to other OCF techniques. However, the transarticular technique requires a steep trajectory that may be impractical in cases of cervical hyperlordosis or obese body habitus [19]. Additionally, the VA may be at greater risk of injury in this technique.

Fusion Mass

Several fusion mass constructs are available for use. At our center we routinely harvest an autologous rib graft. This graft is scored on either side with a fine drill and split in half for use on both sides. This graft has low donor site morbidity and is readily contoured for the occipitocervical junction. Using an autologous graft is especially critical in patients with low bone quality. Once the graft is prepared, a previously contoured rod is placed in each screw head and occipital fixation system.

All set screws are final tightened. The C2 lamina, C1 posterior arch, and occiput are decorticated. The rib autograft is placed posterolaterally from the occiput to C2 and held in place with suture secured around each rod. Demineralized bone matrix is used to supplement the autograft. Alternative bone grafts such as tricortical iliac crest graft [10], cadaveric strut, bone chips, or some combination can also be used to promote bony fusion. The wound is the then closed in standard fashion.

Postoperative Care

After undergoing OCF, additional stabilization using rigid cervical collar should be continued. Patients are typically admitted to the floor bed and can expect to remain in the hospital for 3–7 days depending on their preoperative performance status, medical comorbidities, postoperative mobility, and pain control. Early ambulation is encouraged and facilitated by consulting physical and occupational therapy teams and, if necessary, pain management specialists. Nonetheless, mechanical and medical prophylaxis against deep venous thrombosis should be initiated 24 h following surgery.

Complication Management

As with any surgical procedure, OCF is associated with a variety of potential complications. These include VA injury, dural tears and CSF leak, injury to neural elements, surgical site infection, cerebellar hematoma, failure of instrumentation, and fusion [7, 9, 12].

The most devastating complication from OCF is VA injury. This can occur during exposure or during instrumentation of the C1 lateral mass or C2 pars or pedicle. If injury to the vessel is suspected during exposure, then the vessel should be dissected to control bleeding and attempt repair. The contralateral exposure should be aborted to avoid risk of bilateral VA injury. Postoperative cerebral angiogram should be performed to further identify the anatomy, injury, and options for repair.

VA injury during C1 lateral mass screw is reported to range from 1% to 5.8% [12]. Risk of VA injury is increased in patients with an aberrant VA or a *ponticulus posticus*. The risk of VA injury during C2 instrumentation is increased in patients with small C2 pedicles. C2 pars screws should be placed in these individuals. If brisk arterial bleeding is encountered during placement of C1 or C2 screws, then the screw should be left in place to tamponade bleeding, and the contralateral screw should not be placed to avoid bilateral VA injury. A cerebral angiogram should be obtained immediately to assess the collateral anatomy and feasibility of parent artery occlusion. Detailed preoperative radiographic examination of VA anatomy, C1 lateral mass, and C2 pars and pedicles is most important in avoiding VA injury.

Injury to the intracranial venous sinuses is possible during occipital plating. This can easily be avoided by accurately measuring the thickness of the occipital keel on preoperative CT. Intraoperative fluoroscopy or CT-based navigation can also facilitate accurate instrumentation placement. Nonetheless, sinus bleeding can typically be controlled with direct pressure, hemostatic agents, and placement of instrumentation.

Neurologic injury is possible during OCF and myelopathic patients are at increased risk. The rate of spinal cord injury is 1.3% to 2.1% [7, 12]. The mean arterial pressure should be maintained above 85 mmHg for myelopathic patients. Any postoperative changes in motor or sensory exam should be evaluated with an MRI and CT scan. If there is any compression of neural elements secondary to breached instrumentation, then the appropriate screw should be revised.

The risk of dural tear during occipital screw placement has been reported to be as high as 4.2%. Fortunately, screw placement is typically sufficient to prevent a CSF leak. The inside-outside technique greatly reduces the risk of dural tear and CSF leak. Furthermore, if need be, dural tears can be more easily repaired when using the inside-outside technique than when using occipital screws.

Innovations in instrumentation and fusion graft supplements have improved fusion rates following OCF, but biomechanical complications including pseudoarthrosis and adjacent segment disease may still occur. The rate of pseudoarthrosis following OCF is 8.6% to 16.4% [7]. Optimization of nutrition, strict control of serum glucose, and smoking cessation are critical in minimizing the risks of pseudoarthrosis. Longer OCF constructs that extend to the subaxial cervical spine increase the risk of adjacent segment disease. Therefore, OCF should be limited to the fewest number of levels required to sufficiently achieve stabilization.

References

1. Ando K, Imagama S, Ito Z, Kobayashi K, Yagi H, Shinjo R, Hida T, Ito K, Ishikawa Y, Ishiguro N. Minimum 5-year follow-up results for occipitocervical fusion using the screw-rod system in craniocervical instability. Clin Spine Surg. 2017;30(5):628–32.
2. Bambakidis NC, Feiz-Erfan I, Horn EM, Gonzalez LF, Baek S, Yüksel KZ, et al. Biomechanical comparison of occipitoatlantal screw fixation techniques. J Neurosurg Spine. 2008;8(2):143–52.
3. Dewan MC, Godil SS, Saniya S, Mendenhall SK, Devin CJ, McGirt MJ. C2 nerve root transection during C1 lateral mass screw fixation: does it affect functionality and quality of life? Neurosurgery. 2014;74(5):475–80.
4. Felbaum D, Spitz S, Sandhu FA. Correction of clivoaxial angle deformity in the setting of suboccipital craniectomy: technical note. J Neurosurg Spine. 2015;23(1):8–15.
5. Foerster O. Pain pathways and the surgical treatment of pain syndromes. Berlin: Urban and Schwarzenberg; 1927.
6. Harms J, Melcher RP. Posterior C1-C2 fusion with polyaxial screw and rod fixation. Spine. 2001;26(22):2467–71.
7. He B, Yan L, Xu Z, Chang Z, Hao D. The causes and treatment strategies for the postoperative complications of occipitocervical fusion: a 316 cases retrospective analysis. Eur Spine J. 2014;23(8):1720–4.

8. Huang DG, Hao DJ, He BR, Wu QN, Liu TJ, Wang XD, et al. Posterior atlantoaxial fixation: a review of all techniques. Spine J. 2015;15(10):2271–81.
9. Hwang SW, Gressot LV, Chern JJ, Relyea K, Jea A. Complications of occipital screw placement for occipitocervical fusion in children. J Neurosurg Pediatr. 2012;9(6):586–93.
10. Iyer RR, Tuite GF, Meoded A, Carey CC, Rodriguez LF. A modified technique for occipitocervical fusion using compressed iliac crest allograft results in a high rate of fusion in the pediatric population. World Neurosurg. 2017;107:342–50.
11. Hankinson TC, Anderson RCE. Craniovertebral junction abnormalities in down syndrome. Neurosurgery. 2010;66(3 Suppl):32–8.
12. Lall R, Patel NJ, Resnick DK. A review of complications associated with craniocervical fusion surgery. Neurosurgery. 2010;67(5):1396–403.
13. Lapsiwala SB, Anderson PA, Oza A, Resnick DK, et al. Biomechanical comparison of four C1 to 2 rigid fixative techniques: anterior transarticular, posterior transarticular, C1 to C2 pedicle, and C1 to C2 intralaminar screws. Neurosurgery. 2006;58(3):516–20.
14. Menendez J, Wright N. Techniques of posterior C1-C2 stabilization. Neurosurgery. 2007;60(S1):103–11.
15. Mummaneni PV, Lu DC, Dhall SS, Mummaneni VP, Chou D. C1 lateral mass fixation: a comparison of constructs. Neurosurgery. 2010;66(S3):153–60.
16. Nassos JT, Ghanayem AJ, Sasso RC, Tzermiadianos MN, Voronov LI, Havey RM, et al. Biomechanical evaluation of segmental occipitoatlantoaxial stabilization techniques. Spine. 2009;34(25):2740–4.
17. Pait TG, Al-Mefty O, Boop FA, Arnautovic KI, Rahman S, Ceola W. Inside–outside technique for posterior occipitocervical spine instrumentation and stabilization: preliminary results. J Neurosrug Spine. 1999;90(1 Suppl):1–7.
18. Sandhu FA, Pait TG, Benzel E, Henderson FC. Occipitocervical fusion for rheumatoid arthritis using the inside-outside stabilization technique. Spine. 2003;28(4):414–9.
19. Takigawa T, Simon P, Espinoza Orias AA, Hong JT, Ito Y, Inoue N, et al. Biomechanical comparison of occiput-C1-C2 fixation techniques: C0-C1 transarticular screw and direct occiput condyle screw. Spine. 2012;37(12):E696–701.
20. Thomas JA, Tredway T, Fessler RG, Sandhu FA. An alternate method for placement of C-1 screws. J Neurosurg Spine. 2010;12(4):337–41.
21. Winegar CD, Lawrence JP, Friel BC, Fernandez C, Hong J, Maltenfort M, et al. A systematic review of occipital cervical fusion: techniques and outcomes. J Neurosurg Spine. 2010;13(1):5–16.
22. Wright NM. Translaminar rigid screw fixation of the axis. Technical note. J Neurosurg Spine. 2005;3(5):409–14.
23. Young JP, Young PH, Ackermann MJ, Anderson PA, Riew KD. The ponticulus posticus: implications for screw insertion into the first cervical lateral mass. J Bone Joint Surg Am. 2005;87(11):2495–8.

Chapter 6
Posterior Cervical Laminectomy and Fusion Surgery C3-C7

S. Tim Yoon and Chase Bennett

Introduction

The posterior approach to the cervical spine is effective for multilevel central canal decompression as well as for providing access for posterior instrumentation. A properly performed laminectomy includes lateral mass to lateral mass decompression that fully decompresses the posterior aspect of the spinal canal (Fig. 6.1). Posterior cervical foraminotomies can also be performed in conjunction with this technique for nerve root decompression.

Posterior cervical laminectomy and fusion is most effective in cervical alignments that are either lordotic, neutral, or kyphotic but flexible. This technique coupled with osteotomies may have some ability to correct fixed kyphotic deformity, but more often it is performed in conjunction with an anterior approach when significant anterior pathology prevents adequate decompression from a posterior approach alone. Additionally, some cervical alignments, particularly those with fixed kyphotic deformity, will require adjunctive anterior surgery for deformity correction.

Stand-alone cervical laminectomy has generally fallen out of favor due to a relatively high incidence of post-laminectomy kyphosis. Laminoplasty (covered elsewhere in this text) or laminectomy and fusion procedures are typically chosen instead of laminectomy without fusion [1–3]. In the setting of fusion, several options for subaxial instrumentation exist. In the past, wiring techniques, followed by plating systems, were the predominant method of posterior cervical instrumentation [4]. However, these have almost entirely given way to multi-axial screw and rod con-

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_6

Fig. 6.1 Preoperative MRI in a patient with cervical myelopathy. (Used with permission by Wolters Kluwer Health, Inc.)

structs, which offer superior biomechanics while at the same time adapt easily to patient anatomy and fixation techniques [5, 6].

Currently, subaxial instrumentation is most often performed via lateral mass screw fixation. Pedicle screw fixation in the subaxial cervical spine is sometimes used at C7 because of the small lateral mass and the absence of the vertebral artery; however, it is used less often than lateral mass screw fixation because of the risk to the vertebral artery above C7 and the risk of injuring nerve roots. Accordingly, this chapter will focus on lateral mass fixation techniques (Fig. 6.2).

Exposure

Most patients have reliably palpable landmarks that facilitate exposure of the posterior cervical spine. The inion (external occipital protuberance) should be palpable at the base of the skull, but may be less prominent in female patients. The most cranial spinous process that is routinely palpable is C2. Moving caudally, the C3–C6 spinous processes will form a bony ridge along the midline but are generally not distinctly palpable. The C7 spinous process projects significantly more dorsal than those of C3–C6 and as such is readily palpable. A pre-incision radiograph can be used when the incision cannot be reliably planned from palpable landmarks alone.

The incision should start at the cranial aspect of C2 and extend down 1 cm past the spinous process of C7 in most patients and can be lengthened as necessary to

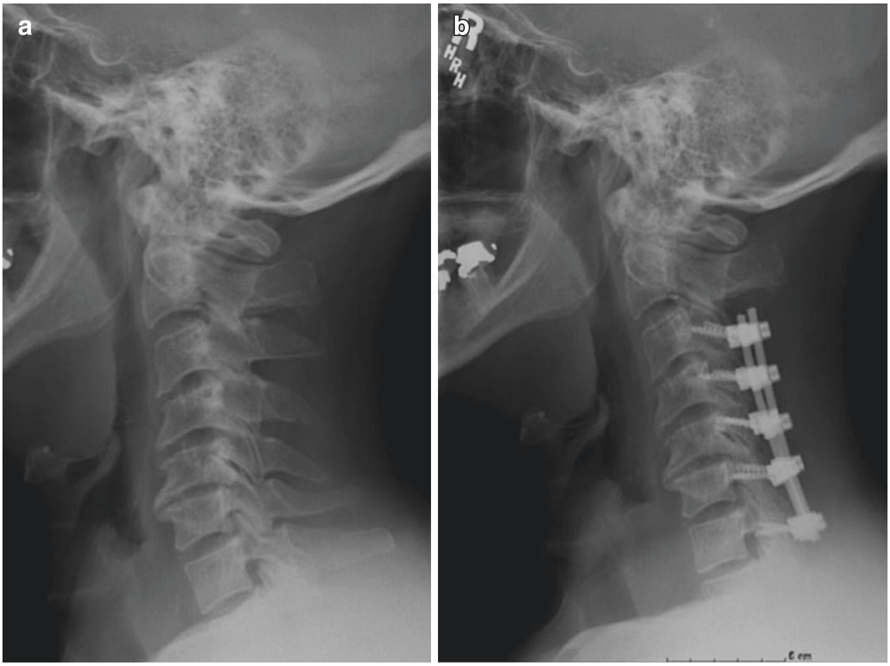

Fig. 6.2 Pre- and postoperative lateral radiographs in a patient who underwent C3–C7 laminectomy and fusion for cervical myelopathy. (**a**) Preoperative lateral cervical radiograph. (**b**) Postoperative lateral cervical radiograph

facilitate adequate exposure. The dissection is carried down through the midline raphe, which is relatively avascular. Intermittent palpation of the spinous processes will facilitate orientation and help the surgeon stay midline and significantly reduce blood loss.

The dissection is carried down to the spinous processes. The fascia is incised at the midpoint of the spinous process at each level from C2 to T1, and then these "dots" are connected to form a complete fascial incision. Skin incision that includes a level above and below the operative levels will greatly improve lateral exposure and minimize lateral retraction force. Care should be taken to preserve the superior fascial attachments at C2, which are important for upper cervical extension and rotation. Once the fascia has been incised, a subperiosteal dissection of the deep posterior cervical musculature is performed. It is important to note that the spinous process of C2–C6 are bifid to various degrees and thus the surgeon will have to come "up and over" the bony lip and then quickly dissect back to midline before carrying the dissection deeper. Failure to conscientiously come back to the midline after dissecting over the tip of the spinous process will cause the surgeon to stray into the paraspinal musculature.

The deep musculature of the posterior cervical spine inserts onto the caudal aspect of the spinous process and lamina. Identifying and releasing this attachment at each exposed level will significantly lessen the retraction force needed to carry out the dissection. When releasing the ligamentous insertion from the spinous process, care should be taken to avoid the canal, which is open in the midline. Once the midline is safely exposed, a Kocher clamp is placed on one of the spinous processes and an XR is taken to confirm the operative level(s).

The dissection is carried out to the lateral aspect of the lateral mass at each level. Care should be taken to preserve the facet capsule at the cranial and caudal most levels of the planned fusion. Cerebellar retractors are effective for maintaining visibility in this location.

With the typical careful exposure, there should be little soft tissue remaining on the bone at this point and blood loss should be minimal. Regardless, any remaining soft tissue, including ligament, tendon, capsule, etc., should be removed, especially if the underlying bone is to be recycled for bone graft. Careful exposure of the medial inferior border of the lamina-lateral mass junction will facilitate identification of the true center of the lateral mass, which is important for lateral mass screw fixation.

Laminectomy Technique

The interlaminar space of the cranial and caudal level is opened with a narrow Leksell Rongeur. The midline raphe in the ligamentum flavum is identified and made more prominent with a micro-curved curette. A small Kerrison Rongeur is then used to remove the ligamentum out to the lateral mass on both sides.

A high-speed burr with a 4-mm non-end-cutting attachment is then used to create a near full thickness trough in the lamina at the lamina-lateral mass junction. The trough is created with the burr using a sweeping motion that allows the surgeon to gradually remove bone in layers. After each pass, the trough is examined and/or palpated as necessary with a micro-curette in order to determine whether or not the trough is full thickness. The lamina is an elongated oval in cross section and is bicortical in the mid portion and with a thick single cortex in the cephalad and caudal ends of the oval. Furthermore, the cephalad end is more ventral and often require more attention to remove sufficient amount of the bone. A 2-mm Kerrison Rongeur is used to open the length of the trough in order to remove the thin shell of bone at the lamina-lateral mass junction any remaining ligamentum flavum.

This same process may be completed on the contralateral side in order to complete the laminectomy. Alternatively, it is the author's preference to create a "hinge" side in which a small amount of bone is left at the base of the trough, similar to the technique used in laminoplasty as described in another chapter. Once the hinge has been made, a small curved curette is used to lift up the open side and a Leksell Rongeur is used to clasp the freely cut end of the lifted lamina and then used to gently break the contralateral hinge. This is done at each laminectomy level. A 2-mm Kerrison Rongeur is then brought down the length of the fractured trough in order to remove the remaining ligamentum flavum and any sharp bone fragments left by breaking through the hinge.

The lamina should be circumferentially freed at this point; however, adhesions can form between the ligamentum and underlying dura. The laminae are gently removed by pulling up with a pituitary rongeur and a small curved curette is used to gently sweep along the undersurface of the lamina, freeing any adhesions. A 2–3-mm Kerrison Rongeur can be used to bite away any remaining lamina to the level of the lateral mass. A small nerve hook should easily pass lateral to the dura once the decompression is complete.

Once the cord is centrally decompressed, foraminotomies (described elsewhere in this text) may be performed to treat any areas of foraminal stenosis, which will not be adequately treated by central decompression alone.

C3–C6 Instrumentation

The lateral mass is a quadrangular piece of bone that is bound by the superior articular process cranially and the inferior articular process caudally. In order to perform safe instrumentation, it is imperative that the surgeon understands the relationship of the lateral mass to the spinal cord, vertebral artery, and exiting nerve root. The spinal cord lies within the spinal canal, between the left and right lateral masses. The entire width of the canal should be exposed following decompression, which will help the surgeon to identify the correct starting point and trajectory, and safely avoid the sensitive anatomic structures.

The vertebral artery lies directly anterior to the medial aspect of the lateral mass. The vertebral artery most commonly traverses the foramen transversarium from C1 to C6; however, variations are common and preoperative imaging should be thoroughly reviewed in order to determine the location of the vertebral artery at each level. Finally, the exiting nerve projects ventrally from the cord, passing through the corresponding cervical foramen, posterior to the vertebral artery, and riding along the superior aspect of the transverse process.

A detailed knowledge of posterior cervical anatomy assists in understanding the most common methods of lateral mass screw. Each was devised to keep the surgeon and screw safe of the cord, vertebral artery, caudal facet joint, and exiting nerve root. The three most common methods in use today are those described by An, Magerl, and Roy-Camille [7–9]. The starting point and the sagittal and axial trajectories of each technique are described in Table 6.1.

Table 6.1 Starting point and sagittal and axial trajectories

	An	Magerl	Roy-Camille
Start point	2 mm medial of the center of the lateral mass	2 mm superomedial of the center of the lateral mass	Direct center of the lateral mass
Cranial angulation	15°	Parallels the plane of the articular facet	The screw is perpendicular to the posterior aspect of the lateral mass and is directed just cranial to the ventral aspect of the caudal joint
Lateral angulation	30°	25°	10°

As described by Heller et al., the lateral mass can be divided into three anatomic zones [10]. The first extends from the superior border of the superior articular process to the top of the transverse process. The second zone is between the superior and inferior margins of the transverse process. The third zone extends from the caudal aspect of the transverse process to the caudal aspect of the inferior articular process. The exiting nerve root lies within zone two and each of the above techniques is designed to land the tip of the screw in zone 1 (An & Magerl) or zone 3 (Roy-Camille), which may be important if the screw is bicortical and penetrates the ventral cortex of the lateral mass. Similarly, the lateral trajectory of the screw is to prevent inadvertent injury to the vertebral artery.

Regardless of which technique is used, the most important technical point is to anchor the screw in solid bone while minimizing danger to neurovascular structures. A thorough understanding of the regional anatomy of the subaxial cervical spine is more important than the individual technique used. Furthermore, the individual anatomy of each lateral mass should be examined on preoperative images in further improve safety and efficacy of lateral mass fixation. In some cases, mixing trajectories may be beneficial as the angle of screw insertion may be dictated by the exposure. For example, it is the author's preference to use the Magerl technique in the upper subaxial spine and then transition to a Roy-Camille trajectory at the more inferior levels where the thoracic spine and caudal extent of the exposure may prevent the surgeon from dropping their hand sufficiently to parallel the facet joint.

C7 Instrumentation

C7 may be instrumented either with lateral mass screws (as described above) or pedicle screws. Unlike the rest of the cervical spine where the vertebral artery travels within the transverse foramen, the transverse foramen of C7 usually lies empty. This along with the larger size of the C7 pedicle makes it an easier target for pedicle screw fixation. If pedicle screws are chosen, the start point should be 2-mm lateral and 2-mm superior to the center of the lateral mass. In the sagittal plane, the trajectory of the screw should parallel the superior endplate. The C7 pedicle has approximately 30 degrees of medial angulation in the axial plane. The laminectomy allows palpation or even visualization of the pedicle to facilitate placement of the C7 pedicle screw.

Fusion/Decortication Technique

Once the screw start points and trajectories have been identified, the fusion bed is then prepped and grafted prior to instrumentation. Preparing the fusion bed once the screws have been placed significantly limits access to the lateral masses and facet joint. The lateral masses should be decorticated lateral to the screw hole and the appropriate facets should be decorticated as well. Following decortication, any bone taken as part of the decompression is thoroughly debrided of soft tissue, morselized, and recycled as local autograft. Depending on the quantity of local autograft, this may be supplemented with allograft or iliac crest as needed. Once the fusion bed has been sufficiently prepped, the graft is placed both within the decorticated facet joints as well as lateral to the screw start sites.

Final Steps

The screw start points and trajectories are then reidentified using a ball tip probe and are sequentially inserted. The set screws and rods are placed and final tightened. Final radiographs confirm hardware position and cervical alignment.

It is the author's preference to place 1 g of vancomycin powder deep to the fascia. A drain is placed deep to the fascia. The fascia is closed with interrupted #1 vicryl in a figure-of-8 fashion. The dermis is closed with interrupted 2–0 vicryls. The skin is closed with 3–0 monocryl and dermabond. A sterile dressing is applied.

Complications

Surgical site infection occurs in 1–3% of all cases. Smoking, obesity, the use of immunomodulatory drugs and/or steroids, and malnutrition are all associated with a high risk of infection [11, 12]. Recently, powered vancomycin powder applied directly to the wound at closure has shown promise in reducing the rate of postoperative infection [11, 13, 14].

Pseudoarthrosis can occur following posterior cervical laminectomy and fusion, though many may be minimally or not symptomatic [15, 16]. After cervical laminectomy and fusion, the fusion bed is confined to the lateral masses, which is a relatively small surface area available for grafting. Therefore, it is vital that the surgeon is meticulous in their preparation of the graft bed by decorticating the facet joints. Additionally, iliac crest bone graft, biologic enhancers, or anterior spinal surgery may be used to increase fusion rates.

Though reports vary widely, the incidence of C5 palsy following laminectomy is somewhere between 5% and15% [17–19]. The etiology of C5 palsy is unclear but several hypotheses have been posited. One theory recognizes the C4–C5 foramen is often near the apex of the cervical lordosis and therefore the C5 nerve root might be put on maximal tension during any drift back. A second hypothesis is that the deltoid is more singularly innervated by C5 and therefore may be "unmasked" more readily as compared to other myotomes. The evidence to support prophylactic C4–C5 foraminotomy to prevent C5 palsy is conflicting [20, 21]. Regardless C5 palsy generally improves with time, especially if it is relatively mild [22].

Neck pain and stiffness complaints occurs with some frequency. Adjecent segmen disease at C7-T1 is also common, so many surgeons prefer to fuse down to the upper thoracic level. Finally, spinal cord injury, nerve root injury, and vertebral artery injury are rare but described complications of posterior cervical laminectomy and fusion. Careful positioning, detailed knowledge of cervical anatomy, and careful surgical technique may help to reduce the risk of these events.

Summary

The posterior approach to the cervical spine is effective for central canal decompression as well as for providing access for posterior instrumentation. It is generally safe and effective though infections rates are somewhat higher than in anterior approach to the cervical spine, and a detailed anatomical knowledge of the cervical spine is needed in order to minimize iatrogenic injury. The posterior cervical laminectomy and fusion can be used alone, or in conjunction with anterior procedures for effective neurological decompression, restoration of cervical alignment, and high union rates.

References

1. Kaptain GJ, Simmons NE, Replogle RE, Pobereskin L. Incidence and outcome of kyphotic deformity following laminectomy for cervical spondylotic myelopathy. J Neurosurg [Internet]. 2000 [cited 2018 Feb 4];93(2 Suppl):199–204. Available from: http://www.ncbi.nlm.nih.gov/pubmed/11012049.
2. Kaminsky SB, Clark CR, Traynelis VC. Operative treatment of cervical spondylotic myelopathy and radiculopathy. A comparison of laminectomy and laminoplasty at five year average follow-up. Iowa Orthop J [Internet]. University of Iowa. 2004 [cited 2018 Feb 4];24:95–105. Available from: http://www.ncbi.nlm.nih.gov/pubmed/15296214.
3. Woods BI, Hohl J, Lee J, Donaldson W, Kang J. Laminoplasty versus laminectomy and fusion for multilevel cervical Spondylotic myelopathy. Clin Orthop Relat Res [Internet]. 2011 [cited 2018 Feb 4];469(3):688–95. Available from: http://www.ncbi.nlm.nih.gov/pubmed/21089002.
4. Omeis I, DeMattia JA, Hillard VH, Murali R, Das K. History of instrumentation for stabilization of the subaxial cervical spine. Neurosurg Focus [Internet]. 2004 [cited 2018 Feb 4];16(1):E10. Available from: http://www.ncbi.nlm.nih.gov/pubmed/15264788.
5. Grubb MR, Currier BL, Stone J, Warden KE, An KN. Biomechanical evaluation of posterior cervical stabilization after a wide laminectomy. Spine (Phila Pa 1976) [Internet]. 1997 [cited 2018 Feb 4];22(17):1948–54. Available from: http://www.ncbi.nlm.nih.gov/pubmed/9306522.
6. Mummaneni PV, Haid RW, Traynelis VC, Sasso RC, Subach BR, Fiore AJ, et al. Posterior cervical fixation using a new polyaxial screw and rod system: technique and surgical results. Neurosurg Focus [Internet]. 2002 [cited 2018 Feb 4];12(1):E8. Available from: http://www.ncbi.nlm.nih.gov/pubmed/16212335.
7. An HS, Gordin R, Renner K. Anatomic considerations for plate-screw fixation of the cervical spine. Spine (Phila Pa 1976) [Internet]. 1991 [cited 2018 Feb 4];16(10 Suppl):S548–51. Available from: http://www.ncbi.nlm.nih.gov/pubmed/1801270.
8. Jeanneret B, Magerl F, Ward EH, Ward JC. Posterior stabilization of the cervical spine with hook plates. Spine (Phila Pa 1976) [Internet]. 1991 [cited 2018 Feb 4];16(3 Suppl):S56–63. Available from: http://www.ncbi.nlm.nih.gov/pubmed/2028342.
9. Roy-Camille R, Mazel C, Saillant G. Treatment of Cervical Spine Injuries by a Posterior Osteosynthesis with Plates and Screws. Cervical Spine I [Internet]. Vienna: Springer

Vienna; 1987 [cited 2018 Feb 4]. pp. 163–74. Available from: http://www.springerlink.com/index/10.1007/978-3-7091-8882-8_29.

10. Heller JG, Carlson GD, Abitbol JJ, Garfin SR. Anatomic comparison of the Roy-Camille and Magerl techniques for screw placement in the lower cervical spine. Spine (Phila Pa 1976) [Internet]. 1991 [cited 2018 Feb 4];16(10 Suppl):S552–7. Available from: http://www.ncbi.nlm.nih.gov/pubmed/1801271.
11. Pahys JM, Pahys JR, Cho SK, Kang MM, Zebala LP, Hawasli AH, et al. Methods to decrease postoperative infections following Posterior cervical spine surgery. J Bone Jt Surg [Internet]. 2013 [cited 2018 Feb 5];95(6):549–54. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23515990.
12. Sebastian A, Huddleston P, Kakar S, Habermann E, Wagie A, Nassr A. Risk factors for surgical site infection after posterior cervical spine surgery: an analysis of 5,441 patients from the ACS NSQIP 2005–2012. Spine J [Internet]. 2016 [cited 2018 Feb 5];16(4):504–9. Available from: http://www.ncbi.nlm.nih.gov/pubmed/26686605.
13. Caroom C, Tullar JM, Benton EG, Jones JR, Chaput CD. Intrawound vancomycin powder reduces surgical site infections in Posterior cervical fusion. Spine (Phila Pa 1976) [Internet]. 2013 [cited 2018 Feb 5];38(14):1183–7. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23474597.
14. Strom RG, Pacione D, Kalhorn SP, Frempong-Boadu AK. Decreased risk of wound infection after Posterior cervical fusion with routine local application of vancomycin powder. Spine (Phila Pa 1976) [Internet]. 2013 [cited 2018 Feb 5];38(12):991–4. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23324930.
15. Leven D, Cho SK. Pseudarthrosis of the Cervical Spine: risk factors, diagnosis and management. Asian Spine J [Internet]. Korean Society of Spine Surgery. 2016 [cited 2018 Feb 5];10(4):776–86. Available from: http://www.ncbi.nlm.nih.gov/pubmed/27559462.
16. Park DK, An HS. Problems related to cervical fusion: malalignment and nonunion. Instr Course Lect [Internet]. 2009 [cited 2018 Feb 5];58:737–45. Available from: http://www.ncbi.nlm.nih.gov/pubmed/19385582.
17. Nassr A, Eck JC, Ponnappan RK, Zanoun RR, Donaldson WF, Kang JD. The Incidence of C5 Palsy After Multilevel Cervical Decompression Procedures. Spine (Phila Pa 1976) [Internet]. 2012 [cited 2018 Feb 5];37(3):174–8. Available from: http://content.wkhealth.com/linkback/openurl?sid=WKPTLP:landingpage&an=00007632-201202010-00004.
18. Gu Y, Cao P, Gao R, Tian Y, Liang L, Wang C, et al. Incidence and risk factors of C5 palsy following posterior cervical decompression: a systematic review. Shamji M, editor. PLoS One [Internet]. Public Library of Science. 2014 [cited 2018 Feb 5];9(8):e101933. Available from: http://dx.plos.org/10.1371/journal.pone.0101933.
19. Nakashima H, Imagama S, Yukawa Y, Kanemura T, Kamiya M, Yanase M, et al. Multivariate analysis of C-5 palsy incidence after cervical posterior fusion with instrumentation. J Neurosurg Spine [Internet]. American Association of Neurological Surgeons. 2012 [cited 2018 Feb 5];17(2):103–10. Available from: http://thejns.org/doi/10.3171/2012.4.SPINE11255.
20. Katsumi K, Yamazaki A, Watanabe K, Ohashi M, Shoji H. Can prophylactic bilateral C4/C5 Foraminotomy prevent postoperative C5 palsy after open-door Laminoplasty? Spine (Phila Pa 1976) [Internet]. 2012 [cited 2018 Feb 5];37(9):748–54. Available from: http://content.wkhealth.com/linkback/openurl?sid=WKPTLP:landingpage&an=00007632-201204200-00006.
21. Bydon M, Macki M, Kaloostian P, Sciubba DM, Wolinsky J-P, Gokaslan ZL, et al. Incidence and Prognostic Factors of C5 Palsy. Neurosurgery [Internet]. Oxford University Press. 2014 [cited 2018 Feb 5];74(6):595–605. Available from: https://academic.oup.com/neurosurgery/article-lookup/doi/10.1227/NEU.0000000000000322.
22. Sakaura H, Hosono N, Mukai Y, Ishii T, Yoshikawa H. C5 palsy after decompression surgery for cervical myelopathy. Spine (Phila Pa 1976) [Internet]. 2003 [cited 2018 Feb 5];28(21):2447–51. Available from: http://content.wkhealth.com/linkback/openurl?sid=WKPTLP:landingpage&an=00007632-200311010-00004.

Chapter 7
Cervical Laminoplasty

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Introduction

The concept of laminoplasty is very enticing as it promises a motion-preserving definitive cervical decompression surgery with a relatively low risk of secondary deformity or complications. Despite many variations that this procedure has undergone over the quarter century since its introduction, the common denominator of the procedure remains unchanged: a posteriorly based motion-preserving comprehensive cervical neural element decompression procedure which preserves key posterior structural elements such as the laminae, spinous processes, and the posterior ligamentous complex with its supra- and interspinous ligaments as well as the facet capsules. Conventional cervical laminectomies, which consist of removal of the laminae and the spinous process, can lead to instability, kyphosis, and pain [1], all circumstances which are associated with poor outcomes [2–6]. In contrast, the concept of laminoplasty affords effective posterior cervical decompression while preserving the posterior elements, thus limiting the risk of instability, kyphosis, secondary posterior cord compression, and pain. Originally, this procedure variant was conceived by Japanese neurosurgeons to offer more effective treatment of symptomatic cervical stenosis brought on by ossification of the posterior longitudinal ligament (OPLL) [7]. Over time, there have been a rather large number of surgical techniques variations described for laminoplasties, more recently even "minimally invasive" modifications [8]. Further variants include use of selective laminectomies between arch expansion surgeries and skip level procedures. General indications for cervical laminoplasty largely revolve around various clinical manifestations of cervical stenosis, including compressive myelopathy, multilevel disc herniations and spinal canal stenosis such as brought on by OPLL. The basic idea is

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_7

to let the cord "float" posteriorly away from the anterior column by about 3 mm or more through the posterior arch expansion procedure [9]. Consequently, a laminoplasty is therefore usually contraindicated in cases of cervical kyphosis, single- or two-level stenosis, severe anterior focal compression of the spinal cord, and predominance of radicular symptoms [10, 11]. It has also been suggested for the treatment of central cord injuries in the presence of a structurally stable spine without major fractures, ligament disruption, or larger traumatic disc herniations. In addition to decreasing the likelihood of developing kyphosis, instability, and pain, laminoplasty has been shown to lower the occurrence of recurrent posterior cord compression from dorsal scar or muscle entrapment seen occasionally after laminectomy [12]. It also allows the surgeon to add posterior foraminotomies and – with the addition of posterior instrumentation – enhances stability of the posterior arch reconstruction to minimize secondary collapse of the arch expansion by assuring bone healing of the posterior arch in the originally desired position [7]. Some of the reported disadvantages of cervical laminoplasties revolve around general problems associated with more extensile posterior spine procedures such as infection and other wound complications, loss of range of motion [1, 13–21] and a prolonged and a more painful recovery due to myofascial pain, rarely also neurologic injuries such as painless 5th cervical nerve root palsies. Overall, cervical laminoplasties have been shown to be either comparable or superior to laminectomies with or without posterior cervical fusions.

Surgical Technique (Open Door Versus French Door)

As with any surgical technique preoperative decision-making is an important foundation towards achieving success with the actual procedure. In general, laminoplasty can be indicated for the treatment of symptomatic cervical stenosis of two or more levels. This procedure requires absence of kyphosis, a structurally reasonably stable spine unaffected by inflammatory arthropathy and ideally features an intact posterior ligamentous complex as well as a patient able to cooperate with an active postoperative treatment program.

The goal of all cervical laminoplasty techniques is to effectively increase the spinal canal space while preserving all structural posterior spinal column elements along their tendinous attachments, thereby minimizing perineural scar formations and preserving cervical stability and alignment [13]. Although there is a confusing variety of surgical laminoplasty techniques and modifications presented in the literature they all essentially boil down to one of two basic techniques, the "open-door" or the "French-door" technique.

The "open-door" technique is also known as the "Hirabayashi," "open-hinged," or "single-door" technique. Hirabayashi described this unilateral expansive open-door laminoplasty based on the Z-shaped plasty described by Oyama in the early 1980s [17, 22]. The procedure can be performed on either side from C2 to the upper thoracic spine, but is most commonly performed from C3 to C7. Standard prone neck surgery positioning is usually achieved through cranial tongs to secure the head. Head position is either neutral or can be slightly flexed as tolerated by the patient. A posterior midline approach through the nuchal ligament is followed by subperiosteal dissection of the paraspinal muscles from the posterior elements while carefully preserving the facet capsules and interspinous and supraspinous ligaments. Longitudinal narrow laminectomy cuts are performed at the junction of laminae and lateral masses under preservation of the facet joint capsules. Emphasis of facet joint integrity has been made to decrease the risk of segmental hypermobility and secondary instability [11, 23, 24]. It is generally recommended to make the opening side full thickness laminotomy cut on the side with more predominant symptoms or greater neural canal compression to maximize the benefits of greater direct decompression on that side. On the contralateral side a similar cut is made with the difference that the deepest layer of laminar bone is tinned out but not completely cut to allow for creation of a controlled “greenstick-type” fracture to act as hinge during the elevation of the lamina on the side of the full thickness laminotomy. The elevation of the lamina is usually facilitated by a simultaneous application of an upbiting curette placed under the lamina on the full thickness cut side and a cantilever pulling force applied through a clamp placed on the respective spinous process. Following opening of the spinal canal, it is advisable to resect the lateral ligamentum flavum attachments and to control epidural venous bleeding. As the newly created laminar gap will not remain open by itself, many different techniques have been described to secure the opening defect with some device or technique. This includes tethering procedures with sutures or cables placed on the hinged side and also various interposition “blocking” devices placed on the opened side to prevent reclosure. For the latter, a variety of interposition grafts have been described over time, including biologic spacers made from auto- or allogenic sources and a variety of inorganic devices such as metal, ceramic, and other materials. Some authors have even questioned the need for any interposition grafts, by relying on primary healing of the hinged side [25, 26] while others have suggested the use of a more comprehensive posterior element reconstruction by using rigid stabilization through application of segmental miniature plates to secure interposition grafts from redisplacing [27–31]. There is usually no need for fixation on the hinged side, but attention should be directed to the lamina not being intussuscepted underneath the lateral mass during expansion and fixation. An important recommendation is to avoid overdistraction of the opening side to avoid radiculopathy on the hinged side. Similarly, the trough cuts on either side should be placed as close as possible at the junction of the lamina and lateral mass protuberance in order to achieve maximal spinal canal expansion while minimizing the risk of radiculopathy [32–35].

The “French-door” technique has also been referred to as “double-door” laminoplasty, “spinous process-splitting,” “midline opening,” or “T-Saw” laminoplasty. This technique was first described by Kurokawa, who suggested a symmetrical midline split of the spinous processes in contrast to the asymmetrical “open-door” laminoplasty [36]. After performing bilateral full thickness longitudinal narrow laminotomy trough cuts at the lamina/facet joint junction, a central splitting cut through the midportion of the spinous processes is added over the dorsal apex of the spinous processes. This allows for each of the hemilaminae to be split open centrally, thus resulting in a symmetric canal reexpansion. Similar to the open-door laminoplasty technique, the hemilaminae usually require some form of interposition or tethering procedure to prevent reclosure. Similar to "open-door" technique over time, a variety of interposition grafts have been described ranging from biologic to inorganic device. In contrast to the "open-door" technique, a natural press fit of an interposition graft in the French-door technique may somewhat decrease the need for rigid stabilization of the respective lamina [13, 36–41].

Shared to both approaches is the ability to add foraminotomies as needed in case of radiculopathy. Conversion to a posterior fusion with segmental fixation may become indicated in case of a failed laminoplasty such in case of bilateral radicular symptoms, mechanical instability or kyphosis and with recalcitrant severe axial neck pain [13]. In this context several studies have shown that laminoplasties may provide a safer and more feasible conversion to a posterior fusion compared to laminectomies alone [2, 42].

As laminoplasties are intended to be a motion preserving surgery relatively early mobilization is encouraged. Therefore, any immobilization is usually limited to not more than 2 weeks in a rigid or soft cervical collar return to gentle early range of motion exercises and emphasis on shoulder girdle reactivation and strengthening. Return to a physiologic posture is also generally encouraged but has not been formally studied as an important element of aftercare.

Graft Materials

The function of interposition grafts in laminoplasty is to prevent reclosure of the expanded laminar arch on a lasting basis. The need for osseous integration of this interposition graft has remained unclear, as the hinged side has been found to be capable of healing by primary bone healing, thus seemingly rendering the need for bony laminar incorporation of the expansion side less important. That said, most authors have recommended using bone material, regardless of autologous or, if available, allogenic sources, as intuitively preferable choice for creation of a stable laminar reexpansion. More recently devices with porous surfaces that allow for some bone osseous have also been introduced, as have plates, which feature an interposition bar incorporated in their design.

Comparison of Several Surgical Techniques

Both the "open-door" and "French-door" laminoplasties have been reported to result in high success rates [43–45], without significant differences in their respective neurological outcome [46]. In contrast, Nakashima et al. and Okada et al. reported less blood loss, decreased axial neck pain, decreased loss of cervical lordosis and a greater range of motion for the French-door technique. In contrast, Lee et al. suggested that the open-door technique may be superior in terms of clinical and radiological outcome [47]. Overall, in comparison to multilevel anterior corpectomy and fusion surgeries laminoplasties were found to have similar clinical outcomes, with a lower complication and reoperation rate, less blood loss and shorter operative time for a subset of patients with cervical spondylotic myelopathy [42, 48]. When laminectomies with posterior fusion were compared to laminoplasties in multilevel cervical myelopathic patients, Heller et al. found that patients with laminoplasty showed a greater functional improvement and had a lower complication rate [2]. Other studies showed no difference in long-term neurologic outcome between laminoplasties and laminectomies with fusion [40, 49, 50]. Of note is a general trend to try to minimize surgical trauma during posterior exposure by minimizing or altogether avoiding disinsertion of the rectus and obliquus capitis tendons from the C2 spinous process and the splenius cervicis from the C7 spinous processes, as this refinement has been associated with decreased neck pain [51, 52].

Complications

Complications after laminoplasties mainly revolve around the following entities: persistent axial neck pain, loss of lordosis and alignment, reduced range of motion, neurologic decline, and impaired wound healing [15, 16, 20]. Posterior approaches including laminoplasties and laminectomies with or without posterolateral instrumentation and fusion generally have been reported to have a higher wound infection rate in comparison to anterior approaches (3–4% vs. <1%, respectively) [53]. Nevertheless, studies have shown an overall satisfactory outcome with a relatively low rate of complications [19, 21, 27, 39, 42, 46, 54–57]. The incidence of persistent postoperative axial neck pain seems to be independent on the laminoplasty technique performed, with a causal association between laminoplasty and axial neck pain remaining unclear to date. While some authors suggest that postoperative axial neck and shoulder pain is a common problem for patients who underwent laminoplasties [15, 20], others concluded that laminoplasties did not "have any significant influence on the development or resolution of axial symptoms" [58]. Rhee et al. suggested that the previously reported neck pain in the older literature is related to the different postoperative treatment with prolonged postoperative immobilization as well as bone grafting of the hinge side [53, 59]. This in part may also be reflective of the type of stabilization used. Rigid stabilization of the interposition graft may facilitate earlier safe mobilization of the patient, while a nonrigid form of posterior element stabilization, for instance with retention sutures, may require external immobilization to minimize the risk of nonunion and redisplacement. Another contributing factor in postoperative neck pain may arise from the type of soft tissue dissection. Preservation of tendinous attachments of the rectus and obliquus capitis and splenius cervicis tendons, respectively, at their C2 and C7 spinous process insertion sites – where possible – may further help reduce some of the perioperative myofascial neck pain. There are, however, no comparative studies to validate this claim.

Restricted range of motion after laminoplasty has been another concern. Wada et al. reported a 29% decrease in the range of motion (40.2°–11.6°) after laminoplasty. Obvious possible causes for this may arise from postoperative mobilization, poor neck/shoulder girdle posture, incomplete laminar arch stability, scar tissue formation, and patient selection.

Spontaneous fusion may be another contributing factor. Spontaneous postoperative ankylosis at C2–C3 was observed in 40% in one study [60]. Postoperative nerve root palsy may affect any level, but most commonly present at the C5 root. Its reported incidence after laminoplasties ranges from 5% to 12% [61] and is attributed to a traction phenomenon of the C5 root.

Infections and excessive bleeding are postoperative complications that have been routinely reported for posterior multilevel cervical procedures. Laminoplasties seem to have lower comparative blood loss and postoperative infections compared to laminectomies and posterior fusions [62].

Reclosure of a laminoplasty arch expansion is a relatively rare occurrence and as such unusual in case of rigid posterior element stabilization [63–66]. Tethering and other nonrigid posterior element reconstruction techniques may be a greater setup for nonunion and displacement of posterior elements prior to posterior bony healing of the lamina. Duration of myelopathy symptoms in excess of 12 months and hemoglobin A1c levels above 6.5% as well as disease presence more than 10 years were also identified as poor prognostic factors for unfavorable outcomes [67].

Another important and potentially disconcerting observation was the potential for progressive overgrowth of OPLL bone formation into the spinal canal reported year after a successful index procedure. Within 5 years the authors of one center identified radiographic progression of the ossification process in over 70% of patients, albeit without clear symptoms correlation [68, 69]. This troublesome observation has been made for posterior fusions procedures as well, but to a lesser degree and not in statistically significant fashion [70].

Outcomes

Laminoplasties are a safe and effective posterior cervical decompressive procedure especially for patients affected by multilevel cervical myelopathy. In a study of 520 consecutive patients, Machino reported preservation of cervical motion in 87.9% of patients, with some improvement of lordosis from an average 11.9 degrees preoperatively to 13.6% postoperatively and an average loss of motion of 6.6%. The authors attributed this in part to early range of motion and avoidance of neck collars, with stale internal fixation of the laminar arches. The most important prognostic factor for a good outcome seems to be the baseline grade of myelopathy. Patients older than 60, with symptoms of bowel or bladder dysfunction, advanced lower-extremity dysfunction, and longer duration of symptoms, are associated with a poor prognosis [13, 54, 71–73]. Nonetheless, studies show that laminoplasties have an overall satisfactory outcome with a relatively low rate of complications when compared to both laminectomies with or without adjuvant fusion and multilevel anterior decompression and fusion [19, 21, 27, 39, 42, 46, 54–57]. Loss of cervical lordosis can lead to sagittal malalignment and subsequently lead to pain and functional disability [74–76]. Precise preoperative planning, correct patient selection, and prevention of postoperative instabilities resulting in kyphosis are crucial for a preferable outcome.

Age as a determinant for complications and neurologic outcomes has been assessed in a study of 505 patients treated with laminoplasty. There were no statistical differences in complications between patients younger than 65 and older than 75 years and those in between, while the neurologic improvement was no different in terms of JOA scores (around 3 points for the three cohorts), as well as 10 s grasp and release tests and 10 s step tests [77].

In a prospective comparison study of 92 patients who received either open- or French-door laminoplasties by Nakashima et al., there were no reported differences in terms of parameters, such as surgical duration, complications, and neurologic improvement. The authors found a greater loss of lordosis in the open-door cohort of 5.6 degrees compared to the French-door group with 3 degrees and a greater loss of range of motion in the open-door cohort of 26 degrees compared to 19.3 degrees in the French-door group [44]. In clinical practice the greater amount of surgical cutting of the posterior elements and higher chance of causing disruption of the posterior elements with very marginal actual surgical outcomes differences is the likely reason why the “French-door” technique has not achieved the popularity of the “open-door” technique (Fig. 7.1).

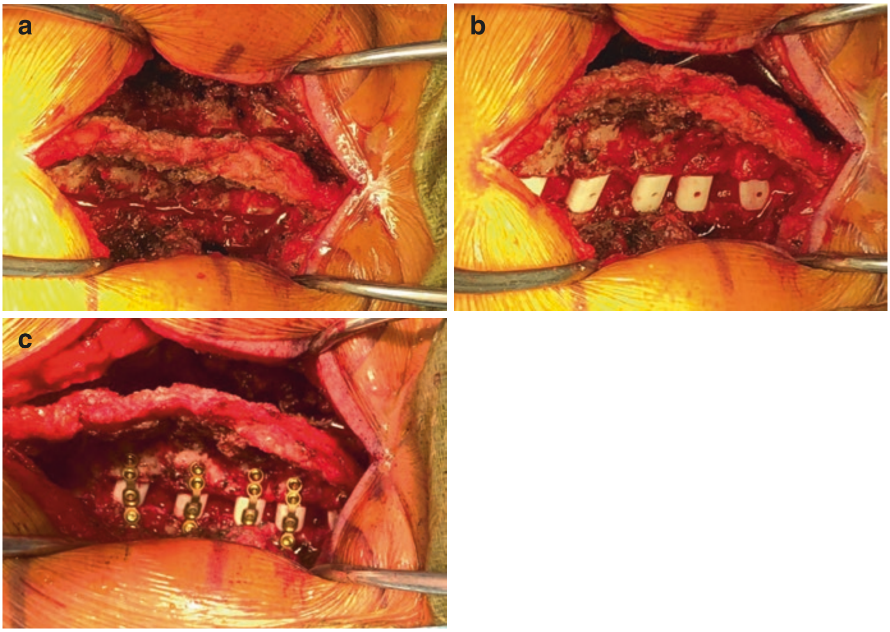

Fig. 7.1 (**a**–**c**). The “open-door” technique

Conclusions

In Asian countries laminoplasties have been a well-established procedure for more than two decades, arising to the level of a preferred treatment for the treatment of symptomatic compressive cervical spondylotic myelopathy. Its acceptance in other regions of the world has been far more reserved. Over time several clear advantages of laminoplasty have emerged:

- Laminoplasty can lead to improvement of neurologic conditions such as symptomatic myelopathy and associated radiculopathy while combining the advantages of a motion-preserving procedure minus the instability and malalignment concerns plaguing multilevel cervical laminectomies alone. Earlier intervention can be expected to have a better chance at symptom improvement or even resolution, but even more advanced cases will usually benefit from effective decompression. Reported improvement rates have been on par with laminectomies and fusion and multilevel anterior decompression and fusion surgeries.
- Indications for laminoplasty range from symptomatic spondylotic compressive myelopathy ossification of the posterior longitudinal ligament (OPLL) to patients with central cord syndrome in absence of unstable fracture, dislocation, and acute disc herniation. The latter indications remain under some debate as OPLL may increase in its ventral mass effect on the cord despite posterior decompression and longer-term outcomes of central syndromes treated with laminoplasty are spotty at present.
- Contraindications for laminoplasties remain unchanged since its initial introduction: kyphosis, cervical instability, connective tissue disease, and inflammatory arthropathies. Laminoplasties continue to be applied under a variety of adjuvant circumstances – such as adjacent to fusions, alternating with selective laminectomies. Larger-scale evidence remains sparse, but conceptually seems to be possible based on limited reports.
- Complications more specifically associated with laminoplasty are its potential conversion to fusion, loss of range of motion, emergence of kyphosis, and persistent neck pain. Overall reported complications compare favorably to posterior laminectomy and fusion in terms of lower blood loss and postoperative infection.
- Of the two main techniques – open-door and French-door technique – the prior has seemingly gained much greater acceptance as reflected in an overview of the literature. The reason for this can likely be seen in the relatively easier and reproducible surgical technique of the open-door technique. The opening door technique also facilitates foraminotomies on the expanded side. The addition of posterior hardware and a biologic interposition graft capable of solid bone healing are conceptually appealing with no apparent downside aside from cost. The evidence base for their use compared to simple opening procedures with non-rigid arch expansion, however, remains unclear [78]. Despite absence of a clear evidence-based support for such, these authors clearly favor rigid plate and screw-based arch expansion and use of a custom-sized and precut allograft that

is press fit into place to allow for early mobilization with little or no risk of secondary closure.
- Despite its favorable performance on the literature over several decades laminoplasty remains relatively rarely used in North America and Europe. Causes for this are likely multifactorial including different patient populations, surgical training, and reimbursement [79].
- Moreover, laminoplasty has been subject to multiple variations almost from the onset, making a more systematic evaluation harder. Nonetheless this surgical procedure, if done well for the correct application, remains a valuable addition to the surgical treatment of symptomative cervical myelopathy patients [80, 81].

References

1. Hirabayashi K, Satomi K. Operative procedure and results of expansive open-door laminoplasty. Spine (Phila Pa 1976). 1988;13(7):870–6.
2. Heller JG, Edwards CC, Murakami H, Rodts GE. Laminoplasty versus laminectomy and fusion for multilevel cervical myelopathy: an independent matched cohort analysis. Spine (Phila Pa 1976). 2001;26(12):1330–6.
3. Butler JC, Whitecloud TS. Postlaminectomy kyphosis. Causes and surgical management. Orthop Clin North Am. 1992;23(3):505–11.
4. Guigui P, Benoist M, Deburge A. Spinal deformity and instability after multilevel cervical laminectomy for spondylotic myelopathy. Spine (Phila Pa 1976). 1998;23(4):440–7.
5. Yasuoka S, Peterson HA, MacCarty CS. Incidence of spinal column deformity after multilevel laminectomy in children and adults. J Neurosurg. 1982;57(4):441–5.
6. Sim FH, Svien HJ, Bickel WH, Janes JM. Swan-neck deformity following extensive cervical laminectomy. A review of twenty-one cases. J Bone Joint Surg Am. 1974;56(3):564–80.
7. Ito M, Nagahama K. Laminoplasty for cervical myelopathy. Global Spine J. 2012;2(3):187–94.
8. Minamide A, Yoshida M, Simpson AK, Yamada H, Hashizume H, Nakagawa Y, et al. Microendoscopic laminotomy versus conventional laminoplasty for cervical spondylotic myelopathy: 5-year follow-up study. J Neurosurg Spine. 2017;27(4):403–9.
9. Sodeyama T, Goto S, Mochizuki M, Takahashi J, Moriya H. Effect of decompression enlargement laminoplasty for posterior shifting of the spinal cord. Spine (Phila Pa 1976). 1999;24(15):1527–31; discussion 31–2.
10. Aita I, Hayashi K, Wadano Y, Yabuki T. Posterior movement and enlargement of the spinal cord after cervical laminoplasty. J Bone Joint Surg Br. 1998;80(1):33–7.
11. Aebi M, Arket V, Webb JK. AO spine manual. Principles and techniques (Vol 1). Thieme Verlag: Stuttgart, New York; 2007.
12. Stamm S, McClellan JW, Knierim A, Suiter IP, Riew KD. Dynamic MRI reveals soft-tissue compression causing progressive myelopathy in postlaminectomy patients: a report of three cases. JBJS Case Connect. 2013;3(1):e17.
13. Mitsunaga LK, Klineberg EO, Gupta MC. Laminoplasty techniques for the treatment of multilevel cervical stenosis. Adv Orthop. 2012;2012:307916.
14. Hosono N, Sakaura H, Mukai Y, Yoshikawa H. The source of axial pain after cervical laminoplasty-C7 is more crucial than deep extensor muscles. Spine (Phila Pa 1976). 2007;32(26):2985–8.
15. Hosono N, Yonenobu K, Ono K. Neck and shoulder pain after laminoplasty. A noticeable complication. Spine (Phila Pa 1976). 1996;21(17):1969–73.
16. Hosono N, Sakaura H, Mukai Y, Fujii R, Yoshikawa H. C3-6 laminoplasty takes over C3-7 laminoplasty with significantly lower incidence of axial neck pain. Eur Spine J. 2006;15(9):1375–9.

17. Hirabayashi K, Watanabe K, Wakano K, Suzuki N, Satomi K, Ishii Y. Expansive open-door laminoplasty for cervical spinal stenotic myelopathy. Spine (Phila Pa 1976). 1983;8(7):693–9.
18. Herkowitz HN. Cervical laminaplasty: its role in the treatment of cervical radiculopathy. J Spinal Disord. 1988;1(3):179–88.
19. Hirabayashi K, Toyama Y, Chiba K. Expansive laminoplasty for myelopathy in ossification of the longitudinal ligament. Clin Orthop Relat Res. 1999;359:35–48.
20. Kawaguchi Y, Matsui H, Ishihara H, Gejo R, Yoshino O. Axial symptoms after en bloc cervical laminoplasty. J Spinal Disord. 1999;12(5):392–5.
21. Satomi K, Nishu Y, Kohno T, Hirabayashi K. Long-term follow-up studies of open-door expansive laminoplasty for cervical stenotic myelopathy. Spine (Phila Pa 1976). 1994;19(5):507–10.
22. Hirabayashi K, Miyakawa J, Satomi K, Maruyama T, Wakano K. Operative results and postoperative progression of ossification among patients with ossification of cervical posterior longitudinal ligament. Spine (Phila Pa 1976). 1981;6(4):354–64.
23. Zdeblick TA, Zou D, Warden KE, McCabe R, Kunz D, Vanderby R. Cervical stability after foraminotomy. A biomechanical in vitro analysis. J Bone Joint Surg Am. 1992;74(1):22–7.
24. Raynor RB, Pugh J, Shapiro I. Cervical facetectomy and its effect on spine strength. J Neurosurg. 1985;63(2):278–82.
25. O'Brien MF, Peterson D, Casey AT, Crockard HA. A novel technique for laminoplasty augmentation of spinal canal area using titanium miniplate stabilization. A computerized morphometric analysis. Spine (Phila Pa 1976). 1996;21(4):474–83; discussion 84.
26. Rhee JM, Register B, Hamasaki T, Franklin B. Plate-only open door laminoplasty maintains stable spinal canal expansion with high rates of hinge union and no plate failures. Spine (Phila Pa 1976). 2011;36(1):9–14.
27. Mochida J, Nomura T, Chiba M, Nishimura K, Toh E. Modified expansive open-door laminoplasty in cervical myelopathy. J Spinal Disord. 1999;12(5):386–91.
28. Shaffrey CI, Wiggins GC, Piccirilli CB, Young JN, Lovell LR. Modified open-door laminoplasty for treatment of neurological deficits in younger patients with congenital spinal stenosis: analysis of clinical and radiographic data. J Neurosurg. 1999;90(2 Suppl):170–7.
29. Gillett GR, Erasmus AM, Lind CR. CG-clip expansive open-door laminoplasty: a technical note. Br J Neurosurg. 1999;13(4):405–8.
30. Kihara S, Umebayashi T, Hoshimaru M. Technical improvements and results of open-door expansive laminoplasty with hydroxyapatite implants for cervical myelopathy. Neurosurgery. 2005;57(4 Suppl):348–56. discussion -56
31. Itoh T, Tsuji H. Technical improvements and results of laminoplasty for compressive myelopathy in the cervical spine. Spine (Phila Pa 1976). 1985;10(8):729–36.
32. Park JH, Ahn JS, Lee HJ, Shin BK. Comparison between radiological and clinical outcomes of laminoplasties with titanium miniplates for cervical myelopathy. Clin Orthop Surg. 2016;8(4):399–406.
33. Zhang H, Lu S, Sun T, Yadav SK. Effect of lamina open angles in expansion open-door laminoplasty on the clinical results in treating cervical spondylotic myelopathy. J Spinal Disord Tech. 2015;28(3):89–94.
34. Yeh KT, Yu TC, Chen IH, Peng CH, Liu KL, Lee RP, et al. Expansive open-door laminoplasty secured with titanium miniplates is a good surgical method for multiple-level cervical stenosis. J Orthop Surg Res. 2014;9:49.
35. Yeh KT, Chen IH, Yu TC, Liu KL, Peng CH, Wang JH, et al. Modified expansive open-door laminoplasty technique improved postoperative neck pain and cervical range of motion. J Formos Med Assoc. 2015;114(12):1225–32.
36. Kurokawa T, N T HT. Enlargement of the spinal canal by sagittal splitting of the spinous processes: Bessatsu Seikeigeka; 1982.
37. Hase H, Watanabe T, Hirasawa Y, Hashimoto H, Miyamoto T, Chatani K, et al. Bilateral open laminoplasty using ceramic laminas for cervical myelopathy. Spine (Phila Pa 1976). 1991;16(11):1269–76.
38. Nakano K, Harata S, Suetsuna F, Araki T, Itoh J. Spinous process-splitting laminoplasty using hydroxyapatite spinous process spacer. Spine (Phila Pa 1976). 1992;17(3 Suppl):S41–3.

39. Edwards CC, Heller JG, Silcox DH. T-Saw laminoplasty for the management of cervical spondylotic myelopathy: clinical and radiographic outcome. Spine (Phila Pa 1976). 2000;25(14):1788–94.
40. Tomita K, Nomura S, Umeda S, Baba H. Cervical laminoplasty to enlarge the spinal canal in multilevel ossification of the posterior longitudinal ligament with myelopathy. Arch Orthop Trauma Surg. 1988;107(3):148–53.
41. Tomita K, Kawahara N, Toribatake Y, Heller JG. Expansive midline T-saw laminoplasty (modified spinous process-splitting) for the management of cervical myelopathy. Spine (Phila Pa 1976). 1998;23(1):32–7.
42. Yonenobu K, Hosono N, Iwasaki M, Asano M, Ono K. Laminoplasty versus subtotal corpectomy. A comparative study of results in multisegmental cervical spondylotic myelopathy. Spine (Phila Pa 1976). 1992;17(11):1281–4.
43. Okada M, Minamide A, Endo T, Yoshida M, Kawakami M, Ando M, et al. A prospective randomized study of clinical outcomes in patients with cervical compressive myelopathy treated with open-door or French-door laminoplasty. Spine (Phila Pa 1976). 2009;34(11):1119–26.
44. Nakashima H, Kato F, Yukawa Y, Imagama S, Ito K, Machino M, et al. Comparative effectiveness of open-door laminoplasty versus French-door laminoplasty in cervical compressive myelopathy. Spine (Phila Pa 1976). 2014;39(8):642–7.
45. Protopsaltis TS, Choi CE, Kaplan DJ. Double-door or “French-door” cervical laminoplasty. J Spinal Disord Tech. 2015;28(9):319–23.
46. Yue WM, Tan CT, Tan SB, Tan SK, Tay BK. Results of cervical laminoplasty and a comparison between single and double trap-door techniques. J Spinal Disord. 2000;13(4):329–35.
47. Lee DG, Lee SH, Park SJ, Kim ES, Chung SS, Lee CS, et al. Comparison of surgical outcomes after cervical laminoplasty: open-door technique versus French-door technique. J Spinal Disord Tech. 2013;26(6):E198–203.
48. Edwards CC, Heller JG, Murakami H. Corpectomy versus laminoplasty for multilevel cervical myelopathy: an independent matched-cohort analysis. Spine (Phila Pa 1976). 2002;27(11):1168–75.
49. Hukuda S, Ogata M, Mochizuki T, Shichikawa K. Laminectomy versus laminoplasty for cervical myelopathy: brief report. J Bone Joint Surg Br. 1988;70(2):325–6.
50. Nakano N, Nakano T, Nakano K. Comparison of the results of laminectomy and open-door laminoplasty for cervical spondylotic myeloradiculopathy and ossification of the posterior longitudinal ligament. Spine (Phila Pa 1976). 1988;13(7):792–4.
51. Shiraishi T. A new technique for exposure of the cervical spine laminae. Technical note. J Neurosurg. 2002;96(1 Suppl):122–6.
52. Kotani Y, Abumi K, Ito M, Sudo H, Takahata M, Nagahama K, et al. Impact of deep extensor muscle-preserving approach on clinical outcome of laminoplasty for cervical spondylotic myelopathy: comparative cohort study. Eur Spine J. 2012;21(8):1536–44.
53. Rhee JM, Basra S. Posterior surgery for cervical myelopathy: laminectomy, laminectomy with fusion, and laminoplasty. Asian Spine J. 2008;2(2):114–26.
54. Lee TT, Manzano GR, Green BA. Modified open-door cervical expansive laminoplasty for spondylotic myelopathy: operative technique, outcome, and predictors for gait improvement. J Neurosurg. 1997;86(1):64–8.
55. Yonenobu K, Wada E, Suzuki S, Kanazawa A. The dorsal approach in degeneratively changed cervical spine. Orthopade. 1996;25(6):533–41.
56. Seichi A, Takeshita K, Ohishi I, Kawaguchi H, Akune T, Anamizu Y, et al. Long-term results of double-door laminoplasty for cervical stenotic myelopathy. Spine (Phila Pa 1976). 2001;26(5):479–87.
57. Yoshida M, Otani K, Shibasaki K, Ueda S. Expansive laminoplasty with reattachment of spinous process and extensor musculature for cervical myelopathy. Spine (Phila Pa 1976). 1992;17(5):491–7.
58. Yoshida M, Tamaki T, Kawakami M, Nakatani N, Ando M, Yamada H, et al. Does reconstruction of posterior ligamentous complex with extensor musculature decrease axial symptoms after cervical laminoplasty? Spine (Phila Pa 1976). 2002;27(13):1414–8.

59. Kawaguchi Y, Kanamori M, Ishiara H, Nobukiyo M, Seki S, Kimura T. Preventive measures for axial symptoms following cervical laminoplasty. J Spinal Disord Tech. 2003;16(6):497–501.
60. Wada E, Suzuki S, Kanazawa A, Matsuoka T, Miyamoto S, Yonenobu K. Subtotal corpectomy versus laminoplasty for multilevel cervical spondylotic myelopathy: a long-term follow-up study over 10 years. Spine (Phila Pa 1976). 2001;26(13):1443–7; discussion 8.
61. Uematsu Y, Tokuhashi Y, Matsuzaki H. Radiculopathy after laminoplasty of the cervical spine. Spine (Phila Pa 1976). 1998;23(19):2057–62.
62. Lau D, Winkler EA, Than KD, Chou D, Mummaneni PV. Laminoplasty versus laminectomy with posterior spinal fusion for multilevel cervical spondylotic myelopathy: influence of cervical alignment on outcomes. J Neurosurg Spine. 2017;27(5):508–17.
63. Matsumoto M, Watanabe K, Hosogane N, Tsuji T, Ishii K, Nakamura M, et al. Impact of lamina closure on long-term outcomes of open-door laminoplasty in patients with cervical myelopathy: minimum 5-year follow-up study. Spine (Phila Pa 1976). 2012;37(15):1288–91.
64. Matsumoto M, Watanabe K, Tsuji T, Ishii K, Takaishi H, Nakamura M, et al. Risk factors for closure of lamina after open-door laminoplasty. J Neurosurg Spine. 2008;9(6):530–7.
65. Lee DH, Park SA, Kim NH, Hwang CJ, Kim YT, Lee CS, et al. Laminar closure after classic Hirabayashi open-door laminoplasty. Spine (Phila Pa 1976). 2011;36(25):E1634–40.
66. Wang HQ, Mak KC, Samartzis D, El-Fiky T, Wong YW, Luo ZJ, et al. "Spring-back" closure associated with open-door cervical laminoplasty. Spine J. 2011;11(9):832–8.
67. Machino M, Yukawa Y, Ito K, Inoue T, Kobayakawa A, Matsumoto T, et al. Risk factors for poor outcome of cervical laminoplasty for cervical spondylotic myelopathy in patients with diabetes. J Bone Joint Surg Am. 2014;96(24):2049–55.
68. Iwasaki M, Kawaguchi Y, Kimura T, Yonenobu K. Long-term results of expansive laminoplasty for ossification of the posterior longitudinal ligament of the cervical spine: more than 10 years follow up. J Neurosurg. 2002;96(2 Suppl):180–9.
69. Kawaguchi Y, Kanamori M, Ishihara H, Nakamura H, Sugimori K, Tsuji H, et al. Progression of ossification of the posterior longitudinal ligament following en bloc cervical laminoplasty. J Bone Joint Surg Am. 2001;83-A(12):1798–802.
70. Lee CH, Jahng TA, Hyun SJ, Kim KJ, Kim HJ. Expansive laminoplasty versus laminectomy alone versus laminectomy and fusion for cervical ossification of the posterior longitudinal ligament: is there a difference in the clinical outcome and sagittal alignment? Clin Spine Surg. 2016;29(1):E9–15.
71. Machino M, Yukawa Y, Hida T, Ito K, Nakashima H, Kanbara S, et al. Can elderly patients recover adequately after laminoplasty?: a comparative study of 520 patients with cervical spondylotic myelopathy. Spine (Phila Pa 1976). 2012;37(8):667–71.
72. Machino M, Yukawa Y, Hida T, Ito K, Nakashima H, Kanbara S, et al. Persistent physical symptoms after laminoplasty: analysis of postoperative residual symptoms in 520 patients with cervical spondylotic myelopathy. Spine (Phila Pa 1976). 2012;37(11):932–6.
73. Machino M, Yukawa Y, Hida T, Ito K, Nakashima H, Kanbara S, et al. Modified double-door laminoplasty in managing multilevel cervical spondylotic myelopathy: surgical outcome in 520 patients and technique description. J Spinal Disord Tech. 2013;26(3):135–40.
74. Tang JA, Scheer JK, Smith JS, Deviren V, Bess S, Hart RA, et al. The impact of standing regional cervical sagittal alignment on outcomes in posterior cervical fusion surgery. Neurosurgery. 2012;71(3):662–9; discussion 9
75. Sakai K, Yoshii T, Hirai T, Arai Y, Shinomiya K, Okawa A. Impact of the surgical treatment for degenerative cervical myelopathy on the preoperative cervical sagittal balance: a review of prospective comparative cohort between anterior decompression with fusion and laminoplasty. Eur Spine J. 2017;26(1):104–12.
76. Suda K, Abumi K, Ito M, Shono Y, Kaneda K, Fujiya M. Local kyphosis reduces surgical outcomes of expansive open-door laminoplasty for cervical spondylotic myelopathy. Spine (Phila Pa 1976). 2003;28(12):1258–62.

77. Machino M, Yukawa Y, Imagama S, Ito K, Katayama Y, Matsumoto T, et al. Surgical treatment assessment of cervical laminoplasty using quantitative performance evaluation in elderly patients: a prospective comparative study in 505 patients with cervical spondylotic myelopathy. Spine. 2016;41:757–63.
78. Humadi A, Chao T, Dawood S, Tacey M, Barmare A, Freeman B. A meta-analysis of cervical laminoplasty techniques: are mini-plates superior? Global Spine J. 2017;7(4):373–81.
79. Kaye ID, Hilibrand AS, Morrissey PB, Vaccaro AR. Laminoplasty is the preferred procedure for a posteriorly based multilevel surgery in a patient with a neutral spine and cervical spondylotic myelopathy: true or false? Clin Spine Surg. 2018;31(1):1–5.
80. Duetzmann S, Cole T, Ratliff JK. Cervical laminoplasty developments and trends, 2003–2013: a systematic review. J Neurosurg Spine. 2015;23(1):24–34.
81. Cho SK, Kim JS, Overley SC, Merrill RK. Cervical laminoplasty: indications, surgical considerations, and clinical outcomes. J Am Acad Orthop Surg. 2018;26(7):e142–e52.

Chapter 8
Minimally Invasive Posterior Cervical Foraminotomy and Discectomy

Joel Z. Passer, Shahin Manoochehri, and Bong-Soo Kim

Introduction

Cervical radiculopathy is a common problem typically encountered by spinal surgeons. It is defined as a syndrome of pain and/or sensorimotor deficits due to compression of a cervical nerve root. Common causes of the syndrome include cervical disc disease, spondylosis, instability, trauma, and tumors. Typical symptoms of cervical radiculopathy include arm pain typically in a dermatomal distribution, neck pain, numbness, and weakness [1].

Most patients (75–90%) with cervical radiculopathy will have symptomatic improvement with conservative, nonoperative management, which includes treatments such as physical therapy, cervical traction, and epidural steroid injections. However, when patients either fail conservative management or begin to experience progressive neurologic deficits, surgical intervention is warranted. Numerous techniques from both anterior and posterior approaches have been investigated in the treatment of cervical radiculopathy, each having its own distinct advantages and disadvantages. The two most common procedures are anterior cervical discectomy and fusion (ACDF) and posterior cervical foraminotomy (PCF).

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_8

History of Procedure

PCF was first described by Spurling and Scoville [2], and Frykholm [3]. This procedure became the preferred technique in the treatment of herniated cervical discs until Smith and Robinson introduced the anterior approach [4], modified later by Cloward in 1958 [5]. Over the following decades, the anterior approach became much more commonly used. Although the PCF remained a viable procedure, after this time, there was a paucity of quality data in the literature for the next several decades [6]. Using minimally invasive lumbar discectomy as a model, the minimally invasive technique for PCF was first described in cadaver studies in 1998 [7] and 2000 [8]. In 2001, Adamson described the MIS PCF endoscopic technique and results in his first 100 consecutive patients, showing 97% of patients with good or excellent outcome [9]. In 2002, Fessler and Khoo further described the technique, demonstrating equivalent results of microendoscopic PCF to traditional open PCF, with 87–92% symptomatic improvement in both groups [10].

Indications

The posterior cervical foraminotomy is indicated in patients with a lateral soft disc herniation or foraminal stenosis causing nerve root compression and subsequent progressive or intractable radiculopathy [11, 12]. While indications are narrow, in a carefully selected patient, the complications associated with ACDF can be avoided. Relative contraindications to ACDF, including previous surgery, history of radiation, or history of infection, may influence the decision to perform PCF.

Although the anterior approach has become popular, it is associated with potential complications such as tracheal or esophageal injury, injury to the carotid or vertebral arteries, injury to the jugular vein, or injury to the recurrent laryngeal nerve. Additionally, removal of disc material and subsequent fusion of the spine limits spinal motion, leading to stress on adjacent levels. Subsequent adjacent segment disease as well as pseudarthrosis, graft subsidence and kyphosis can all occur as a result [13, 14].

The procedure is contraindicated in primary axial neck pain, central disc herniation, diffuse spondylotic disease causing central stenosis, or bilateral radicular symptoms. The procedure is also contraindicated in patients with evidence of cervical spine instability or deformity [13].

Surgical Technique

In the operating room, general endotracheal anesthesia is induced. A Mayfield head holder is affixed to the patient's head. Neuromonitoring should be utilized throughout the procedure with somatosensory evoked potentials (SSEPs) to monitor the integrity of the spinal cord. Electromyography can also be used when manipulating the involved nerve root to monitor for any potential damage to the nerve. The procedure can then be performed in either of two positions: prone or sitting.

For positioning into the prone position, the patient is carefully turned onto the open Jackson table with C-flex head positioning system (Allen Medical). The arms are then tucked at the patient's side. SSEPs should be checked after positioning to confirm that neurologic function has not been compromised. Advantages of prone positioning include decreased risk of intraoperative hypotension and air embolism. Disadvantages include greater blood loss and more blood in the operative field, although using reverse Trendelenburg position may prevent pooling of blood in the field.

Sitting position is performed when using the endoscope. Potential advantages of the sitting position include decreased operative time and blood loss compared to prone position. Disadvantages include risk of venous air embolism and intraoperative hypotension.

Regardless of positioning, fluoroscopy is then brought into the field for lateral x-ray to localize the appropriate level. Once the appropriate level is marked, the patient is then prepped and draped in the standard fashion. A 2 cm incision is then made approximately 1.5 cm lateral from midline, extending through the fascial layer. Under fluoroscopic guidance, sequential dilators from a tubular retractor system are passed and the final tubular retractor system (between 16 and 21 mm) is held in place with the attachment secured to the operative table. The microscope or endoscope is then brought into the field.

Soft tissues are then removed from the operative field using Bovie electrocautery and pituitary rongeurs, moving cautiously, in order to avoid penetrating through the interlaminar space. After soft tissue removal and bony visualization, a curved currete is used to define the anatomy of the lamino-facet complex and remove ligamentum flavum from the underside of the lamina. 1 or 2 mm Kerrison punch is then utilized to perform the laminotomy and the procedure extends laterally to perform the foraminotomy. Often, a high-speed drill will need to be utilized for appropriate bony removal. It is crucial to avoid >50% of facet removal in order to maintain mechanical stability. The ligamentum flavum can then be removed to visualize the dura and proximal nerve root. Epidural bleeding from the nerve root venous plexus is to be expected during this portion of the procedure. It can be controlled with Gelfoam and cotton patties. If identified, the venous plexus can be coagulated using the bipolar electrocautery on low setting, and then divided.

Once the nerve root is visualized, a 45-degree-angled nerve hook is used to palpate the neural foramen to assess if decompression is adequate and to identify any disc fragments or osteophytes. To facilitate removal of disc or osteophyte and minimize nerve root retraction, approximately 2 mm of the superior medial portion of the rostral pedicle can be drilled.

In the case of soft disc herniation, once identified, the posterior longitudinal ligament can be incised with a #11 blade. Fragments can then be mobilized using a micro nerve hook and removed using a pituitary rongeur. In the case of osteophyte, a down-angled curette can be used to reduce them or break them apart to facilitate their removal.

Once satisfactory nerve root decompression has been achieved, the wound is then copiously irrigated with antibiotic-soaked saline, hemostasis is achieved, and the tube retractor system is removed from the field. The fascial, subcutaneous, and skin layers are then closed with absorbable sutures, and a skin glue is used as the final layer.

Literature Review

Overall, PCF is an effective procedure. The literature reports good-excellent relief of radiculopathy symptoms in 85–100% of patients [15–18]. Several studies have shown statistically significant improvements in Neck Disability Index, Visual Analog Scale for Neck, and Visual Analog Scale for Arm scores at both 1- and 2-year follow-up [19, 20].

Minimally invasive posterior cervical foraminotomy has been shown to be a viable alternative to anterior cervical discectomy and fusion in a select patient population, notably those with a lateral soft disc herniation or foraminal stenosis. A meta-analysis by McAnany et al. in 2015 comparing the effectiveness between open and minimally invasive techniques demonstrated that outcomes were not statistically different between the two procedures [21]. However, in a systemic review by Clark et al., which included the only reported randomized clinical trial [22], which compared outcomes between MIS and open PCF, the authors found that blood loss, pain medication use and hospital length of stay were reduced in patients who underwent MIS PCF over open PCF [23].

In a retrospective review of patients undergoing ACDF or PCF at a single institution between 2005 and 2011, Lubelski et al. reported that both procedures have a statistically equivalent 2-year reoperation rate [24]. Another retrospective review by Ruetten et al. comparing ACDF vs PCF in unilateral single-level radiculopathy in posterolateral or foraminal disc herniation showed no significant difference between the groups in terms of the overall outcome, complication rate, or revision rate [25]. Several studies have also shown a significantly higher cost of ACDF over PCF (one study showing an average cost of $8192 for ACDF and $4320 for PCF), largely related to cost of surgical implants [26, 27].

A long-term follow-up study by Bydon et al. investigating 151 patients who underwent PCF found a reoperation rate of 9.9% an average of 2.4 years after initial surgery, with a rate of 16.4% reoperation in patients with at least 2-year follow-up. It was noted that patients with preoperative neck pain had a higher incidence of reoperation. Reoperation of the same level was statistically more significant over surgery at adjacent/distant level. A majority of these patients (80%) underwent ACDF as the reoperation procedure, with cervical laminectomy and fusion (13.3%) and PCF (6.7%) behind [16]. Skovlrj et al. also showed similar results, with a reoperation rate of 7.1% in patients undergoing ACDF after PCF at index level an average of 55 months after initial procedure [20].

Lastly, PCF has been shown to lead to significant improvements in overall patient mobility, ability to perform daily activities and self-care, relief of pain, and decrease in anxiety/depression [28].

Minimally invasive posterior cervical foraminotomy has been shown to be a safe, and cost-effective treatment for patients with lateral disc herniation or foraminal stenosis, achieving similar long-term outcomes to that of ACDF, while avoiding both potential complications seen in anterior procedures and spinal fusion that could disrupt normal spinal biomechanics.

References

1. Caridi JM, Pumberger M, Hughes AP. Cervical radiculopathy: a review. HSS J. 2011;7(3):265–72.
2. Scoville W, Whitcomb B, McLaurin R. The cervical ruptured disc: report of 115 operative cases. Trans Am Neurol Assoc. 1951;(56):222–4.
3. Frykholm R. Cervical nerve root compression resulting from disc degeneration and root sleeve fibrosis. Acta Chir Scand. 1951;(Suppl 160).
4. Smith GW, Robinson RA. The treatment of certain cervical-spine disorders by anterior removal of the intervertebral disc and interbody fusion. J Bone Joint Surg Am. 1958;40-A(3):607–24.
5. Cloward RB. The anterior approach for removal of ruptured cervical disks. J Neurosurg. 1958;15(6):602–17.
6. Heary RF, Ryken TC, Matz PG, Anderson PA, Groff MW, Holly LT, et al. Cervical laminoforaminotomy for the treatment of cervical degenerative radiculopathy. J Neurosurg Spine. 2009;11(2):198–202.
7. Roh SW, Kim DH, Cardoso AC, Fessler RG. Endoscopic foraminotomy using MED system in cadaveric specimens. Spine (Phila Pa 1976). 2000;25(2):260–4.
8. Burke TG, Caputy A. Microendoscopic posterior cervical foraminotomy: a cadaveric model and clinical application for cervical radiculopathy. J Neurosurg. 2000;93(1 Suppl):126–9.
9. Adamson TE. Microendoscopic posterior cervical laminoforaminotomy for unilateral radiculopathy: results of a new technique in 100 cases. J Neurosurg. 2001;95(1 Suppl):51–7.
10. Fessler RG, Khoo LT. Minimally invasive cervical microendoscopic foraminotomy: an initial clinical experience. Neurosurgery. 2002;51(5 Suppl):S37–45.
11. Epstein NE. A review of laminoforaminotomy for the management of lateral and foraminal cervical disc herniations or spurs. Surg Neurol. 2002;57(4):226–33; discussion 233–4.
12. Dodwad SJ, Dodwad SN, Prasarn ML, Savage JW, Patel AA, Hsu WK. Posterior cervical foraminotomy: indications, technique, and outcomes. Clin Spine Surg. 2016;29(5):177–85.
13. Ahn J, Tabaraee E, Bohl DD, Singh K. Minimally invasive posterior cervical foraminotomy. J Spinal Disord Tech. 2015;28(8):295–7.
14. Gala VC, O'Toole JE, Voyadzis JM, Fessler RG. Posterior minimally invasive approaches for the cervical spine. Orthop Clin North Am. 2007;38(3):339–49; abstract v.
15. Harrop JS, Silva MT, Sharan AD, Dante SJ, Simeone FA. Cervicothoracic radiculopathy treated using posterior cervical foraminotomy/discectomy. J Neurosurg. 2003;98(2 Suppl):131–6.
16. Bydon M, Mathios D, Macki M, de la Garza-Ramos R, Sciubba DM, Witham TF, et al. Long-term patient outcomes after posterior cervical foraminotomy: an analysis of 151 cases. J Neurosurg Spine. 2014;21(5):727–31.
17. Kerry G, Hammer A, Ruedinger C, Ranaie G, Steiner HH. Microsurgical posterior cervical foraminotomy: a study of 181 cases. Br J Neurosurg. 2017;31(1):39–44.
18. Jagannathan J, Sherman JH, Szabo T, Shaffrey CI, Jane JA. The posterior cervical foraminotomy in the treatment of cervical disc/osteophyte disease: a single-surgeon experi-

ence with a minimum of 5 years' clinical and radiographic follow-up. J Neurosurg Spine. 2009;10(4):347–56.

19. Lawton CD, Smith ZA, Lam SK, Habib A, Wong RH, Fessler RG. Clinical outcomes of microendoscopic foraminotomy and decompression in the cervical spine. World Neurosurg. 2014;81(2):422–7.
20. Skovrlj B, Gologorsky Y, Haque R, Fessler RG, Qureshi SA. Complications, outcomes, and need for fusion after minimally invasive posterior cervical foraminotomy and microdiscectomy. Spine J. 2014;14(10):2405–11.
21. McAnany SJ, Kim JS, Overley SC, Baird EO, Anderson PA, Qureshi SA. A meta-analysis of cervical foraminotomy: open versus minimally-invasive techniques. Spine J. 2015;15(5):849–56.
22. Kim KT, Kim YB. Comparison between open procedure and tubular retractor assisted procedure for cervical radiculopathy: results of a randomized controlled study. J Korean Med Sci. 2009;24(4):649–53.
23. Clark JG, Abdullah KG, Steinmetz MP, Benzel EC, Mroz TE. Minimally invasive versus open cervical foraminotomy: a systematic review. Global Spine J. 2011;1(1):9–14.
24. Lubelski D, Healy AT, Silverstein MP, Abdullah KG, Thompson NR, Riew KD, et al. Reoperation rates after anterior cervical discectomy and fusion versus posterior cervical foraminotomy: a propensity-matched analysis. Spine J. 2015;15(6):1277–83.
25. Ruetten S, Komp M, Merk H, Godolias G. A new full-endoscopic technique for cervical posterior foraminotomy in the treatment of lateral disc herniations using 6.9-mm endoscopes: prospective 2-year results of 87 patients. Minim Invasive Neurosurg. 2007;50(4):219–26.
26. Mansfield HE, Canar WJ, Gerard CS, O'Toole JE. Single-level anterior cervical discectomy and fusion versus minimally invasive posterior cervical foraminotomy for patients with cervical radiculopathy: a cost analysis. Neurosurg Focus. 2014;37(5):E9.
27. Alvin MD, Lubelski D, Abdullah KG, Whitmore RG, Benzel EC, Mroz TE. Cost-utility analysis of anterior cervical discectomy and fusion with plating (ACDFP) versus posterior cervical foraminotomy (PCF) for patients with single-level cervical radiculopathy at 1-year follow-up. Clin Spine Surg. 2016;29(2):E67–72.
28. Faught RW, Church EW, Halpern CH, Balmuri U, Attiah MA, Stein SC, et al. Long-term quality of life after posterior cervical foraminotomy for radiculopathy. Clin Neurol Neurosurg. 2016;142:22–5.

Chapter 9

Thoracic Posterior Instrumentation Without Scoliosis

Dany Aouad and Oliver Tannous

Introduction

Thoracic instrumentation and bone-grafting techniques have evolved significantly over the past century. This evolution is a result of repetitive failed attempts and poor outcomes [1]. Since the mid-twentieth century, the use of spinal hardware and bone grafting, as well as the advancement of radiographic imaging, has greatly improved intraoperative precision and postoperative outcomes.

In 1953, Dr. Paul Harrington began developing the Harrington rod system for the treatment of scoliosis, which consisted of sublaminar hooks attached to long stainless steel rods. Bone grafting was eventually introduced into the technique and played a critical role in preventing hardware failure, which was previously a relatively common complication [1]. In the 1970s, Eduardo Luque introduced his rod system which used segmental sublaminar wires attached to a long rod construct. This was a more rigid system that had better fusion rates and helped avoid the use of bracing, but was associated with a greater degree of neurological complications [2].

During the same era, pedicle screw instrumentation was slowly gaining popularity. It was first described by Michele and Krueger in 1949, with the advantage of offering three column stabilization, a higher strength of fixation, and shorter construct length [3]. Pedicle screws insertion technique underwent a series of changes, and widespread adoption began increasing in the 1980s. Today, pedicle screws are the most common method for fixation in the thoracolumbar spine and are used to help treat degenerative, oncologic, traumatic, infectious, as well as deformity conditions.

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_9

Anatomy

The thoracic spine is a relatively rigid region of the vertebral column; its stability is augmented by the costovertebral joints and the surrounding rib cage, which limit lateral flexion as well as rotation. This increased rigidity serves to protect the heart and lungs against compressive forces, with a load-bearing capacity three times greater than other parts of the vertebral column.

Average thoracic kyphosis ranges between 20 and 40 degrees in most humans. This kyphotic curvature is due to the wedge shape of the thoracic vertebrae and discs, as well as the anterior center of gravity when standing upright. It is important to note that thoracic kyphosis increases with age and in patients with ankylosing spondylitis. When instrumenting the ankylosed thoracic spine in a traumatic setting, one must preserve the native thoracic contour, as creating excessive extension can result in neurologic injury as well as place undue tension on the construct and increase the risk of construct failure.

The vertebral foramen between T4 and T9 is considered a narrow zone, with the narrowest diameter at T11. As such, the spinal cord is vulnerable to degenerative changes and mass occupying lesions such as metastatic tumors.

The thoracic pedicles are short, relative to the lumbar spine, measuring 15–20 mm in length. They have a dense outer cortex that is strongest medially and inferiorly. Pedicle diameter is greatest in the upper and lower thoracic spine and becomes most narrow around T4–T6, making it challenging to place pedicle screws in this region. The sagittal angle of the thoracic pedicle is approximately 15 degrees cephalad to the superior endplate, and the transverse angle varies between 20 and 30 degrees for T1 and T2, 10 degrees for the mid-thoracic spine, and 0–10 degrees for T10–T12.

The thoracic pedicle was historically described as a homogeneous cylinder [4, 5], but with the advancement of 3D CT imaging, a great number of anatomical variations were found [6]. The majority of pedicles have an inverted teardrop shape with medial convexity and lateral concavity [6]. Finally, it is important to understand the orientation of the facet joints. The majority of the superior facets in the thoracic spine are oriented posteriorly and slightly lateral. In the lower thoracic spine, the superior facets begin to transition to the medial orientation of the lumbar facets.

Indications

Posterior pedicle instrumentation is commonly used in the traumatic, oncologic, infectious, or degenerative setting. A transpedicular screw is advanced into the vertebral body, which results in anterior and posterior column purchase and rigid segmental fixation [7]. Furthermore, the posterior approach is easily extended and screw placement at additional levels can be performed if needed. In patients with osteoporotic bone, vertebral augmentation can be achieved by injecting polymethyl methacrylate cement into the vertebral body prior to advancing the screw or by placing a cannulated fenestrated screw and injecting the cement through the screw. These techniques result in a 30–90% increase of pullout strength [8]. Thoracic spine pedicle screw fixation is contraindicated when the bony anatomy precludes adequate screw purchase or in the setting of an active infection at the level of the instrumented pedicle. Patients with thoracic pedicle diameters less than 4 mm are not good candidates for transpedicular instrumentation and may require either a hybrid or complete hook/rod construct.

Surgical Management

Pedicle Screw Instrumentation

Thoracic pedicle screw placement can be challenging in the setting of narrow pedicles. The rate of screw misplacement in the thoracic spine has been reported between 3% and 55% [9]. This variability is due to surgeon experience, presence or absence of deformity, as well as the definition of a misplaced screw. Most misplaced screws are not symptomatic and, in fact, can have adequate bony fixation between the pedicle, rib, and vertebral body. Screws that are misplaced medially and inferiorly, however, can cause neurologic injury to the spinal cord or exiting nerve root. As such, understanding the variation of pedicle anatomy throughout the thoracic spine as well as the landmarks for pedicle start points is imperative. Occasionally, the pedicles may be too narrow for placing a pedicle screw, and other fixation methods must be considered.

Preoperative Planning

When instrumenting the posterior thoracic spine, preoperative planning is important and one must be prepared for an alternative fixation strategy. Preoperative CT imaging is the modality of choice for evaluating the bony morphometry and facilitates the surgical planning and measurement of pedicle dimensions. The possibility of alternative fixation with hooks should be accounted for prior to surgery in order to have the necessary instrumentation present during the procedure.

Open Procedure

For most indications, the patient is positioned prone onto an open frame with chest and hip pads, or on a flat top with chest rolls. In patients with a hyperkyphotic thoracic spine (e.g., ankylosing spondylitis), a Wilson frame is a good option. Care must be taken to adequately pad all bony prominences. The arms are abducted and elevated when operating on the mid and lower thoracic segments, and adducted and tucked with a draw sheet when operating on the upper thoracic segments. Prior to making an incision, AP and lateral fluoroscopic imaging is obtained to mark the planned operative levels on the skin. After standard skin sterilization and draping, a midline approach is performed and the paraspinal muscles are dissected laterally to expose the transverse processes at the indicated levels. Care is taken to preserve the posterior tension band (supraspinous and interspinous ligaments) until the surgical levels are verified with an intraoperative fluoroscopic image. One must avoid iatrogenic injury to the facet joints and supra-/intra-spinous ligaments at the proximal aspect of the planned instrumented fusion, as these are not incorporated into the fusion and doing so will mitigate the risk of developing proximal junctional kyphosis.

The pedicle screw start point is next identified using cranio-caudal and mediolateral landmarks that differ for each region of the thoracic spine. At T1, T2, and T10–T12, the start point is at the intersection of the superior third of the transverse process with the lateral border of the pars interarticularis. At T3–T9, the start point is more cranial, just above the superior ridge of the transverse process where it intersects the lateral half of the superior articular facet (Fig. 9.1).

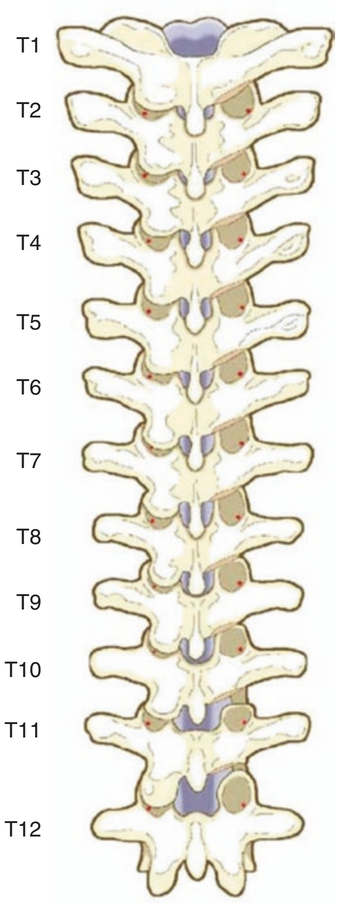

Fig. 9.1 The red dots depict the ideal start point for thoracic pedicle screws. On the left, the facet joint has been preserved; on the right, a facetectomy has been performed. Used with permission from Springer Science and Bus Media BV

Once the start point is identified, a high-speed burr is used to decorticate the posterior cortex. If the start point is correct, one will usually see a blush of blood from the cancellous portion of the pedicle. Next, a pedicle probe is advanced through the cancellous portion of the pedicle. This maneuver requires attention to tactile feedback, and accommodation of the trajectory based on the resistance from the cortical margins of the pedicle. The trajectory of the pedicle probe is generally perpendicular to the pars and varies between 25 and 30 degrees of medialization at T1 to 0–5 degrees at T12. Once it is advanced 20 mm, a ball-tip probe is used to verify the integrity of the pedicle walls, as well as the bony base within the vertebral body.

Once the pedicle screw track is formed, it is under-tapped by 0.5 to 1 mm smaller than the planned screw. The tapped tract is palpated again with the ball-tip probe to feel for breaches. At this point, if there is any concern regarding position or trajectory of the pedicle track, a pedicle marker can be inserted and inspected with fluoroscopic imaging.

Finally, the pedicle screw in inserted. It is helpful to plan the diameter and length of each screw on CT imaging. One must be careful to insert the screw with the same sagittal and transverse trajectory as the gear shift probe. The first few turns of the screw are made with minimal force in order to allow the threads to “find” the pedicle and prevent deviation of the screw outside the track. Once all screws are placed, AP and lateral fluoroscopic imaging is obtained to verify adequate positioning. Electromyography under evoked stimulation can be utilized on intercostal and abdominal muscles to verify correct screw placement, but this method is not sensitive. Thresholds lower than 8 mA are suspicious for inferior or medial breach of the pedicle borders [6].

Following the completion of pedicle instrumentation, the rods are measured and contoured. In the non-scoliotic, non-deformity setting, rod bending is relatively straightforward and should conform to the native kyphotic curvature of the spine.

Bailout Options

In some cases, a transpedicular screw is not possible when pedicles are less than 4 or 5 mm in diameter or when the integrity of the pedicle has been compromised with repetitive failed attempts of fixation. A substitute “in-out-in” technique can be used in this case, which consists of an extrapedicular start point through the transverse process, passage of the screw through the costovertebral joint, and back into the middle-anterior portion of the vertebral body [7].

Alternatively, hooks can be used with fixation onto the pedicle, lamina, or transverse process. To place a thoracic *pedicle hook*, the inferior articular process is resected with an osteotome. A pedicle finder is passed over the superior facet of the level below, underneath the pars of the indicated vertebra until it reaches the undersurface of the desired pedicle. Next, a cranially pointing pedicle hook is inserted through the same trajectory and attached firmly onto the inferior portion of the pedicle. A *sublaminar hook* can be safely placed at any level in the thoracic spine. A curet or laminar developer is used to detach the ligamentum flavum from the undersurface of the inferior lamina. A cranially pointing sublaminar hook is then placed within this interval and should attach firmly to the undersurface of the lamina. A similar sequence can be used to place a caudally facing *supralaminar hooks*. With this method, however, care must be taken while developing the plane underneath the superior lamina, as the dura within this "bare area" is not protected by the ligamentum flavum. Superior laminar bone may need to be resected with a pituitary rongeur in order to create a safe zone of entry for the supralaminar hook. Finally, *transverse process hooks* can be placed safely from T1 to T10 in patients without osteoporotic bone. A curet or transverse process finder is used to create a subperiosteal plane at the superior and medial aspect of the transverse process. Next, a caudally pointing transverse process hook is placed against the superior transverse process ridge and should have a firm fit.

Complications

Complications of thoracic spine pedicle screw fixation are relatively more common than in the lumbar spine and usually occur intraoperatively. One of the most feared complications is a symptomatic pedicle screw breach which might be the cause of serious neurologic injury. Medial cortical breach rates can reach up to 25%, which can be dangerous since the thoracic spinal cord has a higher tensile load than other spinal levels [10]. In the case of a medial breach, a laminectomy should be performed in order to visualize the dura and a direct suture repair is attempted. In this scenario, intraoperative IV steroids can be given to decrease cord inflammation, although there is a lack of evidence to support this practice.

Lateral breach rates can reach up to 30%, with risks of injuring surrounding structures such as the aorta, the lung (causing pneumothorax), and other visceral structures in proximity. Furthermore, anterior breach rates can reach 8% with the possibility of injuring the aorta, the vena cava, or the esophagus.

Other perioperative complications should also be taken into consideration despite happening at lower rates such as pedicle fracture (1%), screw loosening (1.5%), and infection (up to 4%) [11].

Thoracic Spine Percutaneous Pedicle Screw Fixation

Introduction

Minimally invasive thoracic pedicle screw instrumentation has gained popularity over the past decade. This technique is done percutaneously under fluoroscopic guidance and is a viable option with a staged posterior instrumentation and fusion following an anterior thoracic decompression and fusion, i.e., discectomy, vertebrectomy, or in the traumatic setting. When a posterior decompression is needed, the open approach is generally best.

The advantages of percutaneous thoracic pedicle screw fixation include a lower risk of blood loss and transfusion due to decreased soft tissue dissection [12]. This also lowers this risk of infection and results in less postoperative pain, lower narcotic use, and a shorter recovery and hospitalization period [12, 13]. This is especially applicable to patients with metastatic tumors where posterior pedicle instrumentation is used as a staged procedure after anterior tumor resection [14].

The disadvantages of a percutaneous technique is the lack of visualization and difficulty in achieving a robust fusion bed. Additionally, the increased exposure to ionizing radiation is a concern to the surgeon since extended fluoroscopic use is needed to perform the procedure safely [13].

Surgical Technique

Percutaneous thoracic spine pedicle screw fixation can be done under either CT-based stereotactic or intraoperative fluoroscopic guidance [13]. With the latter method, an AP radiograph is obtained parallel to the endplates and with the spinous process midline and equidistant to the pedicles. The skin is marked in accordance to the lateral aspect of the pedicle and an incision is made long enough to accommodate the size of the screw tower. A Jamshidi needle is then inserted and docked on either the 3 o'clock or 9 o'clock positions of the right and left pedicles, respectively. The needle is advanced approximately 20–25 mm with a lateral to medial trajectory, taking care not to breach the medial wall of the pedicle. At this depth, the tip of the Jamshidi should be within the posterior aspect of the vertebral body and is confirmed with lateral imaging. A guide wire is then passed through the Jamshidi and secures the trajectory within the pedicle. Next, a cannulated tap is passed over the guide wire and advanced through the pedicle, followed by passage of a cannulated pedicle screw into the pedicle. The guide wire is removed, and the step is repeated at each of the desired pedicles. Each screw is attached to a screw tower, and the appropriately sized rod is passed subfascially through the towers.

Conclusion

Posterior instrumentation of the thoracic spine has evolved significantly over the past 70 years, and modern-day fixation techniques have become safe and reproducible. Percutaneous screw placement is a great option for certain conditions, but cannot substitute the need for an adequate decompression or a robust posterior fusion with bone graft. Although pedicle screws have become the mainstay of thoracic instrumentation, the young spine surgeon must not forget that other techniques such as hooks and wires were used for decades and are still important when alternative or bailout options are needed.

References

1. Mohan AL, Das K. History of surgery for the correction of spinal deformity. Neurosurg Focus. 2003;14(1):Article 1.
2. Singh H, Rahimi SY, Yeh DJ. History of posterior thoracic instrumentation. Neurosurg Focus. 2004;16:1.
3. Cotler JM, Simpson M, An HS. Principles, indications, and complications of spinal instrumentation: a summary chapter. In: An HS, Cotler JM, editors. Spinal instrumentation. Baltimore: Williams & Wilkins; 1992. p. 435–53.
4. Berry JL, Moran JM, Berg WS, Steffee AD. A morphometric study of human lumbar and selected thoracic vertebrae. Spine. 1987;12:362–7.
5. Vaccaro AR, Rizzolo SJ, Allardyce TJ, Ramsey M, Salvo J, Balderston RA, Cotler JM. Placement of pedicle screws in the thoracic spine. J Bone Joint Surg Am. 1995;77:1193–9.
6. Panjabi MM, et al. Complexity of the thoracic spine pedicle anatomy. Eur Spine J. 1997;6(1):19–24. https://doi.org/10.1007/bf01676570.
7. Wang JC. Advanced reconstruction: spine: American Academy of Orthopaedic Surgeons; 2011.
8. Charles YP, Pelletier H, Hydier P, Schuller S, Garnon J, Sauleau EA, Steib JP, Clavert P. Pullout characteristics of percutaneous pedicle screws with different cement augmentation methods in elderly spines: an in vitro biomechanical study. Orthop Traumatol Surg Res. 2015;101(3):369–74. https://doi.org/10.1016/j.otsr.2015.01.005. Epub 2015 Mar 6.
9. Perna F, et al. Pedicle screw insertion techniques: an update and review of the literature. Musculoskelet Surg. 2016;100(3):165–9. https://doi.org/10.1007/s12306-016-0438-8.
10. Middleditch A, Oliver J. Functional anatomy of the spine: Langara College; 2016.
11. Li G, et al. Complications associated with thoracic pedicle screws in spinal deformity. Eur Spine J. 2010;19:1576–84.
12. Gazzeri R. Percutaneous pedicle screw fixation technique in the thoracic and lumbar spine-tips and tricks. Surg Technol Int. 2016:303–10.
13. Mobbs RJ, et al. Technique, challenges and indications for percutaneous pedicle screw fixation. J Clin Neurosci. 2011;18(6):741–9. https://doi.org/10.1016/j.jocn.2010.09.019.
14. Hsieh PC, Koski TR, Sciubba DM, et al. Maximizing the potential of minimally invasive spine surgery in complex spinal disorders. Neurosurg Focus. 2008;25:E19.

Chapter 10

Posterior Thoracic Instrumentation for Scoliosis

Fred F. Mo, William D. Zelenty, and Daniel M. Dean

Introduction

Both adult scoliosis and adolescent idiopathic scoliosis are relatively common conditions cared for by the spinal surgeon. Patients who have large, progressive curves often require large spinal fusions that include parts of the thoracic spine. Instrumentation of the thoracic spine can often be more challenging than instrumentation of the lumbar spine due to the difficulty with visualization, the smaller pedicle size, and the proximity to vital structures. However, improvements in pedicle screw designs have allowed for safer and biomechanically stronger correction of thoracic scoliotic curves. Pedicle screw constructs have recently become the most popular means of fixation, supplanting hook and wire constructs as well as anterior approaches.

Epidemiology and Natural History

Scoliosis can be subdivided into congenital scoliosis, adolescent idiopathic scoliosis (AIS), and adult scoliosis. Congenital scoliosis is a rare condition caused by errors in formation or segmentation of the vertebral elements during development. Progression is based on type of congenital scoliosis [1]. AIS is a diagnosis of exclusion and is identified in 1–3% of children aged 10–16 years [2]. Rate of curve progression is associated with time of diagnosis, magnitude of the curve, and location of the curve apex. The majority of cases are treated with observation and bracing. However, large curves greater than 50° are associated with pulmonary compromise

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_10

and curves greater than 40° can be associated with body image issues and psychological disturbances. As a result, large curves often require spinal fusion. Finally, adult scoliosis, defined as a coronal Cobb angle >10° on the coronal plane in a skeletally mature patient, can be secondary to untreated adolescent idiopathic scoliosis (AdIS) or can be a de novo adult degenerative scoliosis (ADS) that occurs later in life [3]. It is estimated that the prevalence of scoliosis in patients older than 50 years is between 1.4% and 9%, affecting approximately 500,000 Americans [4]. Patients often present with back pain secondary to muscle fatigue, trunk imbalance, degenerative disc disease, and facet arthropathy. If left untreated, AdIS thoracic curves of greater than 50° will tend to progress by approximately one degree per year while curves less than 30° tend to be stable [4]. ADS curves are thought to develop secondary to loss of intervertebral disc height, leading to facet arthropathy. In conjunction with weakened paraspinal musculature in the elderly population, this leads to axial rotation of the spinal column and stretching of the surrounding ligaments causing laterolisthesis of the vertebral bodies. Larger curves with increased laterolisthesis have the highest rates of progression. [3]

Assessment

The assessment of scoliosis starts with a thorough history and physical exam. The history should focus on location of symptoms, rate of progression of the deformity, and any neurologic or cardiopulmonary symptoms associated with the condition. Other important factors to consider include medical comorbidities, psychosocial comorbidities, and smoking status.

A complete head to toe physical exam should be performed in the scoliotic patient, paying special attention to the neurologic portion. The scoliotic curve should be assessed in the standing and bending position.

Imaging and Classification

The most commonly utilized imaging modality in the assessment and management of scoliosis is plain radiography, typically standing full-length 36-inch cassettes. Bending films are useful in determining the flexibility of the curves. Sequential AP and lateral full-length films are utilized to monitor the progression of the curve and the response to nonoperative interventions. Prior to surgery, CT scans are typically obtained to help with surgical planning and three-dimensional imaging of multiplanar curves. MRI is useful to obtain in cases where there are neurological deficits, neurologic symptoms, or rapidly progressive scoliosis. In cases of large curves exceeding 60° or patients with any cardiopulmonary complaints, pulmonary function tests should be obtained. The most commonly utilized classification system for the selection of fusion levels is the Lenke classification which utilizes the curve(s) location and mobility of the curve on bending films to determine fusion levels [5].

Treatment

Nonoperative Treatments

Patients with adult scoliosis and back pain should be considered similarly to all other adult patients with back pain. A thorough history and physical examination can elicit whether curvature is related to their symptoms. Nonoperative options are available and should be considered for the treatment of back pain due to scoliotic curves; however, they will not prevent progressive curvature. Nonoperative treatments should also be utilized in instances where the patient may not be able to tolerate a reconstructive procedure due to comorbidities or preference. A course of nonoperative treatment including physical therapy, corticosteroid injections, and nerve blocks may provide substantial benefit in patients that ultimately require surgery by optimizing their fitness. The use of braces in adult scoliosis patients has not shown to have significant effects on quality of life, pain, and does not prevent progression of curvature. It may provide some relief in patients who are not surgical candidates. The same is not true for patients with AIS where bracing protocols can prevent progression. This was developed initially by Nachemson, Peterson, and Daneilsson through the late 1990s and early 2000s, prompting the large-scale BRAIST study. This randomized controlled trial demonstrated significant benefit of bracing over observation, when used effectively, in preventing progression of curves between 20° and 40° [2, 6–10].

Operative Treatments

Non-pedicle Screw Constructs

The anterior approach to the thoracic spine has seen a substantial decline over the last two decades, once accounting for greater than 25% of all instrumented fusions, now seen in less than 5% [11]. Similarly, the use of hook constructs and other instrumentation has seen a rapid decline over the same time period. These approaches and methods have been overtaken by all posterior, all-pedicle-screw constructs [12]. These devices have proven to be safe, have greater biomechanical advantage for curve correction, require fewer fused levels, and have less morbidity. The one major disadvantage of these constructs is cost of implants, though this is expected to decrease with time and is clearly offset by significant advantage [13].

Hook constructs are not used in common practice currently. However, there are instances where hook or hybrid hook-screw constructs may be used or needed as an additional measure. Hooks can be placed in multiple areas of the spine. Pedicle hooks are placed by first removing the inferior articulating process (IAP) of the facet to expose the superior articulating process (SAP). The pedicle hook (with a central notch) can then be engaged directly on the pedicle and buttressed inferiorly by the SAP. A sublaminar hook is placed within the substance of the ligamentum flavum itself. It may require some exposure, either by removal of a portion of the cranial lamina or of the caudal facet. Transverse process (TP) hooks require a wider exposure and cannot be used in isolation; the TP is prone to fracture. The goal of using hooks is to minimize exposure of the dura; however, there is some degree of impingement when placing sublaminar hooks [14]. Hooks can be safely placed beneath the musculature of the spine using a medial or paramedian approach with limited dissection compared to pedicle screws where the facet is typically exposed entirely. Hook constructs are not engaged to the bone outside of the distraction or compressive forces they are creating. They are susceptible to dislodgement as the thoracic curve is corrected and the force profile changes [15]. Multiple hooks can be placed in opposing directions to create a “claw,” creating a compressive force between those levels on one side of the spine – this can correct deformity, but also reduces the likelihood of hook dislodgement. Correction using hooks occurs when the hooks are attached to pre-contoured rods which are rotated into place to produce the final correction – correction with rods is discussed in depth in the pedicle screw construct section. In addition, hooks can be fixed to their rod in a compression or distraction mode depending on orientation to achieve correction [14].

Hybrid constructs utilize a combination of hooks and pedicle screws for deformity correction. A particular construct described by Mousny et al. utilizes a proximal cranial claw consisting of three hooks and caudal pedicle screws to anchor and produce sagittal and coronal deformity correction [13, 16]. Numerous other hybrid constructs have been described and are beyond the scope of this text. Relatively newer technologies have replaced other historical constructs like wires with fiber bands which provide fixation without the same risk of catastrophic failure [17]. However, many of these techniques have failed to become popular against the availability, versatility, mechanics, and familiarity of screw constructs [13].

Pedicle Screw Constructs

Biomechanics of Pedicle Screw Constructs

There are two major mechanical advantages to pedicle screw constructs compared to historical treatments. Relative to other constructs, pedicle screws provide three-column stabilization which provides their main mechanical advantage. Second, screws have a significantly greater pullout strength compared to hooks and wires. Of note, in adolescent patients the pedicle screw size can actually be larger than the pedicle itself due to the plastic quality of their bone, increasing stiffness and pullout strength [18].

Safety of Pedicle Screw Constructs

Despite findings of pedicle wall violation on postoperative CT scan, these constructs are safe. Cortical breach has been reported as high as 43%, whereas neurological injury is reported as high as 1.2% [13]. There is a proposed 4 mm "safe zone" for breach in this region composed of 2 mm of epidural and 2 mm of subarachnoid space medial to the pedicle wall [19]. Subsequent cadaveric studies have challenged this finding. Regardless, accurate placement in the thoracic region is paramount with an established criteria of less than 2 mm of breach, but has been shown to be reliably found even in cases of extreme deformity [20]. In cases of congenital deformity in pediatric patients, placement of thoracic pedicle screws presents an additional challenge not only of curve correction but anomalous anatomy of the thoracic pedicles – additional care must be taken in these situations [1].

Pedicle Screw Technique

Selecting levels for fusion is the first and most important step. Goals of the procedure are to correct alignment (in multiple planes), correct deformity, and preserve motion. There are a number of algorithms available for selection of curves, but no single algorithm has been adopted. In general, instrumentation and fusion of the major, structural curve alone is typically enough. Compensatory curves will spontaneously resolve in up to 70% of cases. In some cases, however, there may be two major, structural curves – failure of fixation may be due to insufficient fusion of double major curves [21]. The King classification has been superseded by the Lenke classification as the main guide of fusion levels. The Lenke classification has six major types which are further subdivided into 42 types. This classification first identifies the primary and minor curves and then adds lumbar and thoracic modifiers – it helps to establish which curves require correction and the proximal and distal extent of the fusion required [5]. Of note, in patients with AIS, up to 10% will have an anomalous number of thoracic vertebrae, so special attention must be paid to counting at this step [22].

Once the levels of fusion have been determined and a preoperative plan has been developed, patients can be brought to the operating room for instrumentation and fusion. Various techniques for pedicle screw placement have been described. Kim et al. developed a method utilizing only anatomic landmarks relying on the superior articular facet, lamina, and transverse process to determine screw trajectory (see Fig. 10.1). A curved, blunt probe (gearshift) is used to find the pedicle and is first advanced with the curve facing lateral to prevent medial breach. At about 20 mm of depth, they recommend redirecting medially to obtain purchase within the vertebral body. Progressing distally within the thoracic spine, they recommended probing to 20–25, 25–30, and 30–35 mm in the upper, middle, and lower thoracic segments, respectively. In their original paper, they reported a 6.2% incidence of breech without neurological injury. Fluoroscopy can be used in addition to anatomic landmarks. Use of fluoroscopy requires a skilled technician as it necessitates frequent move-

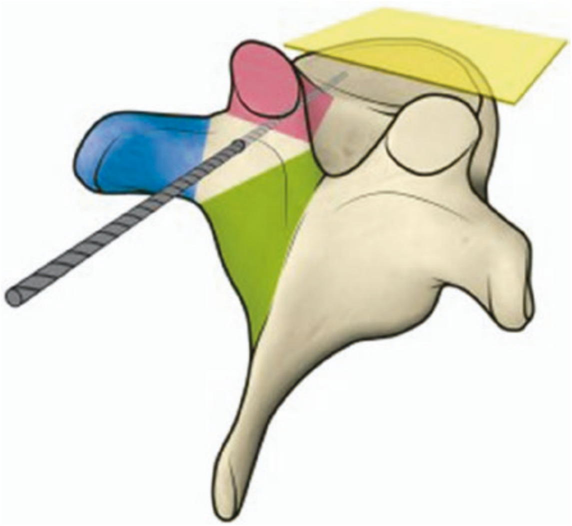

Fig. 10.1 The graphic is a representation of a thoracic vertebra. Red is the superior articular facet, blue is the transverse process, and green is the pars interarticularis. Reproduced and published with permission from Springer Link Publishing**.** (Figure reproduced from Perna with permission)

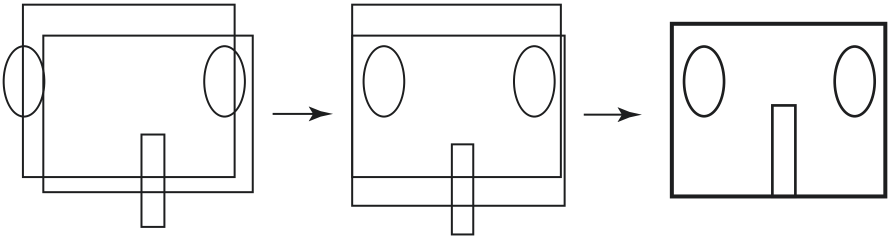

Fig. 10.2 Use of fluoroscopy can help establish proper entry points. The above schematic represents the projection seen. The oblong shapes represent the pedicles and the vertebral body is the rectangular structure. As the body is aligned in multiple planes, the pedicles will align at the superior corners of the rectangle and become more distinct. The endplates will appear denser as they are aligned within the image and the spinous process should be centered within the body. Performing isolated movements with the C-arm will simplify achieving the optimal image (e.g., center the spinous process then align the endplates)

ment of the fluoroscope in multiple planes. Establishing distinct endplates and symmetric appearing pedicles requires adjustments in the mediolateral and cephalocaudad planes (see Fig. 10.2). Once a distinct image is achieved, landmarks can be easily identified and the probe advanced. This process must be repeated for each vertebral segment [23, 24]. Laminotomy for direct palpation of the medial pedicle wall has also been described, but is generally limited to revision surgeries. Lastly, use of new electronic probes in conjunction with electromyography has been described, but predominantly in lumbosacral instrumentation. This is a growing technique and requires further investigation for use in thoracic instrumentation. Once screws have been placed, they can be stimulated and electromyography recorded to confirm placement. A threshold of 11 mA has been established for the thoracic spine with a 97.5% negative predictive value of pedicle breach [25, 26].

Once screws are inserted, attention can be turned to restoration of normal curvature. There are a number of methods to aid in curve correction including musculoligamentous releases, thoracoplasty, and osteotomies. At the most basic level, facetectomies will provide some additional spinal motion. These may have already been performed as part of pedicle screw insertion to identify the entry point. Facetectomy serves to release the joint and ultimately contribute to the fusion. Removal of interspinous ligaments and thorough soft tissue dissection off of the bone will similarly contribute to overall freedom without being substantially destabilizing. The technique of thoracoplasty, whereby the ribs and spine can be disengaged, is somewhat controversial. Thoracoplasty has been linked to changes in lung function, but also linked to superior patient satisfaction (mostly for cosmetic reasons by reduction in "rib hump" deformity) [27, 28]. Lastly, osteotomies and other wide, posterior resections can be used. A Ponte osteotomy, wherein the posterior and middle columns are resected can substantially improve coronal plane correction even though it is typically reserved for sagittal alignment in the lumbar spine [29].

Correction can also be achieved using the rod itself when the spinal column is sufficiently mobile (with or without releases described previously). Several techniques have been described. Traditionally, a rod rotation maneuver is performed. This uses a pre-contoured rod which is engaged with all of the pedicle screws then rotated to achieve correction, prior to final tightening of the set screws. An exaggerated bend for final correction is introduced into the rod. The rod is then sequentially engaged using introducers and cap screws. Single rods can be used for large corrections, placing a slightly shorter rod on the convex side with the expectation of shortening with correction. Double thoracic curves need to be addressed individually with multiple short rods for each correction [30]. In situ bending is also possible by fully engaging a rod and then performing multiple passes of the rod bender between screws to achieve correction. Direct Vertebral Rotation (DVR) is a relatively newer technique by which direct manipulation of the pedicle screws using levers achieves correction prior to applying the rod. The pedicle screw has good purchase on all three columns of the spine and can withstand substantial torque, compared to other constructs such as hooks. Utilizing a rotational tool a pedicle screw (or multiple, to reduce screw pullout) can be rotated in the axial plane to achieve correction in the coronal and sagittal planes. The rotational force is in the opposite direction of the curve and can be done sequentially beginning with the apical vertebra. Multiple passes may be required, gradually achieving correction by rotating and fixing to rod [30, 31].

Outcomes and Complications

Pedicle screw constructs have excellent radiographic and clinical outcomes. They achieve greater curve correction (over 70% correction compared to 50% with hook or other approaches) and maintain the correction longer compared to other approaches and nonoperative treatments. They achieve curve correction without the need for anterior release, saving patients the additional morbidity.

Neurological deficit is the most feared complication of any spinal surgery, but is of particular importance in the thoracic spine where the highly variable anatomy combined with aberrance of scoliosis increases the likelihood of screw malposition. Despite the high level of difficulty and rate of breech reported as high as 65% in some series, root and spinal cord injuries are reported consistently at less than 1% [32]. Kim and his team described a grading system for screw breech with grade 1 being between 0 and 2 mm, grade 2 between 2 and 4 mm, and grade 3 between 4 and 8 mm [33]. Other complications that have been encountered include pulmonary effusions due to screw over penetration, dural tears, pseudoarthrosis, hardware loosening, and infections (both superficial and deep). In each of these cases, the reported rates are less than 1% with a concordant rate between 0.83% and 4.3% for revision of screw placement [34].

Conclusion

Posterior instrumentation for the thoracic spine presents some unique challenges. The anatomy of the thoracic spine is highly variable and requires a strong understanding of three-dimensional structures and adequate, reproducible imaging in the operating room. In many cases, instrumentation is performed for correction of curvatures which distorts already complex bony anatomy and necessitates an algorithmic approach to soft tissue releases and corrective osteotomies. Lastly, there exist a number of implant options both for fixation and curvature correction. Pedicle screw constructs are the gold standard for thoracic instrumentation, but new techniques and implants are always under development.

References

1. Hedequist D, Emans J. Congenital scoliosis: a review and update. J Pediatr Orthop. 2007;27:106–16.
2. Weinstein SL, Dolan LA, Wright JG, Dobbs MB. Effects of bracing in adolescents with idiopathic scoliosis. N Engl J Med. 2013;369:1512–21.
3. York PJ, Kim HJ. Degenerative scoliosis. Curr Rev Musculoskelet Med. 2017;10:547–58.
4. Bradford DS, Tay BK, Hu SS. Adult scoliosis: surgical indications, operative management, complications, and outcomes. Spine (Phila Pa 1976). 1999;24:2617–29.
5. Lenke LG, Betz RR, Haher TR, et al. Multisurgeon assessment of surgical decision-making in adolescent idiopathic scoliosis: curve classification, operative approach, and fusion levels. Spine (Phila Pa 1976). 2001;26:2347–53.
6. Nachemson A. Physiotherapy for low back pain patients. A critical look. Scand J Rehabil Med. 1969;1:85–90.
7. Nachemson A. Adult scoliosis and back pain. Spine (Phila Pa 1976). 1979;4:513–7.

8. Teles AR, Mattei TA, Righesso O, Falavigna A. Effectiveness of operative and nonoperative care for adult spinal deformity: systematic review of the literature. Global Spine J. 2017;7:170–8.
9. van Dam BE. Nonoperative treatment of adult scoliosis. Orthop Clin North Am. 1988;19:347–51.
10. Danielsson AJ, Hasserius R, Ohlin A, Nachemson AL. A prospective study of brace treatment versus observation alone in adolescent idiopathic scoliosis: a follow-up mean of 16 years after maturity. Spine (Phila Pa 1976). 2007;32:2198–207.
11. Theologis AA, Sing DC, Chekeni F, Diab M. National trends in the surgical management of adolescent idiopathic scoliosis: analysis of a national estimate of 60,108 children from the national inpatient sample over a 13-year time period in the United States. Spine Deform. 2017;5:56–65.
12. Cuartas E, Rasouli A, O'Brien M, Shufflebarger HL. Use of all-pedicle-screw constructs in the treatment of adolescent idiopathic scoliosis. J Am Acad Orthop Surg. 2009;17:550–61.
13. Rose PS, Lenke LG, Bridwell KH, et al. Pedicle screw instrumentation for adult idiopathic scoliosis. Spine. 2009;34(8):852–7.
14. Cotrel Y, Dubousset J, Guillaumat M. New universal instrumentation in spinal surgery. Clin Orthop Relat Res. 1988;227:10–23.
15. Vereijken IMP, de Kleuver M. Late proximal pedicle hook migration into spinal canal after posterior correction surgery of scoliosis causing neurologic deficit: "proximal junctional scoliosis"? Case series and a review of the literature. Spine Deform. 2013;1(3):229–36.
16. Miladi L, Mousny M. A novel technique for treatment of progressive scoliosis in young children using a 3-hook and 2-screw construct (H3S2) on a single sub-muscular growing rod: surgical technique. Eur Spine J. 2014;23(Suppl 4):S432–7.
17. Sales de Gauzy J, de Gauzy JS, Jouve J-L, et al. Use of the Universal Clamp in adolescent idiopathic scoliosis. Eur Spine J. 2014;23(S4):446–51.
18. O'Brien MF, Lenke LG, Mardjetko S, et al. Pedicle morphology in thoracic adolescent idiopathic scoliosis: is pedicle fixation an anatomically viable technique? Spine (Phila Pa 1976). 2000;25:2285–93.
19. Gertzbein SD, Robbins SE. Accuracy of pedicular screw placement in vivo. Spine (Phila Pa 1976). 1990;15:11–4.
20. Kuklo TR, Lenke LG, O'Brien MF, Lehman RA, Polly DW, Schroeder TM. Accuracy and efficacy of thoracic pedicle screws in curves more than 90 degrees. Spine (Phila Pa 1976). 2005;30:222–6.
21. Suk S-I, Kim J-H, Kim S-S, Lim D-J. Pedicle screw instrumentation in adolescent idiopathic scoliosis (AIS). Eur Spine J. 2011;21(1):13–22.
22. Ibrahim DA, Myung KS, Skaggs DL. Ten percent of patients with adolescent idiopathic scoliosis have variations in the number of thoracic or lumbar vertebrae. J Bone Joint Surg Am. 2013;95:828–33.
23. Lee CS, Kim MJ, Ahn YJ, Kim YT, Jeong KI, Lee DH. Thoracic pedicle screw insertion in scoliosis using posteroanterior C-arm rotation method. J Spinal Disord Tech. 2007;20:66–71.
24. Carbone JJ, Tortolani PJ, Quartararo LG. Fluoroscopically assisted pedicle screw fixation for thoracic and thoracolumbar injuries: technique and short-term complications. Spine (Phila Pa 1976). 2003;28:91–7.
25. Shi YB, Binette M, Martin WH, Pearson JM, Hart RA. Electrical stimulation for intraoperative evaluation of thoracic pedicle screw placement. Spine (Phila Pa 1976). 2003;28:595–601.
26. Isley MR, Zhang XF, Balzer JR, Leppanen RE. Current trends in pedicle screw stimulation techniques: lumbosacral, thoracic, and cervical levels. Neurodiagn J. 2012;52:100–75.
27. Suk SI, Kim JH, Kim SS, Lee JJ, Han YT. Thoracoplasty in thoracic adolescent idiopathic scoliosis. Spine (Phila Pa 1976). 2008;33:1061–7.
28. Kim YJ, Lenke LG, Bridwell KH, Kim KL, Steger-May K. Pulmonary function in adolescent idiopathic scoliosis relative to the surgical procedure. J Bone Joint Surg Am. 2005;87:1534–41.

29. Shufflebarger HL, Geck MJ, Clark CE. The posterior approach for lumbar and thoracolumbar adolescent idiopathic scoliosis: posterior shortening and pedicle screws. Spine (Phila Pa 1976). 2004;29:269–76; discussion 76.
30. Trobisch PD, Ducoffe AR, Lonner BS, Errico TJ. Choosing fusion levels in adolescent idiopathic scoliosis. J Am Acad Orthop Surg. 2013;21:519–28.
31. Lee SM, Suk SI, Chung ER. Direct vertebral rotation: a new technique of three-dimensional deformity correction with segmental pedicle screw fixation in adolescent idiopathic scoliosis. Spine (Phila Pa 1976). 2004;29:343–9.
32. Kwan MK, Chiu CK, Gani SM, Wei CC. Accuracy and safety of pedicle screw placement in adolescent idiopathic scoliosis patients: a review of 2020 screws using computed tomography assessment. Spine (Phila Pa 1976). 2017;42:326–35.
33. Kim YJ, Lenke LG, Bridwell KH, Cho YS, Riew KD. Free hand pedicle screw placement in the thoracic spine: is it safe? Spine (Phila Pa 1976). 2004;29:333–42; discussion 42.
34. Hicks JM, Singla A, Shen FH, Arlet V. Complications of pedicle screw fixation in scoliosis surgery: a systematic review. Spine (Phila Pa 1976). 2010;35:E465–70.

Chapter 11
Anterior Thoracic Decompression and Fusion: Open and Minimally Invasive

Jason Kappa, Jeffrey H. Weinreb, Warren Yu, and Joseph R. O'Brien

Background

Minimally invasive surgery (MIS) of the spine has become increasingly popular with the advent of advanced intraoperative imaging, electromyographic monitoring, and innovative minimally invasive biotechnology [1]. The goals of minimally invasive spine surgery are to theoretically decrease tissue damage and therefore to provide improved morbidity, faster recovery, and improved functional outcomes [2]. Although theoretically beneficial, there are limited high-quality studies comparing minimally invasive and open procedures. Nevertheless, evidence for improved outcomes for both open and minimally invasive procedures has been described. The decision to perform an open versus minimally invasive approach therefore depends on surgeon experience, preference, system availability, and patient preference [3–5].

The anterior approach to thoracic spine has unique benefits and limitations. This approach provides excellent access to the anterior aspects of the thoracic spine and limits manipulation of the spinal cord [6]. Additional reported benefits specific to the minimally invasive approach include avoiding the use of rib resection or retractors, reduced blood loss, and diminished postoperative pain. However, the minimally invasive approach also required increased anesthetic monitoring due to single lung ventilation, and it is a technically demanding procedure with a steep learning curve [7].

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_11

Indications

A thorough understanding of the indications for the anterior thoracic approach to the spine is critical to ensure optimal surgical outcomes. Reported indications for this approach include anterior thoracic spine fractures classified as AO Classification type A1.2, A1.3, A2, A3, B, and C with significant curvature displacement of 20° or more in the sagittal or AP plane, thoracic disc herniation, discoligamentous segmental instability, degenerative stenosis or deformity, osteomyelitis/tuberculosis, and tumor [7, 8]. Of note, approximately two-thirds of spinal metastases are found anteriorly in the vertebral bodies and pedicles. The anterior approach enables direct decompression and restoration of stability as laminectomy alone is not adequate for anteriorly located pathology [6]. Contraindications are similarly important to ensure optimal outcomes and include previous chest trauma or surgery, adhesions, infection, or comorbidity that would make single-lung ventilation dangerous [8].

Approaches/Techniques

Multiple approaches have been described to perform anterior thoracolumbar decompression and fusion. The variations largely hinge on avoiding vital structures during the approach. Traditionally, an open transthoracic approach was performed [9]. This technique involves placing the patient in the lateral decubitus position, with the hips and knees flexed to relax the ipsilateral psoas. Fluoroscopy is used to identify the targeted vertebral level. An oblique incision 4–6 inches in length is centered over the rib two at the desired surgical level. A right-sided approach is performed between the 3rd and 10th thoracic levels to avoid the great vessels, whereas a left-sided approach is employed to address the 11th thoracic through the 1st lumbar level. After incision through subcutaneous tissue, a thoracotomy is performed. Self-retaining retractors are placed and the lung is retracted carefully. The caudad rib is traced and the base excised subperiosteally taking care to divide the costovertebral ligaments. The corresponding intercostal nerve is identified and traced to confirm the correct level for disc excision. Once this level has been identified, the parietal pleura is then reflected, taking care to identify the segmental vessels that lie in the fatty tissue midway between the vertebral bodies above and below the level of the desired disc. The parietal pleura is then split longitudinally and segmental vessels ligated and divided. Subperiosteal dissection is performed to delineate the adjacent vertebral bodies, as well as the pedicle of the caudad vertebral body. The isolated intercostal nerve is again traced to identify the appropriate foramen. The inferior pedicle is removed, exposing the underlying dura and revealing the herniated disc. This window allows visualization of the lateral disc space. An annulotomy is performed and the mid-lateral portion of the disc is removed with a pituitary rongeur. The posterior annulus is addressed last and is bluntly freed from the dura using a penfield. Extruded or herniated disc material is then pulled into the cavity created by already removed disc material. After the disc has been addressed, the PLL is then bluntly dissected off the cord and removed. After discectomy, a cage or bone graft can be placed if fusion is desired. The windows created in the parietal pleura and thoracic cavity are closed with watertight layer [9].

In addition to an open approach, multiple minimally invasive approaches have been described. The first is a posterolateral extracavitary technique [10]. In this approach, the patient is positioned prone on a Jackson frame with the abdomen free. Neuromonitoring with SSEPs and MEPs are employed during the case. Fluoroscopy is used to identify the desired level, and a K-wire is placed percutaneously down the rib angle to the transverse process of the caudad verterbral body. A 2-cm vertical incision is made through fascia. A finger is then used to bluntly dissect and dilate muscle fibers to the transverse process and facet of the target level. Progressive dilators are placed to form port, typically up to 22 mm, and secured to the surgical able using a mounted arm. Biplanar fluoroscopy is again used to identify correct level. Ideally, the target disc should be parallel to and in the center of the working access of the portal on the lateral radiograph. On the AP, the lateral aspect of the pars interarticularis should lie in approximately the 20% horizontal meridian of the portal, ensuring that the trajectory is lateral and oblique enough to minimize the need for spinal cord retraction. Using an operating microscope, a combination of cautery and rongeurs are used to free the remaining soft tissue from the inferior transverse process-facet complex. A drill is used to remove the transverse process and expose the intertranverse ligament, which is opened sharply to access the underlying disc space. The lateral aspect of the lamina and the pars overlying the neural foramen are decompressed from lateral to medial, and the cephalad portion of the inferior pedicle is flattened with a drill to allow better access to the disc space. The ligamentum flavum is dissected off the underlying nerve root and lateral cord. Decompression of the flavum allows a near-lateral view of the spinal cord and disc space is obtained, highlighting any disc fragments. An annulotomy is performed allowing access to the disc space. Discectomy then performed, and endplates are curetted with placement of interbody cage if fusion is desired. Position of the cage is confirmed on fluoroscopy. It is important to slowly remove your retractors with cautery available as bleeding can be encountered during closure [10].

A lateral minimally invasive approach has also been described via a transthoracic window [11]. The patient is similarly placed in a lateral decubitus position with the bed broken at the affected level. The junction between the posterior and middle thirds of the disc space is marked on the skin under fluoroscopy. A 3–5 cm incision is centered over the mark which is perpendicular to the direct posterior approach. The subcutaneous tissue and intercostal muscle is divided, allowing access to the thoracic cavity. The cavity is entered over the superior edge of the rib is that overlying the affected disc space in order to avoid the neurovascular bundle. For a single level, dissection between the adjacent ribs and intercostal muscle is performed and pleural access is provided through blunt dissection. For a multi-level case, a small portion of the rib must be resected to allow adequate access. A dilator is used in the plane of the disc space to access posterior to the thoracic cavity, stopping at the junction of the rib head and vertebral body. Decompression of the disc space is then performed in similar fashion. This approach can also allow a transpleural window.

During this approach, the parietal pleura is divided longitudinally. The rib head overlying the posterolateral corner of the disc is identified and removed, allowing access to the disc space. Standard closure is performed and a chest tube is placed if a transpleural window is employed [11].

In addition to open procedures, a thoracoscopic approach for discectomy has also previously been described [12]. General anesthesia is performed using a double lumen ET tube to allow for collapse of the ipsilateral lung. The patient is also placed in a lateral decubitus position. AP and lateral fluoroscopy used to localize endoscopic ports. Three or four ports are typically needed: one on the posterior axillary line, and an additional two ports on the anterior axillary line. The first port placed blindly above the superior aspect of the rib above, and the remaining two ports triangulated 8–10 cm apart, centered over the affected level. A Steinman pin is placed for spinal level localization. Lung retraction performed by rotating the surgical table anteriorly by 30°, with resection of pleural adhesions as needed. The parietal pleura over the proximal 2 cm of the rib head adjacent to the desired level is resected, and the proximal 2 cm of the rib is resected using a burr, exposing the lateral pedicle, neural foramen, and disc. The pedicle is removed using a drill, as well as small portions of the vertebral bodies adjacent to the affected disc. The target disc fragments are removed endoscopically and the spinal canal is decompressed [12].

Postoperative Care

Following extubation, the patient is transferred to the intensive care unit for monitoring. Antibiotics, analgesia, and drain removal protocol may differ based on the institution. Similar to other spinal procedures, deep venous thrombosis prophylaxis is generally mechanical. Due to the nature of single lung ventilation, the patient should be instructed to utilize incentive spirometry. The patient should ambulate early with a skilled physical therapist and postoperative standing X-rays should be taken [8]. Patients should be restricted from bending, twisting, or lifting for 4–6 weeks while the fusion forms. Bracing is not generally required.

Outcomes

Certain complications are unique to the anterior thoracic approach to the spine. Due to the intrathoracic nature of the approach, pulmonary effusion, or hemo/pnuemothorax are possible. As mentioned previously, incentive spirometry is critical to decrease atelectasis and subsequent pneumonia. Additionally, vascular or lymphatic structures such as the aorta, vena cava or thoracic duct, is possible. This approach should only be undertaken at a facility where a thoracic surgeon is available. As with other approaches to the spine, a low threshold for neurologic injury must be maintained. Evidence of Horner's syndrome, changes in the neuromonitoring during the case, and postoperative neurologic deficits should raise suspicion for hematoma, dural injury, hardware malpositioning, or graft dislodgment. Radiography including MRI, CT, and X-ray should be obtained quickly to evaluate these possible etiologies [8].

In a case series of 121 patients treated with thoracoscopic resection of symptomatic herniated thoracic discs over 14 years, Wait et al. demonstrate improvements in myelopathy, radiculopathy, and back pain of 91.1%, 97.6%, and 86.5%, respectively, at a mean follow-up of 2.4 years [13]. Additionally, 97.4% reported they would undergo the same operation again. The thoracoscopic group was also reported to have shorter hospital stays, shorter chest tube duration, less estimated blood loss, fewer transfusions, and less risk of intercostal neuralgia compared to an unmatched thoracotomy cohort. These authors also report an initial complication rate of 28.3% in the first 6 years of the study which improved to 5.3% in the following 9 years. These complications included pleural effusion, durotomy, reintubation for respiratory distress, delayed fusion, and reoperation for residual disc [13].

Khoo et al. demonstrated that a MIS approach to the thoracic spine for discectomy and interbody fusion produced similar radiographic and clinical outcomes to an open approach at 1-year follow-up in 13 MIS patients compared to a matched cohort. [10] The MIS group had statistically significant improvements in estimated blood loss, operative time, duration of ICU stay, transfusion incidence, and overall length of stay [10].

Thoracic disc herniation is rare, with the incidence at 0.15 to 1.8%. In a small retrospective series of 12 patients with thoracic disc herniation, Ohnishi et al. describe an anterior open approach to the spine [14, 15]. These authors report results as excellent in two patients, good in two, fair in six and unchanged in two using the Japanese Orthopaedic Association score for thoracic myelopathy. No patient was classified as worse. They report pneumonia, chylothorax, and incisional pain as complications that resolved postoperatively [14].

Utilizing an anterior manubrium splitting and an extrapleural approach to the thoracic spine in 33 patients with a follow-up average of 8 years and 2 months, Fujimura et al. reported outcomes of thoracic myelopathy due to ossification of the posterior longitudinal ligament [16]. The authors report that the Japanese Orthopaedic Association score for thoracic myelopathy improved significantly at 1 year postoperatively, remained consistent through 5 years postoperatively, and decreased significantly at final follow-up. Postoperative complications included three cases of deterioration of thoracic myelopathy and four cases of extrapleural cerebrospinal fluid leakage [16].

References

1. Steinmetz MP, Benzel EC. Benzel's Spine Surgery E-Book: Techniques, Complication Avoidance, and Management. Amsterdam: Netherlands: Elsevier Health Sciences; 2016.
2. McAfee PC, Phillips FM, Andersson G, Buvenenadran A, Kim CW, Lauryssen C, et al. Minimally invasive spine surgery. Spine. 2010;35(26S):S273.

3. Foley KT, Smith MM, Rampersaud YR. Microendoscopic discectomy. In: Schmidek HH, editor. Operative neurosurgical techniques: indications, methods, and results. Philadelphia: WB Saunders; 2000.
4. Asgarzadie F, Khoo LT. Minimally invasive operative management for lumbar spinal stenosis: overview of early and long-term outcomes. Orthop Clin North Am. 2007;38(3):387–99.
5. Arts MP, Brand R, van den Akker, Elske M, Koes BW, Bartels RH, Peul WC, et al. Tubular diskectomy vs conventional microdiskectomy for sciatica: a randomized controlled trial. JAMA. 2009;302(2):149–58.
6. Massicotte EM, Witiw CD, Vaccaro AR, Fehlings MG. Anterior and anterolateral thoracic and lumbar spine decompression and fusion. benzel's spine surgery. 4th ed; 2017. p. 645.e3.
7. Heider F, Beisse R. Anterior thoracoscopic approaches, including fracture treatment. Minimally invasive spine surgery—techniques, evidence, and controversies, 1st ed. AO Spine, Thieme-Verlag; 2012. p. 191–210.
8. Baron EM, Vaccaro AR. Operative Techniques: Spine Surgery E-Book. Amsterdam, Netherlands: Elsevier Health Sciences; 2016.
9. Bohlman HH, Zdeblick TA. Anterior excision of herniated thoracic discs. JBJS. 1988;70(7):1038–47.
10. Khoo LT, Smith ZA, Asgarzadie F, Barlas Y, Armin SS, Tashjian V, et al. Minimally invasive extracavitary approach for thoracic discectomy and interbody fusion: 1-year clinical and radiographic outcomes in 13 patients compared with a cohort of traditional anterior transthoracic approaches. J Neurosurg Spine. 2011;14(2):250–60.
11. Nacar OA, Ulu MO, Pekmezci M, Deviren V. Surgical treatment of thoracic disc disease via minimally invasive lateral transthoracic trans/retropleural approach: analysis of 33 patients. Neurosurg Rev. 2013;36(3):455–65.
12. Oskouian RJ Jr, Johnson JP, Regan JJ. Thoracoscopic microdiscectomy. Neurosurgery. 2002;50(1):103–9.
13. Wait SD, Fox DJ Jr, Kenny KJ, Dickman CA. Thoracoscopic resection of symptomatic herniated thoracic discs: clinical results in 121 patients. Spine. 2012;37(1):35–40.
14. Ohnishi K, Miyamoto K, Kanamori Y, Kodama H, Hosoe H, Shimizu K. Anterior decompression and fusion for multiple thoracic disc herniation. J Bone Joint Surg Br. 2005;87(3):356–60.
15. Okada Y, Shimizu K, Ido K, Kotani S. Multiple thoracic disc herniations: case report and review of the literature. Spinal Cord. 1997;35(3):183–6.
16. Fujimura Y, Nishi Y, Nakamura M, Toyama Y, Suzuki N. Long-term follow-up study of anterior decompression and fusion for thoracic myelopathy resulting from ossification of the posterior longitudinal ligament. Spine. 1997;22(3):305–11.

Chapter 12
Thoracic Corpectomy: Indications and Techniques

Steven Spitz and Anthony Conte

Introduction

Thoracic vertebral body resection and reconstruction is one of the most technically demanding operations in neurological surgery. Adjacent critical structures, including the pleura, lungs, mediastinum, and great vessels, along with the rigidity of the spine from rib head articulation, present challenges in accessing the anterior column of the thoracic spine. A variety of approaches have been developed over the last several decades to maximize access to and minimize manipulation of the thoracic spinal cord [1–11]. These approaches carry their unique advantages and disadvantages. Anterior, lateral, and posterior trajectories have been mastered with varying degrees of success and complications. Recently, mini-open and minimally invasive approaches to the anterior column have been advanced in an attempt to minimize muscle dissection, blood loss, wound infection rates, and postoperative pain [9, 12–15]. A spine surgeon must contemplate multiple factors, including a patient's overall health and functional status, pathology, surgical goals, levels involved, and one's own comfort level before undertaking a thoracic corpectomy.

Indications

The anterior vertebral column of the thoracic spine may be compromised and destabilized by a number of different pathologies. Additionally, these same pathologies may cause direct compression of the spinal cord and neural elements, leading to radiculopathy, myelopathy, and motor weakness. Thoracic corpectomy allows for

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_12

direct decompression of the spinal cord, while graft placement additionally offers indirect decompression via vertebral height restoration and deformity correction [16]. Mechanical instability and focal kyphotic deformity of the thoracic spine may be corrected with corpectomy and instrumented stabilization and fusion.

Tumors, trauma, infection, and deformity are the most common pathologies necessitating a thoracic corpectomy. Coronal facet joint orientation, articulation with the rib head, and an extensive ligamentous support structure will provide a rigid construct for the thoracic spine that will often prevent excessive degeneration or trauma and hence the subsequent need for an extensive corpectomy. Regardless, high-impact axial loading or flexion injuries may cause significant two or three column injuries, most notably at the thoracolumbar junction where the spine is less protected by the rib cage and ligamentous attachments [17]. Burst fractures with canal compromise, facet dislocation, and flexion distraction injuries may all present with focal kyphotic deformity, requiring anterior column reconstruction and spinal cord decompression. Additionally, thoracic hyperkyphosis and degenerative/iatrogenic spinal deformity require a partial or complete thoracic vertebral body osteotomy or corpectomy to restore sagittal and coronal spinal alignment.

The thoracic spine is the most common site for epidural and vertebral body metastasis from metastatic tumors [18]. Although less common, primary bony tumors may also affect the thoracic spine. Degree of epidural compression, tumor histology, systemic extent of tumor, and regional stability must all be taken into consideration when deciding whether to perform a more aggressive resection with thoracic corpectomy or en-bloc resection versus a less extensive "separation surgery," where a posterior approach is used to carefully dissect tumor from the thoracic dura and allow adjuvant radiosurgery to be safely administered [1].

Osteomyelitis and erosive discitis are additional indications for vertebral body corpectomy in the thoracic spine. Osteomyelitis and epidural abscesses of the thoracic spine often necessitate operative management due to instability caused by bony destruction and limited tolerance of deformity of the thoracic cord in the setting of a rapidly expanding lesion [19]. Often, conservative management with antibiotics fails to eradicate the infection, requiring surgical debridement and stabilization. Certain infections, such as tuberculosis, favor the thoracic spine and often involve multiple levels. Infection in the thoracic spine is regularly not found until advanced stages, when erosive changes to the vertebral body have led to instability, neurologic deficit, and kyphotic deformity. This requires extensive debridement with corpectomy and stabilization with anterior column graft/cage placement and posterior pedicle screw instrumentation.

Open Approaches

Posterior and Posterolateral Approaches

Transpedicular Approach

The transpedicular approach is primarily employed for pathology anterolateral to the thoracic spinal cord [1, 16, 17]. The patient is placed prone on longitudinally oriented gel rolls with three-point Mayfield fixation. Pressure points are padded and arms are placed along sides. Neurophysiologic monitoring with SSEPs, EMGs, and MEPs should be performed and an arterial line placed for accurate monitoring of mean arterial pressure. A midline incision is performed 1–2 levels above and below the level of interest. The fascia is incised and a subperiosteal dissection of the paraspinal musculature off of the lamina is performed along with their respective transverse processes. A complete laminectomy and unilateral facetectomy is then performed, in order to gain access to the pedicle (Fig. 12.1). With significant ventral pathology requiring corpectomy and anterior column reconstruction, bilateral facetectomy with partial resection of the transverse processes is performed to gain access to both pedicles. The pedicle(s) is then resected using either a high-speed drill or curettes and rongeurs. If the thoracic nerve root obscures visualization, then the root may be sacrificed proximal to the dorsal root ganglion. A silk tie is used to tie off the root proximal to the DRG to prevent a CSF leak. Pedicle screw stabilization is performed 1–2 levels above and below the affected level, often depending on pathology and extent of involvement. Pedicle screws should be placed prior to the decompression and corpectomy at the affected level [17]. Following resection of one or both pedicles, and prior to the corpectomy, a temporary rod should be placed on one side to prevent neurologic injury resulting from instability. Once temporarily stabilized, the vertebral body is resected with a high-speed drill, curettes, pituitary rongeurs, and osteotomes. An expandable cage or strut graft is then placed to reconstruct the anterior column. If the working view following pedicle and transverse process resection does not allow room to implant a cage, disarticulation or “trap-door osteotomy” of the rib head will allow mobilization of the rib without

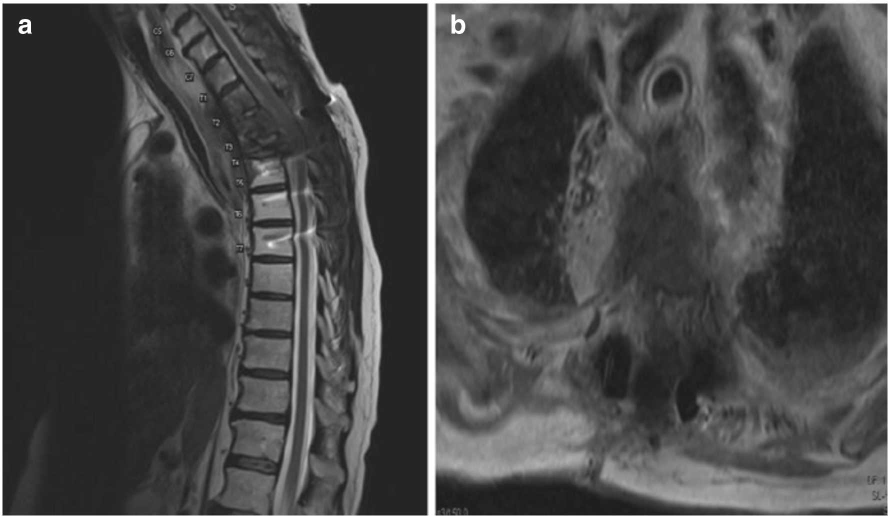

Fig. 12.1 (**a**) T2 sagittal and (**b**) T1 post-contrast axial MRI of a 79-year-old female with metastatic squamous cell carcinoma of the lung who had previously underwent a C5-T7 posterior instrumented fusion with focal laminectomy over T3–T4. She subsequently presented with extension of ventral vertebral body tumor at T3–T4 with pull-out of previously placed hardware. She was taken back to the operating room for T3–T4 lateral extracavitary corpectomy and decompression with replacement of posterior pedicle screw instrumentation

an increased risk of pleural injury [3]. Following graft implantation into the corpectomy site, posterior stabilization is completed and the fascia and subcutaneous tissue are closed in layers.

Costotransversectomy

The costotransversectomy approach offers greater access to the posterolateral thoracic spine while offering better visualization of midline ventral pathology than the transpedicular approach [2, 20]. The positioning and setup are similar to the transpedicular approach. Some surgeons employ a paramedian incision, two inches off midline, dissecting down to the costotransverse joint. Otherwise, a midline dissection is carried out over the transverse process to the costotransverse joint and proximal rib head. The transverse process is removed and a hemilaminectomy or full laminectomy is performed. The rib head and approximately three centimeters of the rib are dissected in a subperiosteal fashion, with care to protect the pleura underneath and neurovascular bundle inferiorly. The rib head is then disarticulated from the costotransverse joint and carefully removed with a Leksell rongeur or skeletonized to protect the pleura underneath. Posterior instrumentation and a temporary rod are placed prior to decompression in order to stabilize the spine. The pleura and endothoracic fascia are retracted anteriorly and the nerve root may be ligated prior to the dorsal root ganglion to maximize exposure. The contralateral pedicle screws may also be distracted to maximize the working channel to the vertebral body. This approach may be performed bilaterally at the affected level to maximize exposure and extent of corpectomy of the vertebral body [21]. After removal of the vertebral body, an expandable cage filled with morselized rib graft is inserted. The wound is then copiously irrigated to observe for air bubbles, which if present indicates a pleura violation. If the pleura has been violated, it should be primarily closed or a chest tube must be inserted if primary closure cannot be achieved. The wound is then closed in layers.

Lateral Extracavitary

The lateral extracavitary approach allows better posterolateral visualization over the transpedicular and costotransversectomy approach while offering direct visualization of the ventral midline dura for ventral decompression and corpectomy [5, 6, 21]. The extent of visualization of the vertebral body is satisfactory to undertake a one-sided approach for total corpectomy or spondylectomy. However, more extensive muscle and rib dissection places the patient at greater risk of injury to the pleura and neurovascular bundle, leading to complications such as hemothorax, pneumothorax, or intercostal neuralgia. Positioning is, as previously described, employing a midline incision with subperiosteal exposure of the spinous process and lamina 2–3 levels above and below the affected level. The transverse process and rib head on the ipsilateral side is also exposed. Pedicle screw instrumentation is placed bilaterally, and a temporary rod is inserted on the contralateral side. For upper-mid thoracic lesions, a hockey-shaped incision with the transverse limb extending just below the inferior scapular margin may be performed to mobilize the scapula [21]. Alternatively, an arc-shaped incision is employed, with the arc 7.5 cm off midline at its apex on the ipsilateral side of the pathology [4]. A separate vertical incision is made in the latissimus dorsi fascia and dissected down to the rib. The intact latissimus dorsi and underlying paraspinal muscles are reflected medial and lateral, allowing for subperiosteal dissection of the rib with careful dissection off the intercostal muscles, neurovascular bundle, and pleura. This dissection is carried out in a lateral to medial direction. The rib is cut 6–10 cm from the rib head. The rib head is disarticulated and resected along with the ipsilateral transverse process and facet complex. This may need to be performed at the level of pathology and the level below to gain adequate exposure to the vertebral body. The ipsilateral nerve root may also be ligated and transected proximal to the DRG. The OR table may also be rotated away from the surgeon to maximize exposure of the vertebral body. The pedicle of the pathologic site is resected with a high-speed drill, curettes, and Kerrison rongeurs in order to expose the lateral thecal sac. The intervertebral discs are then removed with curettes and rongeurs, and a corpectomy is performed. An expandable cage with morselized rib graft or a strut graft is then inserted. The wound is then irrigated and a Valsalva maneuver is performed to assess for a pleural violation. If an air leaked is detected, the pleural defect is sutured primarily or a chest tube is left in place if the primary closure is inadequate. The wound is then closed in multiple layers with re-approximation of the deep muscle fascia.

Anterior and Anterolateral Approaches

Transthoracic: Intrapleural and Retropleural Approach

The transthoracic approach is a popular approach for resection of the vertebral body between T3 and T10 without disruption of the posterior elements. The transthoracic approach allows for aggressive corpectomy at the level of pathology without retracting the dura and spinal cord, thus mitigating the risk of neurologic injury [22]. If there is significant pathology on both sides, a right-sided approach is preferred due to the location of the aorta, adjacent to the mid-thoracic spine on the left. Lower thoracic lesions should be approached from the left side to avoid the liver and inferior vena cava [21]. Care must be taken however, as the Artery of Adamkiewicz most commonly originates on the left side. A double-lumen endotracheal tube is inserted to allow for unilateral lung deflation. Given the invasiveness of this procedure, the transthoracic approach is contraindicated in medically ill patients with significant cardiac or pulmonary disease.

The patient is placed in the lateral decubitus position with an axillary roll. Often, the site of the approach is dictated by the location of the pathology. The incision starts 4–5 cm lateral to the spinous process and runs along the rib to the costochondral junction [10]. The overlying rib is identified on lateral radiographs, and will generally start two levels above the vertebral body of interest. Superficial and deep muscles are dissected to expose the outer periosteum of the overlying rib. Next, a Doyen elevator is used to dissect the underlying periosteum away from the neurovascular bundle. Eight to ten centimeters of the rib is then cut and the edges are covered with bone wax to achieve hemostasis as well as to prevent injury to the pleura.

In the intrapleural approach, a small incision is made in the pleura anterior to the rib head [22]. The lung is retracted ventrally, exposing the parietal pleura overlying the spine. A small transverse incision is made along the rib head to expose the segmental vessels. These vessels are clipped and divided. The great vessels are also dissected away from the ALL to maximize exposure. The rib head is then skeletonized and removed with curettes and a variety of rongeurs. This will expose the ipsilateral pedicle and help identify the posterior vertebral body cortex and the lateral thoracic dura. Next, the intervertebral discs are identified and removed, followed by removal of the pathologic vertebral body. A chest tube is left in place and set to wall suction or waterseal if dura is violated. The parietal pleura is closed when possible.

The retropleural approach is carried out in a similar manner, with the exception that the pleura is not violated. Once the rib is removed, the endothoracic fascia is incised and blunt dissection is carried out over the parietal pleura. This dissection will be extended to the vertebral body. The remainder of the approach is similar to that of the intrapleural approach. This approach is favorable in patients with preexisting lung pathology in that it prevents necessary collapse of the lung and potential chest tube drainage. However, this approach affords less exposure to the vertebral body and anterior dura than the intrapleural approach.

Transsternal/Transmanubrial

A transsternal or transmanubrial approach may be used for upper thoracic pathology between T1 and T4. This approach allows direct visualization of the vertebral body for tumor resection or deformity correction, without disruption of the posterior elements [23]. The patient is placed midline with the neck in slight extension. The incision follows the medial border of the sternocleidomastoid muscle, curving midline to extend straight down the sternum. The dissection begins by following the avascular plane medial to the sternocleidomastoid to the prevertebral fascia. The dissection is followed caudally and the sternocleidomastoid and infrahyoid muscles are cut 2 cm prior to their insertion into the manubrium. A plane is then created above and below the manubrium, dissecting laterally to the sternoclavicular joints. A medial manubriotomy is then performed. The great vessels and retrosternal fat are retracted caudally to achieve access to the upper thoracic spine. Discectomy and corpectomy of the vertebral body is then performed with a high-speed drill and a combination of curettes and rongeurs.

Thoracoabdominal

The thoracoabdominal approach is a retroperitoneal dissection that may be employed to reach the lower thoracic spine from T9 to T12. The patient is placed in the lateral decubitus position and the table is bent to increase the distance between the pelvis and rib cage. A left-sided approach is preferred to avoid the inferior vena cava and liver which obstruct the trajectory. The skin incision is made over the rib at the axillary line to the lateral border of the rectus sheath. The external oblique, internal oblique, and transverse abdominus muscles are then split. The rib is removed and costal cartilage is cut, allowing entrance into the retroperitoneal space. The diaphragm is then transected 1–2 cm medial to its attachment to the rib cage. Sutures are placed in the diaphragm to mobilize and reapproximate the muscle at the end of the procedure. The parietal pleura is incised and elevated along with the diaphragm. The psoas muscle is reflected dorsally, and a working channel is created to perform a discectomy and corpectomy. The parietal pleura and diaphragm are reapproximated upon closure [9].

Minimally Invasive Approaches

Thoracoscopic Corpectomy

Corpectomy using video-assisted thoracoscopic surgery (VATS) may offer several advantages over a more invasive open thoracotomy. Smaller incisions negate the need for rib resection and intercostal muscle dissection. By avoiding a large thoracotomy incision, blood loss is minimized and visualization of multiple vertebral levels is not compromised. Similar to thoracotomy, using VATS to approach the thoracic spine should be avoided in patients with significant cardiopulmonary disease. VATS may be used for anterior column reconstruction after traumatic vertebral body fractures, in combination with posterior pedicle screw instrumentation and stabilization [15]. It is also ideal for primary or secondary neoplasms that affect only the vertebral body and ventral epidural space. Lateral plating may be employed depending on the extent of pathologic vertebral involvement.

In thoracoscopic corpectomy surgery, the patient is intubated with a double-lumen endotracheal tube for single-lung ventilation and placed in the lateral decubitus position. A right-sided approach is preferred for mid-thoracic lesions, whereas a left-sided approach is traditionally used in lower thoracic lesions to avoid the liver and IVC. The level of pathology is localized with X-ray fluoroscopy and outlined on the skin. The main operating portal incision is centered over the level of pathology and extended 3 cm. Three additional portal incisions are made for camera insertion, suction/irrigation, and lung retraction. The prevertebral soft tissue is swept off the vertebral bodies and any segmental vessels overlying the midportion of the vertebral body are ligated and incised. The parietal pleura is incised along the proximal rib head. Next, polyaxial screws are inserted into the vertebral body cranial and caudal to the pathologic level with or without the aid of K-wires. The screws should be inserted 10 mm anterior to the posterior vertebral body cortical border, 10–15 mm superior to the cranial inferior endplate, and 10–15 mm inferior to the caudal superior endplate [24]. The intervertebral discectomy and corpectomy are then performed with a series of thoracoscopic curettes, rongeurs, and high-speed drill. The ipsilateral rib head and pedicle are drilled to expose the ventral surface of the dura prior to the corpectomy. An expandable cage with autograft/allograft or bone strut graft is then inserted into the corpectomy site and a lateral plate/rods are affixed to the polyaxial screw heads. Following hemostasis and irrigation, all trocars are removed, a chest tube is left in place, and the incisions are closed in anatomic layers.

"Mini-Open" Transpedicular Corpectomy

The "mini-open" transpedicular corpectomy is a variation of the well-known transpedicular surgical technique that aims to provide circumferential decompression and anterior column reconstruction for trauma, tumors, or degenerative disease of thoracic spine. This approach is utilized to minimize muscle and fascial dissection in an attempt to decrease blood loss and hospital length of stay [7]. The patient is placed prone on a flat Jackson table or gel rolls. A midline incision is made 2–3 levels above and below the level of pathology. The fascia, however, is not violated in the initial midline approach. Percutaneous pedicle screws are placed through separate small fascia incisions without significant dissection of the muscle. The fascia is then opened at the level of pathology, and the operative window is maintained with a self-retaining retractor. A complete laminectomy is then performed, and a temporary rod is placed on one side to maintain stability of the thoracic spine. The facet and transverse process are removed, the nerve root is ligated and cut, and both pedicles are resected with a high-speed drill and rongeurs. An aggressive discectomy above and below the vertebral body of interest are performed, and the corpectomy is undertaken with pituitary rongeurs, high-speed drill, and osteotomes. A trap-door rib head osteotomy is performed and the rib head is mobilized to allow room for the insertion of an expandable cage. The incision is then closed in layers and a surgical drain is left in place.

Minimally Invasive Lateral Retropleural Corpectomy

The minimally invasive lateral retropleural approach aims to provide a direct approach for vertebral body corpectomy without disruption of the posterior elements while mitigating the risk factors associated with open thoracotomy, including hemothorax, pneumothorax, intercostal neuralgia, and prolonged chest tube drainage. A minimally invasive approach requires a smaller incision and less rib dissection, potentially decreasing intraoperative blood loss, postoperative pain, and complications [11, 25, 26].

The minimally invasive lateral retropleural approach may be used for pathology from T4 to T12. The scapula will limit the approach in the upper thoracic spine, while the diaphragm will need to be incised for lesions in the lower thoracic spine. The patient is placed in the lateral decubitus position with an axillary roll. A 5 cm oblique skin incision is made parallel to the rib overlying the pathology, starting at the mid-axillary line [11]. The underlying rib is subperiosteally dissected away from the underlying pleura and neurovascular bundle, and 5 cm is resected. The plane between the parietal pleura and endothoracic fascia is bluntly dissected. The lung is then retracted anteriorly to expose the lateral surface of the vertebral body and intervertebral disc. The segmental vessels at the midpoint of the vertebral body are clipped and cut, and a sequence of tubular dilators are docked onto the pathologic vertebral body, followed by an expandable self-retaining retractor. The ipsilateral pedicle is removed with a high-speed drill and a combination of rongeurs. The intervertebral discs above and below the vertebral body are removed, and the corpectomy is undertaken with a high-speed drill, rongeurs, and osteotomes. An expandable cage or strut graft is used to reconstruct the anterior column. The wound is closed in layers, without the need for chest tube drainage, unless the pleura has been violated.

Grafting Technique

The need for corpectomy and ventral decompression has been discussed previously in this chapter. Following decompression, a graft is often inserted into the corpectomy site, in addition to posterior pedicle screw instrumentation, to prevent further instability and to promote bony fusion [27]. The corpectomy site must be properly prepared for graft insertion to prevent subsidence or dislodgement of the implant and promote fusion. Care must be taken not to violate the end plates of the vertebral bodies, as doing so drastically increases the risk of subsidence and loss of correction. The vertebral bodies above and below the corpectomy site may be distracted, and the endplates are drilled and contoured to allow a secure fit for the implant.

Traditionally, local rib or iliac crest autograft, contoured as a strut graft, was inserted in a stand-alone fashion for anterior column reconstruction. Insertion of silastic tubing, filled with polymethylmethacrylate, has also been used in patients with poor prognosis and significant vertebral body destruction, where stabilization (and not fusion) is the primary goal. Expandable titanium and polyetheretherketone (PEEK) cages have now supplanted strut grafts as the primary choice for anterior column reconstruction due to their ease of use and ability to provide superior deformity correction and fusion rates. These cages can be filled with local autograft from the patient's rib or vertebral body. Autograft bone should not be used in cases involving neoplastic vertebral body destruction. It is unclear whether expandable cages lead to higher subsidence rates over static cages in the thoracic spine. When examining graft failure, one study found footplate-to-VB endplate ratio less than 0.5, infectious/traumatic pathology, and shorter posterior construct length are predictors of higher rates of subsidence [27].

Complications

Complications in thoracic spine corpectomies vary according to the pathology and approach taken. The most common major complication in thoracic corpectomy is wrong-level surgery. The thoracic spine may be difficult to assess on X-ray fluoroscopy depending on the patient's body habitus. If needed, fiducial markers may be placed preoperatively under CT guidance to confirm the affected level at surgery. Subsidence of the vertebral body graft may result in pseudoarthrosis and destabilization of the thoracic spine. Violation of the vertebral body endplate and limited interface of the graft with the endplate of the vertebral body will lead to higher levels of subsidence. Violation of the anterior longitudinal ligament may place the graft at greater risk of migration.

Anterior approaches to the thoracic vertebral body, including transthoracic and retropleural approaches, pose the risk of injury to the neurovascular bundle or intercostal neuralgia. Infection will likely lead to vertebral osteomyelitis, epidural abscess, or pleural empyema. Injury to the thoracic duct may result in a chylothorax requiring reoperation. Manipulation of the lung may lead to increased pulmonary dysfunction and pneumonia, which leads to increased morbidity, especially in older patients with poor cardiopulmonary reserve. Dural tears obtained via an anterior approach are especially concerning. Dura-pleural fistulas can form, causing persistent CSF leakage into the pleural space.

References

1. Bilsky M, Boland P, Lis E, Raizer J, Healey J. Single-stage posterolateral transpedicle approach for spondylectomy, epidural decompression, and circumferential fusion of spinal metastases. Spine. 2000;25(17):2240–50.
2. Chandra SP, Ramdurg SR, Kurwale N, Chauhan AC, Ansari A, Garg A, Sarkar C, Sharma BS. Extended costotransversectomy to achieve circumferential fusion for pathologies causing thoracic instability. Spine J. 2014;14:2094–101.
3. Chou D, Wang V. Trap-Door Rib-Head osteotomies for posterior placement of expandable cages after transpedicular corpectomy: an alternative to lateral extracavitary and costotransversectomy approaches. J Neurosurg Spine. 2009;10:40–5.
4. Foreman P, Naftel R, Moore T, Hadley M. The lateral extracavitary approach to the thoracolumbar spine: a case series and systematic review. J Neurosurg Spine. 2016;24:570–9.
5. Hartmann S, Wipplinger C, Tschugg A, Kavakebi P, Orley A, Girod PP, Thome C. Thoracic corpectomy for neoplastic vertebral bodies using a navigated lateral extracavitary approach-A

single-center consecutive case series: techniques and analysis. Neurosurg Rev. 2017;41:575. https://doi.org/10.1007/s10143-017-0895-z.

6. Holland C, Bass D, Gary M, Howard B, Refai D. Thoracic lateral extracavitary corpectomy for anterior column reconstruction with expandable and static titanium cages: clinical outcomes and surgical considerations in a consecutive case series. Clin Neuro Neurosurg. 2015;129:37–43.
7. Lau D, Chou D. Posterior Thoracic Corpectomy with Cage Reconstruction for Metastatic Spinal Tumors: Comparing the Mini-Open Approach to the Open Approach. J Neurosurg Spine. 2015;23:217–27.
8. Lu D, Lau D, Lee J, Chou D. The transpedicular approach compared with the anterior approach: an analysis of 80 thoracolumbar corpectomies. J Neurosurg Spine. 2010;12:583–91.
9. Park M, Deukmedjian A, Uribe J. Minimally invasive anterolateral corpectomy for spinal tumors. Neurosurg Clin N Am. 2014;25:317–25.
10. Schuschert M, McCormick K, Abbas G, Pennathur A, Landreneau J, Landreneau J, Pitanga A, Gomes J, Franca F, El-Kadi M, Peitzman A, Ferson P, Luketich J, Landreneau R. Anterior thoracic surgical approaches in the treatment of spinal infections and neoplasms. Ann Thorac Surg. 2014;97:1750–7.
11. Yen CP, Uribe J. Mini-open lateral retropleural approach for symptomatic thoracic disc herniation. Clin Spine Surg. 2017;00:00.
12. Adkins D, Sandhu F, Voyadzis JM. Minimally invasive lateral approach to the thoracolumbar junction for corpectomy. J Clin Neurosci. 2013;20:1289–94.
13. Ahmadian A, Uribe J. Mini-open lateral retropleural thoracic corpectomy for osteomyelitis. Neurosurg Focus. 2013;35:17.
14. Moran C, Ali Z, McEvoy L, Bolger C. Mini-open retropleural transthoracic approach for the treatment of giant thoracic disc herniation. Spine. 2012;37(17):1079–84.
15. Shawky A, Al-Sabrout AAR, El-Meshtawy M, Hasan K, Boehm H. Thoracoscopically assisted corpectomy and percutaneous transpedicular instrumentation in management of burst thoracic and thoracolumbar fractures. Eur Spine J. 2013;22:2211–8.
16. Sasanui M, Ozer AF. Single-stage posterior corpectomy and expandable cage placement for treatment of thoracic or lumbar burst fractures. Spine. 2008;34(1):33–40.
17. Hofstetter C, Chou D, Newman B, Aryan H, Girardi F, Hartl R. Posterior approach for thoracolumbar corpectomies with expandable cage placement and circumferential arthrodesis: a multicenter case series of 67 patients. J Neurosurg Spine. 2011;14:388–97.
18. Fang T, Dong J, Zhou X, McGuire R, Li X. Comparison of mini-open anterior corpectomy and posterior total en-bloc spondylectomy for solitary metastases of the thoracolumbar spine. J Neurosurg Spine. 2012;17:271–9.
19. Lubelski D, Abdullah K, Mroz T, Shin J, Alvin M, Benzel E, Steinmetz M. Lateral extracavitary vs. costotransversectomy approaches to the thoracic spine: reflections on lessons learned. Neurosurgery. 2012;71:1096–102.
20. Lau D, Song Y, Guan Z, Sullivan S, La Marca F, Park P. Perioperative characteristics, complications, and outcomes of single-level versus multilevel thoracic corpectomies via modified costotransversectomy approach. Spine. 2013;38:523–30.
21. Lubelski D, Abdullah K, Steinmetz M, Masters F, Benzel E, Mroz T, Shin J. Lateral extracavitary, costotransversectomy, and transthoracic thoracotomy approaches to the thoracic spine: review of techniques and complications. J Spinal Disord Tech. 2013;26:222–32.
22. Gokaslan Z, York J, Walsh G, McCutcheon I, Lang F, Putnam J, Wildrick D, Swisher S, Abi-Said D, Sawaya R. Transthoracic vertebrectomy for metastatic spinal tumors. J Neurosurg Spine. 1998;89:599–609.
23. Pointillart V, Aurouer N, Gangnet N, Vital JM. Anterior Approach to the Cervicothoracic Junction Without Sternotomy: A Report of 37 Cases. Spine. 2007;32(25):2875–9.
24. Kalra R, Schmidt M. Thoracoscopic Corpectomy and Reconstruction. In: Benzel's Spine Surgery. 4th ed; 2016. p. 646–54.

25. Nacar OA, Ulu MO, Pekmezci M, Deviren V. Surgical Treatment of Thoracic Disc Disease Via Minimally Invasive Lateral Transthoracic Trans/Retropleural Approach: Analysis of 33 Patients. Neurosurg Rev. 2013;36:455–65.
26. Petteys R, Sandhu F. Minimally invasive lateral retroperitoneal corpectomy for treatment of focal thoracolumbar kyphotic deformity: case report and review of the literature. J Neurol Surg. 2014;75:305–9.
27. Lau D, Song Y, Guan Z, La Marca F, Park P. Radiologic outcomes of static vs expandable titanium cages after corpectomy: a retrospective cohort analysis of subsidence. Neurosurgery. 2012;72:529–39.
28. Archavlis E, Papadopoulos N, Ulrich P. Corpectomy in destructive thoracolumbar spine disease: cost-effectiveness of three different techniques and implications for cost reduction of delivered care. Spine. 2015;40(7):433–8.
29. Han S, Lau D, Lu D, Theodore P, Chou D. Anterior thoracolumbar corpectomies: approach morbidity with and without an access surgeon. Neurosurgery. 2010;68:1220–6.
30. Jandial R, Kelly B, Chen MY. Posterior-Only Approach for Lumbar Vertebral Column Resection and Expandable Cage Reconstruction for Spinal Metastases. J Neurosurg Spine. 2013;19:27–33.
31. Krisht K, Mumert M, Schmidt M. Management considerations and strategies to avoid complications associated with the thoracoscopic approach for corpectomy. J Neurosurg Spine. 2011;31(4):14.
32. Kim JH, Rhee J, Enyo Y, Hutton W, Kim SS. A Biomechanical Comparison of 360 Degree Stabilizations for Corpectomy and Total Spondylectomy: A Cadaveric Study in the Thoracolumbar Spine. J Ortho Surg Res. 2015;10:99. https://doi.org/10.1186/s13018-015-0240-6.
33. Shen F, Marks I, Shaffrey C, Ouellet J, Arlet V. The use of an expandable cage for corpectomy reconstruction of vertebral body tumors through a posterior extracavitary approach: a multicenter consecutive case series of prospectively followed patients. Spine J. 2008;8:329–39.
34. Smith Z, Li Z, Chen NF, Raphael D, Khoo L. Minimally invasive lateral extracavitary corpectomy: cadaveric evaluation model and report of three clinical cases. J Neurosurg Spine. 2012;16:463–70.
35. Viljoen S, Watson NAD, Grosland N, Torner J, Dalm B, Hitchon P. Biomechanical analysis of anterior versus posterior instrumentation following a thoracolumbar corpectomy. J Neurosurg Spine. 2014;21:577–81.

Chapter 13
Thoracic Discectomy

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Introduction

Disc herniation is a fairly common condition with a frequency of 40 to 50 per 100,000 people. Conversely, symptomatic thoracic disc herniation (TDH) is significantly less common. Modern imaging developments in computed tomography (CT) and magnetic resonance imaging (MRI) have revealed an incidence of asymptomatic TDH to be estimated at 11% to 37% [1]. Nevertheless, symptomatic TDH continues to be rare, with an incidence of 1 to 1,000,000 in the general population [2]. TDH accounts for 0.25% to 0.75% of all protruded discs [3]. It is most commonly seen in mid to late adult life, with the peak of 80% occurring between 40 and 50 years of age [4]. There is no significant difference in gender [5].

Surgical procedures for symptomatic TDH represent only 0.15% to 4% of all surgeries for intervertebral disc herniation [6]. TDH has been reported at every level. However, in 75% of cases, the TDH is below the T7–T8 disc due to this being the more mobile portion of the thoracic spine and due to weakness of the posterior longitudinal ligament (PLL) at this level [4]. Only 4% of TDHs are located above T3–T4. The T11–T12 disc is the most vulnerable to TDH, with a peak of 26% occurring at this level [7]. Centrolateral disc herniations are most common, making up 94% of cases, while 6% of cases are lateral [7]. A history of trauma may be elicited in 11–25% of cases [8].

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_13

Presentation

The diagnosis of symptomatic TDH can often be missed due to mismatch between the symptoms and location of the herniation [9]. Up to 90% of patients may describe insidious onset of symptoms [8]. The most common presenting symptoms for TDH include pain, sensory disturbances, myelopathy, and lower extremity weakness [8]. Pain is present in 57% of the cases at presentation [10]. The classic character of thoracic radicular pain from a TDH is a stabbing pain that begins posteriorly and radiates unilaterally or bilaterally around the chest wall in a dermatomal distribution [11]. Radicular pain may often occur in association with a concurrent myelopathy; it may also occur in isolation with no spinal cord injury. The pain usually occurs with no loss of motor or sensory function at the level of the spinal root because the innervation of adjacent intercostal nerves overlaps [11]. By the time of diagnosis, 90% of patients have signs of spinal cord compression [10]. An early and accurate diagnosis, coupled with improvements in surgical approaches, offers a much better prognosis for patients with TDH [10].

Non-operative Management

Isolated thoracic radicular pain will often respond to a regimen of restricted activity, a hyperextension brace, nonsteroidal anti-inflammatory agents, oral steroids, and/or epidural steroids [11]. Patients who fail a full course of non-operative management, which includes 3 to 6 months of therapy, may be considered for surgical treatment of the TDH [11].

Indications for Surgery

The strongest indication for surgery is injury to the spinal cord caused by compressive lesions. When myelopathy is present, the goals of surgery are to prevent further irreversible damage to the spinal cord and to improve function [11]. The more severe and the longer the patient has experienced the myelopathy at presentation, the less likely the patient is to recover neurological function [11].

Herniated thoracic discs requiring surgery are rare [7]. Indications for surgery include intractable pain, which usually presents in a radicular or band-like distribution. Progressive myelopathy and axial back pain are also indications for surgical treatment [4]. Less common symptoms of TDH include symptomatic syringomyelia originating at level of disc herniation. Over the past decades, the treatment of TDH has changed profoundly. There has been a considerable improvement in the surgical treatment of TDH, with an over 80% success rate for surgical approaches other than decompressive laminectomy [10].

Evaluation

MRI is the mainstay of diagnosis for TDH. As discs frequently become calcified, a CT is usually necessary in order to determine if the disc is soft or calcified. A calcified disc may affect the choice of surgical approach. The CT may also be useful in demonstrating bony detail to help determine if instrumentation will be required.

Surgical Considerations

Preoperative preparation is especially critical in cases of TDH. Efforts should be made to characterize whether the disc is hard or soft, or if it is eccentric to one side or central in location, as these data points will influence the surgical approach. The placement of fiducials with subsequent CT myelogram can assist the surgeon in correctly identifying the level of interest intraoperatively, thus avoiding wrong-level surgery. Once all preoperative studies have been obtained and reviewed, the surgeon can determine the best surgical corridor to safely decompress the neural elements.

The approaches to the thoracic spine can be arranged in a circumferential manner from a transpedicular approach to a transthoracic approach. We will discuss each approach in detail below.

Posterior Approaches

Transpedicular Approach

The transpedicular approach is the most commonly described procedure for thoracic discectomy. It involves the unilateral removal of the pedicle and facet, and it provides the most direct of the posterior approaches to the disc space. It allows access to the lateral aspect of the spinal canal. The advantages of this technique include the ability to preserve the radicular arteries, as well as lack of manipulation of spinal cord. Its major disadvantage is limited visualization of the spinal dura.

The patient is positioned prone on gel rolls or a Wilson frame. A midline vertical incision is made centered over the level of interest. Sharp dissection is performed through the thoracodorsal fascia with monopolar electrocautery until the spinous process is reached, followed by a unilateral subperiosteal dissection with a combination of electrocautery and Cobb elevators along the bony elements to expose the lateral aspect of the facet.

After the soft tissue exposure is completed, the pedicle of the inferior vertebral level is drilled. It is entered below the edge of the inferior facet of the superior vertebra. A laminotomy is performed prior to drilling the pedicle using a high-speed drill and Kerrison rongeurs to visualize the lateral aspect of the thecal sac and avoid injury to it. Once the exiting nerve root is visualized and protected, the pedicle is drilled to the depth of the vertebral body and disc space. One can further protect the nerve root by drilling the inferior portion of the pedicle first, using the superior and medial cortex of the pedicle to shield the nerve root, which are then removed with curettes and rongeurs.

Removal of the pedicle allows the surgeon to visualize the lateral disc space. The annulus is then incised, and the discectomy performed with pituitary ronguers and curets. After satisfactory decompression, hemostasis is achieved, and closure is done in standard layered, interrupted fashion.

Costotransversectomy Approach

The costotransversectomy entails a more lateral working corridor than the transpedicular approach and thus provides more access to the anterior spinal canal. It is a relatively more invasive approach that involves resection of medial aspect of rib and removal of transverse process.

The patient is positioned prone or partly lateral. The skin incision can be curvilinear toward midline or straight paramedian and centered over the level of interest extending two to three levels above and below. The muscle layers are elevated medially with a combination of sharp and blunt dissection to expose the ribs and transverse processes. The rib associated with the inferior vertebral body is identified and disarticulated from the transverse process and vertebral body and then removed with rongeurs. The associated transverse process is also removed.

After removal of the appropriate bony elements, the pleura is visualized and retracted anteriorly. The neurovascular bundle at that level, as well as the corresponding pedicle, is also identified prior to approaching the disc space of interest. The pedicle is partially drilled to maximize exposure of the disc herniation. The annulus is incised, and the discectomy is performed from a lateral to medial trajectory with curettes and pituitary ronguers. Prior to closure, the pleura must be inspected for tears, which can be visualized by irrigating during positive pressure ventilation. Any tears may be repaired, or a chest tube placed based on the surgeon's discretion. Closure is performed in usual fashion.

Lateral Extracavitary Approach

The lateral extracavitary approach provides the most lateral exposure and thus medial and ventral access of the posterior approaches to thoracic discectomies. It is limited, however, above the T5 level by the scapula. It also requires the largest incision and most signification dissection.

The patient is positioned prone or partly lateral, and the incision can be curvilinear toward midline or a hockey stick centered over the affected level. The dissection is similar to that of a costotransversectomy, but a more extensive resection of the inferior rib is necessary. This trajectory allows for more visualization of the anterior canal. A laminotomy may be performed for greater exposure. The exiting nerve root is identified and can either be spared or sacrificed and used to mobilize the thecal sac. The discectomy and closure are performed as previously described. This approach can also be used for more extensive vertebral body resections and interbody instrumentation.

Anterior Approaches

Lateral Retropleural Approach

The lateral retropleural approach is advantageous for patients with central disc herniations. It avoids the need of more extensive posterior surgical approaches, as there is no longer a need to work “around” the spinal cord. However, greater risk of injury to the lung and great vessels exists. In the lower thoracic spine, consideration must be given to the diaphragm and its attachments.

Surgical Technique

The lateral retropleural approach invokes a similar surgical strategy with the lateral transpsoas approach. After intubation and administration of general endotracheal anesthesia, the patients are placed in the lateral decubitus position, and secured to the operating table once carefully ensuring the proper padding of all pressure points. Neuromonitoring leads are placed to obtain somatosensory-evoked and motor-evoked potentials. Intraoperative fluoroscopy is then used to identify the level of interest. An incision is then planned over the disc space of interest (either above or between rib(s) for single level surgery). After careful dissection of the intercostal muscle layers, the parietal pleura is incurred. The parietal pleura is then carefully swept off of the rib cage using blunt digital dissection. With the aid of serial dilation, a lateral retractor is introduced into the retro pleural space, centered over the targeted disc space. Once fixed in place, the retractor is deployed, and exposure of the herniated disc can commence. In cases of large herniated fragments, it may be necessary to remove a portion of the rib head corresponding to the lower vertebral body (i.e., T_9 rib head in a T_8/T_9 disc herniation). Additional exposure can be gained by removal of a portion of the vertebral bodies and/or the corresponding pedicle in order to provide earlier identification of the posterior longitudinal ligament and dura prior to attempting to remove the disc fragment.

After adequate exposure is obtained and the dura is identified, central debulking of the intervertebral disc is performed. This creates a space into which the herniated component can be manipulated before it can be safely removed. All motion(s) should be away from the thecal sac to avoid injury to the underlying spinal cord. This can be carried out by the use of straight and down-going curettes.

Once adequate removal of disc is completed, it can be determined whether or not fusion is required. In the lateral approach, this can range from anterolateral plating to interbody fusion based on the level or pathology and degree of instability.

Prior to removal of the lateral retractor and closure, it is necessary to ensure that there has not been any violation of the parietal pleura. In the event of an injury to the pleura, one should be prepared to place a chest tube to treat the pneumothorax.

Transthoracic Approach

This approach is similar to the lateral retropleural approach in that it allows access to central disc herniations without having to work around or manipulate the thecal sac. However, this approach typically requires the assistance of an approach surgeon to retract the lung in order to gain access to the thoracic spine.

Surgical Technique

The patient is intubated using a double lumen endotracheal tube and placed in the lateral decubitus position. All pressure points are padded, and intraoperative fluoroscopy is used to identify the level of interest. Neuromonitoring leads are placed to obtain somatosensory-evoked and motor-evoked potentials. Exposure is achieved by a thoracic surgeon. Any rib taken during the approach may be saved and morselized into autograft if fusion is planned.

Once access to the spine is obtained, the discectomy is carried out in similar fashion to that described above. Bony work is completed first to provide adequate exposure of extruded fragment. This includes removal of the proximal pedicle and posterior portions of the adjacent vertebral bodies. Central debulking is then carried out to make room for manipulation of the extruded fragment. The PLL and dura are then identified to establish a plane lateral to the herniated disc fragment. Using curettes (straight and down-going) and Kerrison rongeurs, the disc fragment is then carefully removed, paying special attention to avoid any motion in the direction of the thecal sac, which could injure the underlying spinal cord. Upon completion of the decompression, the decision can be made to augment stabilization with a lateral plate, place an interbody graft, or rely on the integrity of the rib cage.

Closure is performed by the approach team. A chest tube is left in place to treat the iatrogenic pneumothorax. Serial plain films of the chest are obtained to confirm resolution of the pneumothorax.

Complications

TDHs have a particular progression, primarily concerning for risk of medullary compression. Surgery for TDH historically has had a poor reputation due to technical difficulty and risk of potentially serious and hard-to-treat complications [1]. Thoracic discectomy has a complication rate of 15% to 30% [6]. A meta-analysis of 545 patients who underwent surgical treatment for TDH found a 24% complication rate, which included 6% lung complications and 6% intercostal neuralgia [11]. Another analysis of 13,387 patients that underwent surgical treatment for TDH with myelopathy reported the rate of developing a complication post-operatively was 14.5% [12]. In one study, the overall complication rate for the thoracoscopic approaches was 15% versus 23% early in their practice, suggesting there is a required learning curve associated with TDH surgical procedures [8].

Other concerning complications in TDH surgery include cerebrospinal fluid (CSF) leak, spinal cord injury, and misidentification of surgical level.

The incidence of CSF leakage has been reported to range from 0% to 15% [13]. There are two courses of a CSF leak during thoracic disc surgery: iatrogenic or intradural disc herniation [13]. Intradural TDHs have been reported in up to 12% of cases, most of which involved discs that were densely calcified [14]. One study found that 7% of TDH had intradural extension at the time of surgery [15]. Management of CSF leaks typically involves a combination of primary or graft closure, fibrin glue application, and lumbar drain placement [13].

A high rate of neurological deterioration from spinal cord injury was observed in surgical treatment of TDH when thoracic laminectomy was the procedure performed [13]. It has been proposed that spinal cord manipulation required for removal of the disc ventral to the spinal cord may induce mechanical injury [13]. This manipulation may also interfere with blood supply to the spinal cord [13]. Tethering of the spinal cord, caused by minor kyphotic deformities resulting from the laminectomy, over incompletely removed disc or osteophyte can lead to neurologic deficit [16]. However, paresis and paralysis as operative complications have become relatively rare since laminectomy has become essentially abandoned [13].

Accurate intraoperative localization of thoracic vertebral levels remains a concern in thoracic spine surgery [17]. A 2008 survey reported that 50% of spine surgeons reported a wrong level surgery during their career [18]. Overlying scapular shadows, variation in the number of rib-bearing vertebrae, and osteopenia are all factors that complicate accurate intraoperative localization of specific thoracic vertebral levels [17]. Counting spinal levels and ribs on pre- and perioperative imaging, as well as identifying osteophytes and landmarks, can help avoid such complications [13]. In addition, preoperative placement of radiopaque markers using fluoroscopy or CT at the pedicle of interest may aid in avoiding this complication [19].

In a comparison of anterior/anterolateral decompression and spinal fusion (ASF), posterior/posterolateral decompression and spinal fusion (PSF), and disc decompression/excision without fusion (DDE), ASF had the highest complication rate at 24.2%, followed by PSF at 15.5% and DDE at 10.4% [12]. Patients undergoing ASF had 1.1% mortality, while DDF had 0.39% mortality and PSF 0.56% mortality [12]. Over the period of this analysis, the preferred treatment shifted substantially from DDE (performed in 30% of the patients in 2000) to PSF (performed in almost 50% of all patients by 2010) [12].

References

1. Court C, Mansour E, Bouthors C. Thoracic disc herniation: surgical treatment. Orthop Traumatol Surg Res. 2018 Feb;104(1S):S31–40.
2. Simpson JM, Silveri CP, Simeone FA, Balderston RA, An HS. Thoracic disc herniation. Spine (Phila Pa 1976). 1993;18(13):1872–7.
3. El-Kalliny M, Tew JM, van Loveren H, Dunsker S. Surgical approaches to thoracic disk herniations. Acta Neurochir. 1991;111:22–32.
4. Yoshihara H. Surgical treatment for thoracic disc herniation: an update. Spine (Phila Pa 1976). 2014;39(6):E406–12.
5. Uribe JS, Smith WD, Pimenta L, Härtl R, Dakwar E, Modhia UM, Pollock GA, Nagineni V, Smith R, Christian G, Oliveira L, Marchi L, Deviren V. Minimally invasive lateral approach for symptomatic thoracic disc herniation: initial multicentral clinical experience. J Neurosurg Spine. 2012;16:264–79.
6. Yoshihara H, Yoneoka D. Comparison of in-hospital morbidity and mortality rates between anterior and nonanterior approach procedures for thoracic disc herniation. Spine (Phila Pa 1976). 2014;39(12):E728–33.
7. Stillerman CB, Chen TC, Couldwell WT, Zhang W, Weiss MH. Experience in the surgical management of 82 symptomatic herniated thoracic discs and review of the literature. J Neurosurg. 1998;88:623–33.
8. Quint U, Bordon G, Preissl I, Sanner C, Rosenthal D. Thoracoscopic treatment for single level symptomatic thoracic disc herniation: a prospective followed cohort study in a group of 167 consecutive cases. Eur Spine J. 2012 Apr;21(4):637–45.
9. Shirzadi A, Drazin D, Jeswani S, Lovely L, Liu J. Atypical presentation of thoracic disc herniation: case series and review of the literature. Case Rep Orthop. 2013;2013:621476.
10. Arce CA, Dohrmann GJ. Herniated thoracic disks. Neurol Clin. 1985;3(2):383–92.
11. Elhadi AM, Zehri AH, Zaidi HA, Almefty KK, Preul MC, Theodore N, Dickman C. Surgical efficacy of minimally invasive thoracic discectomy. J Clin Neurosci. 2015;22:1708–13.
12. Jain A, Menga EN, Hassanzadeh H, Jain P, Lemma MA, Mesfin A. Thoracic disc disorders with myelopathy: treatment trends, patient characteristics, and complications. Spine (Phila Pa 1976). 2014;39(20):E1233–8.
13. McCormick WE, Will SF, Benzel EC. Surgery for thoracic disc disease. Complication avoidance: overview and management. Neurosurg Focus. 2000;9(4):e13.
14. Dietze DD Jr, Fessler RG. Thoracic disc herniations. Neurosurg Clin North Am. 1993;4:75–90.
15. Stillerman CB, Chen TC, Couldwell WT, et al. Experience in the surgical management of 82 symptomatic herniated thoracic discs and review of the literature. J Neurosurg. 1998;88:623–33.
16. Maiman DJ, Larson SJ, Luck E, et al. Lateral extracavitary approach to the spine for thoracic disc herniation: report of 23 cases. Neurosurgery. 1984;14:178–82.
17. Willson MC, Ross JS. Postoperative spine complications. Neuroimaging Clin N Am. 2014;24(2):305–26.
18. Mody MG, Nourbakhsh A, Stahl DL, et al. The prevalence of wrong level surgery among spine surgeons. Spine. 2008;33:194–8.
19. Upadhyaya CD, Wu JC, Chin CT, et al. Avoidance of wrong-level thoracic spine surgery: intraoperative localization with preoperative percutaneous fiducial screw placement. J Neurosurg Spine. 2012;16:280–4.

Chapter 14

Lumbar Microdiscectomy

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Introduction

Low back pain (LBP) is one of the most common conditions, affecting up to 70% of the population [1]. A large portion of patients with LBP have sciatica correlating to a lumbar herniated disc [1, 2]. Lumbar microdiscectomy is offered to those who fail non-operative measures or have a progressive neurologic deficit or cauda equina syndrome. Conventional open microdiscectomy and minimally invasive (MIS) tubular microdiscectomy are the most common techniques employed to treat this condition.

Pathophysiology

The intervertebral lumbar disc is composed of (1) the nucleus pulposus (a centrally located gelatinous structure rich in proteoglycans), (2) the annulus fibrosus (concentric layers of collagen surrounding the nucleus and restricting its egress especially during axial loading) [3, 4], and (3) the cartilaginous end plates that abut the vertebral bodies. The adult disc is largely avascular and relies on passive diffusion for the uptake of necessary nutrients [3].

Age-related dehydration of the nucleus and subsequent weakening of the annulus fibrosus due to cumulative biomechanical axial load may lead to a defect in the annulus resulting in disc extrusion [4, 5]. The posterolateral herniation occurs more frequently because the posterior longitudinal ligament (PLL) is thickest at the midline and becomes thinner laterally. While the pathophysiology of radiculopathy is poorly understood, it is generally accepted to be compressive in nature [3, 6, 7].

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_14

Clinical Presentation

Symptoms

Radicular symptoms correlate with the level and laterality of lumbar disc herniations. Central, paracentral, and posterolateral disc herniations cause mass effect and irritation on the traversing nerve root. Foraminal and extraforaminal disc herniations compress the exiting nerve root and are considered to be more painful if compression on the dorsal root ganglion exists.

Patients often present after an acute onset of lower extremity radiculopathy and less commonly have a temporal correlation to an inciting event. Pain, paresthesia, and/or numbness often occurs in the respective nerve root dermatomes with or without correlative myotomal deficits.

Physical Examination

A complete neurological exam should be performed paying particular attention to lower extremity individual motor group testing, dermatomal sensory changes, nerve root tension signs, and reflexes.

Imaging

Magnetic resonance imaging (MRI) is the diagnostic imaging study of choice for herniated discs. For patients who cannot obtain an MRI, non-contrasted computed tomography (CT) can be obtained. CT imaging can be the first-line imaging for those with the inability to lay supine, claustrophobia, or implanted metallic hardware. However, a CT myelogram study is typically necessary for those unable to undergo MRI.

Treatment

Non-operative Management

Initial management of lumbar disc herniation typically entails a spectrum of medications and non-surgical interventions. Radiculopathy of short duration is frequently managed initially by NSAIDs, muscle relaxants, short course corticosteroids, and if necessary, opioids. Activity modification is typically required. Mechanical interventions including physical therapy, core stabilization, and other exercises may be beneficial if pain levels are not too high [3, 6, 7]. For persistent pain, epidural steroid injections can be offered. Interventions such as chiropractic manipulations, acupuncture, and trigger point injections have also been used with variable success [8]. Non-operative treatment strategies are aimed at reducing disability and pain and returning patients to activities of daily living since the majority of lumbar disc herniation cases will resolve without surgery.

Surgical Indications

Most data support a trial of non-operative management for at least 4 weeks, if not longer [3, 6, 7]. While early surgery may lead to earlier resolution of symptoms, long-term outcomes have been shown to be similar in both surgical and non-surgical groups [6, 7]. Persistent and/or worsening pain is the primary non-urgent indication for surgical intervention, and some patients undergo early decompression as they are unable to tolerate the severity of pain. More urgent surgical intervention is indicated in those with cauda equina syndrome or acute and disabling motor weakness [7].

Surgical Techniques

Positioning

Most commonly patients are positioned prone using gel rolls or the Wilson frame on a radiolucent table. The patient’s arms are externally rotated and abducted to less than or equal to 90 degrees at the shoulder, raised above the head, and padded at the pressure points to avoid a brachial plexus injury. The head rests on foam padding, making sure the eyes are free of compression. Other positioning techniques including knee-chest and lateral decubitus are available but much less commonly used.

Central and Posterolateral Disc Herniation

Following standard, sterile skin preparation and draping, a conventional open microdiscectomy begins by localizing the correct level on fluoroscopy, and a midline skin incision is made. Monopolar cautery is used to dissect the subcutaneous tissue and fascia and perform a subperiosteal dissection along the spinous process to expose the facet capsule laterally, the laminar edge inferiorly, and the lamina and pars interarticularis superiorly.

Alternatively, MIS tubular approach may be performed. The entry site is planned as previously described, but the incision is made approximately 1.5 cm off midline to the affected side. A guide wire is used to pierce the fascia and, using fluoroscopy, is docked on the laminofacet junction. Sequential tubular dilation is then used with intermittent fluoroscopy to dock the tube at the level of the index disc space. For MIS microdiscectomy, we prefer to use tubes 18 mm in diameter. A microscope is then brought in for visualization.

For conventional open as well as MIS discectomies, a laminotomy is performed using a high-speed drill. The lamintomy begins inferiorly and medially and is carried superiorly to the insertion of the ligametum flavum and laterally to the medial facet. A medial facetectomy is often necessary for visualization taking care to maintain 50% of the facet if possible. The ligamentum flavum is dissected away from and resected using a combination of curettes and Kerrison rongeurs. The dura and traversing nerve root are identified and retracted medially. The disc is localized, its capsule incised and the herniation removed using a combination of rongeurs, nerve hooks and ball-tipped probes.

Decompression of the neural structures is confirmed with angled dissectors. Hemostasis is achieved and the retractor is removed slowly, obtaining hemostasis through the various soft tissue layers. The fascia and subcutaneous layer are closed with absorbable suture and the skin sealed with topical adhesive.

Foraminal/Extraforaminal Disc Herniations

True foraminal disc herniations can be approached by a “cross-canal” technique that involves either a full laminectomy or a unilateral approach (from the contralateral side) for bilateral decompression. The former can be performed open, the latter, MIS. Either will allow observation of the foramen from the contralateral side, and the disc herniation can be removed easily. True extraforaminal disc herniations often require the far lateral approach. The target for a tubular or open conventional dissection is the lateral facet-transverse process junction. The inferolateral facet and pars interarticularis are identified and the intertransverse membrane dissected off the bone. The pedicle of the level below is palpated and the disc herniation encountered in Kambin’s triangle. The inferolateral facet can be shaved back if necessary to visualize the exiting nerve root. The disc fragment is removed and the nerve root inspected to ensure adequate decompression.

Postoperative Care and Pain Management

Most patients can be discharged on the day of surgery. Postoperative care focuses on pain management and a rapid return to activity and daily routines [9]. Early ambulation and other low-impact activities are strongly recommended. Multimodal pharmacologic management of postoperative pain can reduce the overall need for opioids that can lead to urinary retention, ileus, cognitive changes, and medication dependence.

Complications

Incidental durotomy is the most common complication during lumbar discectomy, ranging from 0.5% to 18% with risk factors including recurrent disc herniation or concomitant pathology (stenosis, spondylolisthesis, juxtafacet cysts) [10, 11]. Postoperative vision loss occurs at an exceedingly low rate with an incidence of 0.017–0.92% in non-cardiac patients undergoing spine surgery [12, 13]. Risk factors include male sex, obesity, longer anesthesia time, use of a Wilson frame, larger estimated blood loss, hypotension, and direct ocular compression [12]. Great vessel injury occurs with a range of 0.1–0.17% [14]. Postoperative wound infection occurs in less than 1% of patients [15].

Outcomes

The natural history of lumbar disc herniation is generally favorable. Weinstein et al. published the largest randomized control trial (SPORT trial) comparing surgery to conservative management. An intention to treat (ITT) analysis found no significant difference between groups. However, high rates of crossover patients confounded the ITT analysis, such that an as-treated analysis revealed a superiority of surgery over non-operative care [7]. The most common postoperative complication after lumbar discectomy is reherniation, with estimates ranging from 5% to 15% [16].

Conclusions

Lumbar disc herniation is one of the most frequently encountered entities in spinal surgical practice. Surgical treatment of patients who have failed an initial trial of non-operative care results in excellent results and is superior to non-operative care. Both open and MIS surgical techniques produce similar long-term outcomes, and surgeons should be familiar with both approaches.

References

1. Konstantinou K, Dunn KM. Sciatica: review of epidemiological studies and prevalence estimates. Spine. 33:2464.
2. Koes BW, van Tulder MW, Ostelo R, Kim Burton A, Waddell G. Clinical guidelines for the management of low back pain in primary care: an international comparison. Spine. 26:2504–13; discussion 2513-2514, 2001.

3. Raj PP. Intervertebral disc: anatomy-physiology-pathophysiology-treatment. Pain Pract. 2008;8(1):18–44.
4. Roberts S, Evans H, Trivedi J, Menage J. Histology and pathology of the human intervertebral disc. J Bone Joint Surg Am. 2006;88(Suppl 2):10–4.
5. Buckwalter JA. Aging and degeneration of the human intervertebral disc. Spine. 1995;20(11):1307–14.
6. Saal JA. Natural history and nonoperative treatment of lumbar disc herniation. Spine. 1996;21(24 Suppl):2S–9S.
7. Weinstein JN, Lurie JD, Tosteson TD, et al. Surgical versus nonoperative treatment for lumbar disc herniation: four-year results for the spine patient outcomes research trial (SPORT). Spine. 2008;33(25):2789–800.
8. Cohen SP, Argoff CE, Carragee EJ. Management of low back pain. BMJ. 2008;337:a2718.
9. Buvanendran A, Thillainathan V. Preoperative and postoperative anesthetic and analgesic techniques for minimally invasive surgery of the spine. Spine. 2010;35(26 Suppl):S274–80.
10. Albayrak S, Ozturk S, Ayden O, Ucler N. Dural tear: a feared complication of lumbar discectomy. Turk Neurosurg. 26:918.
11. Takahashi Y, Sato T, Hyodo H, Kawamata T, Takahashi E, Miyatake N, et al. Incidental durotomy during lumbar spine surgery: risk factors and anatomic locations: clinical article. J Neurosurg Spine. 18:165.
12. Gabel BC, Lam A, Chapman JR, Oskouian RJ, Nassr A, Currier BL, et al. Perioperative vision loss in cervical spinal surgery. Glob Spine J. 7:91S.
13. Lee LA. Perioperative visual loss and anesthetic management. Curr Opin Anaesthesiol. 26:375. Opin Anae.
14. Altun G, Hemsinli D, Kutanis D, Gazioglu G. Silent killer: a scalpel in the aortic wall after spinal surgery. Neurol Neurochir Pol. 50:294.
15. Shousha M, Cirovic D, Boehm H. Infection rate after minimally invasive noninstrumented spinal surgery based on 4350 procedures. Spine. 40:201.
16. Swartz KR, Trost GR. Recurrent lumbar disc herniation. Neurosurg Focus. 2003;15(3):E10.

Chapter 15

Approaching Far Lateral Disc Herniations: The MIS Perspective

Kyle Mueller and Amjad Anaizi

Introduction

Lumbar disc disease is a common condition that is treated by spine surgeons. The degenerative process can result in disc herniations causing severe pain and disability. Disc herniations can be central, paracentral, or far lateral depending on which compartment the herniation occurs. Far lateral disc herniations (FLDHs) occur in about 1–12% of all symptomatic lumbar disc herniation syndromes [1–3]. Various conservative and surgical management strategies exist for treatment [4–8]. Minimally invasive surgical techniques have become more prevalent over the last decade. Using these techniques often leads to shorter hospital stays, reduced blood loss, and reduced narcotic usage [9]. This chapter aims to review FLDH with an emphasis on the minimally invasive surgical approach to treatment.

Presentation/Work-Up

Patients with FLDH can present with pain and motor or sensory disturbances depending on which nerve root is being compressed. Pain is often a more significant component of the presentation owing to compression of the dorsal root ganglion (DRG) [10, 11]. As compared with herniated discs in other compartments, FLDHs compress the exiting nerve root. Physical exam may be significant for pain with lateral bending and the absence of pain with straight leg raise; however, no maneuver is very sensitive or specific. The diagnosis often is made radiographically with clinical correlation.

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_15

The imaging work-up entails a non-contrast lumbar magnetic resonance image (MRI) as well as full set of lumbar x-rays that include dynamic views. MRI is the imaging modality of choice that shows the soft tissue structures including the neural elements the best. X-rays are used to assess alignment and to make sure there is no underlying instability present.

Treatment

There are a variety of treatment options that are available to patients with FLDHs [12–19]. Similar to treatments for other lumbar disc diseases, there are conservative and surgical options. Conservative treatment typically involves some combination of physical therapy, steroid injections, or pain medication. Consultation with a pain management specialist can assist in optimizing these therapies. Surgery is usually considered after failure of conservative pain management strategies or if there is progressive neurological deficit.

Surgical Technique: Minimally Invasive Far Lateral Discectomy

A minimally invasive tubular technique is the preferred approach to far lateral disc herniations. The patient is induced under general anesthesia and placed in the prone position on a Jackson table with a Wilson frame. All pressure points are padded. The midline is marked and AP and lateral radiographs are obtained. AP radiographs must show the pedicles clearly with the spinous process in the midline. The endplate borders should be crisp and without parallax. Failing to obtain quality images prior to starting the procedure can lead to a poorly positioned incision and suboptimal trajectory raising the likelihood of complications. Patients undergo a unilateral approach using a tubular retractor system. A 2 cm incision is made approximately 4 cm lateral to the midline on the ipsilateral side of pathology centered over the disc space of interest. This will allow medial angulation of the tubular retractor. A Steinman pin or initial dilator is docked on the junction of the transverse process (TP) and the facet joint of the level of interest under fluoroscopic guidance. A series of progressively larger muscle splitting dilators are then inserted with a twisting motion to create the surgical corridor. A 20 mm working channel is fixed to the table-mounted flexible arm and directed to the disease disc space. Prior to locking the flexible arm, fluoroscopic imaging is used to confirm location and trajectory (Fig. 15.1). The remainder of the procedure is performed with a microscope. The TP and lateral aspect of the pars interarticularis are carefully defined by removing the overlying soft tissue with a straight curette and bovie electrocautery. Brisk arterial bleeding can sometimes be encountered from the spinal or dorsal branch of the lumbar segmental artery. This can often be cauterized with bipolar forceps without

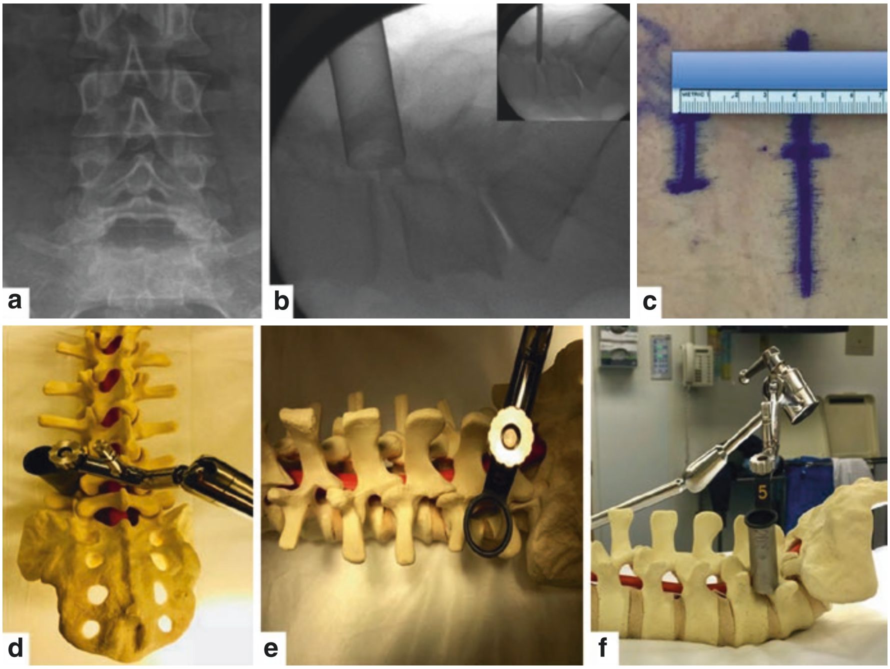

Fig. 15.1 (**a**) AP view that shows crisp endplate borders and symmetric pedicles with the spinous process midline. Establishing good imaging prior to proceeding with the procedure is key. (**b**) Lateral view that shows the final docking position of the retractor. The insert shows the dilator prior to placing the tubular retractor. It is important to be parallel with the disc space. (**c**) The incision is usually 3.5–4 cm off of midline and spans 2 cm. (**d**–**f**) Anatomical models with the retractor in various views that demonstrate how the tubular retractor should be positioned in relation to the TP and disc space

difficulty. The intertransverse ligament is identified and divided often using a kerrison rongeur. Great care is taken to expose and protect the exiting nerve root and ganglion. It is crucial to limit manipulation of the DRG to prevent postoperative dysthetic pain. The herniated disc is then identified and a discectomy is performed in a routine manner (Fig. 15.2). The sacral ala often can obstruct the path to a far lateral L5-S1 disc herniation. This can be addressed by removal of the sacral ala using a high-speed drill. The remainder of the procedure is similar as other levels. Hemostasis is then achieved in standard fashion. Epidural steroids can be used to reduce the likelihood of any potential dysthetic pain. The incision is then closed in a multilayer fashion.

A list of the key steps is listed below.

Summary of Key Steps:

1. Position the patient.
2. AP and lateral radiographs.
3. Docking on the TP/facet junction of the level of interest.

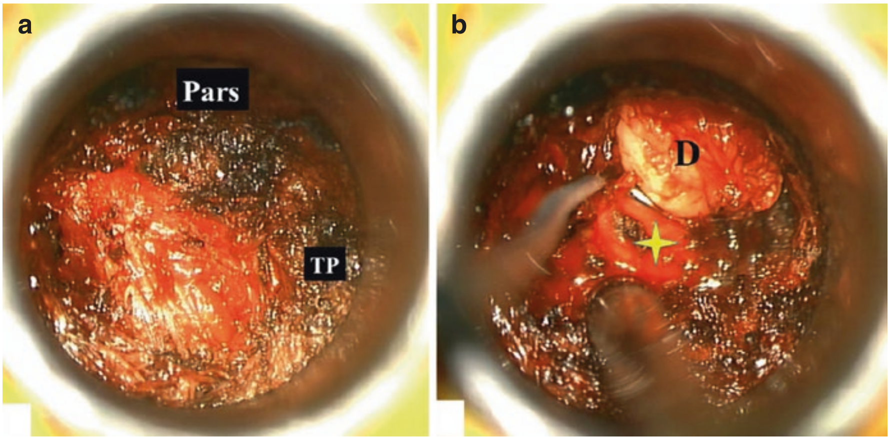

Fig. 15.2 (**a**, **b**) Intraoperative pictures of a left side approach to a L4–L5 FLD. The TP and pars are defined. Further dissection reveals the intertransverse ligament as noted by the yellow star. The herniated disc is seen medial in which it was found to be compressing the nerve root and the result of the patient's left L4 radiculopathy

4. Define the TP and lateral pars border.
5. Identify and divide the intertransverse ligament.
6. Identify nerve root and DRG. Minimized DRG manipulation.
7. Herniated disc identified and removed in usual fashion.

MIS Versus Open

Traditional open approaches to FLDH involve a larger midline incision with significant muscle dissection and retraction. This can lead to significant postoperative muscle spasm and muscle atrophy. Additionally, in order to access the lateral compartment where the herniated disc is located, there must be bony removal. In some cases the entire facet joint is removed. This can lead to instability potentially necessitating a fusion operation. Minimally invasive surgical techniques result in less blood loss, less muscle dissection, better preservation of the facet joint and shorter hospital stays than do traditional open techniques [4, 16, 20–25]. Over the last decade minimally invasive techniques have become more common in training programs, which has improved the learning curve associated with minimally invasive spine surgery.

Postoperative Care

After the surgery patients are extubated and taken to the recovery room. No postoperative imaging is needed. Often, patients are able to go home the same day or, if needed, the following day. Perioperative use of narcotics for incisional pain and a muscle relaxant for muscle spasm are utilized. These medications are often needed for only a short time period after surgery, and often are not needed by the first postoperative visit. Pain improvement is typically what patients notice first, followed by improvement in strength and lastly numbness. Patients are discharged on activity restrictions that encompass no bending, lifting, or twisting (BLTs) for a total of 6 weeks. After this time we discuss possible physical therapy. Depending on the nature of the patient's occupation, return to work time can be as early as 1–2 weeks after surgery.

Conclusions

FLDHs are an uncommon presentation of lumbar herniation syndromes. A variety of conservative and surgical treatment strategies are available. For patients who fail conservative management or present with neurological deficit, minimally invasive techniques are an excellent surgical option.

Pearls of the Practice

- Ensure AP and lateral x-rays have the anatomy well defined before proceeding with the operation.
- Define the TP and lateral pars border.
- Limit manipulation of the DRG.

References

1. Abdullah AF, Ditto EW III, Byrd EB, Williams R. Extreme lateral lumbar disc herniations: clinical syndrome and special problems of diagnosis. J Neurosurg. 1974;41:229.
2. Abdullah AF, Wolber PG, Warfield JR, Gunadi IK. Surgical management of extreme lateral lumbar disc herniations: review of 138 cases. Neurosurgery. 1988;22:648.
3. Donaldson WF III, Star MJ, Thorne RP. Surgical treatment for the far lateral herniated lumbar disc. Spine (Phila Pa 1976). 1993;18:1263.
4. Epstein NE. Evaluation of varied surgical approaches used in the management of 170 far-lateral lumbar disc herniations: indications and results. J Neurosurg. 1995;83:648.
5. Garrido E, Connaughton PN. Unilateral facetectomy approach for lateral lumbar disc herniation. J Neurosurg. 1991;74:754.
6. Hazlett JW, Kinnard P. Lumbar apophyseal process excision and spinal instability. Spine (Phila Pa 1976). 1982;7:171.
7. Hood RS. Far lateral lumbar disc herniations. Neurosurg Clin North Am. 1993;4:117.
8. Jane JA, Haworth CS, Broaddus WC, et al. A neurosurgical approach to far-lateral disc herniation: technical note. J Neurosurg. 1990;72:143.
9. Lejeune JP, Hladky JP, Cotten A, et al. Foraminal lumbar disc herniation: experience with 83 patients. Spine (Phila Pa 1976). 1994;19:1905.
10. Maroon JC, Kopitnik TA, Schulhof LAA, et al. Diagnosis and microsurgical approach to far-lateral disc herniation in the lumbar spine. J Neurosurg. 1990;72:378.

11. Schlesinger SM, Fankhauser H, de Tribolet N. Microsurgical anatomy and operative technique for extreme lateral lumbar disc herniations. Acta Neurochir. 1992;118:117.
12. Pirris SM, Dhall S, Mummaneni PV, Kanter AS. Minimally invasive approach to extraforaminal disc herniations at the lumbosacral junction using an operating microscope: case series and review of the literature. Neurosurg Focus. 2008;25(1).
13. Siebner HR, Faulhauer K. Frequency and specific surgical management of far lateral lumbar disc herniations. Acta Neurochir. 1990;105:124.
14. Tessitore E, de Tribolet N. Far-lateral lumbar disc herniation: the microsurgical transmuscular approach. Neurosurgery. 2004;54.
15. Porchet F, Chollet-Bornand A, de Tribolet N. Long-term follow up of patients surgically treated by the far-lateral approach for foraminal and extraforaminal lumbar disc herniations. J Neurosurg. 1999;90:59.
16. Eichholz KM, Hitchon PW. Far lateral lumbar disc herniation. Contemp Neurosurg. 2003;25:1.
17. Darden BV, Wade JF, Alexander R, et al. Far lateral disc herniations treated by microscopic fragment excision. Techniques and results. Spine (Phila Pa 1976).
18. Foley KT, Smith MM, Rampersaud YR. Microendoscopic approach to far-lateral lumbar disc herniation. Neurosurg Focus. 1999;7:E5.
19. Epstein NE, Epstein JA, Carras R, Hyman R. Far lateral lumbar disc herniations and associated structural abnormalities: an evaluation in 60 patients of the comparative value of CT, MRI, and Myelo-CT in diagnosis and management. Spine (Phila Pa 1976). 1990;15:534.
20. Lanzino G, Shaffrey CI, Jane JA, Surgical treatment of lateral lumbar herniated discs, Rengachary SS, Wilkins RH. Neurosurgical operative atlas. Park Ridge: American Association of Neurological Surgeons; 1999. p. 243.
21. Kornberg M. Extreme lateral lumbar disc herniations: clinical syndrome and computed tomography recognition. Spine (Phila Pa 1976). 1987;12:586.
22. Epstein NE. Different surgical approaches to far lateral lumbar disc herniations. J Spinal Disord. 1995;8:383–94.
23. Epstein NE. Foraminal and far lateral lumbar disc herniations: surgical alternatives and outcome measures. Spinal Cord. 2002;40:491–500.
24. O'Toole. Minimally invasive far lateral microendoscopic discectomy for extraforaminal disc herniation at the lumbosacral junction: cadveric dissection and technical case report. Spine J. 2007;7:414–21.
25. Voyadzis JM. Minimally invasvie approach for far lateral disc herniations: results from 20 patients. Minim Invasive Neurosurg. 2010;53:122–6.

Chapter 16
Open Transforaminal Lumbar Interbody Fusion with Posterior Spinal Instrumentation and Fusion

Sean K. Jandhyala and Saad B. Chaudhary

Introduction

The intervertebral disc space offers several biomechanical and biologic advantages for spinal fusion and stabilization. The anterior column of the spine supports 80% of the body's compressive load, the disc space represents a shorter gap to span, and the blood supply provided from the endplates after curettage of the cartilage creates an environment conducive for fusion. By contrast, the fusion mass in the posterolateral space is under greater tensile forces, bone healing must bridge a larger distance between transverse processes, and there is less surface area of vascular cancellous bone.

Anterior lumbar interbody fusion via a transforaminal posterior approach (TLIF) is a variant of posterior lumbar interbody fusion (PLIF) and was first described by Harms and Rolinger in 1982 [1]. The PLIF and TLIF are versatile techniques that offer several advantages. Both techniques address all three columns of the spine for a circumferential fusion achieved through a single posterior approach. Combined with standard posterolateral instrumentation, decortication, and bone grafting, radiographic fusion rates greater than 90% can be achieved [2]. Both techniques can directly address the disc as a potential pain generator in patients with discogenic pain syndromes. Additionally, both techniques can permit for some correction of spinal deformities including spondylolisthesis, kyphosis, and disc space collapse.

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_16

Anatomy

The PLIF procedure utilizes a bilateral and more medial posterior approach to the spine that involves retraction of the thecal sac, radical discectomy, and endplate preparation combined with interbody fusion. The TLIF technique involves a unilateral approach with complete removal of one facet that permits more lateral access to the disc space. The traversing nerve root is in greater risk utilizing the PLIF technique, and the exiting nerve root is in greater risk when performing a TLIF. Access to the posterior annulus and interbody region requires knowledge of local neurologic anatomy and the triangular working window (Kambin's triangle) to the annulus. The triangular working window consists of the traversing nerve root and thecal sac that forms the medial border of the triangle, the exiting nerve root from the cephalad vertebral level forms the lateral border, and the superior aspect of the caudal pedicle forms the base of the triangle. Following precise and careful exposure, epidural veins should be cauterized and a triangular window measuring up to 1.5 cm can be created. On average a non-collapsed disc space height in the adult lumbar spine measures 12–14 mm in height, with an anteroposterior diameter of about 35 mm [3].

Biomechanics and Biology

The anterior column of the spine supports compressive forces; therefore, intervertebral structural grafts are subjected to compressive loading which facilitates fusion. Additionally, intervertebral structural grafts are load sharing, and they reduce cantilever bending forces to posterior spinal implants effectively protecting posterior implants from failure.

The disc space is involved with degenerative disc disease because the disc space undergoes progressive loss of height as part of the degenerative process. This subsequent loss of height results in progressive micro-motion that is thought to contribute to degeneration followed by instability of the posterior elements. Restoration of disc space height provides an indirect decompression of the neural foramen while simultaneously addressing issues of sagittal imbalance. Achieving disc space height restoration, indirect decompression, and interbody fusion is the surgical goal. Although there is some degree of disc space height restoration with TLIF, the magnitude of restoration has been shown to be less than that achieved through an anterior lumbar interbody fusion [4, 5].

It has been shown that without posterior augmentation, there is an increased rate of anterior graft subsidence [6, 7]. The combination of anterior augmentation with a posterior lateral instrumented fusion has been shown to yield fusion rates greater than 95% [8].

The interbody space has been shown to provide an ideal environment for promoting arthrodesis. There is a large surface area of highly vascular cancellous bone; the disc space represents a relatively shorter gap to span for fusion, and the outer annulus provides a border that reduces fibrous tissue ingrowth into the fusion mass.

Indications

Low-grade isthmic spondylolisthesis can be treated with a TLIF procedure as an alternative to combined anterior and posterior fusion [9]. TLIF allows for direct decompression of the spinal canal and exiting nerve roots, in addition to an indirect decompression of neural foramen by disc height restoration. Interbody fusion raises the arthrodesis rate over stand-alone posterior procedures.

Discogenic back pain syndromes and post-discectomy chronic low back pain have been shown to benefit from TLIF procedures [10, 11]. These procedures can directly address the disc as a pain generator and have also shown to have superior clinical outcomes to isolated posterior spinal fusions alone.

TLIF procedures can be used as an adjunct in adult deformity cases such as spondylolisthesis and degenerative scoliosis. TLIF Interbody grafts can provide anterior column support at the caudal end of long fusion constructs and at the lumbosacral junction without an additional anterior approach. TLIF can allow for deformity correction by restoring asymmetrically collapsed disc spaces and providing interbody structural support.

Contraindications

PLIF/TLIF is generally limited in its use to below the level of the conus owing to the degree of thecal sac retraction necessary. Significant osteoporosis is a relative contraindication to these procedures as disc space preparation could lead to end plate violations with subsequent implant subsidence. Anomalous neural anatomy such as conjoined nerve root can prevent utilizing a TLIF procedure. Irreducible high-grade spondylolisthesis can be a contraindication as the surface area of the opposing vertebral endplates is minimized. Severe focal kyphosis may be best addressed from an anterior approach that can release the anterior longitudinal ligament.

Non-operative Management

Prior to surgical considerations, standard non-operative options should be exhausted. Non-operative treatment typically involves a combination of anti-inflammatory/analgesic medications, physical therapy, and activity/lifestyle modifications. Interventional pain management in the form of trigger point, facet block, and epidural steroid injections could serve as a useful adjunct in certain cases.

Surgical Procedure

Preoperative planning involves obtaining appropriate imaging to determine disc space height, adjacent disc space height, and overall lumbar alignment to help determine interbody implant size. Additionally, appropriate size and trajectory of pedicle screw insertion is important. A careful assessment of neurologic structures and the extent of decompression should be evaluated. When utilizing the TLIF procedure, the interbody approach should be performed on the patient's symptomatic side or the side of maximal compression if symptoms are of equal severity on both sides.

The patient should be positioned in the prone position on a table that allows fluoroscopic imaging such as a Jackson spine frame. The knees are slightly flexed to minimize tension on nerve roots, and the hips are extended to maintain lordosis. The abdomen should be free to decompress the vena cava and reduce epidural venous bleeding. A Foley catheter and sequential compression devices should be used routinely. Imaging should be obtained prior to prepping and draping to ensure appropriate visualization and localization.

Surgical Approach

A standard midline incision should be utilized through the skin and subcutaneous tissues, and subperiosteal dissection is carried down to the spine in standard fashion. The transverse process and pars interarticularis at the cephalad and caudal level should be exposed. Care should be taken not to violate the cephalad facet joint capsule. An intraoperative localizing film should be obtained to confirm the appropriate level.

Pedicle Screw Insertion

After exposure, pedicle entry points are identified at the junction of the superior articular process and the transverse process. Typically, a high-speed burr or awl is used to access each pedicle. A tap is then usually used to ensure proper path for the screws. Polyaxial pedicle screws are then placed bilaterally in the standard fashion. Fluoroscopy and electromyographic responses can then be utilized to confirm appropriate placement of screws and to help detect any inadvertent pedicle wall breaches. It is recommended that the transverse processes be decorticated prior to pedicle screw placement to facilitate posterolateral fusion and exposure could be limited once screws are in place. Typically the pedicle screws on the ipsilateral side should be placed after the interbody space has been prepped and the TLIF spacer has been placed.

Disc Space Distraction

The lumbar disc is lordotic in nature and can make access to the disc difficult. Posterior distraction can be utilized to facilitate access to the interbody region. Distraction can be utilized in several ways including: the use of rods and screw, spinous process distraction, and the use of interbody dilators. When utilizing the rod and screw technique, distraction is carried out using the rods on both sides and a distractor. It is recommended that vigorous distraction through the pedicle screws be avoided as it weakens their biomechanical fixation. Spinous process distraction can be achieved by utilizing a lamina spreader between the spinous processes. This technique can also reduce the risk of screw loosening. Interbody dilators can also be used by placing them into the disc space and rotating to restore disc space height. This technique can only be utilized once the disc space has been accessed.

Complete Unilateral Facetectomy

Access to the transforaminal space requires removal of the entire facet joint effectively on one side. This can be accomplished by removing the inferior articular process of the cephalad level using an osteotome and rongeur. Prior to the osteotomy, the ligamentum flavum should be freed from the lamina to decrease the risk of incidental durotomy. The superior articular process of the caudal vertebra is then resected flush with the pedicle. The lateral recess can be decompressed, and the caudal portion of the pars interarticularis is resected to provide access to the neural foramen and posterolateral annulus.

The triangular working zone (Kambin's triangle) between the exiting and traversing nerve roots and the superior aspect of the pedicle should be identified (Fig. 16.1). The exiting nerve root is located below the pedicle of the cephalad vertebrae. Care

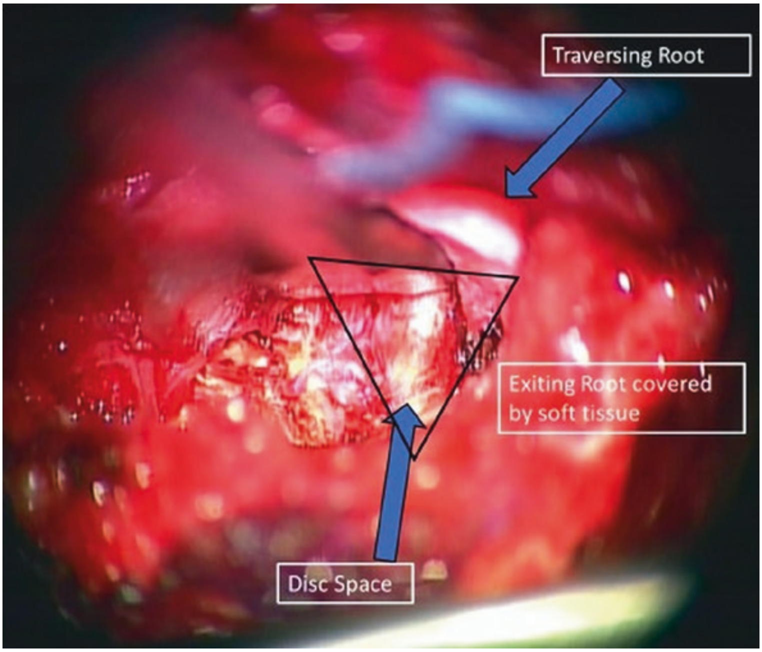

Fig. 16.1 Kambin's triangle

should be taken not to injure the exiting nerve root while locating it, particularly the sensitive dorsal root ganglion. The traversing nerve root and lateral aspect of the thecal sac are located in the medial portion of the triangle and can be retracted carefully using nerve root retractors. Once all neurologic structures are identified, and the borders of the triangular working zone are identified, it is important to coagulate any obstructing epidural veins using bipolar cautery.

Disc Space Preparation

Once the disc space has been identified and hemostasis has been achieved, a scalpel is then used to incise a rectangular region of the annulus lateral to the traversing nerve root to create a window into the disc space. Typically shavers or dilators of increasing sized are introduced into the disc space and rotated. It is important to utilize lateral fluoroscopy to determine the depth of penetration into disc space and to determine size of graft necessary. It is critical never to breach the anterior annulus which could lead to catastrophic vascular injury. After dilation and shaving, typically a combination of curettes and pituitary rongeurs are used to perform an adequate discectomy. It is important to prepare the disc space to cancellous bleeding bone without violating the endplate.

Techniques to Minimize Neurologic Injury

It is important during disc space preparation to minimize risk for neurologic injury and post-operative dysesthetic pain. Retraction of neurologic elements should be minimized or it should be released intermittently. The thecal sac should be protected and should not be retracted past midline. Implants should be selected to minimize nerve root retraction and to prevent injury during insertion. An appropriate size cage should be selected.

Graft/Cage Placement

After endplate preparation, cage trials should be used to determine the appropriate size, and fluoroscopic imaging should be utilized to confirm proper sizing of the trial. The interspace should be bone grafted with indicated graft material. Anterior and lateral aspects of the disc space should be packed with morselized graft. Bone tamps should be used to pack the anterior disc space and tightly packed. Prior to inserting the actual implant, a trial should be placed to confirm appropriate placement and that there is no blocked pathway for insertion. The implant should then be inserted into the interbody space and placed anteriorly and centrally as possible. It has been shown that anterior cage placement is biomechanically superior to posterior cage placement [12]. Additional graft should then be placed posteriorly behind the implant.

Posterolateral Grafting

A complete decortication of the fusion bed should be completed. Bone graft should be placed in the posterolateral gutters. Rods should be measured, cut, and bent into lordosis. Compression is then applied to the pedicle screw construct, and the set screws are finally tightened. Final intraoperative fluoroscopic images should be obtained to confirm appropriate positioning of all implants.

Outcomes

The TLIF procedure provides for an effective interbody and posterolateral fusion with fusion greater than 90% [9, 13, 14]. Studies evaluating clinical outcomes of the PLIF and TLIF procedures using a visual analog scare and Oswestry disability index scores demonstrate an overall patient satisfaction rate of approximately 80% [13, 15, 16].

Complications

TLIF has a relatively low complication rate as compared to anteroposterior lumber interbody fusion [17]. The incidence of misplaced pedicle screws during a TLIF procedure is approximately 5%. Transient neurologic deficit is reported to range from 2% to 7%. In cases with post-operative radiculopathy, the most commonly affected nerve root is L5 [2]. There have been recent studies that suggest an anatomic association exists between recalcitrant post-operative radiculopathy and neuroformainal bone grown with bone morophogenic protein allograft [17]. A large series of 124 consecutive TLIF procedures reported a 20% incidence of cerebrospinal fluid leak in open cases [17]. Postoperative infections have an incidence of approximately 5% [2].

Summary

It has been established that anterior interbody lumbar fusion provides an increased rate of fusion, restoration of sagittal balance, and indirect decompression of neural elements. A posterior transforaminal approach to the intervertebral disc space provides the biomechanical advantages of an anterior approach while avoiding the approach-related morbidity of an anterior approach. TLIF provides a viable option for a surgeon seeking to address degenerative disc disease, isthmic spondylolisthesis, and recurrent disc herniations.

References

1. Harms J, Rolinger H. A one-stage procedure in operative treatment of spondylolisthesis: dorsal raction-reposition and anterior fusion. Z Orthop Ihre Grenzgeb. 1982;120:343–7.
2. Potter BK, Freedman BA, Verwiebe EG, et al. Transforaminal lumbar interbody fusion: A safe technique with satisfactory three to five year results. Eur Spine J. 2005;14:551–8.
3. Herkowitz HN, Rothman RH, Simeone FA, editors. The spine. 6th ed. Philadelphia: Saunders Elsevier; 2011.
4. Hsieh PC, Koski TR, O'Shaughnessy BA, et al. Anterior lumbar interbody fusion in comparison with transforaminal lumbar interbody fusion: Implications for the restoration of foraminal height, local disc angle, lumbar lordosis and sagittal balance. J Neurosurg Spine. 2007;7:379–86.
5. Kim JS, Kang BU, Lee SH, et al. Mini-transforaminal lumbar interbody fusion versus anterior lumbar interbody fusion augmented by percutaneous pedicle screw fixation: A comparison of surgical outcomes in adult low-grade isthmic spondylolisthesis. J Spinal Disord Tech. 2009;22:114–21.
6. Resnick DK. Lumbar interbody fusion: Current Status. Neurosurg Q. 2008;18:77–82.
7. Dennis S, Watkins R, Landaker S, et al. Comparison of disc space heights after anterior lumbar interbody fusion. Spine (Phila Pa 1976). 1989;14:876–8.
8. Kwon BK, Hilibrand AS, Malloy K, et al. A critical analysis of the literature regarding surgical approach and outcome for adult low-grade isthmic spondylolisthesis. J Spinal Disord Tech. 2005;18.(Suppl:S30–40.
9. McAfee PC, Devine JG, Chaput CD, et al. The indications for interbody fusion cages in the treatment of spondylolisthesis: analysis of 120 cases. Spine. 2005;30:S60–5.
10. Lin PM. Posterior lumbar interbody fusion (PLIF): past, present, and future. Clin Neurosurg. 2000;47:470–82.
11. Moskowitz A. Transforaminal lumbar interbody fusion. Orthop Clic North AM. 2002;33:359–66.
12. Kwon BK, Berta S, Daffner SD, et al. Radiographic analysis of transforaminal lumbar interbody fusion for the treatment of adult isthmic spondylolisthesis. J Spinal Disord Tech. 2003;16:469–76.
13. Lauber S, Schulte TL, Liljenqvist U, et al. Clinical and radiologic 2 to 4 year results of transforaminal lumbar interbody fusion in degenerative and isthmic spondylolisthesis grades 1 and 2. Spine. 2006;31:1693–8.
14. Hackenberg I, Halm H, Bullmann V, et al. Transforaminal Lumbar Interbody fusion a safe technique with satisfactory three to five year results. Eur Spine J. 2005;14:551–8.
15. Villavicencio AT, Burneikine S, Bulsara KR, et al. Perioperative complications in transforaminal lumbar interbody fusions versus anterior-posterior reconstruction for lumbar disc degeneration and instability. J Spinal Disord Tech. 2006;19:92–7.
16. Hee HT, Castro FP Jr, Majd ME, et al. Anterior/posterior lumbar fusion versus transformainal lumbar interbody fusion: analysis of complications and predictive factors. J Spinal Disord. 2001;14:533–40.
17. Ahn J, Jorgenson AY, Bohl DD, et al. Neuroforaminal Bone growth following minimally invasive transforaminal lumbar interbody fusion with BMP: a computed tomographic Analysis. 30:E754.

18. Miura Y, Imagama S, et al. Is local bone viable as a source of bone graft in posterior lumbar interbody fusion? Spine. 2003;28:2386–9.
19. Lee CK, Vessa P, Lee JK. Chronic disabling low back pain syndrome caused by internal derangements: The results of disc excision and posterior lumbar interbody fusion. Spine. 1995;20:356–61.

Chapter 17
Lumbar Corpectomy

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Introduction

There are many effective treatment modalities for operative correction of lumbar sagittal deformity and its resultant nerve compression. Although spinal fusion has been used since the beginning of the twentieth century, corpectomy has recently gained prominence. Fusion procedures often did not sufficiently improve back pain due to degenerative disc disease (DDD) that was complicated by vertebral body/vertebral height compromise [1–3]. By utilizing corpectomy, surgeons can address spinal nerve root compression that arises from reduced vertebral height in addition to DDD. Additionally, lumbar corpectomy can be utilized to decompress ventral pathology such as burst fractures and vertebral osteomyelitis.

Indications for lumbar corpectomy in addressing spinal pathology include neurological dysfunction, axial instability pain, and intractable radicular pain that may have resulted from deterioration of the vertebral body via malignancy, infection, and trauma/fracture that requires direct decompression of the spinal canal to prevent increasing pathological kyphosis [4, 5]. Other indications for operative management must be considered in patients with spinal tumors including overall prognosis, mechanical instability, primary pathology, and neurological function [6].

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_17

Contraindications for lumbar corpectomy are similar to those of fusion procedures: suboptimal quality of adjacent vertebral segments due to low bone mineral density (BMD), infection, malignancy, etc. may fail to correct vertebral height and spinal deformity [6]. In these patients, conservative management should be pursued as the risk of operative intervention outweighs the potential benefits. Furthermore, patients with abdominal aortic aneurysms (AAA) should not undergo lumbar corpectomy (particularly the retroperitoneal approach) as corpectomy of the L5 vertebra has been associated with increased blood loss due to the anatomy of the great vessels – manipulation during lumbar corpectomy in a patient with AAA could lead to catastrophic blood loss, and operative management should be deferred until resolution of the AAA [6, 7].

There are various means of access to the lumbar spine when performing corpectomy. Standalone anterior approaches, anterior approaches with subsequent posterior instrumentation, and posterior approaches have previously been reported to be effective in the resolution of symptoms that stem from burst fractures, vertebral osteomyelitis, neoplasms, and osteo-radio-necrosis [5, 8–20]. However, these approaches are not without surgical risks and morbidities. Traditionally, open anterior approaches have been associated with risk of injury to the great vessels, ureters, abdominal wall, and greater incisional pain, whereas posterior approaches compromise paraspinal musculature [4, 21]. Furthermore, arterial erosion over time due to instrumentation overhang against pulsatile blood vessels is a concern for the anterior approach to lumbar corpectomy [4]. With proper patient selection, lateral approaches to lumbar corpectomy theoretically avoid these complications. With the advent of minimally invasive surgery (MIS) of the spine, new MIS approaches are gaining popularity due to advantages in decreased soft-tissue trauma, postoperative pain, blood loss, and immobilization [22–30]. However, this minimally invasive lateral approach to the thoracolumbar spine is not without risks. Baaj et al. report favorable outcomes with this approach but cite various complications including dural tear, intercostal neuralgia, deep vein thrombosis (DVT), and hardware failure – highlighting simultaneously the efficacy and technical demand of the procedure [31]. This chapter will focus on the lateral access for lumbar corpectomy and its associated outcomes previously reported in the literature.

Procedure

Operative Planning

There are multiple approaches to performing an anterior lumbar corpectomy. The anterior vertebral body can be accessed with the patient in a lateral position through either an anterolateral-retroperitoneal or a lateral extracavitary approach. In the supine position, the vertebral body can be accessed through an anterior-transperitoneal or an anterior-retroperitoneal approach. As with all anterior approaches to the spine, a vascular surgeon may be appropriate for access based on the surgeon's experience. Based on the level and laterality of the approach, considerations must be made for patient anatomy. Above L2, the diaphragm must be considered, and below L5, the iliac crest must be considered. A left-sided approach is preferable to the right side because of the location of the liver and the risk of damage to the inferior vena cava. The aorta is more robust to mobilization, although if significant aortic aneurysm, calcifications, or disease exists, a left-sided approach may be relatively contraindicated.

Additionally, one must consider prior abdominal and/or retroperitoneal surgery. Prior surgery on the kidneys, in particular, partial nephrectomy, will make the approach quite difficult. Intraperitoneal surgery is generally not a contraindication. Hysterectomy, due to its intraperitoneal location, is also generally a non-factor in the difficulty of the approach. Additionally, for approaches to L5, radiation to the prostrate may generate scarring of the retroperitoneum to the great vessels.

Positioning

A left-sided anterolateral-retroperitoneal approach will be described. Neuromonitoring with motor-evoked potentials and somatosensory-evoked potentials is recommended [6]. The patient is first positioned on the right lateral decubitus position with beanbags, bumps, or gel rolls to support and stabilize the body based on surgeon preference. An axillary roll is placed and tape with padding is used to secure the patient on the bed. The hips are flexed to relax the hip flexors as well as the lumbar plexus [4]. The break in the table may be used to gain better exposure to the intended vertebral body, but this is contraindicated in the context of unstable fracture [6]. Using fluoroscopy, the level may be identified with a metal instrument. The incision should be centered over the planned vertebrae. This step is crucial to avoid unnecessary and avoidable wrong-level exposure. For the novice spine surgeon working with an experienced vascular/exposure surgeon, this point must be emphasized before beginning. For thoracolumbar corpectomy, the best rib to excise is the rib directly lateral in the midaxillary line. The incision may be marked before or after the skin is prepared in a sterile fashion along with the ipsilateral iliac crest if bone graft harvest is planned [4].

The incision is made at the lateral border of the rectus to the lateral border of the paravertebral musculature at the appropriate level. A dissection to the retroperitoneum is undertaken. Once the retroperitoneum is entered, the peritoneum, including the kidneys and ureters, is swept anteriorly. It is important to recognize that three major nerves cross the surgical field in between the external and internal oblique muscle layers. The iliohypogastric, ilioinguinal, and subcostal nerves are important motor and sensory nerves that may be damaged. In open approaches, this damage may be unavoidable. However, damage to two of the nerves will result in pseudohernia or loss of abdominal wall tone on the ipsilateral side.

Preoperatively, ureteral stents may be placed to help identification and to avoid injury. However, the senior author has not found this needed, even in the instance of prior partial nephrectomy. Once the vertebral body is encountered, the segmental vessels that course over its surface must be ligated. For more distal lumbar corpectomies, the iliolumbar vein may be encountered tethering the aorta at L4–5, where it should be identified and ligated proximal. The aorta and iliac artery may then be mobilized from left to right. The left iliac vein may be mistaken for soft tissue if it is flattened on the L5 body [4]. Therefore, retraction during exposure should be relaxed prior to sectioning any soft tissue overlying the vertebral bodies.

After verifying the appropriate level, the lateral aspect of the pedicle is excised to expose the dura and neural elements for identification and protection [6]. The superior and inferior discs are then excised. Consideration for a temporary trial spacer is made to help orient the course of the vertebral body exposure under lateral c-arm control. A high-speed burr may be used to access the bony endplates without disrupting them. The corpectomy is then undertaken utilizing high-speed burr and rongeurs. Profuse cancellous bone bleeding may be controlled with Gelfoam™ or Surgiflo™, based on surgeon preference. The contralateral and anterior cortices are left intact, along with the anterior longitudinal ligament to help protect the great vessels. If corpectomy is undertaken in the context of a fracture, retropulsed fragments should be excised from the spinal canal [4]. Once adequate decompression is complete, reconstruction may be undertaken. Available implants may differ in technique, but generally, an interbody cage is placed with autograft or allograft. Rigid fixation of adjacent vertebral bodies with plates, rods, or screws is generally performed. Prior to final tightening of fixation, any distraction should be released and the patient's position on the table should be confirmed in the intended location. The implants should not abut and critical structures at risk for erosion [4].

After hemostasis is achieved, critical structures should be examined as allowed. The diaphragm should be approximated if it was incised during the approach. Chest tubes and drains may be placed based on surgeon preference. Fascial layers are closed followed by the layers of the abdominal wall. The skin is then closed in the preferred fashion [4].

Outcomes

Adkins et al. previously reported on the case of a 58-year-old female who presented with an acute L1 burst fracture with significant neurological deficits who was successfully treated with an MIS lateral approach lumbar corpectomy [32]. The postoperative course was complicated by a moderate left-sided pleural effusion that was treated with thoracentesis. At 1-year follow-up, the patient remained neurologically intact with moderate residual bilateral foot dysesthesias that required pregabalin, but hardware failure or compression of the spinal cord was not appreciated [32]. In the same case report, Adkins et al. also reported on a 68-year-old female who presented with a T12 burst fracture at the thoracolumbar junction that was successfully treated with the same surgical approach with minimal blood loss. A 6-month follow-up demonstrated minimal back pain, intact neurological physical exam, and no evidence of hardware failure or further subsidence [32]. Similarly, Amaral et al. reported on the case of a 55-year-old male who presented with an L2 burst fracture with 32% loss of vertebral height that was treated with a mini-open lateral corpectomy [33]. Intraoperative/postoperative courses were uncomplicated and postoperative length of stay was limited to one day with ambulation achieved before discharge. Like Adkins et al., Amaral et al. reported similarly favorable postoperative follow-up results – imaging at both 1-year and 2-year follow-up demonstrated significant improvement in sagittal and coronal alignments with satisfactory fusion [33]. In a case series of 52 patients who were treated with a mini-open lateral approach for thoracolumbar corpectomy for thoracolumbar fractures, Smith et al. reported favorable results as well [34], where 13.5% of the patients ($n = 7$) experienced complications including dural tear, intercostal neuralgia, and DVT. However, only one patient required revision due to pain from postoperative subsidence. American Spinal Injury Association (ASIA) scores were significantly improved for all patients who returned for follow-up at postoperative, 12-month, and 24-month time intervals ($p < 0.001$) [34]. Gandhoke et al. similarly reported favorable outcomes on two patients with thoracolumbar burst fractures treated with the MIS extreme lateral approach for lumbar corpectomy [35]. Patel et al. reported good outcomes in a case series of six elderly patients with multiple comorbidities who underwent the minimally invasive lateral transpsoas approach for discitis and osteomyelitis [36]. All patients completed a postoperative 6-week intravenous antibiotic regimen followed by a 6-week oral antibiotic regimen. Although one patient experienced hardware failure 2 months postoperatively due to refractory infection despite compliance with the postoperative antibiotic course, all patients at 1-year follow-up demonstrated stable spinal hardware with satisfactory fusion [36].

In a recent retrospective study of 19 patients, Tan et al. report favorable outcomes in the minimally invasive direct lateral corpectomy approach for metastatic spinal cord compression in the thoracolumbar spine [37]. All patients exhibited excellent neural decompression at 1-year follow-up with pain Visual Analogue Scale (VAS) scores significantly improved for all patients ($p < 0.05$); 36.1% of patients exhibited improvement of ≥1 Frankel grades. No neurological deterioration for any patient was reported [37]. Knoeller et al. similarly reported on a prospective and retrospective study of 45 patients who underwent single-stage lateral lumbar corpectomy for spinal metastases as well. At mean 3 years follow-up, Frankel scale scores improved by 0.65 points ($p < 0.05$), and the Oswestry disability index (ODI) improved by 40.69 points ($p < 0.05$) [18]. Serak et al. reported similar results in a retrospective database analysis of eight patients with the application of an extreme lateral approach for corpectomy in the treatment of thoracolumbar vertebral body metastases [38].

Conclusions

Lumbar corpectomy and subsequent fusion is a viable option for the restoration of vertebral height and relieving nerve compression given proper patient selection. A variety of pathologies that lead to vertebral body compromise can be addressed by utilizing lumbar corpectomy including trauma, malignancy, infection, and osteoradionecrosis. Reports in the literature of case reports, case series, and smaller institutional retrospective studies indicate the viability and success of lumbar corpectomy in the management of back pain due to vertebral compromise by preventing progressive kyphosis. However, larger prospective/retrospective studies and meta-analyses are ultimately needed to accurately measure the success of these procedures.

Minimally invasive surgery of the spine is a rapidly expanding discipline that has been gaining popularity due to various advantages in decreased soft-tissue trauma, postoperative pain, blood loss, and expedited mobilization that ultimately decrease the length of stay. The minimally invasive lateral approach to lumbar corpectomy has distinct advantages in that it avoids risk to peritoneal organs and immediately retroperitoneal nerves/vasculature with the anterior approach. Advantages of the lateral approach compared to the posterior approach include decreased soft-tissue trauma of the paraspinal musculature. These advantages of the lateral MIS of lumbar corpectomy lead to expedited recovery of patients with decreased morbidities. However, this approach is not without risk as dural tear, intercostal neuralgia, DVT, and hardware failure have all been reported with the lateral approach. Future propensity score-matched analyses may prove useful in comparing outcomes and complication rates among lateral, anterior, posterior, and combined approaches to lumbar corpectomy.

References

1. Badrinath R, Sullivan TB, Garfin SR, Allen RT. Posterolateral and lateral Corpectomies. In: Garfin SD, Eismont FJ, Bell GR, Fischgrund JS, Bono CM, editors. Rothman-Simeone and Herkowitz's the spine. 7th ed. Philadelphia: Saunders, Elsevier; 2018.
2. Mixter WJ, Barr JS. Rupture of the intervertebral disc with involvement of the spinal canal. NEJM. 1934;211(5):210–5.
3. Barr JS. Ruptured intervertebral disc and sciatic pain. J Bone Joint Surg Am. 1947;29(2):429–37.
4. Waters JD, Ciacci JD. Anterior lumbar Corpectomy. In: Jandial R, McCormic PC, Black PM, editors. Core techniques in operative neurosurgery. 1st ed. Philadelphia: Saunders, Elsevier; 2011.
5. Metcalfe S, Gbejuade H, Patel NR. The posterior Transpedicular approach for circumferential decompression and instrumented stabilization with titanium cage Vertebrectomy reconstruction for spinal tumors – consecutive case series of 50 patients. Spine. 2012;37(16):1375–83.
6. Murray-Ortiz G, Park MS, Uribe JS. Anterior and lateral lumbar instrumentation. In: Winn HR, editor. Youmans and Winn neurological surgery. 7th ed. Philadelphia: Sunders, Elsevier; 2017.
7. Shousha M, El-Saghir H, Boehm H. Corpectomy of the fifth lumbar vertebra, a challenging procedure. J Spinal Disord Tech. 2014;27(6):347–51.
8. Richardson B, Paulzak A, Rusyniak WG, Martino A. Anterior lumbar Corpectomy with expandable titanium cage reconstruction: a case series of 42 patients. World Neurosurg. 2017;108:317–24.
9. Schnake KJ, Stavridis SI, Kandziora F. Five-year clinical and radiological results of combined anteroposterior stabilization of thoracolumbar fractures. J Neurosurg Spine. 2014;20:497–504.

10. Keshavarzi S, Newman B, Ciacci JD, Aryan HE. Expandable titanium cages for thoracolumbar vertebral body replacement: initial clinical experience and review of the literature. Am J Orthop. 2011;40(3):E35–9.
11. Yang X, Song Y, Liu L, Liu H, Zeng J, Pei F. Anterior reconstruction with nano-hydroxyapatite/polyamide-66 cage after thoracic and lumbar Corpectomy. Orthopedics. 2012;35(1):e66–73.
12. Joubert C, Adetchessi T, Peltier E, Graillon T, Dufour H, Blondel B, Fuentes S. Corpectomy and vertebral body reconstruction with expandable cage placement and Osteosynthesis via the single stage posterior approach: a retrospective series of 34 patients with thoracic and lumbar spine vertebral body tumors. World Neurosurg. 2015;84(5):1412–22.
13. Carminucci A, Assina R, Hernandez RN, Goldstein IM. Direct midline posterior Corpectomy and fusion of a lumbar burst fracture with Retrosponyloptosis. World Neurosurg. 2017;99:809.e11–4.
14. Palejwala SK, Lawson KA, Kent SL, Martirosyan NL, Dumont TM. Lumbar corpectomy for correction of degeneration scoliosis from osteoradionecrosis reveals a delayed complication of lumbar myxopapillary ependymoma. J Clin Neurosci. 2016;30:160–2.
15. Mulbauer M, Pfisterer W, Eyb R, Knosp E. Minimally invasive retroperitoneal approach for lumbar corpectomy and anterior reconstruction. Technical note. J Neurosurg. 2000;93(1 Suppl):161–7.
16. Eck JC. Minimally invasive corpectomy and posterior stabilization for lumbar burst fracture. Spine J. 2011;11(9):904–8.
17. Elnady B, Shawky A, Abdelrahman H, Elmorshidy E, El-Meshtawy M, Said GZ. Posterior only approach for fifth lumbar corpectomy: indications and technical notes. Int Orthop. 2017;41(12):2535–41.
18. Knoeller SM, Huwert O, Wolter T. Single stage corpectomy and instrumentation in the treatment of pathological fractures in the lumbar spine. Int Orthop. 2012;36(1):111–7.
19. Choi JI, Kim BJ, Ha SK, Kim SD, Lim DJ, Kim SH. Single-stage Transpedicular Vertebrectomy and expandable cage placement for treatment of unstable mid and lower lumbar burst fractures. Clin Spine Surg. 2017;30(3):E258–64.
20. Pham MH, Tuchman A, Chen TC, Acosta FL, Hseih PC, Liu JC. Transpedicular Corpectomy and cage placement in the treatment of traumatic lumbar burst fractures. Clin Spine Surg. 2017;30(8):360–6.
21. Dimar JR, Fisher C, Vaccaro AR, Akonkwo DO, Dvorak M, Fehlings M, Rampersaud R, Carreon LY. Predictors of complications after spinal stabilization of thoracolumbar spine injuries. J Trauma. 2010;69(6):1497–500.
22. Dhall SS, Wang MY, Mummaneni PV. Clinical and radiographic comparison of mini-open transforaminal lumbar interbody fusion with open transforaminal lumbar interbody fusion in 42 patients with long-term follow-up. J Neurosurg Spine. 2008;9(6):560–5.
23. Foley KT, Gupta SK. Percutaneous pedicle screw fixation of the lumbar spine: preliminary clinical results. J Neurosurg. 2002;97(1 Suppl):7–12.
24. Guiot BH, Khoo LT, Fessler RG. A minimally invasive technique for decompression of the lumbar spine. Spine (Phila Pa 1976). 2002;27(4):432–8.
25. Jaikumar S, Kim DH, Kam AC. History of minimally invasive spine surgery. Neurosurgery. 2002;51(5 Suppl):S1–14.
26. Khoo LT, Plamer S, Laich DT, Fessler RG. Minimally invasive percutaneous posterior lumbar interbody fusion. Neurosurgery. 2002;51(5 Suppl):S166–81.
27. Ozgur BM, Aryan HE, Pimenta L, Taylor WR. Extreme Lateral Interbody Fusion (XLIF): a novel surgical technique for anterior lumbar interbody fusion. Spine J. 2006;6(4):435–43.
28. Peng CW, Yue WM, Poh SY, Yeo W, Tan SB. Clinical and radiological outcomes of minimally invasive versus open transforaminal lumbar interbody fusion. Spine (Phila Pa 1976). 2009;34(13):1385–9.
29. Dakwar E, Cardona RF, Smith DA, Uribe JS. Early outcomes and safety of the minimally invasive, lateral retroperitoneal transpsoas approach for adult degenerative scoliosis. Neurosurg Focus. 2010;28(3):E8.

30. Anand N, Rosemann R, Khalsa B, Baron EM. Mid-term to long-term clinical and functional outcomes of minimally invasive correction and fusion for adults with scoliosis. Neurosurg Focus. 2010;28(3):E6.
31. Baaj AA, Dakwar E, Le TV, Smith DA, Ramos E, Smith WD, Uribe JS. Complications of the mini-open anterolateral approach to the thoracolumbar spine. J Clin Neurosci. 2012;19(9):1265–7.
32. Adkins DE, Sandhu FA, Voyadzis JM. Minimally invasive lateral approach to the thoracolumbar junction for corpectomy. J Clin Neurosci. 2013;20(9):1289–94.
33. Amaral R, Marchi L, Oliveria L, Coutinho T, Pimenta L. Acute lumbar burst fracture treated by minimally invasive lateral corpectomy. Case Rep Orthop. 2013;2013:953897.
34. Smith WD, Dakwar E, Le TV, Christian G, Serrano S, Uribe JS. Minimally invasive surgery for traumatic spinal pathologies. Spine. 2010;35(26S):S338–46.
35. Gandhoke GS, Tempel ZJ, Bonfield CM, Madhok R, Okonkwo DO, Kanter AS. Technical nuances of the minimally invasive extreme lateral approach to treat thoracolumbar burst fractures. Eur Spine J. 2015;24(Suppl 3):S353–60.
36. Patel NB, Dodd ZH, Voorhies J, Horn EM. Minimally invasive lateral transpsoas approach for spinal discitis and osteomyelitis. J Clin Neurosci. 2015;22(11):1753–7.
37. Tan T, Chu J, Thien C, Wang YY. Minimally invasive direct lateral Corpectomy of the thoracolumbar spine for metastatic spinal cord compression. J Neurol Surg A Cent Eur Neurosurg. 2017;78(4):358–67.
38. Serak J, Vanni S, Levi AD. The extreme lateral approach for treatment of thoracic and lumbar vertebral body metastases. J Neurosurg Sci. 2015;63(4):473–8.

Chapter 18
Minimally Invasive Transforaminal Lumbar Interbody Fusion

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Introduction

Lumbar fusion is an effective treatment for low back pain secondary to degenerative lumbar pathology [1]. The posterior lumbar interbody fusion (PLIF), described by Cloward in the 1952, has long been considered the most popular technique of achieving lumbar fusion. Indeed, these methods of interbody fusion, now typically supplemented with posterior instrumentation, are still routinely performed today. Unfortunately, both of these techniques are known to have high complication rates: ALIF with its visceral, vascular, and male reproductive complications and PLIF with its complications associated with bilateral neural retraction [2].

Unilateral PLIF, first described by Blume and then popularized by Harms as the TLIF, reduced the risks of PLIF associated with excessive retraction of the neural elements. Compared to PLIF, TLIF allows for lateralized access to the disc space and foramen with less exposure and retraction of the neural elements all with preservation of the contralateral structural anatomy. Despite these potential advantages of TLIF over PLIF, open TLIF, like other open spinal procedures performed via midline incisions, is still quite destructive. The midline incisions and prolonged retraction time seen with open TLIF are associated with significant iatrogenic injury to supporting anatomical structures and thus may result in poor clinical outcomes [3–8].

The MIS-TLIF was introduced by Foley et al. in 2003 as a way to mitigate the collateral damage to supporting anatomical structures seen in open TLIF [9]. Despite an initial steep learning curve, experience with MIS-TLIF grew rapidly, and the procedure has become widely accepted [10–13]. Like other minimally invasive, muscle-sparing techniques, MIS-TLIF is associated with less blood loss, decreased

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_18

risk of infection, faster return to ambulation, and shorter hospitalization [14–16]. Also, especially important in the era of value-based care, MIS-TLIF has been shown to be more cost-effective when compared to open TLIF [17, 18]. Certainly, circumferential fusions have improved clinical outcomes and are more cost-effective when compared to posterolateral fusions only. [19, 20]

Today, technologies such as image guidance, surgical robotics, expandable interbody spacers, and advanced spacer materials have only increased the ease and effectiveness of MIS-TLIF. Here we discuss indications, technical nuances, and outcomes of MIS-TLIF.

Indications

MIS-TLIF has the same indications as its open analog, namely, spondylolisthesis/instability, unilateral foraminal stenosis, recurrent disc herniation, focal kyphotic deformity, and discogenic pain [21]. Due to the significant reduction in wound/incision size, it is arguably a superior choice for obese and healing-challenged patients (i.e., diabetes mellitus, rheumatologic disease, etc.) [22–24].

Surgical Management

Positioning

This procedure is typically performed under general endotracheal anesthesia and, due to the brevity of the procedure, a Foley catheter is seldom necessary for one and two level cases. Preoperative antibiotics are given and serial compression devices placed. Neural monitoring is commonly used and significantly improves the safety and predictability of the procedure.

After induction the patient is placed in the prone position on the operating table (we prefer an open Jackson table) with the hips extended and the knees slightly flexed in order to maximize lordosis.

Radiation Reduction

MIS-TLIF is a fluoroscopy-intensive procedure. There are numerous studies in the literature documenting the health risks of excessive radiation exposure to the patient as well as the treatment team [25]. ALARA (As Low As Reasonably Achievable) is the practice of adopting methodologies to lower the radiation exposure in medical procedures as much as possible. With most modern C arms, there are some simple actions can dramatically lower the radiation exposure for both the patient and the team. Simple measures such as turning off auto-contrast, activating low-dose mode, and going to pulse mode (decreasing the number of pulses down to the lowest number where the image is still diagnostic and usable) can achieve 90–95% dose reduction. New technologies such as LessRay® can further help reduce the radiation exposure and improve image quality. Procedurally, standing on the image intensifier side of the table and using predominately AP flouro (and more sparing use of lateral imaging) further help to lower exposure for the team.

Pedicle Screw Placement

The skin is then prepped widely as the paramedian incisions are at times farther from the midline than is initially expected, particularly in obese and wide girth patients. The C-arm is then brought in, and using AP imaging the boundaries of the pedicles are marked. The bilateral, paramedian incisions are then marked out between 3 and 5 cm lateral to the midline. This is variable and is largely dependent on patient girth, with larger patients requiring more lateral incisions to achieve the necessary lateral-to-medial trajectory for pedicle cannulation. The Jamshidi needles are then docked on the 9 and 3 o'clock positions of the left and right pedicles, respectively. There are common variations on how this step is done. For some, there is no dissection and the needles are passed right after incision. Others perform a Wiltse-type dissection to get to the junction of the lateral facet and the transverse process. K-wires are then passed and after removal of the Jamshidi needle, serial dilation follows. Next, the holes are typically tapped and then the screws are placed. Triggered EMG is often used during Jamshidi needle placement, tapping, and screw placement to lower the risk of screw malpositioning and neural impingement.

There are two basic variations of MIS retractor systems used in TLIF: tubular retractor systems (e.g., Quadrant®, Medtronic Corp.) and pedicle-based refractor systems (e.g., MAS TLIF®, Nuvasive Corp.). With tubular retractor systems, the pedicle screws are typically placed after decompression and cage placement in order to avoid interference with proper docking of the tubular dilators. With pedicle-based retractor systems, pedicle screws are placed prior to decompression in order to serve as anchor points for the cephalad and caudad retractor blades. If needed, medial and lateral retractor blades are then placed to facilitate wider exposure of working corridor to the disc space.

Decompression

At this point, the operating microscope is typically brought in, and the remaining soft tissue is removed with a combination of electrocautery and pituitary rongeurs to expose the lamina and facet complex. First, the inferior articulating process is removed using the high-speed drill or bayoneted osteotomes by making a series of cuts: (a) horizontally across the pars interarticularis, (b) longitudinally along the lamina just medial to the facet complex, and (c) separating the facet joint articulation. This releases the inferior articulating process which, after careful dissection away from the synovium and ligamentum flavum, is then removed en bloc with a pituitary rongeur. The superior articulating facet is then drilled away or removed in a piecemeal fashion using a Kerrison rongeur. Morcellized bone may be collected for later use as autograft. Finally, the ligamentum flavum is removed to expose the thecal sac and neural elements. While not necessary, we advocate exposure of both the exiting and traversing nerve roots so that they can be clearly seen and avoided during disc preparation and cage placement. This exposure of the two nerve roots, and the disc space within Kambin's Triangle, is only possible after a complete bony decompression from the inferior edge of the cephalad pedicle and the superior edge of the caudad pedicle. In cases of severe central stenosis, a contralateral decompression can also be achieved after angling the retractor across midline.

Cage Placement

The approach corridor to the disc space occurs within Kambin's Triangle with its lateral boundary of the exiting nerve root, its medial boundary of the traversing nerve root, and its inferior boundary of the caudal pedicle. A generous annulotomy is performed and the disc space is prepped. Pituitary rongeurs, rasps, curettes, and rotating paddle shavers are used to help accomplish this. Meticulous care must also be taken to avoid violating the endplates to mitigate the risk of subsidence as the cages are typically placed on the weakest part of the endplate. At the same time, as these surfaces are the primary fusion surface, the endplates must be thoroughly debrided of cartilaginous disc material. One of the most common causes of non-union or cage malpositioning in MIS-TLIF is poor disc space preparation. Thus, the surgeon must take time to perform a complete discectomy and adequate endplate preparation. The space is then sized with either the paddle shavers or interbody trials.

Bone graft is typically packed into the prepped disc space and tamped to the contralateral side so as not to impede interbody graft placement. Most MIS TLIF systems have a funnel which can be packed with graft and introduced into the disc space, greatly facilitating adequate graft volumes. We typically aim for delivery of 12 cc or more of grafting material. The graft is then tamped to the contralateral side of the disc space. The interbody graft or cage is then packed with grafting material and impacted into the disc space.

As with open TLIF, a variety of sizes and shapes of intervertebral spacers exist. The so-called bullet cages may be the easiest to place via an MIS corridor. Banana or boomerang cages, while more technically demanding to place, may offer two theoretical benefits: (a) decreased risk of subsidence as the graft abuts the more compact of the apophyseal ring anteriorly, and (b) greater potential restoration of segmental lordosis due to the more anterior location of the spacer. Finally, expandable intervertebral spacers can be quite advantageous in tight spaces where excessive retraction might be necessary to place a static graft. These devices may also allow for greater correction of foraminal height and segmental lordosis. Back-filling the space and or interbody device with grafting material is then an option.

Rod Placement

Rods are then sized with calipers. The rods are contoured. A tissue blade is then passed to facilitate rod passage. The rods are passed with particular attention being paid to staying subfascial on the rod pass. It is also important to avoid over-sizing the rods to avoid suprajacent facet impingement. Proper rod contouring can help maximize lordosis.

Lordotic Restoration

As stated previously, positioning has a significant influence on preservation and restoration of lordosis. The Jackson table and similar frames facilitate hyperextension of the lumbar spine. Using pillows to extend the hips and flex the knees further exerts a lordotic force on the lumbar spine. Maximizing the fulcrum effect of the interbody device is accomplished in two ways: anterior placement of the interbody device and avoiding oversizing (as the intact, taught anterior longitudinal ligament will resist lordosis). Existing MIS system compressors have some utility but often fail to provide maximal, angular compressive force.

Multilevel Cases

It is possible to perform multi-level MIS TLIF. Two level cases are quite common, and, with the tubular retractor method, the surgeon simply dilates and places the tube over each of the facets for the levels to be fused. With the pedicle screw-based systems, the blades on the pedicles are simply rotated 180° to treat each level. Three or more levels are possible but not commonly done. Frequently, MIS-TLIF will be done at L5/S1 as a second phase while placing the pedicle screws to back up lateral lumbar interbody fusions (LLIF) of L4/5 and more cephalad levels.

Spondylolisthesis Reduction

Spondylolisthesis correction on single level cases can be challenging. Distraction of the disc space by the interbody graft will often at least partially correct the listhesis. Similarly, prone positioning can influence the listhesis. Posterior translation of the pedicle screw towers on the cephalad screws while deploying the cage (particularly expandable cages) can be helpful on single-level cases. On multi-level cases, underbending the rod and sequentially reducing the middle vertebral body are an effective method for correction of spondylolisthesis.

Grafting

While the primary fusion by design occurs within the disc space and is outlined above, contralateral facet and laminar fusion are popular adjuncts. Dilators are typically docked on the facet or laminar surface and the microscope is used for visualization. The high-speed drill is used to decorticate the surfaces, and grafting material is packed onto them.

Outcomes and Complications

MIS-TLIF has been proven to be a safe and effective alternative to open TLIF [26, 27]. Reduced blood loss, infection rate, hospital stay, postoperative narcotic usage, and return to work have been demonstrated in the literature [14–16]. Fusion rates have been shown to be comparable to traditional fusion techniques [28].

The challenging learning curve associated with minimally invasive spinal procedures in general is particularly relevant for MIS-TLIF [29, 30]. The extended working distance, constricted field of view, paucity of orienting structures, and the disparity in screw placement technique (vs percutaneous versus open screw placement) can create a barrier to adoption. With experience, the surgeon experience is typically felt to be less physically demanding with this minimally invasive technique.

The limited incision size and muscle sparing nature of this procedure help minimize wound complications. This is particularly relevant to healing challenged treatment populations, especially the obese and diabetic [22–24].

There is a pervasive current trend toward shifting surgical treatment to the outpatient setting. MIS-TLIF has been proven to be a safe, effective, and lower-cost procedure in the outpatient model in contradistinction to open fusion [31].

While initially spinal deformity was felt to be a relative contraindication, increasingly MIS-TLIF is being employed in corrective strategies. It can be a useful adjunct in the minimally invasive treatment of spinal deformity when implemented along with lateral interbody fusion and long-segment percutaneous constructs. This is particularly true at L5/S1 and even L4/5 in cases of anterior psoas anatomy precluding the lateral approach.

Complications of MIS-TLIF are in general similar to those of its open analog and include pseudoarthrosis, hardware failure, cerebrospinal fluid leak, subsidence, neural injury, and vascular/visceral injury. Due to the limited exposure of MIS-TLIF, some of these potential complications take on a unique character and deserve special attention. Pseudoarthrosis is a concern in this operation as the grafting surfaces are inherently more limited than those afforded by an open procedure. As stated earlier, meticulous care must be taken during disc preparation so that the endplates are clean and abraded but remain intact. The disc space is the sole fusion surface in this operation in most cases. Advances in biologics cannot make up for poor carpentry. Facet/laminar fusion is another adjunct to help achieve solid arthrodesis but the disc space remains the primary fusion surface. While a thorough direct decompression is part of MIS-TLIF, there is an indirect component that comes from distraction of the interspace. Subsidence can result in recurrent stenosis and is best avoided by appropriate patient selection (avoiding patients with poor bone quality), careful endplate preparation, and avoidance of graft oversizing (which includes over expansion of expandable grafts). Cerebrospinal fluid leak, while thankfully uncommon in MIS-TLIF, can be challenging to address due to the narrow and deep working corridor. Repair techniques are the same as those used in open procedures except that primary closure is not always feasible due to the aforementioned working corridor. The suboptimal suturing ergonomics increase the risk of ensnaring neural elements. Placing a small piece of Gelfoam® just inside the dura can stem the flow of CSF and displace the neural elements away from the suture line. This technique is useful even when suturing is not possible as it gives dural sealant (DuraSeal®) a surface to adhere to. A lumbar drain is usually not necessary but meticulous closure of the fascia up to the skin is paramount. In the authors' experience, pseudomeningocele has not been an issue.

Tips, Pearls, and Bailouts

- Measuring pedicle screw lengths preoperatively on the MRI or CT can be very helpful and allows consideration of facet pathology for screw placement. Maximizing lordosis by hyperextending the hips and flexing the knees with pillows is paramount as most of the MIS devices used for compression are not as effective as their open iterations.
- Rotating the table away from the surgeon can be extremely helpful in enhancing visualization, particularly of the contralateral side. If contralateral decompression is necessary, leaving the ligamentum flavum intact until bone removal is complete facilitates thecal retraction and lowers the risk of cerebrospinal fluid leak.
- Again, the point of adequate discectomy and end plate preparation cannot be stressed enough. The most common obstacle to proper cage insertion and positioning is inadequate discectomy. Especially early on in the learning curve, the surgeon must be sure to take enough time to remove as much disc material as possible from within the disc space. Special care must be taken to remove the disc material from the contralateral, dorsal quadrant of the disc space as this material is poorly visualized.

Summary

MIS-TLIF is a safe and reproducible technique for the treatment of spondylolisthesis, foraminal stenosis, and recurrent disc herniation as well as in less common indications where fusion is required. It results in significantly less tissue trauma than the traditional open version of the technique with literature-proven decreases in blood loss, infection, postoperative narcotic usage, and hospital stay. Due to the decreased incision size and tissue trauma, it is particularly suited for use in obese and diabetic patients. This technique represents an important tool in the treatment of degenerative spine disease.

References

1. Carreon LY, Glassman SD, Howard J. Fusion and nonsurgical treatment for symptomatic lumbar degenerative disease: a systematic review of Oswestry Disability Index and MOS Short Form-36 outcomes. Spine J. 2008;8:747–55.
2. Teng I, Han J, Phan K, Mobbs R. A meta-analysis comparing ALIF, PLIF, TLIF and LLIF. J Clin Neurosci. 2017;44:11–7.
3. Datta G, Gnanalingham KK, Peterson D, Mendoza N, O'Neill K, Van Dellen J, et al. Back pain and disability after lumbar laminectomy: is there a relationship to muscle retraction? Neurosurgery. 54:1413–20; discussion 1420, 2004.
4. Gejo R, Matsui H, Kawaguchi Y, Ishihara H, Tsuji H. Serial changes in trunk muscle performance after posterior lumbar surgery. Spine (Phila Pa 1976). 1999;24:1023–8.
5. Gille O, Jolivet E, Dousset V, Degrise C, Obeid I, Vital J-M, et al. Erector spinae muscle changes on magnetic resonance imaging following lumbar surgery through a posterior approach. Spine (Phila Pa 1976). 2007;32:1236–41.
6. Kawaguchi Y, Matsui H, Tsuji H. Back muscle injury after posterior lumbar spine surgery. A histologic and enzymatic analysis. Spine (Phila Pa 1976). 1996;21:941–4.
7. Kawaguchi Y, Matsui H, Tsuji H. Changes in serum creatine phosphokinase MM isoenzyme after lumbar spine surgery. Spine (Phila Pa 1976). 1997;22:1018–23.
8. Styf JR, Willén J. The effects of external compression by three different retractors on pressure in the erector spine muscles during and after posterior lumbar spine surgery in humans. Spine (Phila Pa 1976). 1998;23:354–8.
9. Foley KT, Holly LT, Schwender JD. Minimally invasive lumbar fusion. Spine (Phila Pa 1976). 2003;28:S26–35.
10. Isaacs RE, Podichetty VK, Santiago P, Sandhu FA, Spears J, Kelly K, et al. Minimally invasive microendoscopy-assisted transforaminal lumbar interbody fusion with instrumentation. J Neurosurg Spine. 2005;3:98–105.
11. Mummaneni PV, Rodts GE. The mini-open transforaminal lumbar interbody fusion. Neurosurgery. 2005;57:256–61; discussion 256-61.
12. Ozgur BM, Yoo K, Rodriguez G, Taylor WR. Minimally-invasive technique for transforaminal lumbar interbody fusion (TLIF). Eur Spine J. 2005;14:887–94.
13. Schwender JD, Holly LT, Rouben DP, Foley KT. Minimally invasive transforaminal lumbar interbody fusion (TLIF): technical feasibility and initial results. J Spinal Disord Tech. 2005;18(Suppl):S1–6.
14. Goldstein CL, Macwan K, Sundararajan K, Rampersaud YR. Perioperative outcomes and adverse events of minimally invasive versus open posterior lumbar fusion: meta-analysis and systematic review. J Neurosurg Spine. 2016;24:416–27.

15. Khan NR, Clark AJ, Lee SL, Venable GT, Rossi NB, Foley KT. Surgical outcomes for minimally invasive vs open transforaminal lumbar interbody fusion: an updated systematic review and meta-analysis. Neurosurgery. 2015;77:847–74.
16. Villavicencio AT, Burneikiene S, Roeca CM, Nelson EL, Mason A. Minimally invasive versus open transforaminal lumbar interbody fusion. Surg Neurol Int. 2010;1:12.
17. Parker SL, Mendenhall SK, Shau DN, Zuckerman SL, Godil SS, Cheng JS, et al. Minimally invasive versus open transforaminal lumbar interbody fusion for degenerative spondylolisthesis: comparative effectiveness and cost-utility analysis. World Neurosurg. 2014;82:230–8.
18. Singh K, Nandyala SV, Marquez-Lara A, Fineberg SJ, Oglesby M, Pelton MA, et al. A perioperative cost analysis comparing single-level minimally invasive and open transforaminal lumbar interbody fusion. Spine J. 2014;14:1694–701.
19. Soegaard R, Bünger CE, Christiansen T, Høy K, Eiskjaer SP, Christensen FB. Circumferential fusion is dominant over posterolateral fusion in a long-term perspective. Spine (Phila Pa 1976). 2007;32:2405–14.
20. Videbaek TS, Christensen FB, Soegaard R, Hansen ES, Høy K, Helmig P, et al. Circumferential fusion improves outcome in comparison with instrumented posterolateral fusion: long-term results of a randomized clinical trial. Spine (Phila Pa 1976). 2006;31:2875–80.
21. Holly LT, Schwender JD, Rouben DP, Foley KT. Minimally invasive transforaminal lumbar interbody fusion: indications, technique, and complications. Neurosurg Focus. 2006;20:E6.
22. Lau D, Khan A, Terman SW, Yee T, La Marca F, Park P. Comparison of perioperative outcomes following open versus minimally invasive transforaminal lumbar interbody fusion in obese patients. Neurosurg Focus. 2013;35:E10.
23. Rosen DS, Ferguson SD, Ogden AT, Huo D, Fessler RG. Obesity and self-reported outcome after minimally invasive lumbar spinal fusion surgery. Neurosurgery. 2008;63:956–60.
24. Terman SW, Yee TJ, Lau D, Khan AA, La Marca F, Park P. Minimally invasive versus open transforaminal lumbar interbody fusion: comparison of clinical outcomes among obese patients. J Neurosurg Spine. 2014;20:644–52.
25. Kim CH, Lee C-H, Kim KP. How high are radiation-related risks in minimally invasive transforaminal lumbar interbody fusion compared with traditional open surgery? Clin Spine Surg. 2016;29:52–9.
26. Adogwa O, Parker SL, Bydon A, Cheng J, McGirt MJ. Comparative effectiveness of minimally invasive versus open transforaminal lumbar interbody fusion: 2-year assessment of narcotic use, return to work, disability, and quality of life. J Spinal Disord Tech. 2011;24:479–84.
27. Sulaiman WAR, Singh M. Minimally invasive versus open transforaminal lumbar interbody fusion for degenerative spondylolisthesis grades 1-2: patient-reported clinical outcomes and cost-utility analysis. Ochsner J. 2014;14:32–7.
28. Isaacs RE, Sembrano JN, Tohmeh AG. Two-year comparative outcomes of MIS lateral and MIS transforaminal interbody fusion in the treatment of degenerative spondylolisthesis. Spine (Phila Pa 1976). 2016;41:s133–44.
29. Lee K, Yeo W, Soeharno H. Learning curve of a complex surgical technique: minimally invasive transforaminal lumbar interbody fusion (MIS TLIF). J Spinal Disord Tech. 2014;27:E234–40.
30. Silva PS, Pereira P, Monteiro P, Silva PA, Vaz R. Learning curve and complications of minimally invasive transforaminal lumbar interbody fusion. Neurosurg Focus. 2013;35:E7.
31. Emami A, Faloon M, Issa K, Shafa E, Pourtaheri S, Sinha K, et al. Minimally invasive transforaminal lumbar interbody fusion in the outpatient setting. Orthopedics. 2016;39:e1218–22.

Chapter 19
Lateral Lumbar Interbody Fusion L3–L4, L4–L5

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History of the Direct Lateral Approach

The first laparoscopic lumbar discectomy was described in 1991 [1, 2], and minimally invasive lumbar surgery has continued to evolve. Stemming from the initial laparoscopic lumbar discectomy were the laparoscopic anterior lumbar approach and mini-open anterior lumbar interbody fusion which were complicated by sexual dysfunction, visceral damage, and large vessel bleeding [3, 4]. First described in 2001, the lateral lumbar interbody fusion (LLIF) also known as extreme lateral interbody fusion (XLIF) has become increasingly popular as it avoids the aforementioned complications of anterior intra-abdominal procedures [3, 5]. Since the introduction of the LLIF technique, reported outcomes include decreased blood loss, decreased operative times, short hospital stays, and less postoperative pain [3, 6, 7] with comparable fusion rates to the anterior lumbar interbody fusion (ALIF) [8, 9]. Furthermore, advantages include indirect decompression, coronal and sagittal plane correction, and stabilization through a less invasive approach [2]. Compared to the posterior approaches, the LLIF does not require retraction of nerve roots or the cauda equina, and leaves bony and ligamentous structures intact [10].

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_19

Anatomy and Anatomic Considerations

The LLIF approach involves using a lateral retroperitoneal transpoas corridor [11], and an understanding of anatomy to the iliopsoas muscle and nerves of the lumbar plexus is vital in order to avoid complications. The direct lateral approach is primarily concerned with the psoas major and psoas minor portions of the iliopsoas [10]. The psoas muscle originates on the transverse processes and lateral borders of the vertebral bodies of T12–L5 [10]. As shown in cadaveric studies, the lumbar plexus is generally found within the psoas muscle between the transverse processes and vertebral body and dorsal to the posterior fourth of the vertebral bodies [12, 13]. The nerve roots exit along the medial edge of the psoas and course anteriorly as they move distally [11, 13]. The iliac vessels course more laterally at more caudal levels [11]. Safe anatomical zones at the disc spaces have been defined using cadavers and show that the anterior 3/4 of the disc space at L3–L4 and the anterior 2/3 of the disc space at L4–L5 are generally free of motor nerves [2, 10, 14]. The genitofemoral nerve is at particular risk at the anterior quarter of the vertebral body at L3–L4 and L4–L5, and the plexus overall is at greatest risk at the L4–L5 level [12]. Furthermore, following the skin incision, care needs to be taken to avoid the subcostal nerves supplying the abdominal wall muscles [10].

Operating Room Setup and Operative Technique

The C-arm is placed across the surgeon with the monitor at the side. The patient is placed in the lateral decubitus position on a radiolucent table with the knees slightly flexed to relax the psoas muscle. The greater trochanter is placed at the table break. The patient is then secured to the table. The table is then flexed to increase the distances between the iliac crest and rib cage which is particularly important when approaching L4–L5. Neuromonitoring is mandatory using the direct lateral approach [6] and a twitch test should be performed prior to initial incision to ensure that no neuromuscular blocking agent has been administered. An anterioposterior (AP) orientation on fluoroscopy should be obtained with the spinous processes in the midline and with the pedicles symmetric. Next, the C-arm should be rotated 90 degrees to obtain a true lateral, confirmed when the pedicles are superimposed on one another and the endplates and posterior cortices are linear. The table rather than the C-arm should be adjusted to obtain the true AP and true lateral images.

Next, the surgical site is prepped, and the appropriate level is identified on the lateral view. Two K-wires are crossed slightly posterior to the midpoint of either L3–L4 or L4–L5, and this area is marked on the patient's lateral side. If a second incision is used for instrumentation, it is made posterior to the lateral incision between the erector spinae muscles and the abdominal oblique muscle. An approximately 2 cm posterolateral (PL) incision is made, and then blunt dissection is carried out using blunt scissor and finger dissection. Fingers are used to advance through the abdominal wall musculature and the retroperitoneal space is accessed. Next, the peritoneum is gently swept off the abdominal wall to allow the contents of the abdominal wall to fall forward. The transverse processes are then palpated along with the origin of the psoas muscle. Next, fingers are used to pass through the PL incision to the lateral incision, bluntly sweeping peritoneum off the underportion of the lateral incision entry point and allowing safe passage while making the lateral incision. The lateral incision is then made in a similar fashion as the posterolateral incision.

After the initial surgical approach is complete, dilators are then introduced. The first dilator is inserted through the PL incision and guided to the lateral border of the psoas muscle. The level of the first dilator is then confirmed under fluoroscopy. Neuromonitoring should then be established through the dilator using the EMG-stimulating surface found on the dilator and stimulation should be maintained through psoas dilation. Use blunt dissection through the psoas fibers and advance the dilator toward the lateral disc paying close attention to the neuromonitoring feedback. The position of the dilator is confirmed on fluoroscopy and secured with a K-wire placed midway into the disc. Sequential dilation is performed and a retractor is placed over the last dilator. The position of the retractor is then confirmed on fluoroscopy. The retractor is then stabilized using an articulating arm. Using an EMG-stimulating probe, the absence of nerves within the surgical field is verified.

Next, the disc spaced is prepared. An ipsilateral annulotomy is performed and the disc space is evacuated, avoiding damage to the endplate and decreasing the risk of implant subsidence. The contralateral annulus is then released ensuring parallel distraction. An implant of the correct size is then carefully chosen and gently impacted while observing nerve activity. If desired, supplemental fixation is then performed using anterolateral plating, unilateral pedicle screws and rod fixation, facet screw fixation, or interspinous fixation. The retractor is then slowly removed, and the disc space and psoas muscle examined for bleeding. The muscles of the abdominal wall are sutured and the skin is closed in a standard fashion. Postoperatively, the patient should be encouraged to mobilize. Side effects include hip flexion weakness from violation of the psoas muscle which typically resolves and sensory disturbances from irritation of sensory nerves [3, 10].

Tips and Tricks

- Appropriate preoperative planning and careful review of preoperative imaging is mandatory, especially when performing a direct lateral approach at the L4–L5 level.
- Pelvic morphology often dictates whether or not access to the L4–L5 level can be accomplished. Radiographs.
- Review of the cross-sectional anatomy in Fig. 19.1 demonstrates an L4–L5 level that can be accessed on the left side only. Figure 19.2 demonstrates an L4–L5 level that will be difficult to access from either side due to the height of the pelvic

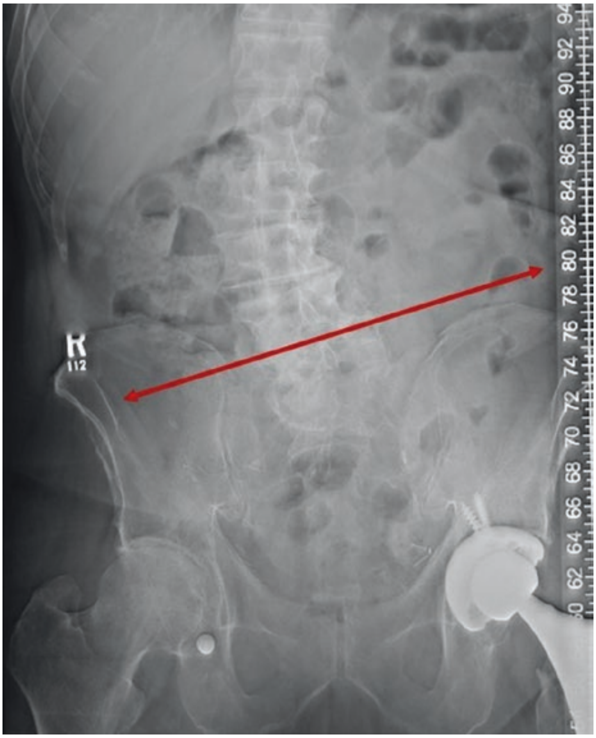


Fig. 19.1 An L4–L5 level that can be accessed on the left side only

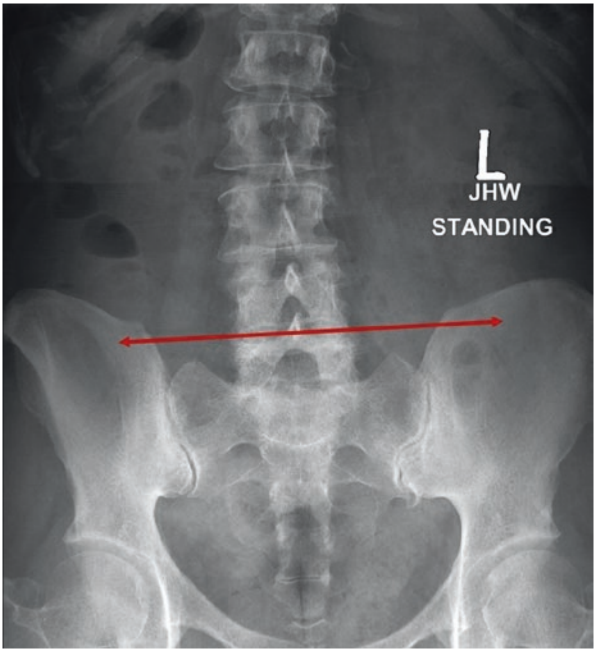


Fig. 19.2 An L4–L5 level that will be difficult to access from either side due to the height of the pelvic brim and the spinal deformity. Pre-operative MRI is imperative

brim and the spinal deformity. Pre-operative MRI is imperative. This includes review of the psoas morphology as well as evaluation of the great vessels. At the level of L4–L5, there is more anatomic variance. Figure 19.3 demonstrates a psoas morphology that is amenable to direct lateral approach; however, the IVC is lateralized and at increased risk for injury. If a direct lateral approach is performed at this level, it is the author's preference to approach the at-risk vessel with the retractor so that direct vision can be used to avoid injury as the vessel is at greatest risk with a contralateral release with the Cobb. Figure 19.4 demonstrates an anteriorly positioned psoas, "mickey mouse ears." This patient would not be candidate for a direct lateral approach as the risk to the lumbar plexus is too great. This psoas anatomy does not allow the retractor to be docked at or behind the "30 yard line."

Fig. 19.3 Psoas morphology that is amenable to direct lateral approach; however, the IVC is lateralized and at increased risk for injury. IVC inferior vena cava

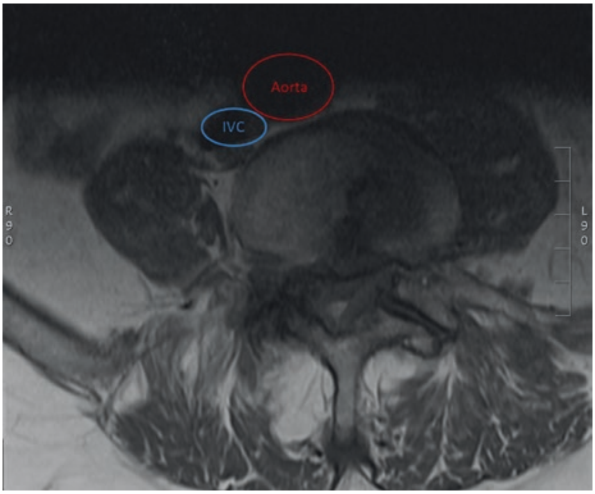
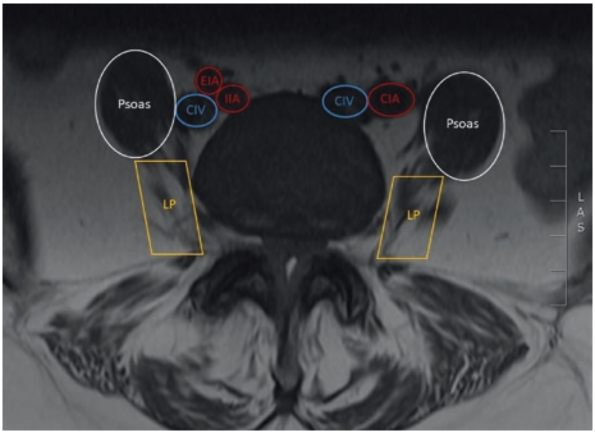


Fig. 19.4 An anteriorly positioned psoas, "mickey mouse ears." EIA external iliac artery, IIA internal iliac artery, CIA common iliac artery, CIV common iliac vein, LP lumbar plexus



- Efficiency is critical during the procedure. Prolonged times with the retractor open in the psoas can result in increased thigh pain and increased risk of neurologic injury or postoperative palsy. We attempt to limit time with the retractor open to approximately 15–20 minutes per level.
- It is important to remove the retractor slowly and observe for bleeding. Large retroperitoneal hematomas have been reported, and these are likely secondary to injury to the segmental artery without adequate hemostasis.
- Careful repair of the abdominal wall musculature is important to prevent postoperative hernia.

Indications and Review of Recent Literature

LLIF is performed for degenerative spinal conditions to provide indirect decompression of neural elements and correction of sagittal and coronal plane deformities. These conditions, similar to those indicated for other lumbar interbody approaches, include degenerative scoliosis, degenerative disc disease, herniated disc, and spondylolisthesis [6, 11, 15]. In rare situations, LLIF can also be indicated for osteomyelitis and tumor excision [6, 11]. The approach for LLIF provides access to the disc space from T12–L1 to L4–L5. The iliac crest prohibits the use of the LLIF technique at the L5–S1 level [11]. The lumbar plexus which lies along the dorsal aspect of the vertebral body courses ventrally, and thus risk of nerve injury increases at the more caudal levels especially at L4–L5 where the safe zone between the nerve roots and the blood vessels anteriorly is reported to be only 13% the diameter of the vertebral body [16]. General contraindications for LLIF are pathology that requires posterior approach, calcified vessels limiting mobility, anatomic renal abnormalities, abnormal plexus, vascular anomalies, severe osteoporosis, retroperitoneal infection, acute fracture, instances where L5–S1 is to be incorporated in the fusion, and when a high-riding iliac crest obstructs the approach [3, 17, 18].

Fusion rates using the LLIF technique vary in the literature from 85% to 97% [19]. In a recent study looking at 77 patients' CT scans following LLIF, 87% were determined to be fused at least 1-year postoperatively [9]. W.B Rodgers 2010 study reported a fusion rate of 97%. 85 of 88 levels in 64 of 66 patients were shown to be fused on CT scan at 1 year postoperatively [19]. Patient-reported outcomes have also been very encouraging. In the same study, 89.4% of patients surveyed at 1 year postoperatively reported they were "satisfied" or "very satisfied" [19]. One systematic review pooled results from 21 studies looking at Visual Analogue Scores (VAS) and Oswestry Disability Index (ODI) following LLIF for correction of spinal deformity. Results showed that VAS scores dropped on average from 6.8 to 2.9 and ODI scores decreased from 44.5 to 20.5 postoperatively [20]. Furthermore, biomechanical studies have shown LLIF to be equally stiff and stable to ALIF [17, 21]. Cost analysis comparing LLIF to traditional posterior lumbar interbody fusion shows an average savings of 9.6% or $2500 per operation [7].

The most common complications following LLIF are iliopsoas weakness secondary to psoas muscle dissection and medial thigh sensory loss shown in one study of 102 patients to occur in 27.5% and 17.6% in respectively. The symptoms were short-lived and resolved in all the patients in this study by the 2-week follow-up. Less commonly, distal motor deficits were reported in 2.9% of the patients but also resolved within 6 months [22]. Other rare but serious complications of LLIF include bowel perforation, post-sympathectomy syndrome, vascular injury, CSF leak, and hardware failure [6, 15, 23]. A large study of 600 patients showed shorter hospital stays and fewer vascular, neurologic, and infectious complications compared to traditional interbody fusion [19]. Overall, recent literature has shown promising results for LLIF with favorable postoperative outcomes and a comparatively low rate of complications.

References

1. Obenchain TG. Laparoscopic lumbar discectomy: case report. J Laparoendosc Surg. 1991;1:145–9. https://doi.org/10.1089/lps.1991.1.145.
2. Bina RW, Zoccali C, Skoch J, Baaj AA. Surgical anatomy of the minimally invasive lateral lumbar approach. J Clin Neurosci. 2015;22:456–9. https://doi.org/10.1016/j.jocn.2014.08.011.
3. Ozgur BM, Aryan HE, Pimenta L, Taylor WR. Extreme Lateral Interbody Fusion (XLIF): a novel surgical technique for anterior lumbar interbody fusion. Spine J. 2006;6:435–43. https://doi.org/10.1016/j.spinee.2005.08.012.
4. Christensen FB, Bünger CE. Retrograde ejaculation after retroperitoneal lower lumbar interbody fusion. Int Orthop. 1997;21:176–80. https://doi.org/10.1007/s002640050145.
5. Pimenta L. Lateral endoscopic transpsoas retroperitoneal approach for lumbar spine surgery. Minas Gerais: VIII Brazilian Spine Society Meeting. Belo Horizonte; 2001.
6. Arnold PM, Anderson KK, McGuire RA. The lateral transpsoas approach to the lumbar and thoracic spine: a review. Surg Neurol Int. 2012;3:S198–215. https://doi.org/10.4103/2152-7806.98583.
7. Deluzio KJ, Lucio JC, Rodgers WB. Value and cost in less invasive spinal fusion surgery: lessons from a community hospital. SAS J. 2010;4:37–40. https://doi.org/10.1016/j.esas.2010.03.004.
8. Rao PJ, Loganathan A, Yeung V, Mobbs RJ. Outcomes of anterior lumbar interbody fusion surgery based on indication: a prospective study. Neurosurgery. 2015;76:7–23; discussion 23–4. https://doi.org/10.1227/NEU.0000000000000561.
9. Berjano P, Langella F, Damilano M, Pejrona M, Buric J, Ismael M, Villafañe JH, Lamartina C. Fusion rate following extreme lateral lumbar interbody fusion. Eur Spine J. 2015;24(Suppl 3):369–71. https://doi.org/10.1007/s00586-015-3929-7.
10. Lehmen JA. Minimally disruptive lateral transpsoas approach for thoracolumbar anterior interbody fusion. In: Phillips FM, Lieberman IH, Polly Jr DW, editors. Minimally invasive spine surgery. Springer; 2014. https://doi.org/10.1007/978-1-4614-5674-2_18.
11. Mobbs RJ, Phan K, Malham G, Seex K, Rao PJ. Lumbar interbody fusion: techniques, indications and comparison of interbody fusion options including PLIF, TLIF, MI-TLIF, OLIF/ATP, LLIF and ALIF. J Spine Surg. 2015;1:2–18. https://doi.org/10.3978/j.issn.2414-469X.2015.10.05.
12. Uribe JS, Arredondo N, Dakwar E, Vale FL. Defining the safe working zones using the minimally invasive lateral retroperitoneal transpsoas approach: an anatomical study. J Neurosurg Spine. 2010;13:260–6. https://doi.org/10.3171/2010.3.SPINE09766.
13. Benglis DM, Vanni S, Levi AD. An anatomical study of the lumbosacral plexus as related to the minimally invasive transpsoas approach to the lumbar spine. J Neurosurg Spine. 2009;10:139–44. https://doi.org/10.3171/2008.10.SPI08479.

14. Smith WD, Youssef JA, Christian G, Serrano S, Hyde JA. Lumbarized sacrum as a relative contraindication for lateral transpsoas interbody fusion at L5-6. J Spinal Disord Tech. 2012;25:285–91. https://doi.org/10.1097/BSD.0b013e31821e262f.
15. Hrabalek L, Adamus M, Gryga A, Wanek T, Tucek P. A comparison of complication rate between anterior and lateral approaches to the lumbar spine. Biomed Pap Med Fac Univ Palacky Olomouc Czech Repub. 2014;158:127–32. https://doi.org/10.5507/bp.2012.079.
16. Regev GJ, Chen L, Dhawan M, Lee YP, Garfin SR, Kim CW. Morphometric analysis of the ventral nerve roots and retroperitoneal vessels with respect to the minimally invasive lateral approach in normal and deformed spines. Spine. 2009;34:1330–5. https://doi.org/10.1097/BRS.0b013e3181a029e1.
17. Winder MJ, Gambhir S. Comparison of ALIF vs. XLIF for L4/5 interbody fusion: pros, cons, and literature review. J Spine Surg. 2016;2:2–8. https://doi.org/10.21037/jss.2015.12.01.
18. Hrabalek L, Adamus M, Gryga A, Wanek T, Tucek P. A comparison of complication rate between anterior and lateral approaches to the lumbar spine. Biomed Pap Med Fac Univ Palacky Olomouc Czech Repub. 2014;158:127–32. https://doi.org/10.5507/bp.2012.079.
19. Rodgers WB, Gerber EJ, Patterson JR. Fusion after minimally disruptive anterior lumbar interbody fusion: Analysis of extreme lateral interbody fusion by computed tomography. SAS J. 2010;4:63–6. https://doi.org/10.1016/j.esas.2010.03.001.
20. Phan K, Rao PJ, Scherman DB, Dandie G, Mobbs RJ. Lateral lumbar interbody fusion for sagittal balance correction and spinal deformity. J Clin Neurosci. 2015;22:1714–21. https://doi.org/10.1016/j.jocn.2015.03.050.
21. Laws CJ, Coughlin DG, Lotz JC, Serhan HA, Hu SS. Direct lateral approach to lumbar fusion is a biomechanically equivalent alternative to the anterior approach: an in vitro study. Spine. 2012;37:819–25. https://doi.org/10.1097/BRS.0b013e31823551aa.
22. Tohmeh AG, Rodgers WB, Peterson MD. Dynamically evoked, discrete-threshold electromyography in the extreme lateral interbody fusion approach. J Neurosurg Spine. 2011;14:31–7. https://doi.org/10.3171/2010.9.SPINE09871.
23. Malham GM, Ellis NJ, Parker RM, Seex KA. Clinical outcome and fusion rates after the first 30 extreme lateral interbody fusions. ScientificWorldJournal. 2012;2012:246989. https://doi.org/10.1100/2012/246989.

Chapter 20
Lateral Lumbar Interbody Fusion L1–2, L2–3

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Background and Indications

The most common indication for lateral lumbar interbody fusion (LLIF) at the L1–L2 and L2–L3 levels is adjacent segment failure. Other reasons for fusion via the lateral approach at these levels include anterior longitudinal ligament (ALL) release, deformity surgery, scoliosis correction, and corpectomy due to tumor, trauma, infection, or deformity [1]. The lateral approach may be useful for fusion of the lumbar spine above L-5 if the anatomy is conducive to the approach. The L2–L3 level is considered one of the most easily and safely accessed levels utilizing the lateral trans-psoas approach. The L1–L2 level, however, can be one of the most challenging lumbar levels due to the proximity to the diaphragmatic crus and thoracic cavity and due to the lower ribs interfering with a direct, in-line exposure [2].

Anatomy

The window to the retroperitoneum can be identified caudally to the twelfth rib. A line drawn from midpoint of the twelfth rib to the iliac crest halfway to anterior superior iliac spine (ASIS), on the lateral portion of the ilium demarcates access to

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_20

the retroperitoneal space while the patient is in the lateral decubitus position. It is critical to understand that the thoracic cavity may be inadvertently entered above the eleventh rib. The diaphragm can be described as an upside down parachute with its attachments to the eleventh rib; it also has a leaflet which can be found posteriorly at the twelfth rib [2, 3]. The pleura covers the superior surface and defines the boundary between pleural cavity superiorly and retroperitoneal cavity inferiorly.

Most often the approach to the L1–L2 level is carried out between the eleventh and twelfth ribs [2]. For this reason, one must avoid the intercostal neurovascular bundle inferior to eleventh rib. The internal and external intercostal muscles are located between the ribs which overly the retroperitoneal cavity. It should be noted for approaches between the tenth and eleventh ribs, the pleural cavity can be entered deep to the intercostal muscles, as the next layer is the inferior reflection of the diaphragm followed immediately by the retroperitoneal cavity [4].

The ilioinguinal and iliohypogastric nerves course on the back wall of the retroperitoneal cavity and are almost never visualized [5]. The retroperitoneal fat and transverse process must be identified to confirm this space. The ureter courses posteriolaterally along the “back side” of the peritoneal sack and can be identified via its peristalsis and pearl white-yellow color but for the most part is not usually visualized [1]. The kidney lies more anteriorly in this space and while patient lies in the decubitus position, it falls away from the surgeon and is rarely an obstruction to adequate exposure as it can be easily moved anteriorly. The kidney may be palpated during these upper level exposures. The L1–L2 and L2–L3 levels are unique with having the confluence of psoas origin and crural insertion of the diaphragm. The insertion appears much different in terms of density and texture than the psoas muscle at the L3–L4 and L4–L5 levels. The tendinous attachments for both the crus of the diaphragm and psoas converge here, while smaller in size than the lower levels of psoas, they can be more restrictive for retractors and the surgeon. Within the musculature at the L1–L2 and L2–L3 levels, the sensory portion of the genitofemoral nerve may be found coursing from the foramen of L2–L3 obliquely at or inferior to the L2–L3 disc space [6]. It should be noted that the starting point of the femoral nerve begins with the L2 nerve which is located well posterior at the L2–L3 disc space or even at the superior portion of the L3 vertebral body [6]. As with the lower levels of the spine, the iliolumbar vein can be found posteriorly adjacent to the neural foramen [7]. Segmental arteries are found at the midportion of the vertebral body, which could be the artery of Adamkiewicz and can be as caudal as the L2 vertebral body, so overzealous opening of the retractor should be avoided [7]. The skin and subcutaneous tissues can be mobilized superiorly with a retractor to access the intercostal muscles between the eleventh and twelfth ribs. Below the twelfth rib in the retroperitoneum, the surgeon can safely push the diaphragmatic reflection superiorly and then use monopolar electrocautery on the superior aspect of the twelfth rib to release the intercostal muscles. Using an index finger to push the diaphragmatic insertion, the surgeon can place an initial dilator into the retroperitoneum. Then, the dilator can be safely docked onto the L1–L2 disc space and stabilized with a K-wire after utilization of neuromonitoring probes.

Intraoperative Imaging

As with any surgery via the lateral approach, one must rely on excellent intraoperative images for successful surgery and complication avoidance. The cross-table anterior-posterior X-ray will require considerable “wig-wag.” The retractor attachment must be well north adjacent to the arm or south by the legs to ensure it does not obscure imaging. A general rule of thumb that will keep the table attachment out of the fluoroscopy field of view is if you are doing L2–L3 or higher, attach the arm to the bed toward the feet in front of the pelvis and if you are operating from L3–L5, place the attachment more toward the head, in front of the chest. Another helpful tip in the set-up for upper lumbar lateral fusions is to place the patient’s arms in the praying position to keep them out of the C-arm’s way. Prior to prepping the patient, the surgeon must check adequate X-ray visualization of the operative level, which must be in the center of the fluoroscope to avoid parallax.

Neuromonitoring

Neuromonitoring is standard of care for approaches to the L1–L2 and L2–L3 levels due to the lateral decubitus position of the patient, femoral nerve, and the spinal cord (which can descend to the L2–L3 level). Somatosensory evoked potential, motor evoked potentials, and electromyography are routinely used for monitoring the L2–L3 and L1–L2 levels [8].

Surgical Techniques

There are three approaches that are defined by the spaces one enters: the infradiaphragmatic retroperitoneal, the retropleural/retroperitoneal, and the transthoracic [2]. The former two approaches will be discussed in this section.

Infradiaphragmatic Retroperitoneal

First, the surgeon marks the incision using X-ray guidance. The initial incision must be inferior to the eleventh rib to avoid entering the thoracic cavity. The intercostal muscles are divided and can be extended posteriorly for better exposure which may be accomplished using digital dissection. Care is taken during dissection of the intercostal muscles to avoid the neurovascular bundle by staying on the superior surface of the twelfth rib. Then, the transversus abdominis is identified and divided by utilizing fingertip dissection or a spreading technique. The retroperitoneal cavity is confirmed by the presence of fat and the transverse process. In order to create a safe working corridor and avoid injury to surrounding tissues, a digital expansion is undertaken by creating a plane in the cephalad direction by pushing the diaphragm superiorly and anteriorly, which will feel as a loose tissue that easily gives way, and in the caudal direction by pushing the peritoneal sac and the associated ureter away. The psoas and crura can then be visualized on lateral aspect of the spine. The dense tendinous attachments of the psoas and crura will need to be opened, often with bipolar electrocautery, under direct visualization. Once the muscle is entered, the disc space is identified by visualizing the annulus. While in the muscle, the nerve arising from the L2 nerve traveling obliquely to create the genitofemoral nerve may be encountered and should be preserved. Posteriorly, the beginning of the femoral nerve at L2–L3 may rarely be observed. It is imperative to identify the anterior aspect of the lumbar spine, both fluoroscopically and in situ. It is common for the aorta and vena cava to be situated up to one cm anteriorly to the lumbar spine at these levels. This fact makes L2–L3 one of the more ideal levels to perform an ALL transection through the use of a specially designed anterior retractor blade that can be slid around the front of the ligament, protecting the vasculature, which will be anterior to this retractor blade. Once this has been accomplished, the discectomy and fusion can be undertaken.

Retropleural/Retroperitoneal

The intercostal muscles are removed from a portion of the eleventh rib using monopolar cautery, a Doyen or Penfield four can be used to dissect periosteum of the rib and the neurovascular bundle from its inferior surface, which is preserved. A portion of the rib four to six centimeters from anterior to posterior is exposed and can be removed. This plane can be developed with the pleura/diaphragm mobilized anteriorly using a finger or a sponge stick. Once this is accomplished, the surgeon has combined the retropleural and retroperitoneal spaces [3].

Pearls and Pitfalls

- Identification of the twelfth rib is paramount and can be more difficult in obese patients. If one inadvertently identifies the eleventh rib as the twelfth, one would enter through the 10–11 intercostal space and likely enter the thoracic cavity.
- Diaphragm openings under four cm do not need to be sutured.
- Preoperative angiogram for planned corpectomy is useful to identify the side and location of the Artery of Adamkiewicz.
- Adequate posterior dissection between the ribs of the 11–12 intercostal space will allow for a better working corridor.
- Use of angled instruments allows for easier access and less tissue exposure for L1–L2.

- Do not inadvertently take the sensory component of the genitofemoral nerve as it can been seen within the psoas at L2–L3.
- There is no femoral nerve at L1–L2 and its location at L2–L3 is posterior which allows for more posterior starting point in the disc space on targeting.
- Colon may be seen on the right side of thin patients: be sure there is no tissue between your working corridor and the transverse process.
- Diliators often do not pierce psoas and crus of the diaphragm at upper lumber levels and they may need to be opened further with a Penfield four and then re-dilated for adequate retraction.
- Obtain a chest X-ray while in the postoperative area to evaluate for pneumothorax.

Cage Selection

The neural anatomy of the upper lumbar levels often allows for larger anterior-posterior cages compared to the caudal lumbar levels as cages may be placed more posteriorly. Based on lateral fluoroscopic intraoperative images, a larger footprint spacer to achieve better end-plate coverage and resistance to subsidence at the L1–L2 and L2–L3 levels may be selected. However, the ribs may push the retractor anteriorly and thus limit space for cage placement.

Final Images

LLIF is approved for use by the U.S. Food and Drug Administration for use with posterior fixation. Oftentimes, these cases are done in a staged manner where the posterior portion of the case will be done as early as a few days after or even up to 2 weeks after the index procedure. By staging these cases, it may be determined if the patient has experienced relief of their preoperative symptoms by mobilizing them early after the LLIF has been done, with physical therapy while in the hospital. In the interval between the two procedures and afterwards, a lumbar sacral orthosis brace is often utilized for support and pain control.

Postoperative Care

Follow-up with patients undergoing these procedures is fairly routine. Hospital stays are generally 1–2 days after an LLIF, unless the procedure is planned as a staged procedure. As with any para-diaphragmatic surgery, diaphragmatic irritation postoperatively may be experienced and should be treated symptomatically as it will usually be self-limited in its course and severity. Certainly, one should always be watchful for any signs or symptoms of pneumothorax, especially when operating at the L1–L2 level. Infrequently, pseudo-paresis of the abdominal musculature that will clinically appear as an abdominal wall hernia may be seen. It is quite infrequent that there is an actual hernia on CT scan, rather a flaccid stripe of abdominal oblique musculature in the area of the exposure. This occurs more commonly when performing multiple levels of fusion but may be more likely when excessive retraction or prolonged retraction of the segmental innervation of the abdominal wall is experienced intraoperatively. This is yet another reason to avoid opening the retractor any more than necessary in the cranial-caudal direction and to be efficacious with one's time spent preparing the disc space for fusion and placing the spacer. Efficiency and attention to detail are the keys to avoiding postoperative neurologic complications.

References

1. Beckman JM, Uribe JS. MIS Lateral Lumbar Interbody Fusion. In: Steinmetz MP, Benzel EC, editors. Benzel's spine surgery. 4th ed: Elsevier; 2017. p. 667–73.
2. Sun JC, Wang JR, Luo T, Jin XN, Ma R, Luo BE, Xu T, Wang Y, Wang HB, Zhang B, Liu X. Surgical incision and approach in thoracolumbar extreme lateral interbody fusion surgery: an anatomic study of the diaphragmatic attachments. Spine. 2016;41(4):E186–90.
3. Dakwar E, Ahmadian A, Uribe JS. The anatomical relationship of the diaphragm to the thoracolumbar junction during the minimally invasive lateral extracoelomic (retropleural/retroperitoneal) approach. J Neurosurg Spine. 2012 Apr;16(4):359–64.
4. Sugrue PA, Kim JCL. Lateral lumbar interbody fusion. In: Kim DH, Vaccaro AR, Dickman CA, Cho D, Lee S, Kim I, editors. Surgical anatomy and techniques to the spine: Elsevier Health Sciences; 2013. p. 459–69.
5. Uribe JS, Arredondo N, Dakwar E, Vale FL. Defining the safe working zones using the minimally invasive lateral retroperitoneal transpsoas approach: an anatomical study. J Neurosurg Spine. 2010;13(2):260–6.
6. Moro T, Kikuchi SI, Konno SI, Yaginuma H. An anatomic study of the lumbar plexus with respect to retroperitoneal endoscopic surgery. Spine. 2003;28(5):423–7.
7. Marco RAW, Bird JE. Anterior retroperitoneal approach to the lumbar spine. In: Kim DH, Vaccaro AR, Dickman CA, Cho D, Lee S, Kim I, editors. Surgical anatomy and techniques to the spine: Elsevier Health Sciences; 2013. p. 375–81.
8. Smith GA, Hart DJ. MIS Lateral Thoracic and Lumbar Decompression. In: Steinmetz MP, Benzel EC, editors. Benzel's spine surgery. 4th ed: Elsevier; 2017. p. 624–629.e1.

Chapter 21

The Ante-Psoas Approach for Lumbar Interbody Fusion

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Background

Several different techniques have evolved to manage degenerative conditions in the lumbar spine. In situations where lumbar arthrodesis is indicated, interbody fusion can be implemented to indirectly decompress the neural elements, restore alignment, and improve fusion rates as well.

As interest in interbody fusion has risen, various approaches have been developed to achieve fusion in a minimally invasive fashion (Fig. 21.1). Traditional posterior lumbar interbody fusion (PLIF) and also transforaminal lumbar interbody fusion (TLIF) techniques approach the intervertebral space posteriorly by traversing the paraspinal musculature; without wide facetectomies and meticulous disc space preparation, these for most surgeons induce kyphosis with insertion of small interbody cages. Anterior approaches have been popularized to obtain fusion in minimally invasive fashions. These anterior approaches include the anterior lumbar interbody fusion (ALIF), the lateral lumbar interbody fusion (LLIF), and the oblique lumbar interbody fusion (OLIF). The ALIF technique allows surgeons to gain access to the lower spinal levels but is associated with risks such as vascular injury and retrograde ejaculation. LLIF has been developed to approach more proximal lumbar levels but is often unable to reliably access caudal levels; it also involves an approach through the psoas muscle, which puts the lumbosacral plexus at risk.

The OLIF utilizes an ante-psoas approach to combine the benefits of the other techniques while minimizing risks to the neurologic structures as well.

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_21

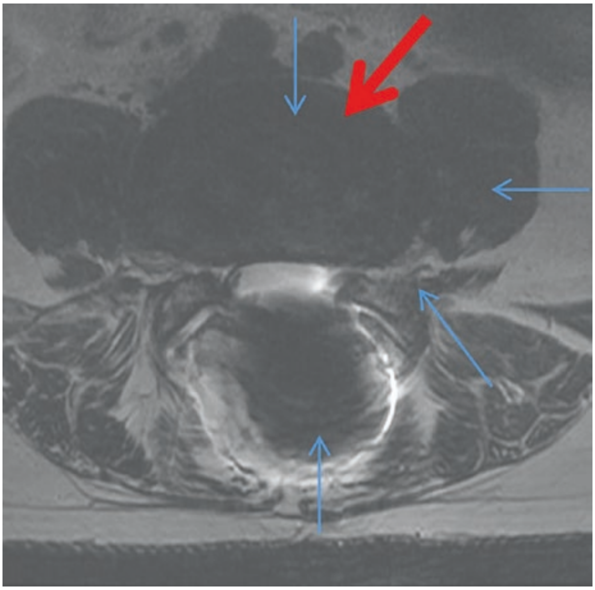

Fig. 21.1 Axial image of the L4–5 level in a patient with prior Harrington instrumentation down to L4. Arrows indicate various approaches to the lumbar interbody space including (clockwise): ALIF, OLIF, LLIF, TLIF, and PLIF

This retroperitoneal approach minimizes muscular dissection and avoids the lumbosacral plexus by going anterior to the psoas. By coming at an oblique angle, the OLIF is able to obtain reliable access to L4–5 and L5–S1 regardless of the iliac crest levels, which the LLIF is unable to do. Additionally, by not requiring the table to be broken (or "jackknifed"), there is no additional risk for neuropraxia. Overall, this allows for a minimally invasive approach to interbody fusion from L2–S1 with such low risk to the lumbosacral plexus that neuromonitoring is not even required.

The advent of robotic surgery has made simultaneous anterior and posterior surgery possible as well. The OLIF can be performed in the lateral position; meanwhile, pedicle screws can be placed posteriorly through a minimally invasive percutaneous approach as well. This can help minimize time required in the OR.

Most studies in the literature on OLIF are small series with short-term follow-up [1]. In 1997, Mayer first described the ante-psoas approach and then reported on 20 cases with mean 11-month follow-up [2]. Mean OR time was 111 minutes, mean blood loss of 67.8 mL, there were no complications, and all patients fused.

In 2012, Silvestre et al. reported on the largest to date series of 179 OLIF cases, with mean 11-month follow-up [3]. Mean OR time was 54 minutes. They reported several complications, including sympathetic chain injury (1.7%) and vascular injury (1.7%). Fusion rates were not reported. A recent systematic review included 16 articles with no randomized clinical trials or direct comparative studies with TLIF and PLIF [1]. Despite the promising early results and theoretical benefits, future larger prospective studies are necessary to truly clarify the risks and benefits of the ante-psoas approach.

Anatomy

When compared to the posterior approach to the lumbar spine, there are unique anatomic structures at risk when performing an ante-psoas approach to the lumbar spine. Superficially, the initial muscular layers encountered are the external oblique, internal oblique, and transversus abdominus muscles. These muscles are thin and can be traversed with blunt dissection or electrocautery to reach the retroperitoneal space. Care should be taken to avoid damaging the ilioinguinal and iliohypogastric nerves, both branches of the L1 nerve root, as they may occasionally cross the surgical field deep to the internal oblique at the L4–5 level [2]. The lateral position of the OLIF approach is a distinct advantage at this point, because it allows the peritoneal contents to move away with gravity, thereby expanding the surgical corridor [4].

The surgical corridor is framed by the psoas major posteriorly and the great vessels anteriorly. Imaging studies have shown that the corridor is 16 mm at L2–3, 14 mm at L3–4, and 10 mm at L4–5 and 10 mm at L5–S1 [5]. These corridors can be expanded with gentle retraction, although care must be taken to avoid injuring the lumbar plexus [6]. The lumbosacral plexus lies within the substance of the psoas major, and is positioned more dorsally in the proximal levels, and more ventrally in the distal levels [7]. Since the ante-psoas approach by definition does not traverse the psoas muscle, neuromonitoring is not required.

Surgical Technique

An important step of the OLIF is preoperative planning. The common iliac vessels must be studied to determine the corridor of approach. A left-sided approach is conventionally used, but analysis of the MRI will help determine, especially at L4–L5, whether the approach will be lateral to the vessels or in between them as would be the case at L5–S1.

Then, the patient should be positioned in right lateral decubitus position so that the left-sided approach can be utilized (Fig. 21.2). A radiolucent table in slight Trendelenburg should be used for radiographic visualization, and the patient should be placed anteriorly on the table so that the abdominal contents hang ventrally away from the operative field. Bony prominences should be padded, and tape should be used to prevent movement of the patient during the operation. A 270-degree prep and drape should be applied to allow for complete abdominal and posterior access as needed.

AP and lateral fluoroscopic images should be taken before incision to ensure that intraoperative imaging will be possible in the current setup. Before making incision, basic markings for localization should be drawn. The iliac crest, the twelfth rib, and the anterior superior iliac spine (ASIS) can be palpated and marked, while the levels of the disc spaces can be marked after fluoroscopic confirmation. These can be used to plan the next set of markings that can be made to guide the incision.

Fig. 21.2 Positioning in right lateral decubitus position with bony prominences padded, the abdomen hanging off the table, and the patient well secured in place

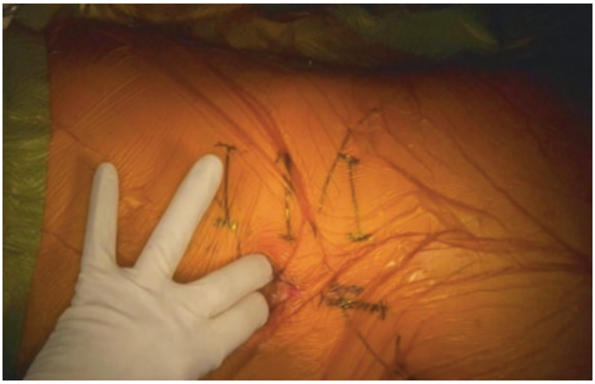

Fig. 21.3 Incision for access to the L4–L5 disc space

For an approach to L5–S1, the line marking the L5–S1 disc space should be extended past the ASIS. Another line should be drawn from the center of the disc space horizontally straight to the table. The incision will be about 6 cm between these two lines through a point 2–3 cm anterior to the ASIS. The L4–L5 level can be approached through this incision as well or can be accessed through a separate incision, such as that would be used for any of the levels from L2–L5. For this approach, a longitudinal incision can be made 6 cm anterior to the disc space of interest (Fig. 21.3).

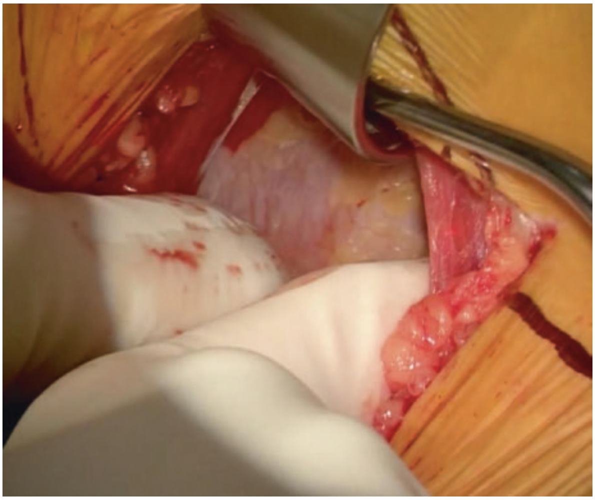

Fig. 21.4 Blunt dissection to enter the retroperitoneal space

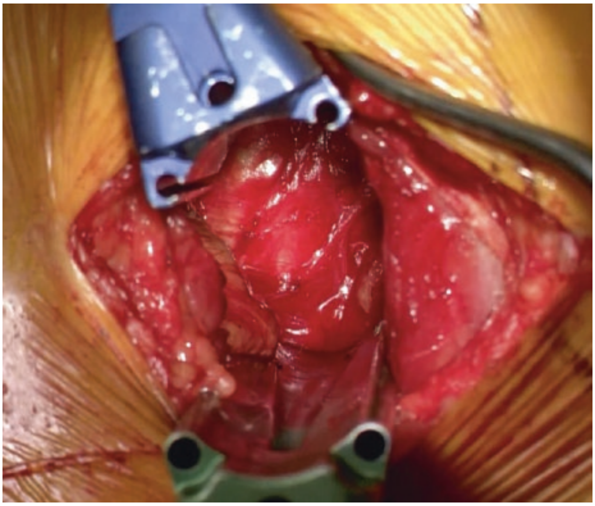

Fig. 21.5 Exposure of the disc space

Then, a digital blunt dissection can be performed through the external oblique, internal oblique, transversus abdominus, and transversalis fascia to enter the retroperitoneal space (Fig. 21.4). Be sure to look out for the iliohypogastric and ilioinguinal nerves which may be in the operative field at this level below the internal oblique, especially at the L4–L5 level.

Blunt dissection and insertion of retractors allows access to the disc space (Fig. 21.5). For access to L5–S1, useful internal landmarks to palpate are the inner table of the ilium, the psoas sling, and the iliac artery. To gain access to the disc space, care must be taken to mobilize the anterior disc space adventitial layer to allow for maximal mobility of the iliac vessels; the iliolumbar vein can be mobilized or sacrificed if in the operative field. The sacral vessels can be preemptively ligated

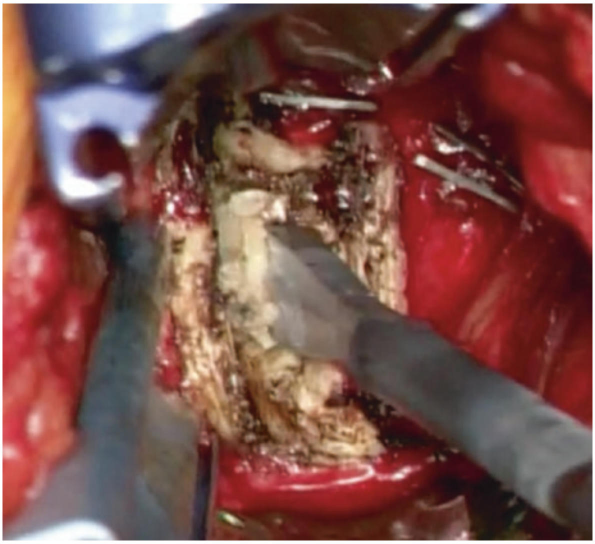

Fig. 21.6 Shavers to facilitate the discectomy

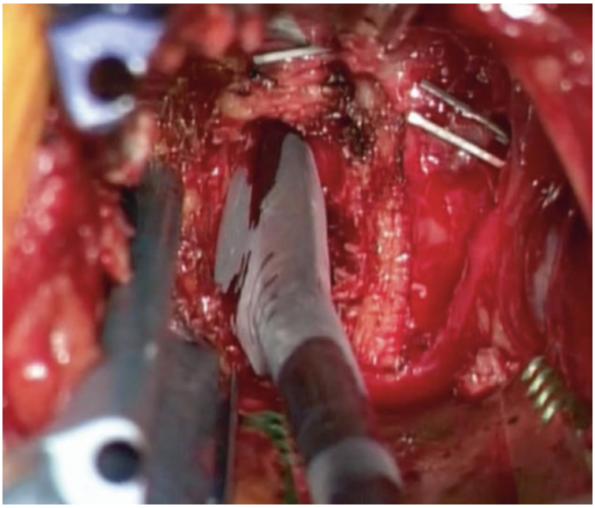

Fig. 21.7 Gentle rotation of the paddle to loosen up the intervertebral space

as well. For the proximal lumbar levels, direct palpation of the psoas posteriorly and sweeping the common iliac vessels ventrally allows direct access to the disc space. Radiographic confirmation of level can be performed, and the psoas and vessels can be gently manipulated in order to maximize exposure.

Once the level has been confirmed, the disc space can be marked with a bovie, and an annulotomy and discectomy can be performed using various instruments such as electrocautery, pituitary and kerrison rongeurs, straight and curved curettes, and disc shavers (Fig. 21.6). A paddle can help gently open up the disc space further

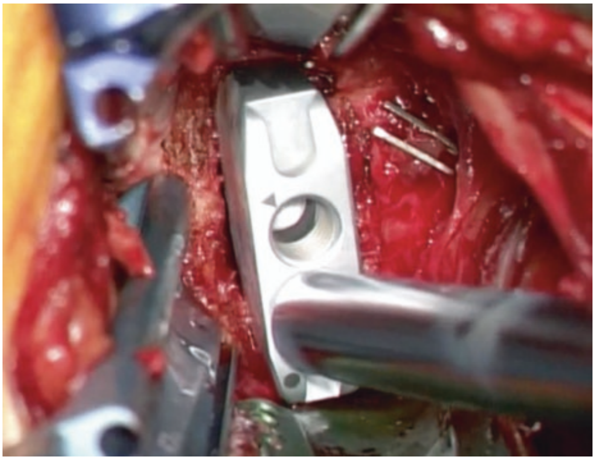

Fig. 21.8 Trialing to determine implant size

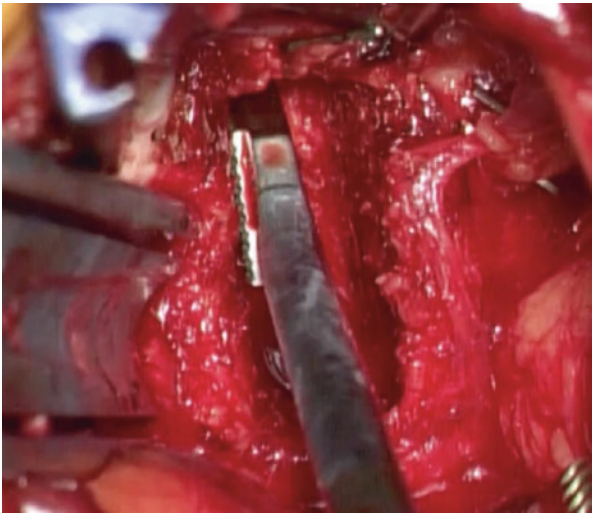

Fig. 21.9 Rasping to denude the cartilage from the endplates

without compromising the endplates (Fig. 21.7). Trialing can help determine the optimal cage dimensions for insertion (Fig. 21.8).

A rasp can be used to denude the endplates of cartilage (Fig. 21.9); the endplate can also be penetrated to induce bleeding, thus enhancing local healing response (Fig. 21.10). The ALL can be removed and the anterior osteophytes smoothened with a burr (Fig. 21.11).

Per the preference of the treating surgeon and the patient, the cage can be stuffed with bone graft and BMP and then inserted (Fig. 21.12). After final radiographic confirmation, the abdominal wall musculature can be closed in layers over drains.

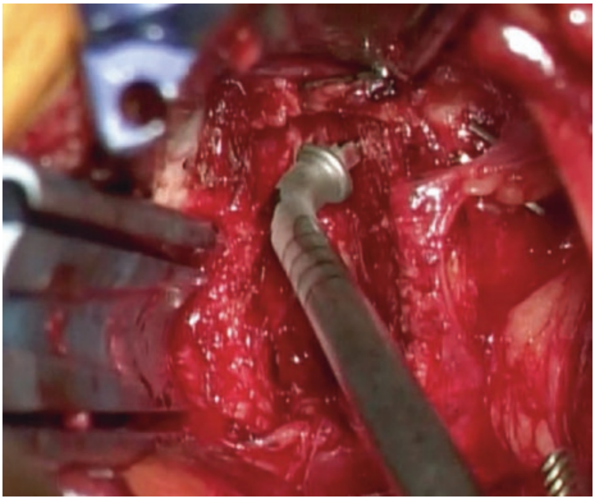

Fig. 21.10 Puncturing the endplates to induce local bleeding

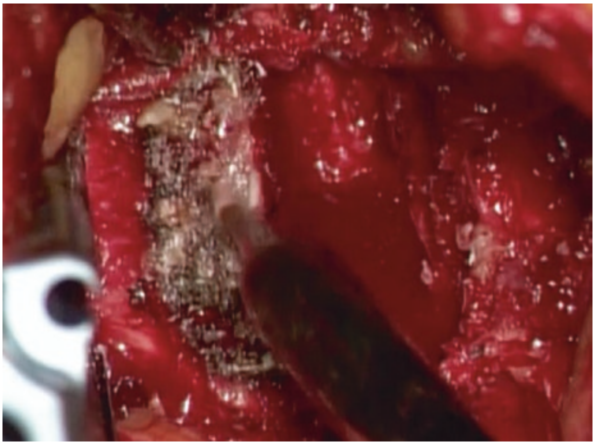

Fig. 21.11 Smoothening of the endplates after removal of the ALL

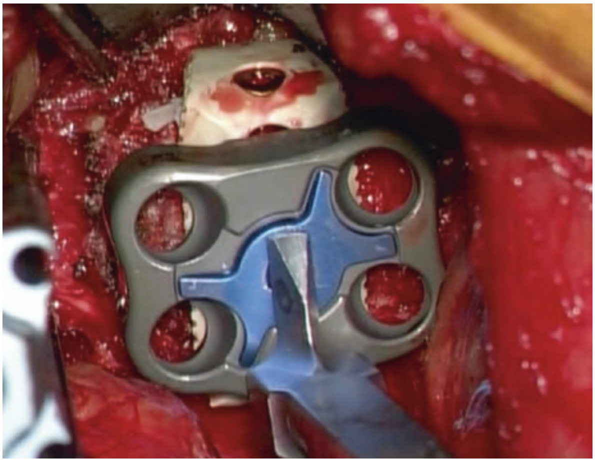

Fig. 21.12 Final insertion of plate and interbody

Summary

The ante-psoas approach to the lumbar spine is a useful addition to the armamentarium of approaches for the spinal surgeon. It maximizes the benefits of anterior approaches to the lumbar spine, including larger interbody cages and minimally invasive approaches, while minimizing complications traditionally associated with ALIF and the LLIF.

References

1. Phan K, Maharaj M, Assem Y, Mobbs RJ. Review of early clinical results and complications associated with oblique lumbar interbody fusion (OLIF). J Clin Neurosci. 2016;31:23–9.
2. Mayer HM. A new microsurgical technique for minimally invasive anterior lumbar interbody fusion. Spine. 1997;22(6):691–9.
3. Silvestre C, Mac-Thiong JM, Hilmi R, Roussouly P. Complications and morbidities of mini-open anterior retroperitoneal lumbar interbody fusion: oblique lumbar interbody fusion in 179 patients. Asian Spine J. 2012;6(2):89–97.
4. Deukmedjian AR, Le TV, Dakwar E, Martinez CR, Uribe JS. Movement of abdominal structures on magnetic resonance imaging during positioning changes related to lateral lumbar spine surgery: a morphometric study. J Neurosurg Spine. 2012;16(6):615–23.
5. Molinares DM, Davis TT, Fung DA. Retroperitoneal oblique corridor to the L2-S1 intervertebral discs: an MRI study. J Neurosurg Spine. 2015;9(1–8).
6. Davis TT, Bae HW, Mok JM, Rasouli A, Delamarter RB. Lumbar plexus anatomy within the psoas muscle: implications for the transpsoas lateral approach to the L4-5 disc. J Bone Joint Surg Am. 2011;93(16):1482–7.
7. Benglis DM, Vanni S, Levi AD. An anatomical study of the lumbosacral plexus as related to the minimally invasive transpsoas approach to the lumbar spine. J Neurosurg Spine. 2009;10(2):139–44.

Chapter 22

Anterior Lumbar Surgery

Tiffany Grace Perry

History

In 1906, the first report of a successful anterior transperitoneal approach to the lumbar spine was performed by W. Muller. He was performing the surgery for a supposed sarcoma and instead he found tuberculoma. The surgery itself proved to be successful, and the patient had a good outcome [1]. However repeated attempts of the same approach for similar indications were unsuccessful. Therefore, the transperitoneal approach was abandoned until about 1933 when B. H. Burns performed an anterior interbody fusion at L5/S1 for spondylolisthesis. The patient was a 14-year-old boy who had a traumatic grade 2 spondylolisthesis with debilitating pain after a jump. His recovery was uneventful, and his axial back pain improved. Prior to this, the only known surgical approach for spondylolisthesis was a dorsal fusion, which had a high failure rate in this setting.

Most of these early anterior approaches were for the setting of tuberculosis. The surgeries were laden with complications due to the approach; however, they were confounded by the fact that postoperative infections were prevalent given the lack of antibiotic therapy at that time period.

Ito and colleagues reported their work from 1923 with 10 surgeries that were used to approach the lumbosacral region for sympathetic ganglionectomies to improve lower extremity circulation. In 1925, they reported a modification to this technique to expose the lumbosacral spine for surgeries for Potts disease.

The advent of improving imaging from X-rays to CT to MRI has been paramount in improving preoperative planning and avoiding complications during surgery. However, a surgeon must understand the anatomy of the region to ensure optimal exposure and outcomes from anterior spinal surgeries.

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_22

Anatomy

Musculature

Lateral to the rectus abdominis muscle, there are three muscles: the external and internal oblique muscles and the transversus abdominis muscle. The fascia of each of these muscles coalesce to comprise the anterior and posterior rectus sheath around the rectus abdominis muscle. Deep to the rectus is the transversalis fascia and the peritoneum. Layers of adipose may be located here variable depending on the patient's habitus. As the peritoneum traverses laterally, it becomes much thinner which is important during the surgical dissection to gently dissect this layer away to minimize peritoneal tears.

The posterior muscles adjacent to the spine include the psoas major muscle and just lateral is the quadratus lumborum muscle superiorly and the iliacus muscle inferiorly. The right crus of the diaphragm inserts at L3 and the left crus inserts into L2.

Genitourinary

The genitourinary system is another important region of concern for the approach surgeon. On the left side, the ureter and ureteral blood vessels and the gonadal vessels track medially over the iliac artery and vein. Care must be taken upon a left retroperitoneal approach to preserve the vascular supply of these structures. Around the L2 region, the inferior border of the left kidney may be encountered.

Vasculature

Vascular structures that may be encountered in this approach are the distal aorta and distal inferior vena cava, bilateral iliac artery and vein, and the middle sacral vessels which may be encountered at the L5/S1 disc space. The iliolumbar vein may also be encountered at the L4/5 disc space. These smaller vessels are more prone to shear injury and may be difficult to repair given their thin non-muscular walls. Vascular injuries may result in significant blood loss. It is critical to have type and cross prepared on these patients preoperatively to ensure blood is ready in the room at the beginning of these cases. The thicker walled arteries are typically easier to repair than the thin-walled veins which can be quite delicate and friable to reapproximate a tear.

Lymphatics

The thoracic duct originates around L1 or L2 and travels superiorly to drain into the left innominate vein. It is important in an anterior approach to the L2/3 disc space to ensure identification without disruption of the duct. Disruption of the duct or lymph node structures may lead to a postoperative lymphocoele. While a rare complication, it is important to identify if possible at surgery so that the lymphatics may be appropriately tied off or clipped to prevent further leakage [2].

Sympathetics

The lumbar sympathetic chain runs along the ventrolateral border of the vertebral bodies on either side. Disruption of this at one level on one side will likely not lead to clinical significance. However, disruption at multiple levels on both sides may lead to significant postoperative ileus as well as retrograde ejaculation if there is disruption of the hypogastric plexus.

Patient Selection

Patients with BMI less than 30 are optimal for this approach. Archer et al. found that patients with higher BMI were also more likely to be re-admitted postoperatively with complications [3]. The larger the body habitus, the more difficult and more risky the exposure through the anterior approach. Patients with multiple prior abdominal surgeries should be evaluated by the vascular surgeon to determine if anterior lumbar approach is an option for them. Phan et al. found that there were no functional differences or complications in patients with elevated BMI compared with normal-weight patients. However, the rates of pseudarthrosis were higher in the elevated BMI group [3]. The other patient population to consider are patients with baseline vascular disease or abnormal vascular anatomy, such as descending aortic aneurysms or anomalous renal arteries.

Patients with tumor, prior radiation, or infection are a subset of patients who will have significant scar tissue and have more difficult access to the lumbosacral spine. An anterior lumbar approach may be possible for these patients but must be performed with caution and respect to the tissues.

Patient age is also a consideration for an anterior surgical approach to the lumbar spine. McDonnell et al. found that patients who were 61–85 years old in their study had a significantly higher overall rate of complications [4].

Surgical Approach

Access to the anterior lumbar spine is an important surgical approach for correction of a deformity as well as building a stable base for a long construct. Anterior access is also useful in tumor and infection lumbar surgery where the vertebral body and/or the disc space is involved. Correction of lumbar kyphosis can be best achieved by providing a tall interbody graft at the disc spaces.

Positioning

The patient is positioned in a supine position with the arms at 90 degrees to the axis of the body to either side of the patient, maintaining the arms out of the surgical X-ray field. All pressure points should be padded, including a pillow under the knees, foam under the ankles, and elbows and a gel rest for the head. The pelvis should be centered on the bed and should be completely neutral on the table. Angulation of the pelvis may lead to off-centered implants or difficulty with exposure. In patients with severe deformities, positioning and exposure may be more tedious. Taking time for positioning at the beginning can prevent time-consuming complications later.

Surgical Approach to Retroperitoneum

If access is needed to only the L5/S1 level or L4/5 level, typically, the approach can be performed with a small transverse lower abdominal incision. If access to multiple lumbar levels is needed a vertical incision facilitates retraction of the skin and soft tissues superiorly or inferiorly as needed. The skin is incised and the midline raphe of the rectus abdominis muscle is then identified. The left rectus muscle may be retracted laterally or medially. The inferior epigastric vessels should be identified and should be spared if possible. The hand or sponge stick is used to perform a sweep along the lateral border to mobilize the intraperitoneal contents and the peritoneum medially. At this point, the left vascular structures should be palpable and visualized as the table-mounted retractors are put into place. The ureter should be identified and retracted medially.

Surgical Approach to the Disc Space

At L5/S1, the bifurcation of the inferior vena cava and the descending aorta usually is located at the L4/5 disc space facilitating approach to the L5/S1 disc space with simple dissection of the medial aspect of the right and left iliac artery and vein on either side [5]. Access to the L4/5 level is accomplished with careful dissection of the bifurcation with retraction of the vessels to the right. Mobilization of these blood vessels is important to achieve adequate visualization of the disc space. Anterior access can also be achieved at the level superior to this if the blood vessels are easily mobilized. The more superior the dissection, the more difficult the blood vessels usually are to mobilize as well as the longer the incision and usually slightly more difficult angles getting interbody grafts in place.

When the appropriate disc space is identified and confirmed via radiography, the disc should be incised in a box fashion with a 10 blade on a long handle. Avoiding monopolar cautery in this region is important due to potential for thermal injury to the sympathetic fibers of the hypogastric plexus to minimize the risk of retrograde ejaculation. The large or medium cobb can be used to dissect along the cartilaginous endplate of the level above and the level below. A large pituitary may be used to remove a large portion of the disc. Up-angled and straight curettes may be used to scrape along cartilaginous endplate to remove any remaining disc. A high-speed drill may be used to decorticate along the endplate to ensure good fusion surface preparation.

There are template trials that can be malleted into the disc space which are used to determine the appropriately sized implant, including amount of lordosis, height, and width. There are several options for implants within the disc space. Historically, tricortical bone may be used with a femoral ring allograft. A washer and a screw are used to hold this into place. This would be used in conjunction with a posterior approach to hold the graft solidly in place. Other options include bone graft with a plate; however this does require slightly more exposure for placement of the plate with concerns of the vasculature scarring to the plate postoperatively. A third option includes PEEK interbody graft packed with bone or other bone growth stimulants. These typically have three or four screws which traverse through the cage to hold the implant in place.

Once the implants are in place and an X-ray confirms appropriate placement and level, closure may be performed. As the table-mounted retractors are removed, care should be taken to ensure that the blood vessels that had been retracted, do not have any tears or injuries that were tamponaded by the retractors. Remove the medial retractor first to ensure that there is no injury to these vessels. If constant oozing is noted, this retractor could easily be placed again, since all the other retractors remained in place. Once all retractors are able to be removed, the peritoneum should be inspected to ensure there are no tears. The anterior rectus sheath is approximated using a running monofilament suture taking care to maintain tension on the fascia. An excellent closure here is key for prevention of ventral hernias postoperatively. The skin may then be closed with a running subcuticular monofilament suture.

Complications

Complications of this approach can be determined by the location of the surgery. First is the potential for a postoperative ventral hernia which should be able to be prevented by meticulous closure at the end of the surgical procedure. Second is the risk for peritoneal tear or injury to the contents of the peritoneum. A tear in the peritoneum can be repaired at the end of the procedure. The key thing is identification of these tears when they occur. Injury to the bowel may also occur in this setting. Identification of this type of injury is critical for a good repair and postoperative management.

Third, injury to the ureter would be a significant complication and in revision surgeries is important for the ureter to be palpable and identified with a ureteral stent that may be placed by a urologist preoperatively. Genitourinary complications have been identified in some studies as the most common minor categorized complication [6].

Fourthly, the most common complication is injury to the iliac vein or artery. This is the primary reason that most spine surgeons have a vascular approach surgeon for these types of procedures. The approach surgeon is able to identify potential complications early and also deal with any complications of the vasculature more readily. At the L4/5 level, the iliolumbar vein will be encountered. It is important to identify this vessel given that superior retractors may shear it during exposure. The most common vascular injury occurs to the vein during retraction of the great vessels [7].

Another complication worthy of mentioning again is retrograde ejaculation that is most likely due to an injury to the hypogastric plexus. This occurs in up to 8% of patients, however may be under-reported. The prevertebral sympathetic chain runs along the ventrolateral border of the vertebral bodies and crosses over the aortic bifurcation and iliac vessels to coalesce as the hypogastric plexus. Thermal injury from the monopolar cautery or direct injury to the plexus may result in retrograde ejaculation. Bateman et al. reported retrograde ejaculation postoperatively from anterior lumbar spine surgery as 2.7% in a systematic review and meta-analysis [8].

Postoperative complications include deep venous thrombosis due to retraction on the deep venous structures during surgery as well as postoperative immobility. Starting patients on DVT prophylaxis post-op is important for prevention. Postoperatively, pulses should be palpated in the lower extremities and feet should be examined daily for edema [9].

An ileus may also develop for normal postoperative reasons including immobility and narcotic and opioid use. Therefore, it is critical to mobilize the postoperative patients early and encourage medication alternatives to opioids and narcotics.

Other complications are related to the structural issues of the spine. These include subsidence of interbody spacers and pseudarthrosis. The keys to avoiding these structural complications are to optimize the patient preoperatively with no nicotine use, evaluation and treatment of osteoporosis, use of posterior instrumentation in the setting of pars defects or grade 2 and above spondylolisthesis, and measuring the sacral slope to determine the patients who are more likely to fail with a standalone anterior approach.

Conclusion

Anterior lumbar interbody fusion is an excellent approach for degenerative disc disease and other pathology of the lumbosacral spine and allows for optimal midline placement of an interbody graft, as well as a larger footprint than that of a posterior interbody approach. This procedure may be used as a standalone procedure but also may be used in conjunction with posterior approaches for deformity correction, infection, tumor, and structural defects. Appropriately sized grafts and placement within the instantaneous axis of rotation is important for loading the graft for osseous integration and fusion. Most spine surgeons collaborate with an excellent vascular approach surgeon to minimize complications in the intraoperative and postoperative periods.

Pearls

- Patient selection is important to determine risks and benefits of an anterior lumbar interbody approach as well as to determine if the patient will need posterior instrumentation.
- Optimal disc space preparation is important for bone fusion.
- In patients with pars defects or fractures, it is important not to over-distract the disc space.
- Be mindful of intraoperative and postoperative complications as early identification of vascular injury and DVT‘s is critical.

References

1. Zhao J, Gum J, Dimar J II, Buchowski J. Anterior lumbar interbody fusion. In: Spondylolisthesis: Diagnosis, Non-surgical management, and Surgical Techniques; 2015. p. 179–80.
2. Schizas C, Foko’o N, Matter M, Romy S, Munting E. Lymphocoele: a rare and little known complication of anterior lumbar surgery. Eur Spine J. 2009;18(Suppl 2):228–31.
3. Phan K, Rogers P, Rao PJ, Mobbs RJ. Influence of obesity on complications, clinical outcome, and subsidence after anterior lumbar interbody fusion (ALIF): prospective observational study. World Neurosurg. 2017;107:334–41.
4. McDonnell MF, Glassman SD, Dimar JR II, Puno RM, Johnson JR. Perioperative complications of anterior procedures on the spine. J Bone Joint Surg Am. 1996;78(6):839–47.
5. Vaccaro AR, Kepler CK, Rihn JA, Suzuki H, Ratliff JK, Harrop JS, Morrison WB, Limthongkul W, Albert TJ. Anatomical relationships of the anterior blood vessels to the lower lumbar intervertebral discs: analysis based on magnetic resonance imaging of patient in the prone position. J Bone Joint Surg Am. 2012;94(12):1088–94.
6. Sivaganesan A, Zucherman S, Chan I, Nian H, Harrell FE Jr, Pennings JS, Harbaugh R, Foley KT, Bydon M, Asher AL, Devin CJ, Archer KR. Predictive model for medical and surgical readmissions following elective lumbar spine surgery: a national study of 33,674 patients. Spine (Phila Pa 1976). 2018.
7. Inamasu J, Guiot BH. Vascular injury and complication in neurosurgical spine surgery. Acta Neurochir. 2006;148(4):375–87.
8. Bateman DK, Millhouse PW, Shahi N, Kadam AB, Maltenfort MG, Koerner JD, Vaccaro AR. Anterior lumbar spine surgery: a systamtic review and meta-analysis of associated complications. Spin J. 2015;15(5):1118–32.
9. Brau SA, Delamarter RB, Schiffman ML, Williams LA, Watkins RG. Left iliac artery thrombosis during anterior lumbar surgery. Ann Vasc Surg. 2004;18(1):48–51.

Chapter 23

Lumbar Total Disc Replacement

Jeffrey H. Weinreb

Introduction

Lumbar total disc replacement (TDR) has been advocated as a method to treat single-level degenerative disc disease in the lumbar spine in skeletally mature patients without high-grade spondylolisthesis who have failed conservative treatment [1]. First implemented in the 1980s in Europe, various implants have been utilized in the United States, with one implant currently approved by the FDA. Currently, decompression and fusion for degenerative disc disease is a commonly utilized procedure to excise degenerative compressive elements and immobilize unstable segments. However, drawbacks of arthrodesis include pseudarthrosis and adjacent segment degeneration likely from alterations in the normal biomechanics of the lumbar spine, thereby putting excessive stresses on adjacent levels [2]. The purpose of TDR is to restore and maintain motion segment mobility which is intended to prevent adjacent segment disease and relieve pain [3].

The normal intervertebral disc consists of the central nucleus pulposus which functions to absorb compressive stress and the outer annulus fibrosis which resists shear force [2]. A healthy lumbar disc bears 80% of compressive loads and is subjected to from one to 10 times body weight depending on activity [2]. As the discs degenerate, the water content of the nucleus pulposus decreases, leading to decreased compliance and subsequent collagen degeneration. The pain caused by disc degeneration is multifactorial. Degenerating discs activate the inflammatory cascade which leads to the systemic release of pain generating inflammatory cytokines [2]. Additionally, as the disc loses height, the facet joints are loaded with eventual narrowing of the foramina and neural element compression [2].

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_23

While most modern TDR implants do not attempt to replace the normal biomechanics of the native disc, current constructs factor in the angular and translational motion exerted on the disc as well as the variable center of rotation. TDR attempts to restore the mobility afforded by the native motion segment that is lost during traditional fusion [2]. Additionally, two implants with inherent viscoelastic properties are currently being implemented in Europe or undergoing investigation in the United States [2].

Indications and Contraindications

Indications for lumbar TDR include one level discogenic back pain between L3 and S1 for patients 18–60 years old who have not responded to 6 months of conservative therapy [4].

Contraindications include active infection, either local, or systemic, as hardware infection may necessitate revision surgery. Bony growth into the implant is crucial for TDR success, so patients must have a dual energy X-ray absorptiometry bone density measured T-score greater than −1.0. As TDR does not directly decompress neural elements, additional contraindications include central or lateral recess stenosis, significant spondylosis/spondylolisthesis, scoliosis, or facet arthropathy [4]. Additionally, as the TDR implant is generally inserted through an anterior approach, prior abdominal surgery or a calcified aorta are contraindications as well. While not an absolute contraindication, morbid obesity may make surgical approach more difficult. Although TDR constructs attempt to recreate some of the mobility afforded by the natural lumbar disc, preparation of the disc space may result in increased rotational instability; therefore, patients with an existing rotational instability as defined by a Cobb angle greater than 11 degrees are contraindicated for TDR [1, 2, 5].

Technique

Preparation and Positioning

For the anterior approach to TDR, the patient should be placed in a supine position with the arms taped across the chest with adequate pressure point padding. Fluoroscopy may be used to position the break of the table in the surgical level to allow better access to the intended disc space. Additionally, the plane of the pelvis should be parallel to the floor to ensure correct implant placement [1].

Approach

The surgical approach differs based on the level of the TDR. The TDR approach for L3–4 or L4–5 is lateral to the descending aorta and inferior vena cava while the approach for TDR at L5–S1 is inferior to the bifurcation of the aorta into the common iliacs [4]. Collaboration with a vascular access surgeon for exposure is recommended.

For L3–L5 discs, both a midline rectus and a paramedian lateral rectus approach have been described [6]. A vertical incision is made either at midline or over the lateral border of the left rectus muscle depending on the approach. Again, depending on approach, the midline linea alba of the rectus or the external oblique fascia is incised and the retroperitoneal space is entered by retracting the rectus muscles appropriately. A retroperitoneal dissection that starts on the medial border of the rectus and progresses posterolaterally to the muscle belly protects the innervation of the rectus. The inferior epigastric vessels are deep to the rectus muscle and should be avoided. The ipsilateral ureter should be identified, distinguished by its characteristic peristalsis, and retracted towards midline with a handheld retractor along with the peritoneal sac. The ureter should never be dissected from the peritoneal sac due to possible injury. The aorta and inferior vena cava are encountered and retracted to expose the midlumbar discs. Segmental arteries and the ascending iliolumbar vein (at the L4–L5 level) may restrict the ability to reflect the great vessels and may require ligation [1, 2].

Multiple approaches for the L5–S1 disc, including a midline, infraumbilical, and low transverse, have been described. Once the external rectus fascia is encountered, the fascia is divided at the midline linea alba for a midline incision and an additional transverse division if a low transverse incision is used. The rectus muscles are retracted to expose the preperitoneal fat and the peritoneum. The peritoneum and ureter are retracted over the common iliac vessels. Then the middle sacral artery is identified and ligated to expose the disc [1]. Of note, the sympathetic nerves are cleared carefully to decrease risk of retrograde ejaculation. The transperitoneal approach has a ten-time higher incidence of retrograde ejaculation compared to the retroperitoneal approach [7].

Implant Placement

A complete discectomy at the desired level is then performed including thorough removal of the cartilaginous endplates from the superior and inferior vertebral bodies. The lateral annulus and posterior longitudinal ligament (PLL) are left intact. The PLL is then released using a small curved curette. The PLL may be resected if necessary to enable endplate distraction in patients with a contracted or fibrotic PLL [8]. The disc space is then restored with padded distractors. The distractors must be positioned on the posterior aspect of the disc space to avoid endplate fracture [4].

Utilizing orthogonal fluoroscopy, the trial implant should be introduced. The device should be placed as far as possible within the disc space, at the midline, with maintenance of the center of rotation two mm posterior to the midvertebrae. If the trial implant is not midline, additional discectomy or annulotomy may be required to help center the implant. If the disc space is not adequately distracted, the resulting tight soft tissues may result in expulsion of the device [1]. Although different devices have been used, in general, the footprint of the implant should be selected for maximal coverage and to restore normal anatomy based on preoperative imaging or adjacent healthy discs [2].

Postoperative Care

Postoperatively, patients should be admitted for inpatient observation. As the surgery generally involves an anterior approach, patients are typically started on a clear liquid diet which may be advanced as tolerated. Patients should work with physical therapy with a focus on early ambulation and a corset brace may be used for comfort until the wound has healed. Formal physical therapy may begin after wound healing and extension exercises should be avoided for six weeks. Patients may return to low-impact sports without restriction after three months [1].

Outcomes

European centers have utilized TDR for the longest period of time and have published studies with the longest period of follow-up. Lemaire et al. followed 100 patients for an average of 11.3 years following a TDR with Charité™ implant. Clinically, 90% of patients reported good or excellent outcomes and 91.5% of eligible patients returned to work. Motion measurements showed 10.3° of flexion and extension for all levels [9]. Similarly, David et al. retrospectively reviewed 106 patients with an average follow-up of 13.2 years following L4–L5 or L5–S1 TDR with the Charité™ implant. In this study, 82.1% of patients had a good or excellent clinic outcome and 89.6% of patients returned to the same level of work. Additionally, these authors report a low level of adjacent segment disease (2.8%) [10].

A more recent study by Siepe et al. followed 181 patients for an average of 7.4 years with the ProDisc II™ implant. Overall, these patients reported 86.3% satisfactory or highly satisfactory outcomes with improved pain scale scores at all time points. Additionally, there was a statistically significant decrease in visual analogue scale (VAS) scores after the four-year time point. Revision rates were reported to be 7.2% [11].

In a multi-level ProDisc™ implant study, Bertagnoli et al. report 93% satisfaction in 15 patients with two levels of implants and ten patients with three levels at a minimum of two years follow-up. The authors also report disc height increases from five mm to 12 mm. Of note, the authors excluded workers compensation and medical-legal cases from their cohort [12].

In a comparison of the Charité™ TDR system and anterior lumbar interbody fusion (ALIF), Blumenthal et al. conducted a level I study with 205 patients in the TDR group on 99 patients in the ALIF group. Patients in the TDR group demonstrated lower disability at all follow-up points between six weeks and two years with a greater percentage of TDR patients being satisfied with their treatment compared to the ALIF group. Complication rates were similar between the two groups, length of stay was shorter for the TDR group, and ALIF patients underwent a higher rate of reoperation (9.1% vs. 5.4%) [13]. A follow-up to the Blumenthal et al. study was done by Guyer et al. This study examined 133 of the available patients from the original study (90 TDR and 43 ALIF) five years postoperatively. The authors noted that 57.8% of patients in the TDR group had at least a 15-point improvement in the Oswestry Disability Index (ODI), no device failures, no major long-term complications, and maintenance or improvement in neurological status compared to 51.2% in the ALIF group. Additionally, they noted that 78% of the TDR patients were satisfied with the treatment compared to 72% of the ALIF patients [14].

Of note, surgeons and hospitals with greater TDR volumes have been shown to have shorter length of stay and mean operating time but no different in long-term clinical outcomes [15].

Conclusion

With strict surgical indications, the TDR represents a viable option for discogenic low back pain with good results for over ten years across multiple studies. Future implants may attempt to better restore the native biomechanics of the lumbar spine. Meticulous technique and patient selection are critical to good outcomes, which may be seen with increasing frequency as the TDR gains widespread use and patient volume increases.

References

1. Lumbar total disk arthroplasty Michael F. Duffy and Jack E. Zigler operative techniques: Spine Surgery, PRO. 42:371–7.
2. Lumbar total disc arthroplasty Richard D. Guyer and Ernesto Otero-Lopez Benzel's spine surgery, 184:1591–6.e1.
3. van den Eerenbeemt, Karin D, et al. Total disc replacement surgery for symptomatic degenerative lumbar disc disease: a systematic review of the literature. Eur Spine J. 2010;19(8):1262–80.
4. Disc Arthroplasty for the Treatment of Degenerative Disorders of the Lumbar Spine David T. Anderson and Adam L. Shimer. Arthritis and Arthroplasty: The Spine, Chapter 47:357–64.
5. McAfee PC, Cunningham BW, Hayes V, et al. Biomechanical analysis of rotational motions after disc arthroplasty: implications for patients with adult deformities. Spine. 2006;31:S152–60.
6. Bendo JA, Quirno M, Errico T, et al. A comparison of two retroperitoneal surgical approaches for total disc arthroplasty of the lumbar spine. Spine. 2008;33:205–9.
7. Sasso RC, Kenneth Burkus J, LeHuec J-C. Retrograde ejaculation after anterior lumbar interbody fusion: transperitoneal versus retroperitoneal exposure. Spine. 2003;28(10):1023–6.
8. Failed Total Disc Arthroplasty Andrew K. Simpson and Jack E. Zigler Rothman-Simeone and Herkowitz's The Spine, Chapter 104:1889–901.
9. Lemaire JP, Carrier H, Sariali e-H, et al. Clinical and radiological outcomes with the Charité artificial disc: a 10-year minimum follow-up. J Spinal Disord Tech. 2005;18:353–9.
10. David T. Long-term results of one-level lumbar arthroplasty: minimum 10-year follow-up of the CHARITE artificial disc in 106 patients. Spine. 2007;32:661–6.
11. Siepe CJ, Heider F, Wiechert K, et al. Mid- to long-term results of total lumbar disc replacement: a prospective analysis with 5- to 10-year follow-up. Spine J. 2014;14:1417–31.

12. Bertagnoli R, Yue JJ, Shah RV, et al. The treatment of disabling single-level lumbar discogenic low back pain with total disc arthroplasty utilizing the ProDisc prosthesis: a prospective study with 2-year minimum follow-up. Spine. 2005;30:2230–6.
13. Blumenthal S, McAfee PC, Guyer RD, et al. A prospective, randomized, multicenter Food and Drug Administration Investigational Device Exemptions study of lumbar total disc replacement with the CHARITE Artificial Disc versus lumbar fusion: part I: evaluation of clinical outcomes. Spine. 2005;30:1565–75.
14. Guyer RD, McAfee PC, Banco RJ, et al. Prospective, randomized, multicenter Food and Drug Administration Investigational Device Exemption study of lumbar total disc replacement with the CHARITE Artificial Disc versus lumbar fusion: five-year follow-up. Spine J. 2009;9:374–86.
15. Regan JJ, McAfee PC, Blumenthal SL, et al. Evaluation of surgical volume and the early experience with lumbar total disc replacement as part of the investigational device exemption study of the Charite Artificial Disc. Spine. 2006;31:2270–6.

Chapter 24
Lateral Lumbar Interbody Fusion for Lumbar Scoliosis

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Introduction

Minimally invasive surgery (MIS) of the spine, including approaches to the lumbar spine, has become an increasingly important concept in spinal surgery. McAfee et al. describe MIS as a surgical technique that "results in less collateral tissue damage, resulting in measurable decrease in morbidity and more rapid functional recovery than traditional exposures, without differentiation in the intended surgical goal" [1]. Several studies have reported various advantages of MIS of the spine including reduction of (1) soft-tissue trauma, (2) surgical site infections, (3) postoperative pain, (4) narcotic consumption, (5) intraoperative blood loss, (6) doses of rhBMP-2, and (7) expedited mobilization [2–10].

Within the past decade, a lateral MIS approach to the lumbar spine, also known by the trademarked "extreme lateral interbody fusion ™ (XLIF)" (NuVasive, Inc., San Diego, CA), has gained popularity as a new technique. XLIF was first reported in detail in 2006 by Ozgur et al. in which access to the spine was gained through a retroperitoneal transpsoas approach. The initial report described XLIF as having several advantages over traditional anterior approaches. These included eliminating the need for an access surgeon, minimiz-

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_24

ing the chance for peritoneal violation, reducing injury to the great vessels, ureters, and hypogastric nerve plexus, and eliminating the steep learning curve. Advantages of the XLIF over open posterior approaches include reduced risk of dural tear, nerve root, and paraspinal muscle injuries [11]. XLIF also provides an opportunity for improved deformity correction due to the ability to place interbody implants of greater height and width [11].

The reported limitations of XLIF included limited exposure of the T12-L1 and L5-S1 discs due to the anatomical position of the 12th rib and the iliac crest, respectively [7]. Studies indicate that XLIF places the genitofemoral nerve at risk, resulting in postoperative transient thigh numbness, weakness, pain, and dysesthesias, with the highest risk of injury at L4-L5 [9, 10, 12–15]. Hip flexion weakness due to splitting of the psoas muscle has also been reported [14]. A recent systematic review of 21 studies reports that despite these transient problems, XLIF was successful in improving visual analogue scale (VAS) pain scores and Oswestry disability index outcomes [11]. Despite its limitations, lateral MIS to the lumbar spine appears to be an innovative and progressive way of treating deformity and stenosis via indirect decompression.

Technique

Preparation and Positioning

Following sedation and intubation, electromyographic (EMG) monitoring electrodes should be placed. Subsequently, the patient is placed in a true 90° lateral decubitus position with the patient's back close to the edge of the bed to decrease distance to the surgeon. The patient should be carefully padded and secured with tape at multiple points (Fig. 24.1). The right lateral decubitus position is generally

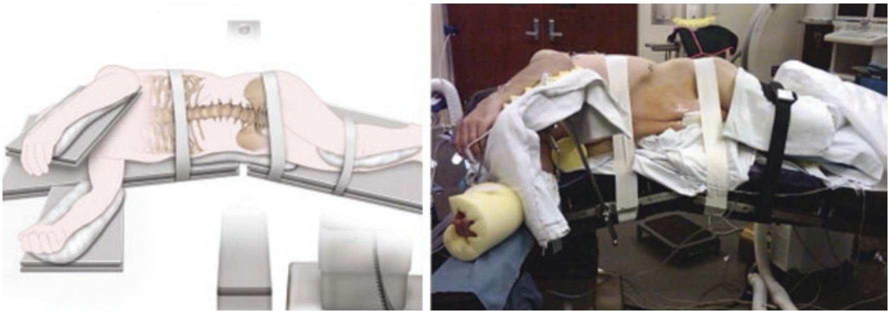

Fig. 24.1 The patient is placed in the lateral decubitus position with the top leg flexed in order to relax the ipsilateral psoas muscle. The patient must be secured in place thoroughly using tape, padding, beanbags, or other methods. (Used with permission from Patrick A. Sugrue and John C. Liu Kim [42])

preferred as the relative posterior location of anatomic variants of the vena cava, and right common iliac vessels lead to increased risk of injury relative to the left [16]. However, in lumbar scoliosis cases with substantial spinal deformity, the patient may be placed such that the concave side of the curvature faces upward enabling access to a greater number of disc spaces [17]. Of note, posterior vessel migration at the L4/5 relative to L1/2 level has been reported, leading to increased risk of injury at the L4/5 level [18]. The patient's hips are flexed to decrease psoas muscle and lumbar plexus tension [19]. Increasing the iliac crest to ribcage distance with a bump or flexion of the bed with the patient positioned over the bed's break is crucial for maximal disc space exposure. An axillary roll is placed to prevent brachial plexus injury, and the patient's upper arm is placed on an arm board and positioned away from the surgical and fluoroscopy fields [17]. AP and lateral fluoroscopy may be used to make positioning adjustments to ensure true AP and lateral orthogonal positioning.

Approach

Lateral fluoroscopy is utilized to locate the desired disc space or spaces. K-wires can be placed over the skin using fluoroscopy in the surgical field to help localize disc space midline, and a marking pen is used to mark the location on the skin. The surgical site is prepped and draped in the standard sterile fashion with attempts made to preserve marking pen markings. Multiple initial incision locations have been described based on surgeon preference and number of surgical levels. These include a single transverse incision, multiple transverse incisions, or transverse and longitudinal incisions. Monopolar electrocautery is then used to control superficial bleeding vessels and to dissect downward in a vertical trajectory. A combination of bipolar electrocautery and blunt dissection is used to dissect through the distinct layers of the abdominal wall including subcutaneous fat, the external oblique fascia, the external and internal oblique muscles, the transversus abdominis muscle, and finally into the yellow retroperitoneal adipose tissue. Attention to protection of the iliohypogastric, ilioinguinal, and subcostal nerves is crucial as damage to them during initial dissection can result in significant leg pain [20]. Careful attention is paid to stay in a strict vertical trajectory as the peritoneum is anterior and the lumbar plexus nerves are posterior.

Once the retroperitoneum has been entered, the surgeon's finger is used to bluntly dilate, sweep the peritoneum anteriorly, and guide the first dilator to the top of the psoas muscle. Of note, the ilioinguinal, iliohypogastric, and lateral femoral cutaneous nerves are located in the abdominal wall between the internal oblique and transversus abdominis [20]. The genitofemoral nerve is located anterior to the psoas muscle and must be avoided. As dilators are advanced between the anterior and middle third of the psoas muscle to avoid lumbar plexus nerves, directional triggered EMG monitoring is used to ensure adequate distance from local motor nerves (Fig. 24.2). As the distance between the stimulator and large nervous structures

Fig. 24.2 Schematic rendering of the lumbar plexus as it passes through the psoas muscle. (From Moro et al. [43])

decreases, the threshold for a stimulus eliciting a response decreases as well. Thresholds for response below five mA indicate direct contact, between five and ten mA indicate close proximity, and more than 11 mA indicates farther proximity from intrapsoas nerves [21]. Lower thresholds posterior and higher thresholds anterior to the dilator indicate posteriorly located femoral plexus nerves, which is preferable. Sensory nerves, however, do not elicit an EMG response, so a high index of suspicion must be maintained during dilation. Direct visualization can be utilized to avoid sensory and minor arborization of the lumbar plexus.

Implant Placement

Once the dilators have been advanced to the disc and positioning confirmed with fluoroscopy, expandable retractors are placed over the final dilator. A shim may be inserted to prevent posterior displacement of the retractors, and the final dilator is removed. Using a light source and direct visualization, a discectomy is performed. The integrity of the anterior longitudinal ligament (ALL) must be maintained, and it should be visualized or its position estimated based on the slope of the anterior vertebral body. An annulotomy centered on the anterior lateral half of the disc space is performed, and a pituitary rongeur is used to excise the disc. A Cobb elevator is used to disrupt the contralateral annulus, which allows for maximal coronal correction in lumbar scoliosis [12]. The posterior and anterior annuli are left intact. An implant with biologic augmentation such as bone morphogenetic protein or bone graft is inserted to rest on the lateral margins of the apophyseal ring. After positioning is confirmed with fluoroscopy, the retractors are removed with direct visualization to assess for bleeding. Finally, the abdominal fascial, subcutaneous, and subcuticular layers are closed in the standard fashion.

Lateral Plating

The lateral plate, which is a disc space spanning plate with anchor points in the superior and inferior vertebral bodies, can serve as a supplement to increase overall construct stability. It provides a comparable amount of biomechanical rigidity with lateral bending and axial rotation as pedicle screws, but not with flexion or extension. Overall, guidelines for lateral plate usage are not well established, and surgeon preference dictates use [22–24].

Posterior Percutaneous Screw Fixation

Using a lateral approach, some cases of spinal stenosis and deformity of the lumbar spine may be addressed by correcting the Cobb angle and improved disc space height without the need for posterior percutaneous screw fixation [25]. However, for most cases of adult spinal deformity, the addition of posterior screw fixation is required. Percutaneous iliac or S2-Alar iliac screw fixation may also be used to provide more stability, especially in constructs L2-S1 or larger [26, 27]. Posterior pedicle screw fixation is further discussed in Chap. 25.

Postoperative Care

For single-level fusions, patients are encouraged to walk in the immediate postoperative period on the same day, which aids functional muscle recovery and helps prevent cardiopulmonary complications. Minimal postoperative pain is expected, and patients can usually be discharged home on the first postoperative day. If a patient has multiple levels addressed, then a short in-hospital stay for pain control and physical therapy is reasonable. Staging the surgery is typically indicated if multiple levels (> 3 levels) are done with posterior instrumentation fixation being performed 2–3 days after XLIF [28–30]. If significant motor disturbance, pain dysesthesia, lower limb myasthenia, and decrease in hematocrit are present, a magnetic resonance imaging (MRI) or computed tomography (CT) should be conducted to rule out a psoas hematoma.

For all patients, restrictions on bending, lifting, and twisting of the lumbar spine are advised until a solid fusion mass can be expected to form, which usually takes a minimum of 4–6 weeks. Patients may use a soft lumbar corset for a back support and pain control. A stronger clamshell brace is usually not necessary.

Outcomes

Phillips et al. published a multicenter prospective study of 107 patients undergoing XLIF for degenerative scoliosis with 24-month follow-up; the mean Cobb angle improved from 20.0° to 15.2°. The degree of correction did not correlate with clinical outcome at 24 months ($P < 0.001$) [31]. The authors report an overall complication rate of 24% with 12% considered major and no mortalities. They note their complication rate to be lower than that of traditional surgical approaches, which have been reported as high as 66% [31]. The authors propose the lower rate of complications is due to the fact that the abdominal vasculature is not mobilized, the ureter is not manipulated, and the peritoneal cavity is not retracted in XLIF [31]. Similar results were demonstrated in a smaller series of 30 consecutive patients undergoing XLIF for scoliosis including improvement in clinical scores and a reportedly lower complication rate of 26.6% compared to traditional approaches [32].

A recent systematic review of 21 studies reports that XLIF was successful in improving VAS pain scores and Oswestry disability index outcomes [11]. Although XLIF was effective at restoring coronal deformity (weight means: coronal segmental Cobb angle 3.6–1.1°; coronal regional Cobb angle 19.1–10°), it appears to have a smaller impact on lumbar lordosis and sagittal balance as compared to transforaminal lumbar interbody fusion (TLIF) or posterior lumbar interbody fusion (PLIF) [11]. Some authors advocate the use of an additional lumbar interbody fusion at the L5-S1 level to help achieve optimal deformity correction [33]. However, limitations at deformity correction with XLIF are counterbalanced by the advantages of the approach over TLIF/PLIF in reducing the risk of dural tear, nerve root, and paraspinal muscle injuries [11]. XLIF also provides an opportunity to place an implant with higher profile and greater width than TLIF or PLIF and provide a better restoration of disc height [11]. In patients with scoliosis and concomitant neurological symptoms, neural decompression through laminectomy, facetectomy, or similar procedures is indicated for symptom relief. However, improvement in leg and back pain and improvement in radiographic parameters have been demonstrated with indirect spinal decompression utilizing ligamentotaxis created with the anterior and posterior longitudinal ligaments during XLIF [34].

In a retrospective data analysis at two centers examining 84 cases of XLIF with and without posterior spinal fusion, patients undergoing the combined XLIF/PSF had increased estimated blood loss (245 vs 81 ml, $p < 0.0001$) and length of stay (3.3 vs 2.1 days, $P = 0.002$). The authors report that, according to the literature, thigh weakness/numbness appears to be the most common postoperative complaint. They attribute this to trauma of the psoas muscle during the approach. The majority of these cases resolved with time, but a small percentage of patients with motor or sensory deficits persisted, which is similar to those following traditional direct anterior approaches and lower than those following traditional posterior approaches [35]. Additionally, a supra-psoas shallow docking approach has been described which suggests that many of these postoperative morbidities may be avoided by docking on top of the psoas instead of passing through it [36, 37].

Vertebral body fractures have also been reported in several case studies following XLIF with interbody cage placement. Predisposing factors for vertebral body fractures have been suggested to include osteoporosis, high body mass index, multilevel constructs, cage subsidence, and fixed-angle lateral plate design [38–40]. Cage subsidence, another concern following XLIF which results in postoperative disc height loss, has been reported in several standalone XLIF series [39, 41]. In one study, subsidence with disc height loss of 50–100% was seen in 30% of standard 18 mm AP length cages following standalone XLIF. Increasing the AP length to 22 mm in this study decreased this rate to 11%, and the authors suggest that using a larger interbody cage, size may decrease subsidence [41].

Case Study

Figure 24.3a, b depict the lateral and AP radiographs of a 45-year-old female who presented with severe sciatic neuritis down her right leg. The AP radiograph shows a 51-degree rightward lumbar scoliotic curve, and the lateral radiograph shows adequate sagittal balance.

The patient failed conservative therapy and, due to her continued symptoms, elected to undergo multilevel lateral interbody fusion with anterior lumbar interbody fusion and plating at L5-S1. Positioning of the patient is shown in Fig. 24.3c, while postoperative radiographs are shown in 24.3d.

At a second stage 14 days later, the patient underwent percutaneous pedicle screw instrumentation L1-pelvis to augment the stability of the construct. Postoperative AP and lateral radiographs are shown in Figs. 24.3e, f. The rightward lumbar curve was corrected to 15°. No blood transfusion was required.

The patient recovered well postoperatively and now four years out of surgery has had maintenance of their deformity correction, no reoperation, and lasting relief of her symptoms.

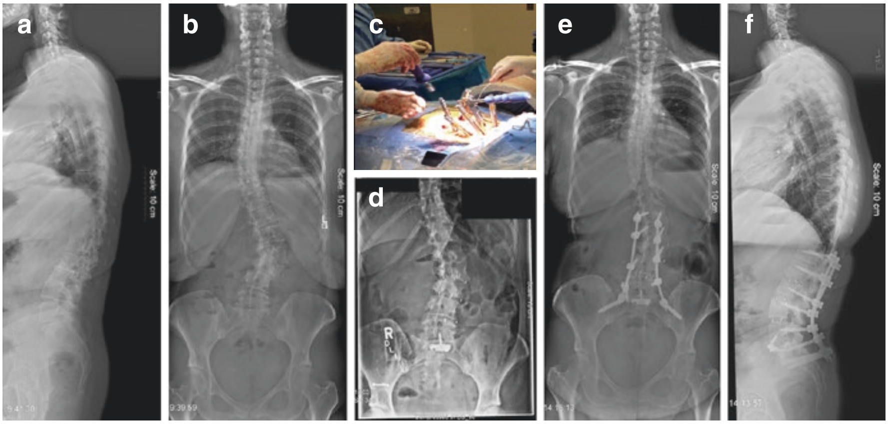

Fig. 24.3 AP (**a**) and lateral (**b**) radiographs of a 45-year-old female who presented with right leg pain. She elected to undergo a two-stage LLIF and posterior spinal fusion. Positioning in the OR (**c**). Postoperative radiographs after the first stage (**d**) and the second stage (**e**, **f**)

Conclusion

Minimally invasive spine surgery as represented by lateral interbody fusion is a new but growing field of spine surgery. The lateral approach has inherent advantages as it is less traumatic to the soft tissues and decreases the risk of neural element injury that is present with traditional transforaminal and posterior approaches. It also avoids vital neurovascular structures and bowel, which are dangers of the anterior approach. This minimalist approach tends to lower patient morbidity and allow for faster recovery.

However, the lateral approach is not without its own risks, including damage to the psoas muscle and the overlying genitofemoral nerve which results in hip flexion weakness and paresthesias in the inguinal region, respectively. Moreover, exposure and access are limited, especially in the L5-S1 and T12-L1 interspaces.

XLIF may be used to treat foraminal stenosis via indirect decompression of the neural elements with restoration of disc height. The lateral approach has also been shown to be effective in addressing scoliotic deformity with measurable improvement in the coronal plane. The impact on sagittal plane deformity is more limited in comparison to anterior and posterior approaches. In many cases, the lateral approach must be supplemented by an additional posterior or anterior procedure.

Further research is warranted to further characterize the long-term outcomes of lateral interbody fusion and to develop new techniques that may enhance its efficacy in decompression and curve correction.

References

1. McAfee PC, Phillips FM, Andersson G, Buvenenadran A, Kim CW, Lauryssen C, et al. Minimally invasive spine surgery. Spine. 2010;35(26S):S273.

2. Dhall SS, Wang MY, Mummaneni PV. Clinical and radiographic comparison of mini–open transforaminal lumbar interbody fusion with open transforaminal lumbar interbody fusion in 42 patients with long-term follow-up. J Neurosurg Spine. 2008;9(6):560–5.
3. Foley KT, Gupta SK. Percutaneous pedicle screw fixation of the lumbar spine: preliminary clinical results. J Neurosurg Spine. 2002;97(1):7–12.
4. Guiot BH, Khoo LT, Fessler RG. A minimally invasive technique for decompression of the lumbar spine. Spine. 2002;27(4):432–8.
5. Jaikumar S, Kim DH, Kam AC. History of minimally invasive spine surgery. Neurosurgery. 2002;51(suppl_2):14.
6. Khoo LT, Palmer S, Laich DT, Fessler RG. Minimally invasive percutaneous posterior lumbar interbody fusion. Neurosurgery. 2002;51(suppl_2):181.
7. Ozgur BM, Aryan HE, Pimenta L, Taylor WR. Extreme Lateral Interbody Fusion (XLIF): a novel surgical technique for anterior lumbar interbody fusion. Spine J. 2006;6(4):435–43.
8. Peng CWB, Yue WM, Poh SY, Yeo W, Tan SB. Clinical and radiological outcomes of minimally invasive versus open transforaminal lumbar interbody fusion. Spine. 2009;34(13):1385–9.
9. Dakwar E, Cardona RF, Smith DA, Uribe JS. Early outcomes and safety of the minimally invasive, lateral retroperitoneal transpsoas approach for adult degenerative scoliosis. Neurosurg Focus. 2010;28(3):E8.
10. Anand N, Rosemann R, Khalsa B, Baron EM. Mid-term to long-term clinical and functional outcomes of minimally invasive correction and fusion for adults with scoliosis. Neurosurg Focus. 2010;28(3):E6.
11. Phan K, Rao PJ, Scherman DB, Dandie G, Mobbs RJ. Lateral lumbar interbody fusion for sagittal balance correction and spinal deformity. J Clin Neurosci. 2015;22(11):1714–21.
12. Anand N, Baron EM, Thaiyananthan G, Khalsa K, Goldstein TB. Minimally invasive multilevel percutaneous correction and fusion for adult lumbar degenerative scoliosis: a technique and feasibility study. Clin Spine Surg. 2008;21(7):459–67.
13. Wang MY, Mummaneni PV. Minimally invasive surgery for thoracolumbar spinal deformity: initial clinical experience with clinical and radiographic outcomes. Neurosurg Focus. 2010;28(3):E9.
14. Moller DJ, Slimack NP, Acosta FL Jr, Koski TR, Fessler RG, Liu JC. Minimally invasive lateral lumbar interbody fusion and transpsoas approach–related morbidity. Neurosurg Focus. 2011;31(4):E4.
15. Kepler CK, Bogner EA, Herzog RJ, Huang RC. Anatomy of the psoas muscle and lumbar plexus with respect to the surgical approach for lateral transpsoas interbody fusion. Eur Spine J. 2011;20(4):550–6.
16. Kepler CK. Minimally invasive exposure techniques of the lumbar spine. In: Baron E, Vaccaro A, editors. Operative techniques: spine surgery. 3rd ed. Philadelphia, PA: Elsevier; 2018. p. 387–97.
17. Beckman JM, Uribe JS. MIS lateral lumbar interbody fusion. In: Steinmetz M, Benzel E, editors. Benzel's spine surgery. 4th ed. Philadelphia, PA: Elsevier; 2017. p. 673.e1.
18. Regev GJ, Chen L, Dhawan M, Lee YP, Garfin SR, Kim CW. Morphometric analysis of the ventral nerve roots and retroperitoneal vessels with respect to the minimally invasive lateral approach in normal and deformed spines. Spine. 2009;34(12):1330–5.
19. O'Brien J, Haines C, Dooley ZA, Turner AW, Jackson D. Femoral nerve strain at L4–L5 is minimized by hip flexion and increased by table break when performing lateral interbody fusion. Spine. 2014;39(1):33–8.
20. Ahmadian A, Deukmedjian AR, Abel N, Dakwar E, Uribe JS. Analysis of lumbar plexopathies and nerve injury after lateral retroperitoneal transpsoas approach: diagnostic standardization: a review. J Neurosurg Spine. 2013;18(3):289–97.
21. Uribe JS, Vale FL, Dakwar E. Electromyographic monitoring and its anatomical implications in minimally invasive spine surgery. Spine. 2010;35(26S):S374.
22. Fogel GR, Parikh RD, Ryu SI, Turner AW. Biomechanics of lateral lumbar interbody fusion constructs with lateral and posterior plate fixation. J Neurosurg Spine. 2014;20(3):291–7.
23. Laws CJ, Coughlin DG, Lotz JC, Serhan HA, Hu SS. Direct lateral approach to lumbar fusion is a biomechanically equivalent alternative to the anterior approach: an in vitro study. Spine. 2012;37(10):819–25.

24. Cappuccino A, Cornwall GB, Turner AW, Fogel GR, Duong HT, Kim KD, et al. Biomechanical analysis and review of lateral lumbar fusion constructs. Spine. 2010;35(26S):S367.
25. Kim CW, Raiszadeh K, Garfin SR. Minimally invasive scoliosis treatment. In: Yue J, Guyer R, Johnson JP, Khoo LT, Hochschuler SH, editors. Comprehensive treatment of the aging spine. Philadelphia, PA: Elsevier Saunders; 2011. p. 396–407.
26. Bach K, Ahmadian A, Deukmedjian A, Uribe JS. Minimally invasive surgical techniques in adult degenerative spinal deformity: a systematic review. Clin Orthop Relat Res. 2014;472(6):1749–61.
27. Wang MY. Percutaneous iliac screws for minimally invasive spinal deformity surgery. Minim Invasive Surg. 2012;2012:173685.
28. Baaj AA, Mummaneni PV, Uribe JS, Vaccaro AR, Greenberg MS. 61 minimally invasive lateral retroperitoneal transpsoas interbody fusion. Handbook of spine surgery. 2nd ed. Stuttgart: Georg Thieme Verlag; 2016.
29. Pimenta L, Coutinho E, Sauri Barraza JC, Oliveira L. Lateral XLIF fusion techniques. In: Yue J, Guyer R, Johnson JP, Khoo LT, Hochschuler SH, editors. Comprehensive treatment of the aging spine. Philadelphia, PA: Elsevier Saunders; 2011 p. 408–12.
30. Sardar ZM, Baron EM, Davis T, Anand N. The transpsoas approach for thoracolumbar interbody fusion. In: Baron E, Vaccaro A, editors. Operative techniques: spine surgery. 3rd ed. Philadelphia, PA: Elsevier; 2018. p. 358–70.
31. Phillips FM, Isaacs RE, Rodgers WB, Khajavi K, Tohmeh AG, Deviren V, et al. Adult degenerative scoliosis treated with XLIF: clinical and radiographical results of a prospective multicenter study with 24-month follow-up. Spine. 2013;38(21):1853–61.
32. Caputo AM, Michael KW, Chapman TM, Massey GM, Howes CR, Isaacs RE, et al. Clinical outcomes of extreme lateral interbody fusion in the treatment of adult degenerative scoliosis. Sci World J. 2012;2012:680643.
33. Tormenti MJ, Maserati MB, Bonfield CM, Okonkwo DO, Kanter AS. Complications and radiographic correction in adult scoliosis following combined transpsoas extreme lateral interbody fusion and posterior pedicle screw instrumentation. Neurosurg Focus. 2010;28(3):E7.
34. Oliveira L, Marchi L, Coutinho E, Pimenta L. A radiographic assessment of the ability of the extreme lateral interbody fusion procedure to indirectly decompress the neural elements. Spine. 2010;35(26S):S337.
35. Youssef JA, McAfee PC, Patty CA, Raley E, DeBauche S, Shucosky E, et al. Minimally invasive surgery: lateral approach interbody fusion: results and review. Spine. 2010;35(26S):S311.
36. Acosta FL Jr, Drazin D, Liu JC. Supra-psoas shallow docking in lateral interbody fusion. Neurosurgery. 2013;73(suppl_1):ons52.
37. O'Brien JR. Nerve injury in lateral lumbar interbody fusion. Spine. 2017;42:S24.
38. Dua K, Kepler CK, Huang RC, Marchenko A. Vertebral body fracture after anterolateral instrumentation and interbody fusion in two osteoporotic patients. Spine J. 2010;10(9):e15.
39. Le TV, Baaj AA, Dakwar E, Burkett CJ, Murray G, Smith DA, et al. Subsidence of polyetheretherketone intervertebral cages in minimally invasive lateral retroperitoneal transpsoas lumbar interbody fusion. Spine. 2012;37(14):1268–73.
40. Keith MW, Yoon ST. Complication avoidance in the lateral approach for interbody fusion. Seminars in Spine Surgery. 2013;25(3):182–90.
41. Marchi L, Abdala N, Oliveira L, Amaral R, Coutinho E, Pimenta L. Radiographic and clinical evaluation of cage subsidence after stand-alone lateral interbody fusion. J Neurosurg Spine. 2013;19(1):110–8.
42. Sugrue PA, Liu Kim JC. Lateral lumbar interbody fusion. In: Kim DH, Vaccaro AR, Dickman CA, Cho D, Lee S, Kim I, editors. Surgical anatomy and techniques to the spine: Philadelphia, PA: Elsevier Health Sciences; 2013. p. 459–69.
43. Moro T, Kikuchi S, Konno S, Yaginuma H. An anatomic study of the lumbar plexus with respect to retroperitoneal endoscopic surgery. Spine (Phila Pa 1976). 2003;28(5):423–8.

Chapter 25
Percutaneous Lumbar Screws

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Introduction

Minimally invasive procedures are growing in popularity due to tissue sparing and minimal postoperative pain. This chapter describes percutaneous lumbar fusion techniques, including advantages and disadvantages, techniques, complications, and patient selection strategies.

Pedicle screw instrumentation can be utilized to stabilize fusion for various spinal pathologies via the creation of a rigid and stable construct. Recent developments in instrumentation have enabled preservation of muscles, ligaments, and bony structures of the spine that help facilitate recovery and improve outcomes. Furthermore, percutaneous techniques preserve muscle and ligaments adjacent segment disease. With these advances in percutaneous pedicle instrumentation and numerous advantages over the traditional method, interest in this approach has and will continue to rise [1, 2].

At first, learning and utilizing this new technique may seem difficult; however, there are some basic principles outlined in this chapter to help guide the surgeon in its safe and effective utilization [1, 3].

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_25

Indication

Percutaneous fixation can be performed in the majority of circumstances in which open pedicle screw fixation is indicated. Specifically, this technique can be utilized in order to provide supplemental fixation to interbody or posterior fusion procedures, to stabilize the spine in cases of infection or tumor, or as a temporal internal brace in a trauma setting [4–6].

Advantages and Contraindications

Minimally invasive surgery is becoming increasingly popular in the treatment of both degenerative and traumatic disorders. Percutaneous lumbar fusion enables the insertion of hardware under the guidance of fluoroscopy or navigation fostering accurate multilevel screw placement while minimizing the trauma associated with the traditional open approach. The reduced paraspinal muscle damage achieved in this approach has led to decreased operative blood loss, postoperative pain, and narcotic usage. Additionally, the use of the percutaneous technique has translated to earlier hospital discharge and return to work, a milder spike in serum/urine muscle breakdown products, and greater trunk strength. Furthermore, percutaneous fixation minimize muscle injury as the muscles are split as opposed to being detached or retracted. Thus, because it spares soft tissue and muscle retraction, percutaneous screw fixation enables medial angulation required for screw placement. This is in opposition to the open approach, in which the fascia-muscles, if not released extensively, may act as an obstacle that can precipitate a lateral breach. Moreover, the use of the AP view for pedicle cannulation fosters efficiency as it enables two skilled surgeons to work simultaneously, further decreasing operative time [1–3, 5, 7–9].

With the advancement of new technologies, minimally invasive techniques are gaining a role in more complex procedures in the spine. For this chapter, we will consider multilevel procedures as those needing a rod passed through at least four screws. Multilevel minimally invasive procedures can be used to treat many conditions ranging from traumatic injuries to adult and children spinal deformities, infections, and tumors [5, 10].

However, this procedure should not be performed if unable to visualize pedicle anatomy with radiographic imaging or navigation. Rod placement strategies will be discussed in a later section [5].

Possible disadvantages of percutaneous screw fixation include potentially increased operative times in less experienced surgeons, the need for a steep learning curve, and loss of surgeon control, feel, or sight of the open anatomy. Thus, the use of this approach may be limited by the surgeon’s willingness and ability to perform it [2]. Moreover, as imaging modalities are vital to percutaneous screw fixation, other approaches should be considered in patients in whom proper images cannot be obtained or interpreted. This may be due to obesity, osteopenia, retained abdominal contrast, severely deformed anatomy, or low-quality C-arm image intensifiers [3, 5, 8, 9, 11]. We will explore possible strategies to overcome some of these challenges later on.

In addition, these imaging modalities increase radiation exposure to the patient as well as the surgical team. Ionization radiation has been associated with a range of morbidities, such as skin erythema or ulceration, cataract formation, reduced fertility or sterility, and malignancies. However, the radiation exposure to the eyes, extremities, and deep tissues in the placement of pedicle screws is far below the occupational exposure limit, thus this procedure has been deemed safe. Still, measures should be taken to reduce its exposure. These include pulsed image acquisition and lead shielding using lead aprons, thyroid shield, and lead-impregnated gloves and goggles. It is recommended that the surgeon be positioned farthest from the beam source, and all hands should be kept as far as possible from the source in order to decrease radiation exposure [12–14]. Navigation and robotics have also enabled minimization of radiation exposure to surgeon, staff, and patient.

Proper Imaging Technique

Percutaneous screw placement requires reliance on intraoperative imaging, as there are vital structures in close proximity and minimal exposure of spinal anatomy. Although there are options in terms of imaging methods, the primary imaging modality in the operating room for minimally invasive procedures is the C-arm. The C-arm is portable and readily available in most hospitals, and it creates two-dimensional photographs of the bony anatomy by superimposing all of the tissue shadows that have been transversed by the fluoroscopic beam [2, 5].

To ensure the success of this technique, proper AP and lateral images must be obtained. On a properly aligned true AP view, the pedicles are symmetrical and lie just inferior to the upper endplate. The anterior and posterior margins of the upper endplate should be superimposed, and no double endplate shadow should be seen. Additionally, the pedicles' outlines should be on the upper half of the vertebral body, and the spinous process shadow should be midline between the pedicles [1, 5, 8]. For lateral images, a flat superior endplate should again be seen, with the lateral aspects of both pedicles seen and superimposed. When rotation of the segment has been eliminated, only a single shadow should be seen on the posterior cortex of the vertebral body [9].

In obtaining both true AP and lateral images, it is preferable to tilt the bed to one side, leaving the C-arm in the 0° and 90° positions. Additionally, due to the normal lordosis of the spine, the C-arm may need to be adjusted for each spinal level in order to keep the pedicle screws parallel to the endplates [8].

Patient Positioning

In the percutaneous placement of lumbar screws, appropriate patient positioning and the radiolucent bed is necessary to ensure fluoroscopic views. The abdomen is free of compression, and all bony and vital structures are padded. Care should be taken to ensure good orthogonal alignment for imaging. Some cases may require slightly altered positioning due to differences in each patient [2, 4, 5, 8].

Surgical Technique

Percutaneous Pedicle Cannulation with True AP (Anteroposterior) Imaging

Once patient is positioned and properly draped, each vertebra is identified fluoroscopically based on rib counting from above or sacrum from below. Once the levels are identified, the fluoroscopy is bought to position for the desired level. As mentioned above, generally, each vertebral level needs a slightly different sagittal angulation of the C-arm due to the sagittal profile of the spine [5, 8].

It is important to identify the appropriate trajectory for each vertebral level. To do so, the surgeon aligns a Kirschner wire (K-wire) horizontally on the skin such that the wire is in line with the center of the pedicles in midline and marked. This is followed by another image along the upper endplate of the vertebral body (VB). The AP image is adjusted to be in the same plane as the horizontal axis of the endplate. Now the K-wire is placed on the lateral aspect of the VB along the lateral border of the pedicles. The vertebral level and necessary sagittal angulation of the C-arm may be marked on the skin to facilitate rapid return to proper view for each level. This process is repeated for each vertebral level to be instrumented [1, 5, 9]. It is recommended to incise the skin slightly lateral to the lateral border of the pedicle on AP imaging in order to ensure medial angulation of screws. A K-wire is placed on the skin so that it is vertically in line with the lateral aspect of the pedicle. Once confirmed with imaging, these cephalocaudal lines are marked on the skin along the K-wire in order to help guide incision locations, which are marked about 1 cm lateral to these lines. Obese patients may require the incisions to be placed more lateral to accommodate for the increased tissue depth [5].

Local anesthetic should be injected into the dermis prior to incision in order to expand the skin to decrease the incision length and scar. Furthermore, a slightly larger incision is preferred to avoid the use of tubular dilator retractors, as these can lead to dusky or necrotic looking skin. The skin is incised down through the subcutaneous tissue and the thoracolumbar fascia is identified. The fascia and muscle may be incised or left intact. Some prefer to incise the fascia in line with the muscle fibers to decrease the subsequent tension on the K-wire and dilators. The muscle fibers are then split via blunt dissection, and the surgeon can now palpate the facet joint and transverse process [1, 2, 5, 8].

Care should be taken to ensure that incisions are large enough to accommodate the instruments, as the instrumentation for muscle dilation and soft tissue protection varies in terms of size. Next, a Jamshidi needle is inserted into the incision and docked over the junction of the transverse process and facet, located adjacent to the lateral aspects of the facet joints. The needle is held in place with long Kocher clamps, while an AP image is obtained in order to ensure proper positioning. The needle tip should be located directly over the mid-lateral wall of the pedicle, termed 3 o'clock on the right side, and 9-o'clock on the left. The AP view is also utilized to ensure that the needle tip is not angled too cranially or caudally. If the needle is not correctly positioned, it should be readjusted and its position should be reconfirmed with AP imaging. Once proper positioning is confirmed with imaging, the Jamshidi needle should be tapped gently with the mallet in order to penetrate a few millimeters into the bony cortex. Positioning should be verified, yet again, by another AP image, as the needle tip may have slipped due to the sloped nature of the bony surface over the pedicle entry [2, 5, 15].

The shaft of the Jamshidi needle should appear in parallel with the upper endplate to enable the cannula to pass through the center of the pedicle. In order to determine the appropriate depth of needle penetration into the pedicle, the shaft is marked 20 mm above the skin edge for the length of the pedicle. Then, while maintaining the Jamshidi needle shaft aligned with the fluoroscopic beam, the needle is tapped gently with the mallet to break the cortical bone followed incremental force to get to the depth of 20 mm. An AP image should be obtained to ensure proper positioning of the needle relative to the pedicle shadow. The needle tip should be approximately at the base of the pedicle and should be viewed within the pedicle shadow, approaching but not beyond, the medial border of the pedicle till the Jamshiti needle is beyond 20-mm depth [5].

The K-wire is then inserted through the cannula and into the cancellous bone of the vertebral body. This cancellous bone should be palpated at the base of the needle, and it should have a slight "crunchy" feel as the wire is driven through it. The K-wire can then be advanced 15–20 mm beyond the tip of the needle and into the vertebral body. The cannula is then removed while holding the K-wire in place [5, 8, 15, 16].

The above technique is then repeated for all indicated levels, maintaining the C-arm in the true AP position. A nonpenetrating clamp can be used to hold the wire against the drape in order to avoid interfering with subsequent cannulation of indicated levels. Once all appropriate pedicles have been cannulated and the K-wires have been inserted, a proper AP image is obtained in order to visualize all the K-wires. This image can be saved to one of the screens of the C-arm monitor in order to compare the K-wire position on this AP view with the lateral image. Then, the C-arm may be shifted to the lateral position and another image obtained. The surgeon should ensure that each K-wire is in the appropriate position in both the AP and lateral views [8, 15].

K-wires that are not in proper position should be removed and reinserted using the above procedure either via the same or a new pilot hole. K-wires that are solely through the posterior half of the vertebral body may be advanced further. However, caution must be taken, as a laterally placed K-wire predisposes an anterior breach, even though the tip appears well behind the anterior vertebral body wall on the lateral image. Thus, the K-wire is not routinely advanced to this point, but it should be advanced deep enough to be located in the anterior half of the body in order to avoid unintentional pullout when removing the tap [5, 15].

The K-wire is then dilated and tapped. Some recommend undertapping (i.e., using a tap 1 mm smaller than the planned screw diameter). Care should be taken to ensure that the tap is not advanced over the tip of the K-wire in order to prevent K-wire pullout. It is once again important to mimic the trajectory of the K-wire as closely as possible with the tap in order to avoid an unintentional binding and advancement of the K-wire. The surgeon should be careful not to make a bend in the wires as this can alter the trajectory and also fracture the K-wire if it is not made of nitinol. It is best to avoid exposing only a small segment of the wire distal to the instrument as this increases the likelihood of kinking the wire [1, 8, 9, 17, 18].

The next step is placing the pedicle screw over the K-wire. In general, screw size is determined using preoperative imaging studies. However, the surgeon may also determine a new screw size using intraoperative lateral images and knowledge about the depth of tap insertion. Here, the same trajectory as the K-wire should also be closely followed. Screw placement is performed in the usual manner according to the specific instrumentation used. Once the screw is embedded in the vertebral body, the K-wire can be removed. This may be difficult, and in some cases requires a little extra force, which can be problematic especially in osteoporotic patients. Care should be taken to avoid pulling out the screw with the K-wire, and the use of pliers or vise grip to pull out the K-wire is recommended. A rotational maneuver, in which the handle of the screw inserter is levered against and the wire is pulled and bent, can be utilized in order to avoid putting force on the screw itself. Additionally, the screw can be loosed 2–3 mm, which typically loosens the K-wire as well, facilitating removal. With this technique, it is important to remember to fully tighten the screw once the K-wire is removed [5].

Rod Passage Techniques for Multilevel Constructs

Preoperative preparation is vital to safe rod placement, as any disparities between adjacent screw saddles would hinder rod-screw connection. Additionally, screw pullout can occur with too great a force placed on the screws during rod attachment. Thus, care should be taken to ensure proper planning of screw entry points and attention given to screw head depths in order to circumvent these obstacles. As with open procedures, it may be necessary to pass the rod multiple times in order to properly bend the rods for complex or multiplane deformities [5].

Once the percutaneous pedicle screws have been placed as outlined above, the rod must be passed down to and through the screw heads. In order to do so, before passage, the rod length must be measured and then contoured before passage. Currently, smaller size rods are already bent in some degree of lordosis; however, the rod can be further manipulated as appropriate for the patient. In order to properly do so, a two-handed technique is preferable. With this technique, the dominant hand is on the rod holder, while the nondominant hand manipulates the screw extensions. As the dominant hand pushes the rod holder toward the contralateral hand, the contralateral hand rotates and derotates the screw extensions. This enables accurate and efficient rod placement in multilevel constructs [2, 5, 17, 19].

Using a specialized rod holder with a ratchet for axial rotation, the rod is tunneled subfascially via either the top or bottom incision. If rod placement seems difficult, the rod may inadvertently be driven above the fascia, and thus may be diverted to an incorrect trajectory. If this is the case, on a lateral image the rod will appear in a too posterior position. To prevent this, care should be taken to avoid cutting the fascia too much superiorly or inferiorly before placing pedicle screws. Additionally, it is generally easier to tunnel the rod from cranial to caudal [5, 8]. In addition, the distal end of the rod should be placed on the proximal screw and slide over the screw head. This enables the rod to be under the fascia at a deeper depth.

After the rod has been passed through all screw extensions, it is axially rotated 180°. Before placing the locking/set screws and disengaging the rod, AP and lateral images should be obtained in order to ensure proper screw-rod engagement and rod lengths (the rod should have enough length at both the top and the bottom). Set screws are then utilized to fix the screws to the rod. A specialized tool may be used to move the rod into the screw saddles if the rod does not fully engage the saddles in its ideal final position [5, 8, 19].

The rod has been accurately placed through the screw extensions if the screw extensions are blocked from turning, and if, with proper lighting and suction, the rod can be directly viewed within the screw extensions. Additionally, correct positioning can be determined by tactile feedback of rod movements when placing a screwdriver into the extensions. It is important to ensure that the screw is not too deep, as this would inhibit angulation of the polyaxial screw and hinder rod accommodation. In order to minimize stress between the rods and the screws, the screw heads should be aligned on lateral image [5].

The last step is wound closure. The wound is closed in layers, and a fascial repair may be performed if it is large using a zero size vicryl with CT-1 needle followed by 2.0 vicryl for subcutaneous layer. Closure is achieved with small-diameter resorbable monofilament suture. This can be buried in the dermis with a subcuticular technique. In cases in which keloid formation is likely, the ends of the suture can be left out of the body and removed 4–7 days after surgery. The wound should be kept dry and covered. In most patients cyanoacrylate glue is utilized in order to reduce stress on the skin and serve as a semiocclusive antibacterial barrier. In general, a drain is solely recommended in instances in which decompression was performed and there is open lamina or exposed dura [5, 8].

Pearls and Pitfalls

- Surgical table and patient positioning are vital in the acquisition of clear unobstructed imaging.
- Proper AP and later images should be obtained in 2-D fluoroscopy for each level to be instrumented on.
- A finger can be used in order to guide the cannula down the transverse process and places the needle near the desired starting point. This decreases the number of images required and thus exposure to radiation. The trocar tip should be removed from the cannula to avoid perforating a glove [8].

- The Jamshidi needles should be docked over the 3 o'clock (right) and 9 o'clock (left) positions before they are entered into the bony cortex.
- Pedicle cannulation and K-wire placement should be performed at all indicated levels utilizing AP images in order to avoid switching between the AP and lateral C-arm positioning.
- K-wires should be advanced to the anterior half of the vertebral body, taking care to avoid violation of the anterior cortex. Additionally, caution should be taken to avoid unintentional K-wire advancement. Marking the needle 20 mm above the level of the skin can help the surgeon remain mindful of advancement.
- A rotational or twisting maneuver can be useful in instances where the K-wire pullout is difficult.
- In order to facilitate rod passage, it is best to avoid sinking the screw too deep.
- Obtain images to verify accurate placement of screws, screw-rod engagement, and appropriate rod length before locking the construct and removing the screw extenders and retractors.
- Keep manual control of the guidewire as all instruments are passed over it.

Owl's Eye (Magerl) Technique for Pedicle Cannulation

Owl's eye or Magerl technique for pedicle cannulation utilizes one fluoroscope for imaging along the long axis of the pedicle as opposed to AP imaging. This is an oblique C-arm view that peers down the barrel of the pedicle. This technique may be considered if the anatomy of the pedicle is not clear using the standard AP technique discussed previously. This is beneficial as it decreases exposure to ionizing radiation. However, some pitfalls include the increased C-arm realignment and increased difficulty in handling the fluoroscope [5, 8].

Percutaneous Pedicle Screw Fixation Using Image Guidance

Image-guided technology utilizes an intraoperative CT scanner to create virtual images that help guide the surgeon and that allow customization of screw size. This technique enables the surgeon to view axial images, which can facilitate more accurate screw placement within the pedicle [20]. It also has the potential to minimize radiation exposure to the surgical team, as they can step out of the room or hide behind lead shields during imaging [8, 20, 21]. Furthermore, the use of navigation has reported accuracy rates of pedicle screw insertion ranging from 92% to 98%. While the approach is similar to the process outlined for true AP images, there are some key differences that the surgeon must be aware of. These include the cumbersome nature of the machine and the need for direct line of sight between the camera and the navigated instruments. Additionally, image-guided technology requires additional time to set up and register the instrumentation and reliance on technology that may fail without bailout. Thus, it may be preferable to utilize the two-dimensional fluoroscopy technique described above per the discretion of the surgeon [20–22]. Navigation set-up will require additional set equipment like the stealth machine, intraoperative O-arm which can be replaced by preoperative CT, or even a robotic arm which can be quite expensive as an upfront investment by the institution.

Complications

As discussed previously, much of the appeal of MIS procedures is the decreased pain and recovery times associated with this approach. Minimizing the risk of wound infection has contributed greatly to the growing popularity of minimally invasive techniques. This decline is due to the decreased soft tissue devascularization, the reduction in operative site dead space, and reduced intraoperative bleeding. Nonetheless, many complications seen in the open approach can also be present with MIS, albeit to a lesser degree. For example, there is still a risk of postoperative anemia secondary to usual intraoperative excessive blood loss; however since MIS techniques confer less intraoperative blood loss, this risk is reduced [23]. Additionally, it is important to note that while many of the possible techniques to avoid complications are the same in both MIS and open procedures, there are some unique considerations in the use of the MIS technique [5].

Percutaneous lumbar fixation enables the muscles to be left intact, thus reducing muscle destruction. However, this may lead to soft tissue irritation in some patients. Although self-limiting, this muscle spasm is extremely painful and should be managed appropriately with non-narcotic agents and physical treatments if necessary. In the use of lumbar screws, complications can arise from misplacement of any of the instruments and damage to any of the nearby vital structures. It is essential to confirm placement with imaging. The K-wire has increased potential for injury as although it is temporary, it remains in the body for a large amount of time and can migrate. Thus, K-wire management is vital to avoid unintentional advancement or pullout. Again, this should be verified with imaging in order to avoid intraoperative complications relating to mechanical instrumentation. Postoperative complications can present differently based on its time of onset and severity. These can include mechanical, neurological, and infectious. Additionally, there have been cases in which the screw head detached from the stem on postoperative day 1. There have also been reports of pullout of pedicle screws later in the 2–3 weeks into the postoperative period [24, 25]. Furthermore, multilevel fusions can negatively affect adjacent vertebral levels. As with any new technique, MIS presents a learning curve that must be acknowledged. The surgeon should be aware of this in order to minimize complications [5, 10].

Postoperative Care

Percutaneous pedicle screw fixation does not require care beyond that given to a regular spine surgical patient. These patients can and should be mobilized almost immediately after surgery in order to reduce the risk of venous thromboembolism, atelectasis, pneumonia, and skin breakdown. An external orthosis should be used in higher risk cases such as long segment fixation, osteopenia, or compromised fixations. In select cases, electronic bone stimulation can be utilized to promote fusion. Physical and occupational therapy can be helpful in providing patients activities that may help reduce the risk of construct failure or nonunion [5, 23].

Limitations

While the advantages of minimally invasive surgery have been disputed in the treatment of localized pathologies, surgeons are recognizing that as the morbidity of the procedure and/or the debility of the patient rises so do the advantages of this approach. Increasingly, many authors are demonstrating the use of minimally invasive surgical techniques in the treatment of adult spinal deformity. While there has not been a study demonstrating that the minimally invasive technique is better than open surgery, the trend is in that direction due to the advantages mentioned above. However, some potential limitations arise from decreased visualization of the anatomy and the necessity of image guidance, which increases operating times and can expose the patient and healthcare workers to additional radiation [1, 7].

References

1. Mobbs RJ, Sivabalan P, Li J. Technique, challenges and indications for percutaneous pedicle screw fixation. J Clin Neurosci. 2011;18:741–9.
2. Mohamed M, Mohi Eldin ASAH. Percutaneous trandpedicular fixation: technical tips and pitfalls of sextent and pathfinder systems. Asian Spine J. 2016;10(1):111–22.
3. Foley KT, Holly L, Schwender JD. Minimally invasive lumbar fusion. Spine J. 2003;28(155):S26–35.
4. Foley KT, Gupta SK, Justis JR, Sherman MC. Percutaneous pedicle screw fixation of the lumbar spine. Neurosurg Focus. 2001;10(4):1–9.
5. Handbook of minimally invasive and percutaneous spine surgery. St. Louis: Quality Medical Publishing, INC; 2011. p. 154.
6. Danison AP, Lee DJ, Panchal RR. Temporary stabilization of unstable spine fractures. Curr Rev Musculoskelet Med. 2017;10:199–206.
7. Michael Y, Wang PVM. Minimally invasive surgery for thoracolumbar spibnal deformity: initial clinical experience with clinical and radiographic outcomes. Neurosurg Focus. 2010;28(3):E9.
8. Sembrano JN, Yson SC, Santos ERG, Polly DW Jr. Percutaneous pedicle screws. In: Minimally invasive spine surgery [Internet]. New York: Springer; 2014. p. 129–39.

9. Harris EB, Massey P, Lawrence J, Rihn J, Vaccaro A, Anderson DG. Percutaneous techniques for minimally invasive posterior lumbar fusion. Neurosurg Focus. 2008;25(2)
10. DeWald CJ, Stanley T. Intrumentation-related complications of multilevel fusions for adult spinal deformity patients over age 65. Spine J. 2006;31(19 Supp):S144–S51.
11. Holly LT, Schwender JD, Rouben DP, Foley KT. Minimally invasive transforaminal lumbar interbody fusion: indications, technique, and complications. Neurosurg Focus. 2006;20(3):1.
12. Mettler FA. Medical effects and risks of exposure to ionising radiation. J Radiol Prot. 2012;32:N9–N13.
13. Mroz TE, Abdullah KG, Steinmetz MP, Klineberg EO, Lieberman IH. Radiation exposure to the surgeon during percutaneous pedicle screw placement. J Spinal Disord Tech. 2011;24(4):264–7.
14. Hubbe U, Sircar R, Scheiwe C, Scholz C, Kogias E, Kruger MT, Volz F, Klingler J-H. Surgeon, staff, and patient radiation exposure in minimally invasive transforaminal lumbar interbody fusion: impact of 3D fluoroscopy-based navigation partially replacing conventional fluoroscopy: study protocol for a randomized controlled trial. Trials. 2015;16(142)
15. Mobbs RJ, Raley D. Complications with K-Wire insertion for percutaneous pedicle screws. J Spinal Disord Tech. 2014;27(7):390–4.
16. Weisse L, Suess O, Picht T, Kombos T. Transpedicular screw fixation in the thoracic and lumbar spine with a novel cannulated polyaxial screw system. Med Devices (Auckl). 2008;1:33–9.
17. Dahdaleh NS, Smith Z, Hitchon PW. Percutaneous pedicle screw fixation for thoracolumbar fractures. Neurosurg Clin N Am. 2014;25:337–46.
18. Scheer JK, Harvey MJ, Dandaleh NS, Smith ZA, Fessler RG. K-wire fracture during minimally invasice transforaminal lumbar interbody fusion: report of six cases and recommendations for avoidance and management. Surg Neurol Int. 2014;5(Suppl 15):S520–S2.
19. Sahoo PK. Percutaneous pedicle screw and rod insertion for fracture of the lumbar spine. Indian J Neurotrauma. 2005;2(2):143–8.
20. Acosta FL Jr, Thompson TL, Campbell S, Weinstein PR, Ames CP. Use of intraoperative isocentric C-arm 3D fluoroscopy for sextant percutaneous pedicle screw placement: case report and review of the literature. Spine J. 2005;5:339–43.
21. Holly LT, Foley K. Three-dimensional fluoroscopy-guided percutaneous thoracolumbar pedicle screw placement. Technical note. J Neurosurg. 2003;99(Spine 3):324–9.
22. Bledsoe JM, Fenton D, Fogelson JL, Nottmeier EW. Accuracy of upper thoracic pedicle screw placement using three-dimensional image guidance. Spine J. 2009;9:817–21.
23. Proiette L, Scaramuzzo L, Shiro GR, Sessa S, Logroscino CA. Complications in lumbar spine surgery: a retrespective analysis. Indian J Orthop. 2013;47(4):340–5.
24. Gasbarrini A, Cappuccio M, Colangi S, Posadas MD, Ghermandi R, Amendola L. Complications in minimally invasive percutaneous fixation of thoracic and lumbar spine fractures and tumors. Eur Spine J. 2013;22(Supp 6):S965–S71.
25. Verlaan JJ, Diekerhof CH, Buskens E, van der Tweel I, Verbout AJ, Dhert WJA, Oner FC. Surgical treatment of traumatic fractures of thoracic and lumbar spine: a systematic review of literature on techniques, complications, and outcome. Spine J. 2004;29(7):803–14.

Chapter 26
Percutaneous Iliac and S2AI Fixation

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Pelvic instrumentation in the form of iliac bolts [1] or S2AI screws provides distal fixation to long-construct fusions for deformity or scoliosis [2]. The techniques, while similar, provide unique challenges, such as necessitating cross-connectors for iliac bolts, or breaching the sacroiliac (SI) joint in S2AI. Anatomically, the axial spine consists of vertebrae from cervical to lumbar, ending atop the sacrum distally. The sacrum articulates with the ilia bilaterally forming a flat sacroiliac (SI) joint with minimal motion. Both the ilium and the sacrum provide distal fixation points for instrumented spinal fusions. Studies have shown a high pseudoarthrosis rate at the lumbosacral junction when distal fixation ends at S1 [3–5]. Several biomechanical studies have shown increased rigidity at the lumbosacral junction with the addition of iliac fixation [6–9]. Alternatively, pelvic fixation can serve as an adjunct to internal fixation or definitive treatment for comminuted sacral fractures and pelvic ring injuries with spinopelvic dissociation.

The ilium provides a bony corridor from the posterior superior iliac spine (PSIS) to the anterior inferior iliac spine (AIIS) that can hold one or two large diameter screws. The sacroiliac joint is a wide, flat joint between the sacrum and the ilium bilaterally. This joint has two areas, the inferior half of which is lined with cartilage and does allow minimal motion. S2AI screw trajectory is such that placement does not always penetrate this area of articulation [10] and the long-term effects of such are not well-studied.

Radiographically, this corridor of bone is visualized on the obturator outlet view and known as the teardrop. The teardrop is the confluence of three points: the posterior superior iliac spine, the sciatic notch, and the anterior inferior iliac spine [11]. This starting point can be entered from the PSIS with trajectory toward the AIIS or via a sacral start point in S2 and directed across the sacroiliac joint toward the

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_26

AIIS. Trajectory should be confirmed on the iliac outlet view to ensure the greater sciatic notch is not penetrated. Alternatively, placement of these screws can be performed with the assistance of CT-guided navigation [12].

Technical Notes

The S2AI start point is inferior and along the lateral edge to the first dorsal foramen. An AP view of the sacrum can provide visualization of the start point as seen in Fig. 26.1. With the trajectory toward the greater trochanter for reference, an incision should be made approximately 1/2 cm medial to the start point to allow placement of the screw without issues with the skin. Sharp incision is made and dissection through the fascia is crucial. A cannulated needle, such as the Jamshidi™, is then placed onto the start point with an AP sacrum. The C-arm is then brought into the obturator outlet view to identify the teardrop which demonstrates the iliac corridor, as shown in Fig. 26.2. The ideal image as shown in Fig. 26.2a shows the teardrop sitting atop the hip joint. The cannulated needle is then advanced down the length of the iliac corridor. The S2AI trajectory appears more horizontal and with more posteriorly oriented as it enters the sacrum more medially. At approximately 40 mm, the c-arm is rotated to view the iliac wing, iliac outlet view (Fig. 26.2c). On this image, one visualizes the SI joint and the needle crossing it into the ilium, as well as the trajectory across the ilium but superior to the greater sciatic notch. Once confirmed that the trajectory is in bone, the cannulated needle can be passed into the ilium to a depth of up to 120 mm [12]. The center needle is removed, and a guidewire is placed down its length. The remainder of the cannulated needle is removed. The guidewire can be used like a ball-tip probe to feel the track and ensure there is no breach.

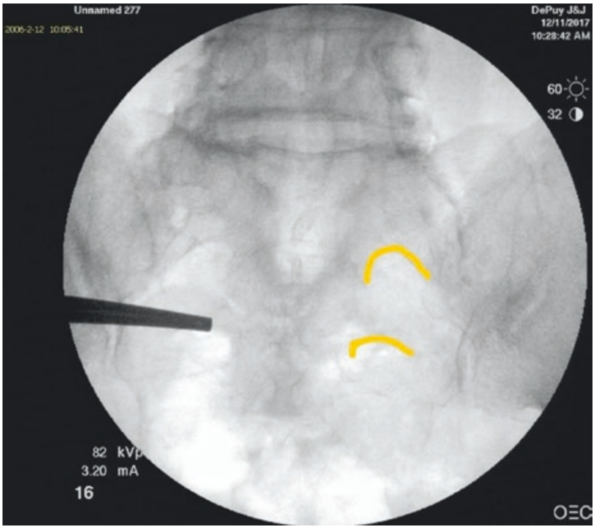


Fig. 26.1 Cadaveric fluoroscopic images of S2AI fixation. AP sacrum demonstrating S2 start point on prone specimen, left. Right-sided first and second dorsal foramen are outlined

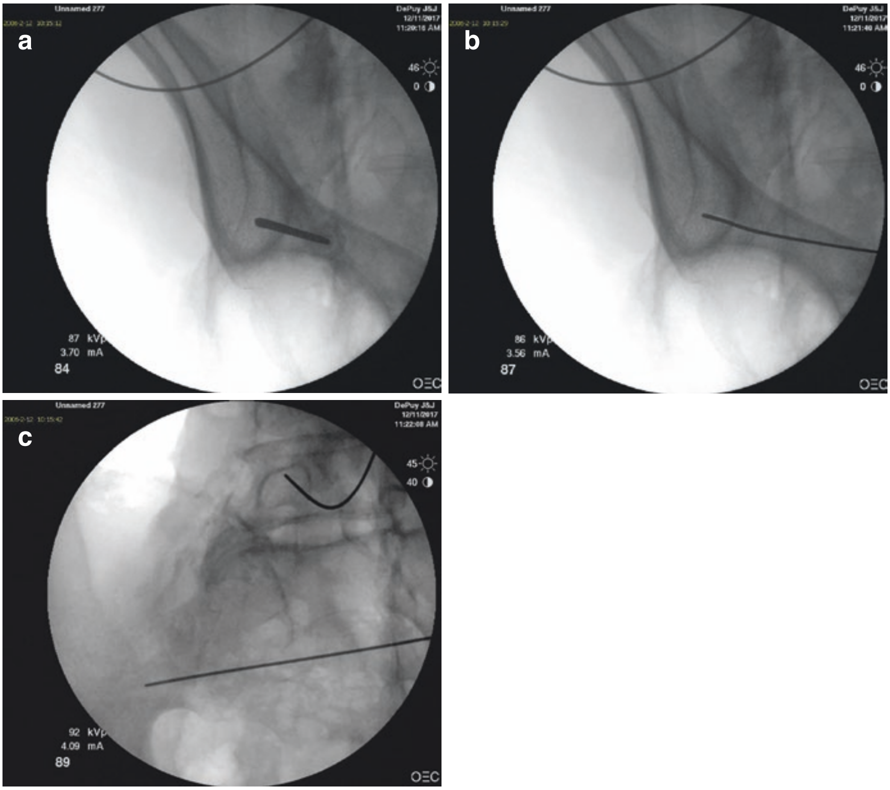
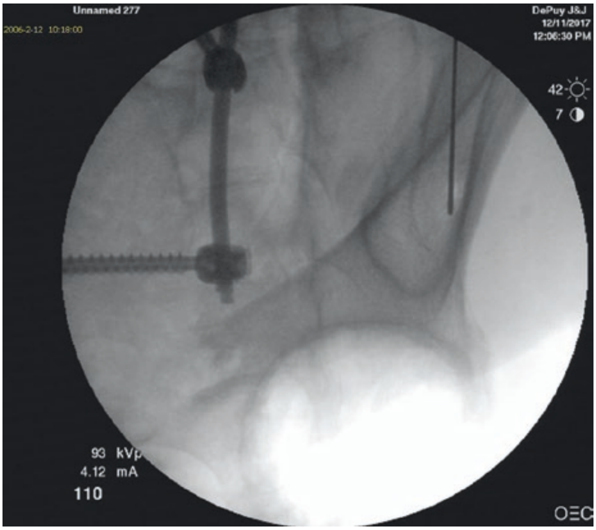


Fig. 26.2 Cadaveric fluoroscopic images of S2AI fixation. Images (**a**) and (**b**) demonstrate the teardrop view from obturator-outlet radiograph. The femoral heads are removed from this cadaveric specimen, but the teardrop is visualized atop the acetabulum. The cannulated needle/guidewire trajectory has a more horizontal and posterior orientation. The notch view (**c**) shows the guidewire across the SI joint and superior to the greater sciatic notch

Fig. 26.3 Cadaveric fluoroscopic image of iliac fixation. Image demonstrates the teardrop view from obturator-outlet radiograph. The femoral heads are removed from this cadaveric specimen, but the teardrop is visualized atop the acetabulum. The guidewire trajectory is directed down the length of the ilium



Placing an iliac bolt requires an incision again medial to its start point on the PSIS. Dissection is carried down through fascia to the PSIS. Through even a small incision, a narrow leksell rongeur can be used to remove cortical bone in order to countersink the head of the screw, making it less prominent. Alternatively, a high-speed burr can be utilized to provide a cortical window for screw placement. Following this, a standard pedicle gearshift probe may be utilized to develop the tract from PSIS to AIIS in the iliac wing for iliac bolt placement. Again, the trajectory is toward the greater trochanter, or visualized on the teardrop, obturator outlet view. Once the iliac wing is probed, a guidewire is placed down the length of the corridor for placement of the cannulated screw, as demonstrated in Fig. 26.3.

Connecting one's S2AI screw to the cephalad construct is simpler than an iliac bolt, as the placement is such that the head of the screw is in-line with the construct. Whereas the iliac bolt may require an additional connection to the cephalad construct requiring larger mini-open incision or a separate incision altogether. In certain cases, such as lumbopelvic fixation for lumbopelvic dissociation, where an S1 screw is not placed, connecting an iliac bolt to L5 is feasible without additional connections, as shown in Fig. 26.4.

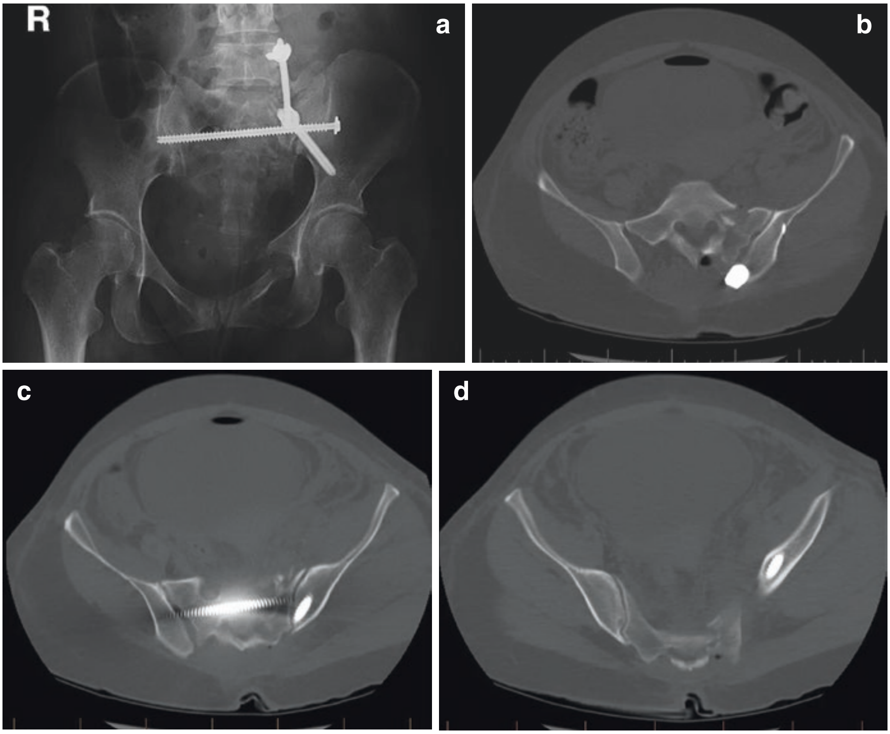


Fig. 26.4 Post-operative radiograph (**a**) and CT (**b**–**d**) images depicting adjunct lumbopelvic fixation for comminuted pelvic ring injury. The iliac bolt traverses the ilium passed the transsacral screw and is affixed to the L5 pedicle screw without the need for a transconnector

Conclusion

Pelvic fixation is an important technique utilized for increased rigidity at the lumbosacral junction to lessen the risk of pseudoarthosis in long-construct fusions, or additional fixation in trauma cases. These techniques have been shown to be feasible and safe in percutaneous fashion. Understanding anatomy provides the knowledge to place screws with minimal risk to vital structures.

References

1. Tsuchiya K, Bridwell KH, Kuklo TR, Lenke LG, Baldus C. Minimum 5-year analysis of L5–S1 fusion using sacropelvic fixation (bilateral S1 and iliac screws) for spinal deformity. Spine. 2006;31(3):303–8.
2. O'Brien JR, Yu WD, Bhatnagar R, Sponseller P, Kebaish KM. An anatomic study of the S2 iliac technique for lumbopelvic screw placement. Spine. 2009;34(12):E439–42.
3. Edwards CC 2nd, Bridwell KH, Patel A, Rinella AS, Berra A, Lenke LG. Long adult deformity fusions to L5 and the sacrum. A matched cohort analysis. Spine. 2004;29(18):1996–2005.
4. Edwards CC 2nd, Bridwell KH, Patel A, Rinella AS, Jung Kim Y, Berra AB, et al. Thoracolumbar deformity arthrodesis to L5 in adults: the fate of the L5-S1 disc. Spine. 2003;28(18):2122–31.
5. Kim YJ, Bridwell KH, Lenke LG, Cho KJ, Edwards CC 2nd, Rinella AS. Pseudarthrosis in adult spinal deformity following multisegmental instrumentation and arthrodesis. J Bone Joint Surg Am. 2006;88(4):721–8.
6. Cunningham BW, Lewis SJ, Long J, et al. Biomechanical evaluation of lumbosacral reconstruction techniques for spondylolisthesis: an in vitro porcine model. Spine. 2002;27:2321–7.
7. Lebwohl NH, Cunningham BW, Dmitriev A, et al. Biomechanical comparison of lumbosacral fixation techniques in a calf spine model. Spine. 2002;27:2312–20.
8. McCord DH, Cunningham BW, Shono Y, et al. Biomechanical analysis of lumbosacral fixation. Spine. 1992;17(suppl 8):S235–43.
9. O'Brien JR, Yu WD, Kaufman BE, Bucklen B, Salloum K, Khalil S, et al. Biomechanical evaluation of S2 alar-iliac screws: effect of length and quad-cortical purchase as compared to iliac fixation. Spine. 2013;38(20):E1250–5.
10. Nottmeier EW, Pirris SM, Balseiro S, Fenton D. Three-dimensional image-guided placement of S2 alar screws to adjunct or salvage lumbosacral fixation. Spine. 2010;10(7):595–601.
11. Schildhauer TA, McCulloch P, Chapman JR, Mann FA. Anatomic and radiographic considerations for placement of transiliac screws in lumbopelvic fixations. J Spinal Disord Tech. 2002;15(3):199–205; discussion 205.
12. O'Brien JR, Matteini L, Yu WD, Kebaish KM. Feasibility of minimally invasive sacropelvic fixation: percutaneous S2 alar iliac fixation. Spine. 2010;35(4):460–4.

Chapter 27
Anterior Odontoid Screws: Tips and Tricks

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Background

Anterior screw fixation as an approach to odontoid neck fractures was first described in a series of papers published throughout the 1980s [8, 10, 23, 40, 49]. Since that time, favorable fusion outcomes and increasing incidence of surgically treatable odontoid fractures have cemented the anterior screw as an essential procedure of the cervical spine surgeon [13, 60]. The purpose of this chapter is to discuss the anatomy and epidemiology of odontoid fractures, to review indications and contraindications for anterior screw fixation, and to describe common procedural pitfalls of this surgery.

Odontoid Anatomy

The odontoid serves as a structural focal point of the C1-C2 atlantoaxial joint. The anterior surface of the odontoid articulates with the anterior arch of the atlas, and the posterior surface of the odontoid articulates with the transverse ligament of the atlas. The apex of the odontoid serves as an attachment site for the apical ligament, which joins the axis to the skull via attachment at the anterior rim of the foramen magnum. Paired alar ligaments insert just below the apex on either side of the odontoid, providing robust connection to the occipital condyles. The odontoid's complex anatomy and intimate association with surrounding structures are explained by

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_27

embryologic contributions of the first and second cervical sclerotomes as well as the early atlas to odontoid process formation [1].

Classification of Odontoid Fractures

In 1974, Anderson and D'Alonzo divided odontoid fractures into three classes: type I, a fracture in the tip of the odontoid process, considered an avulsion fracture of the alar ligaments; type II, a fracture at the base of the odontoid process; and type III, a fracture involving both the odontoid process and the body/lateral masses of C2 [3]. Type I fractures are very rare and relatively stable and are most commonly managed nonoperatively [37, 53]. Type II fractures are common and are typically the result of oblique trauma to the head – "goose egg over the eye" [2, 24]. Type II fractures are typically unstable and preferred management is surgical [37, 53]. They are the primary indication for anterior screw fixation and the focus of this chapter. Type III fractures are relatively stable and are typically the result of midline trauma to the head – "goose egg on the forehead" [24]– and are typically managed nonoperatively [37, 53].

Epidemiology

Odontoid fractures represent 10–20% of all acute cervical spine fractures, and type II is the most common class [53]. The population distribution is bimodal, with peaks in early adulthood and in the elderly [12, 51]. In patients under 40, these fractures usually occur in the setting of high-energy trauma, such as a motor vehicle accident, and anterior displacement of the odontoid process is most common [17, 51]. In patients over 60, these fractures often present after a fall from a standing height or other low-energy mechanism, and displacement of the odontoid process is most commonly posterior [30, 51]. Notably, the incidence of type II fractures has increased compared to other fractures of the spine in the last two decades, which is likely a reflection of the aging population [60].

Anterior Screw Fixation Versus Other Management

In the population of patients with type II odontoid fractures, the literature is convincing that surgical management offers superior fusion outcomes compared to nonoperative management: nonunion rates in these fractures after external immobilization alone typically range from 40% to 80% [31, 44, 54, 64], whereas nonunion rates after surgery are often 25% or much lower [5, 9, 36, 61]. A 2009 meta-analysis of the literature confirmed overall fusion superiority of operative management compared to nonoperative management, but found that outcomes between those two cohorts were not statistically different in patients under the age of 45 or in patients with anteriorly displaced fractures [50]. While there are some reports of high fusion rates for these fractures with halo vest management [19, 59], well-documented complications of halos (cardiac arrest, pneumonia, DVT/PE, pin site infection, pressure sores, respiratory decline, nerve injury, headache), particularly in the elderly, and the benefit of immediate stabilization with operative fixation further compel surgical management in this patient population [7, 39, 45, 51, 62].

In comparing anterior to posterior surgery, the most noticeable advantage of anterior fixation for the patient is the greater postoperative rotational mobility, as no artificial fusion is introduced with screw placement. Up to 83% of patient surgically treated with anterior fixation retain full range of cervical motion [46, 47]. Other advantages to an anterior approach include a simpler procedure, a less extensive dissection, fewer critical anatomical structures in the surgical field, lack of a bone graft, and lower need for postoperative immobilization [53].

Indications

The only current indication for anterior screw fixation is a type II odontoid fracture or a high type III fracture with a shallow base. The fracture must also be reducible, as the technique demands the screw be driven into an anatomic odontoid. Additionally, studies suggest that fusion outcomes are superior for patients who undergone surgery closer to the time of injury as compared to those who undergo delayed surgery, which has been defined as anywhere from 1 week to 6 months between injury and surgery [5, 17]. To this end, some authors consider delay greater than 3 weeks to be a relative contraindication to screw placement [6]. Other risk factors for nonunion include greater than 4–6 mm of fragment displacement and greater than 10 degrees angular deformity [6, 12, 26, 28].

Contraindications

Contraindications to anterior screw fixation include fractures that are irreducible, that have an oblique fracture plane, that are associated with rupture of the transverse atlantal ligament, or that are associated with significant cervical oor cervicothoracic kyphoscoliotic deformity. Additionally, patients are unlikely to experience good outcomes with anterior odontoid fixation if: 1) they have short necks, 2) have a delayed presentation, 3) have a history of osteoporosis, or 4) are greater than 70 years of age.

An irreducible fracture is an absolute contraindication to anterior fixation, as it makes fixation with a screw technically infeasible. In subpopulations with anatomical constraints, it is technically infeasible to achieve the necessary screw trajectory for proper placement; therefore, barrel chests and short necks are considered relative contraindications to this procedure. The ability to achieve the proper trajectory should be determined during preoperative surgical planning and given special consideration, especially in patients with these characteristics.

A properly placed screw will apply a reduction force on the fracture in a posterosuperior to anteroinferior direction. In light of these physics, anterior oblique fractures can be another relative contraindication to screw fixation, as these fractures have a tendency to displace postoperatively under the screw's force [4].

The transverse atlantal ligament (TAL), which articulates with the posterior surface of the odontoid, is the structure most responsible for the anterior stability of the atlantoaxial complex [42]. As such, patients with TAL incompetency will have atlantoaxial instability regardless of the integrity of the odontoid process [27, 42]. Therefore, TAL disruption is a contraindication for anterior screw placement. Up to 10% of patients with a type II odontoid fracture have a concomitant TAL rupture, and these patients are good candidates for surgical fixation via a posterior approach [27].

Anterior Fixation in the Elderly and Osteoporotic

The elderly and osteoporotic deserve special consideration regarding surgical repair of a type II odontoid fracture. Histologic analysis shows that bone mass reduction in those with osteoporosis is particularly pronounced at the base of the odontoid, with the base having only 36% the bone mass of the body of the odontoid and the axis in osteoporotic patients. Furthermore, marked reductions in trabecular bone in osteoporotic patients mean fractured odontoids are less likely to heal [2]. Despite these anatomic concerns, many studies have concluded that anterior screw fixation is a reasonable option with acceptable clinical outcome in the elderly patient [9, 13, 15, 32, 52]. On the other hand, however, anterior screw fixation in the elderly is also shown to carry comparatively higher rates of complication and lower rates of fusion than posterior transarticular fixation or C1 lateral mass/C2 transpedicular fixation [4, 16, 20, 52, 57]. As such, in a 2010 systematic review of the literature, Harrop et al. strongly recommend posterior fixation in the elderly, on the basis of consensus opinion [33]. Lastly, although nonoperative management in the elderly is shown to offer significantly worse fusion, morbidity (mobility, nutrition, sanitation), and mortality outcomes than surgery [11, 58, 63], some studies demonstrate comparable patient satisfaction and quality of life outcomes between these two management strategies [45]; thus, treatment decisions should be made on an individual patient basis.

Radiology

Imaging plays a pivotal role in the evaluation and surgical management of type II odontoid fractures. Multiple modalities are often utilized in order to acquire a complete understanding of the character of the injury. Plain radiographs are inexpensive and widely accessible and are frequently the first line investigation into cervical pain. Cervical spine plain films with odontoid and lateral flexion-extension views can be used to initially assess mobility of the fractured odontoid fragment, but have been shown to have poor sensitivity for cervical fractures (detecting as little as 39%) [65]. Separation distance greater than 3 mm between the anterior C-1 ring and the odontoid may indicate transverse ligament disruption [22]. Follow-up flexion and extension radiographs are commonly used to evaluate postoperative fusion and stability [56].

Computerized tomography (CT) is essential for comprehensive assessment of the odontoid and can be used to subclassify the fracture and determine extent of bony involvement and severity of displacement. CT images are also used for surgical planning, particularly to determine the appropriate screw length for the procedure and to assess the relative density of the cortical shell of C2, if anterior fixation is being considered. Magnetic resonance imaging (MRI) may be a helpful adjunct to determine extent of soft tissue involvement, including the direct evaluation of the integrity of the transverse atlantal ligament and the possibility of a spinal cord injury [48]. CT and MRI play additional important roles in diagnosing congenital conditions of the odontoid and potential underlying pathologies, such as rheumatoid arthritis or infection [34].

Procedure

The patient is placed in a supine position. The patient's mouth is propped open with a cork, bite block, roll of gauze, or other radiolucent object to allow for adequate plain radiograph evaluation of the fracture. To put the cervical spine into extension, a blanket or pad is placed beneath the patient's interscapular region, except in cases of a severely retrolisthesed fragment concerning for potential basilar artery injury. Once the patient's spine is in appropriate alignment, the surgeon may wish to secure the patient's head to the bed (Halter traction, radiolucent Mayfield clamp, or Gardner-Wells tongs with tape) to prevent incidental movement during the operation. At this point, lateral and anteroposterior (AP) images should be taken to ensure that an appropriate view of the cervical spine and odontoid can be attained for purposes of the procedure and also to demonstrate reduction of the fracture. (Historically, biplanar fluoroscopy with two C-arms has been the modality of choice; however, recent studies have described advantages to screw placement that are conferred by the use of the O-arm [66] and neuro- navigation [35, 38].) Flexion or extension of the neck may be judiciously applied as necessary to ensure proper reduction. The patient is prepped and draped in the usual sterile fashion.

After sterilization, imaging is used to visually approximate the desired screw trajectory (the surgeon may wish to use a radiodense tool such as a probe or Kirschner wire to aid in this). A transverse skin incision is made according to the planned trajectory, typically at the level of the C5/C6 disc space, starting medially and continuing laterally. Exposure progresses in the same fashion as is used for anterior cervical discectomy and fusion: division of the platysma, blunt dissection of the plane medial to the sternocleidomastoid, lateralization of the carotid sheath, and mobilization medially of the trachea and esophagus. Upon exposure of the prevertebral space, the longus colli muscles are elevated and retracted. Blunt prevertebral dissection is used to create a tunnel toward C2-C3. Upon reaching the C2-C3 disc space, the level is confirmed by imaging.

A C2-C3 anterior discectomy (removing one-third to one-half the disc) is performed to expose the anterior inferior endplate of C2. If one screw will be placed, an appropriate starting point in the midline of the base of C2 is identified and confirmed by lateral and AP imaging. If two screws will be placed, an appropriate location 3–4 mm off the midline is identified and confirmed. A small pilot hole is drilled at the identified location(s). If a cannulated system is being utilized, a Kirschner wire (K-wire) is directed into the pilot hole and advanced systematically under lateral and AP imaging guidance across the fracture to the tip of the odontoid until the distal cortex is penetrated. Depending on the surgeon preference, a lag screw or a fully threaded screw under lag technique is now placed such that the tip of the screw is in the distal cortex of the odontoid apex and the base of the screw is flush against C2 in the C2-C3 disc space. Hyperextension or flexion of the patient's neck may be required to keep the fracture reduced in anatomic position. Screws should be selected based on the length from odontoid tip to base of C2, as determined by preoperative CT or length of K-wire used. They are typically 4 mm in diameter. If a cannulated system is not being utilized, these steps are carried out without the guidance of a K-wire. Percutaneous approaches to anterior screw fixation have also been described and are an alternative option [11].

Proper final position of the screw is confirmed with lateral and AP imaging. Hemostasis is carefully obtained, and the wound is irrigated. The platysma is re-approximated with interrupted sutures as needed, and the skin incision is closed.

One Screw or Two?

In some of the earliest reports of anterior screw fixation, investigators describe the placement of two screws (Fig. 27.1) [7]. Since then, many studies have shown one screw to be biomechanically and clinically equivalent to two screws for the

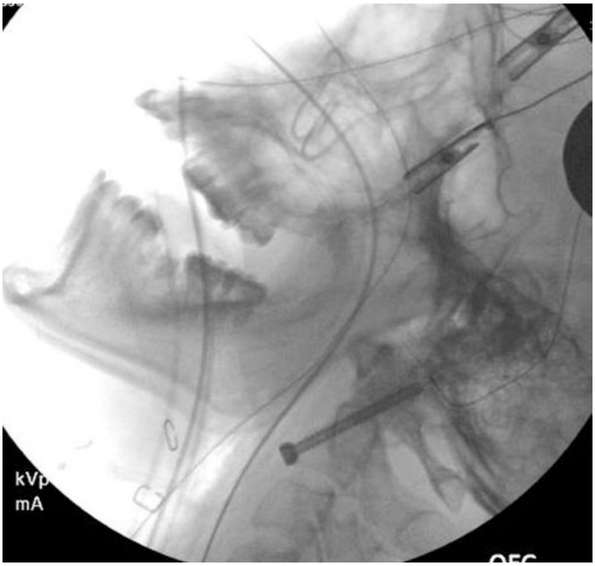

Fig. 27.1 Postoperative radiograph of a properly placed anterior odontoid screw

purposes of this procedure [21, 25, 36, 43, 55, 61]. If the anatomy of the fracture or concerns for stability compel consideration of the use of two screws, it should be noted that cadaveric studies have suggested an odontoid external transverse diameter of at least 9.2 mm is necessary to allow for ideal spacing [13].

Common Pitfalls

Common pitfalls for anterior screw fixation are frequently associated with poor preoperative planning and include screw trajectory, screw insertion site, anterior oblique fracture, screw placement, use of imaging, and Kirschner wire implementation.

Guiding a screw along an ideal trajectory for proper placement within the odontoid process can be a nuanced and challenging task. Barrel chests and short necks are common obstacles to executing an appropriate trajectory. Severe cervicothoracic kyphosis can also impair proper drill bit positioning. Frequent references to intraoperative imaging early on are crucial to mastering the 3D anatomy that is at the center of this meticulous procedure.

The proper site of insertion for an odontoid screw on the inferior endplate of C2 can be awkward to reach and relatively inaccessible compared to the anterior face of C2. Therefore, a common mistake in this procedure is to penetrate C2 too anteriorly, leaving the head of the screw anterior, rather than inferior, to the body of C2. This is problematic for several reasons. First, anterior protrusion of the screw has the potential to irritate the esophagus and/or trachea postoperatively. Moreover, the cortical bone of the anterior surface of C2 is much thinner than the cortex lining the intervertebral disc space [2]. Screws entering into C2 anteriorly are thus far more likely to lose purchase and pull out over time, cause fragment malalignment, and prolong healing time [42]. Improper insertion can be combated by performing an anterior C2-C3 discectomy, which exposes the ideal entry point at the inferior surface of C2.

Anterior oblique fractures can be particularly troublesome for the surgeon performing anterior fixation, as the force applied by the screw is nearly parallel to the direction of the fracture. As a result, nonunion rates are higher in the subpopulation of type II odontoid fractures running anteroinferior to posterosuperior [5]. Patients with this classification of fracture should be considered for posterior fixation or nonoperative management. Alternatively, the surgeon may apply a contoured one-third tubular plate to the fracture to prevent translation of the oblique fragment [29].

In addition to screw trajectory, proper final screw positioning is a concern of millimeters and is a constant challenge. Likely in light of the vital anatomy just distal to the odontoid, a common error is to stop the screw before fixation into the strong apical cortical bone is achieved. If purchase in the cortical bone of the tip is not attained, the screw is more likely to pull out or fail, and fracture compression will not be maximized [5, 15, 42]. If patient anatomy presents safety concerns for strong distal cortical fixation, some studies recommend the use of the fully threaded variable-pitch screw [41] or cannulated cancellous lag screw [18].

Other difficulties with screw positioning arise in the context of the lag technique. If a lag screw is being utilized, it is important that the threaded section of the screw does not span the fracture, or else a lag effect across the fracture is not realized, and compression will not be attained. Likewise, if a lag technique is being utilized, it is important that the proximal fragment of the odontoid is “overdrilled” up to the point of fracture, or else a lag effect will not be realized. Precise determination of proper screw length by preoperative CT or K-wire estimation can aid in achieving robust screw placement.

Another complication of anterior fixation is found in the use of biplanar fluoroscopy. Although the utilization of two C-arms allows for efficient imaging of both the lateral and AP views, a limitation of this set up is that only one view is visualized at a time. As such, it is tempting for the surgical team to follow screw trajectory in only one view – most commonly the more intuitive lateral view. However, without appropriate attention paid to the AP view, it is possible for a screw to seemingly track the odontoid well and still end up in soft tissue. In the cases using biplanar fluoroscopy, frequent consultation of both views is imperative for successful screw placement. The real-time feedback of neuro-navigation is essential to avoid a trajectory error [35].

The last pitfall comes with the use of a K-wire. Proper use of a K-wire requires application of force upon the cannulated screw parallel to the direction of the K-wire. If restrictions of the environment limit ability to apply this force suitably and the screw is driven at an angle to the wire, a shear force may be applied to the K-wire, resulting in the K-wire being driven forward into the brainstem, or the tip of the K-wire breaking off to remain in the odontoid [42]. Thus, due diligence must be paid to the maintenance of force in the appropriate direction when cannulated drill bits and screws are used in conjunction with a K-wire. As an extra precaution, the end of the K-wire may be held with a needle holder to prevent incidental advancement.

Outcomes

Fusion rates for anterior screw fixation range from 73% to 96% in fractures less than 6 months old [5, 9, 13, 36, 61]. Morbidity for this surgery is generally considered to be low [12], with complication rates ranging from 8% to 25% [4, 8, 14]. Major complications include dysphagia, need for a feeding tube, hardware failure, and cervical instability. A 2015 systematic review found that anterior fixation offers a long- and short-term survival advantage for patients older than 60 compared to nonoperative management and that this advantage was not different from that offered by posterior fixation [58]. Qualitatively, a well-placed anterior screw offers instant return of cervical stability, and most patients have near-immediate improvement of neck pain with preserved mobility.

Conclusion

Anterior screw fixation is an effective and valuable procedure in many adult patients with an odontoid fracture. As the population ages and the incidence of type II fractures rises, demand for this procedure can be expected to increase. Although technical expertise is required for success, an anterior screw properly placed offers great quality of life improvement to patients with these unstable fractures and provides several advantages over posterior fixation. Looking forward, there is anticipation of further improvement in outcomes as neuro-navigation modalities become more widely applied and studied in this setting.

References

1. Akobo S, Rizk E, Loukas M, Chapman JR, Oskouian RJ, Tubbs RS. The odontoid process: a comprehensive review of its anatomy, embryology, and variations. Childs Nerv Syst. 2015;31:2025–34.
2. Althoff B. Fracture of the odontoid process. An experimental and clinical study. Acta Orthop Scand Suppl. 1979;177:1–95.
3. Amling M, Pösl M, Wening VJ, Ritzel H, Hahn M, Delling G. Structural heterogeneity within the axis: the main cause in the etiology of dens fractures. A histomorphometric analysis of 37 normal and osteoporotic autopsy cases. J Neurosurg. 1995;83:330–5.
4. Andersson S, Rodrigues M, Olerud C. Odontoid fractures: high complication rate associated with anterior screw fixation in the elderly. Eur Spine J. 2000;9:56–9.
5. Apfelbaum RI, Lonser RR, Veres R, Casey A. Direct anterior screw fixation for recent and remote odontoid fractures. J Neurosurg. 2000;93:227–36.
6. Apuzzo ML, Heiden JS, Weiss MH, Ackerson TT, Harvey JP, Kurze T. Acute fractures of the odontoid process. An analysis of 45 cases. J Neurosurg. 1978;48:85–91.
7. Bednar DA, Parikh J, Hummel J. Management of type II odontoid process fractures in geriatric patients; a prospective study of sequential cohorts with attention to survivorship. J Spinal Disord. 1995;8:166–169.
8. Böhler J. Anterior stabilization for acute fractures and non-unions of the dens. PubMed – NCBI. Available: https://www.ncbi.nlm.nih.gov/pubmed/7033229. Accessed 29 August 2017.
9. Börm W, Kast E, Richter H-P, Mohr K. Anterior screw fixation in type II odontoid fractures: is there a difference in outcome between age groups? Neurosurgery. 2003;52:1089–92; discussion 1092–4.
10. Borne GM, Bedou GL, Pinaudeau M, Cristino G, Hussein A. Odontoid process fracture osteosynthesis with a direct screw fixation technique in nine consecutive cases. J Neurosurg. 1988;68:223–6.
11. Chapman J, Smith JS, Kopjar B, Vaccaro AR, Arnold P, Shaffrey CI, et al. The AOSpine North America Geriatric Odontoid Fracture Mortality Study: a retrospective review of mortality outcomes for operative versus nonoperative treatment of 322 patients with long-term follow-up. Spine. 2013;38:1098–104.
12. Clark CR, White AA. Fractures of the dens. A multicenter study. J Bone Joint Surg Am. 1985;67:1340–8.
13. Collins I, Min W-K. Anterior screw fixation of type II odontoid fractures in the elderly. J Trauma. 2008;65:1083–7.
14. Daher MT, Daher S, Nogueira-Barbosa MH, Defino HLA. Computed tomographic evaluation of odontoid process: implications for anterior screw fixation of odontoid fractures in an adult population. Eur Spine J. 2011;20:1908–14.
15. Dailey AT, Hart D, Finn MA, Schmidt MH, Apfelbaum RI. Anterior fixation of odontoid fractures in an elderly population. J Neurosurg Spine. 2010;12:1–8.
16. Dobran M, Nasi D, Esposito DP, Iacoangeli M. Posterior fixation with C1 lateral mass screws and C2 pars screws for type II odontoid fracture in the elderly: long-term follow-up. World Neurosurg. 2016;96:152–8.

17. Dunn ME, Seljeskog EL. Experience in the management of odontoid process injuries: an analysis of 128 cases. Neurosurgery. 1986;18:306–10.
18. Eap C, Barresi L, Ohl X, Saddiki R, Mensa C, Madi K, et al. Odontoid fractures anterior screw fixation: a continuous series of 36 cases. Orthop Traumatol Surg Res. 2010;96:748–52.
19. Falavigna A, Righesso O, da Silva PG, Siri CR, Daniel JW, Esteves Veiga JC, et al. Management of Type II odontoid fractures: experience from Latin American Spine Centers. World Neurosurg. 2017;98:673–81.
20. Faure A, Graillon T, Pesenti S, Tropiano P, Blondel B, Fuentes S. Trends in the surgical management of odontoid fractures in patients above 75 years of age: retrospective study of 70 cases. Orthop Traumatol Surg Res. 2017. Available: http://www.sciencedirect.com/science/article/pii/S1877056817302153.
21. Feng G, Wendlandt R, Spuck S, Schulz AP. One-screw fixation provides similar stability to that of two-screw fixation for type II dens fractures. Clin Orthop. 2012;470:2021–8.
22. Fielding JW, van Cochran GB, Lawsing JF, Hohl M. Tears of the transverse ligament of the atlas. A clinical and biomechanical study. J Bone Joint Surg Am. 1974;56:1683–91.
23. Geisler FH, Cheng C, Poka A, Brumback RJ. Anterior screw fixation of posteriorly displaced type II odontoid fractures. Neurosurgery. 1989;25:30–37-38.
24. Graham RS, Oberlander EK, Stewart JE, Griffiths DJ. Validation and use of a finite element model of C-2 for determination of stress and fracture patterns of anterior odontoid loads. J Neurosurg. 2000;93:117–25.
25. Graziano G, Jaggers C, Lee M, Lynch W. A comparative study of fixation techniques for type II fractures of the odontoid process. Spine. 1993;18:2383–7.
26. Greene KA, Dickman CA, Marciano FF, Drabier JB, Hadley MN, Sonntag VK. Acute axis fractures. Analysis of management and outcome in 340 consecutive cases. Spine. 1997;22:1843–52.
27. Greene KA, Dickman CA, Marciano FF, Drabier J, Drayer BP, Sonntag VK. Transverse atlantal ligament disruption associated with odontoid fractures. Spine. 1994;19:2307–14.
28. Hadley MN, Dickman CA, Browner CM, Sonntag VK. Acute axis fractures: a review of 229 cases. J Neurosurg. 1989;71:642–7.
29. Haher T, Merola, A, editors. Odontoid fixation. In: Surgical techniques for the spine. New York: Thieme Medical Publishers, Inc.; 2003, p. 16.
30. Hanigan WC, Powell FC, Elwood PW, Henderson JP. Odontoid fractures in elderly patients. J Neurosurg. 1993;78:32–5.
31. Hanssen AD, Cabanela ME. Fractures of the dens in adult patients. J Trauma. 1987;27:928–34.
32. Harrop JS, Przybylski GJ, Vaccaro AR, Yalamanchili K. Efficacy of anterior odontoid screw fixation in elderly patients with Type II odontoid fractures. Neurosurg Focus. 2000;8:e6.
33. Harrop JS, Hart R, Anderson PA. Optimal treatment for odontoid fractures in the elderly. Spine. 2010;35:S219–27.
34. Jain N, Verma R, Garga UC, Baruah BP, Jain SK, Bhaskar SN. CT and MR imaging of odontoid abnormalities: a pictorial review. Indian J Radiol Imaging. 2016;26:108–19.
35. Jaiswal A, Shetty AP, Rajasekaran S. Role of intraoperative Iso-C based navigation in challenging spine trauma. Indian J Orthop. 2007;41:312–7.
36. Jenkins JD, Coric D, Branch CL. A clinical comparison of one- and two-screw odontoid fixation. J Neurosurg. 1998;89:366–70.
37. Julien TD, Frankel B, Traynelis VC, Ryken TC. Evidence-based analysis of odontoid fracture management. Neurosurg Focus. 2000;8:1–6.
38. Kantelhardt SR, Keric N, Giese A. Management of C2 fractures using Iso-C(3D) guidance: a single institution's experience. Acta Neurochir. 2012;154:1781–7.
39. Kuntz C, Mirza SK, Jarell AD, Chapman JR, Shaffrey CI, Newell DW. Type II odontoid fractures in the elderly: early failure of nonsurgical treatment. Neurosurg Focus. 2000;8:e7.
40. Lesoin F, Autricque A, Franz K, Villette L, Jomin M. Transcervical approach and screw fixation for upper cervical spine pathology. Surg Neurol. 1987;27:459–65.

41. Magee W, Hettwer W, Badra M, Bay B, Hart R. Biomechanical comparison of a fully threaded, variable pitch screw and a partially threaded lag screw for internal fixation of Type II dens fractures. Spine. 2007;32:E475–9.
42. Mazur MD, Mumert ML, Bisson EF, Schmidt MH. Avoiding pitfalls in anterior screw fixation for Type II odontoid fractures. Neurosurg Focus. 2011;31:E7.
43. McBride AD, Mukherjee DP, Kruse RN, Albright JA. Anterior screw fixation of Type II odontoid fractures. A biomechanical study. Spine. 1995;20:1855–1859-1860.
44. Molinari RW, Khera OA, Gruhn WL, McAssey RW. Rigid cervical collar treatment for geriatric Type II odontoid fractures. Eur Spine J. 2012;21:855–62.
45. Molinari WJ, Molinari RW, Khera OA, Gruhn WL. Functional outcomes, morbidity, mortality, and fracture healing in 58 consecutive patients with geriatric odontoid fracture treated with cervical collar or posterior fusion. Glob Spine J. 2013;3:21–32.
46. Montesano PX, Anderson PA, Schlehr F, Thalgott JS, Lowrey G. Odontoid fractures treated by anterior odontoid screw fixation. Spine. 1991;16:S33–7.
47. Montesano PX, Juach EC, Anderson PA, Benson DR, Hanson PB. Biomechanics of cervical spine internal fixation. Spine. 1991;16:S10–6.
48. Munakomi S, Tamrakar K, Chaudhary PK, Bhattarai B. Anterior single odontoid screw placement for type II odontoid fractures: our modified surgical technique and initial results in a cohort study of 15 patients. F1000Res. 2016;5. Available: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC5133680/.
49. Nakanishi T. Internal fixation of the odontoid fracture. Cent Jpn J Orthop Surg Traumatol. 1980;23:399–406.
50. Nourbakhsh A, Shi R, Vannemreddy P, Nanda A. Operative versus nonoperative management of acute odontoid Type II fractures: a meta-analysis. J Neurosurg Spine. 2009;11:651–8.
51. Pepin JW, Bourne RB, Hawkins RJ. Odontoid fractures, with special reference to the elderly patient. Clin Orthop. 1985;193:178–83.
52. Platzer P, Thalhammer G, Oberleitner G, Schuster R, Vécsei V, Gaebler C. Surgical treatment of dens fractures in elderly patients. J Bone Joint Surg Am. 2007;89:1716–22.
53. Rao G, Apfelbaum RI. Odontoid screw fixation for fresh and remote fractures. Neurol India. 2005;53:416–23.
54. Ryan MD, Taylor TK. Odontoid fractures in the elderly. J Spinal Disord. 1993;6:397–401.
55. Sasso R, Doherty BJ, Crawford MJ, Heggeness MH. Biomechanics of odontoid fracture fixation. Comparison of the one- and two-screw technique. Spine. 1993;18:1950–3.
56. Sayama CM, Fassett DR, Apfelbaum RI. The utility of MRI in the evaluation of odontoid fractures. J Spinal Disord Tech. 2008;21:524–6.
57. Scheyerer MJ, Zimmermann SM, Simmen H-P, Wanner GA, Werner CM. Treatment modality in Type II odontoid fractures defines the outcome in elderly patients. BMC Surg. 2013;13:54.
58. Schroeder GD, Kepler CK, Kurd MF, Paul JT, Rubenstein RN, Harrop JS, et al. A systematic review of the treatment of geriatric Type II odontoid fractures. Neurosurgery. 2015;77(Suppl 4):S6–14.
59. Schweigel JF. Management of the fractured odontoid with halo-thoracic bracing. Spine. 1987;12:838–9.
60. Smith HE, Kerr SM, Fehlings MG, Chapman J, Maltenfort M, Zavlasky J, et al. Trends in epidemiology and management of Type II odontoid fractures: 20-year experience at a model system spine injury tertiary referral center. J Spinal Disord Tech. 2010;23:501–5.
61. Subach BR, Morone MA, Haid RW, McLaughlin MR, Rodts GR, Comey CH. Management of acute odontoid fractures with single-screw anterior fixation. Neurosurgery. 1999;45:812–819-820.
62. Tashjian RZ, Majercik S, Biffl WL, Palumbo MA, Cioffi WG. Halo-vest immobilization increases early morbidity and mortality in elderly odontoid fractures. J Trauma. 2006;60:199–203.
63. Vaccaro AR, Kepler CK, Kopjar B, Chapman J, Shaffrey C, Arnold P, et al. Functional and quality-of-life outcomes in geriatric patients with Type-II dens fracture. J Bone Joint Surg Am. 2013;95:729–35.

64. Wang GJ, Mabie KN, Whitehill R, Stamp WG. The nonsurgical management of odontoid fractures in adults. Spine. 1984;9:229–30.
65. Woodring JH, Lee C. Limitations of cervical radiography in the evaluation of acute cervical trauma. J Trauma. 1993;34:32–9.
66. Wu J, Wadhwa R, Than K, Mummaneni P. Complication avoidance and management using the O-arm for odontoid screw fixation: technical note. Cureus. 2014;6. Available: http://www.cureus.com/articles/2695-complication-avoidance-and-management-using-the-o-arm-for-odontoid-screw-fixation-technical-note. Accessed 30 August 2017.

Chapter 28
Cerebrospinal Fluid Leak After Spine Surgery

Michelle Feinberg, Kathleen Knudson, Jezer Martinez, Crystal Adams, Fadi Sweiss, and Jonathan H. Sherman

Introduction

Cerebrospinal fluid (CSF) leak is a well-documented complication of spine surgery but can also be associated with trauma and other interventions, such as a lumbar puncture. CSF leak can be associated with headaches and risk of meningitis, as well as other complications, such as deep venous thrombosis (DVT) from prolonged hospitalization. Treatment for CSF leak ranges from nonoperative strategies to primary repair. Unfortunately, there does not appear to be clear consensus on a treatment algorithm in the literature.

This chapter aims to review this common complication, addressing the incidence, etiology, as well as clinical presentation and imaging findings. Additionally, the various different treatment options and their pros and cons will be discussed. This will aim to be guidelines for residents and junior faculty to use to assist their clinical decision-making when addressing their own patients.

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_28

Incidence

An incidental durotomy resulting in a cerebral spinal fluid (CSF) leak is one of the most common complications of spine surgery and spinal procedures [1]. It is very likely that the actual incidence of CSF leaks after spinal surgery is underreported. Rates reported range from 0.5% to as high as 20% in certain cases [2]. These rates appear higher for revision surgery compared to primary surgery. Additionally, these appear higher in surgery involving the lumbar spine compared to the cervical spine [1]. The incidence also appears to be higher for posterior approaches compared to anterior approach [1]. There also appears to be a decreased risk of having a CSF leak with minimally invasive procedures compared to open surgery [3].

Several risk factors for the development of a durotomy have been identified. Older age appears to be a consistent risk factor throughout several reviews. This is likely due to worsening degenerative changes in older patients including narrowing of the spinal canal, thicker ligamentum flavum, and osteophyte formation [4]. Additionally, ossification of the posterior longitudinal ligament can put patients at 13.7 times more likely of having a CSF leak during surgery [5, 6]. Other pathologies can be associated with increased risk of CSF leak, such as synovial cysts, disc fragments, bone spikes, and scar tissue [7]. The presence of juxtafacet cysts also increases the rate of dural tears. The incidence of durotomies with juxtafacet cysts is reported as 17–18% which is at the highest end of this complication [8]. The adhesive nature of these cysts likely increases the likely of a dural tear during their dissection. Prior spinal surgery with the development of scar tissue has consistently been reported as the highest risk factor for unintentional durotomies [9].

The obesity epidemic continues to become an increasingly difficult challenge to spine surgeons and is a well-established independent risk factor for increased complication rates in spinal surgery [10]. The rate of incidental durotomy is also significantly associated with obesity. In a recent comparison between nonobese, obese, and morbidly obese patients, the incidence of having an incidental durotomy was found to be significantly higher in the obese and morbidly obese groups compared to the nonobese patients [11]. Nonobese patients had a 0.9% rate of CSF leak, whereas obese patients had a 1.2% rate, and morbidly obese patients had a 1.4% rate of CSF leaks [11].

There are technical issues during the surgery as well that cause an increased risk of having a CSF leak, the most common being injury to the dura by a Kerrison Rongeur [6]. Making sure that the Kerrison is perpendicular to the thecal sac is a useful method of decreasing this possibility [7]. A fine dissecting instrument can also be used to help separate the dura, so that it is not caught in the Kerrison. The use of a high-speed drill has been associated with dural tears, [3] and so care should also be made to protect the dura with a shield while drilling [7].

Inappropriate placement of spinal instrumentation can also result in a CSF leak [12]. This is usually seen with medial placement of pedicle screws or deep anterior spinal fusion screws. Proper length and placement of screws can avoid such a complication.

Clinical Manifestation

Although patients with a CSF leak after spine surgery can be asymptomatic, there are other signs and symptoms that may manifest. An incomplete closure results in persistent cerebral spinal fluid leak from the subarachnoid space. If a continued CSF leak is present, the decreased pressure causes a caudal displacement of the intracranial contents [13]. This results in the most common symptom of a CSF leak, a postural headache. Nausea, vomiting, photophobia, dizziness, and tinnitus can be associated with the headaches of a CSF leak as well [13]. If a patient has continued spinal fluid leak, he or she risks in developing wound infection and breakdown and meningitis [6]. Additionally, persistent CSF leak can cause psuedomeningocle formation which can lead to herniation of the spinal nerve roots [14]. If this occurs, patients can develop neurological symptoms including radiculopathy or myelopathy. Another complication of CSF leaks is the development of dural cutaneous CSF fistulas which can cause meningitis, arachnoiditis, or epidural abscess [1].

A rare but severe complication of CSF leak is the development of intracranial subdural hematomas or cerebellar hemorrhages. The altered CSF dynamics puts the fragile bridging veins on stretch which can cause them to rupture into the subdural space resulting in hemorrhage. This underscores the importance of adequate dural closure with dural tears [14].

The long-term consequences of unintentional durotomies are unclear. The Spine Patient Outcomes Research Trial (SPORT) was a large prospective trial that followed patients who underwent first time lumbar laminectomies with or without fusion for spinal stenosis. In the short term, there was a significant increase in hospital length of stay by approximately 1 day in the group that had incidental durotomies compared to those that did not [15]. There were no differences in wound healing complications or postoperative nerve root injury. In the long-term data, there was no difference in pain outcomes or physical function scores over the 4-year follow-up period for both groups [15]. Additionally, there was no difference in reoperation rates [15]. These results validate several smaller retrospective series that have found no difference in long-term outcomes following unintentional durotomies [2, 16, 17].

Patients report similar improvements in both back pain and leg pain visual analog scores regardless if a durotomy was made [18]. Additionally, patients have similar improvements in functional status [18]. Despite the lack of long-term deleterious effects, dural tears were the second most common complication resulting in a lawsuit [19]. Although the medicolegal consequences of an incidental durotomy are real, there is little evidence to prove a difference in clinical outcomes with a durotomy.

Imaging Studies

Magnetic resonance imaging (MRI) is currently the gold standard for evaluating and diagnosing a CSF leak after spine surgery. MRI can help to determine the location and characteristics of the fluid collection. On MRI, CSF will appear hypointense on T1 weighted images and hyperintense on T2 weighted images. Contrast enhancement may indicate concern for infection. There may be artifact from spine hardware that can obscure the picture.

Another study that may be useful for evaluation of a CSF leak includes obtaining a computed tomography (CT) myelogram. This study can show details of the subarachnoid space and may help identify the site of the leak [20]. This study can also be done for patients who are unable to complete an MRI, and can show better detail regarding the placement of spine hardware, if any. The incision can also be inspected, and any fluid leakage can be sent for beta-2 transferrin. This peptide is highly sensitive for CSF, and is available at most centers [21].

Treatment

When an incidental durotomy occurs during surgery, adequate repair of the leak is essential. There is no standard of care regarding repair of a CSF leak when identified. If possible, a watertight closure should be attempted with suturing the durotomy site. No difference in leak rates has been shown between running and interrupted sutures [22]. Following closure, the anesthesiologist should perform a Valsalva maneuver to 20–25 cm H_20 for 5–10 s [14]. If no egress of CSF is seen, it can be assumed that a watertight closure was obtained. Most often, continued leaks are from the needle holes and therefore a smaller bore needle is recommended for closure [23].

In cases where a watertight closure could not be obtained or to augment a primary closure, fibrin products or bovine-derived collagen products can be used. Fibrin sealant is a gelatinous matrix that is either human or bovine derived and combines fibrinogen and thrombin. Initially it was created as a hemostatic agent. However, its ability to form instant fibrin cross-links has led to its use as a sealant agent. Over time, the fibrin plug will mature into physiological collagenous granulation tissue [24]. Studies have shown the pressure requiring CSF leakage was greater when fibrin glue augmented a suture closure [22]. One concern using fibrin sealants is that animal studies have shown that they may inhibit bony fusion [25] Moreover, fibrin sealants are cost-prohibitive with a 5 cc volume cited as costing $4592.0 [26]. The resultant hydrogel sealant will remain in place for 4 to 8 weeks before being reabsorbed by the body [27].

Another option to augment closure is fibrin glue products. It consists of thrombin and a pooled sealer protein concentration solution, which is mainly cryoprecipitate [27]. Fibrin glue has not been FDA approved for use in neurosurgical procedures, and therefore its use is strictly off-label although commonly used [27].

Collagen matrix products can also be used as part of a dural tear closure. The collagen attracts fibroblasts to assist in secondary wound healing [28]. It is most commonly used as an onlay over the area of the dural defect and can be used in conjunction with sealants. A major benefit of the use of collagen matrix is that it covers the high-pressure leak created by suture holes from a primary repair [28].

Postoperatively, a common practice involves maintaining strict flat bed rest. The physiologic reason for this is that by maintaining an upright position, the hydrostatic pressure in the lumbar CSF space will be increased and add stress to the recently repaired dura [29]. Although this has traditionally been done, little evidence exists to support any benefit in decreasing persistent CSF leak, and in fact it may be harmful [30]. Patients with prolonged bed rest following dural repair have increased rates of deep venous thrombosis, pulmonary complications, and urinary complications, without any improvement in wound drainage or healing rates [29]. CSF diversion with lumbar drain placement can also be used to manage persistent CSF leaks. It physiologically provides a similar benefit to bedrest as to decrease the pressure gradient along the durotomy site. As an invasive procedure, lumbar drain placement does carry along risks of the procedure.

Conclusion

Incidental durotomy is a common and well-established complication in spinal surgery. By far the most important risk factor for developing a dural tear is due to prior surgery although increased age and obesity are important factors as well. Although an incidental durotomy is a common cause of litigation, patients who do have a dural tear do not exhibit a difference in pain or functional outcomes or need for reoperation. The mainstay for repair remains a primary dural closure although many products including fibrin sealants and collagen matrix are available to reinforce the suture line.

References

1. Guerin P, El Fegoun AB, Obeid I, Gille O, Lelong L, Luc S, Bourghli A, Cursolle JC, Pointillart V, Vital JM. Incidental durotomy during spine surgery: incidence, management and complications. A retrospective review. Injury. 2012;43:397–401.
2. Wang JC, Bohlman HH, Riew KD. Dural tears secondary to operations on the lumbar spine. Management and results after a two-year-minimum follow-up of eighty-eight patients. J Bone Joint Surg. 1998;80:1728–32.
3. Wong AP, Shih P, Smith TR, Slimack NP, Dahdaleh NS, Aoun SG, El Ahmadieh TY, Smith ZA, Scheer JK, Koski TR, Liu JC, Fessler RG. Comparison of symptomatic cerebral spinal fluid leak between patients undergoing minimally invasive versus open lumbar foraminotomy, discectomy, or laminectomy. World Neurosurg. 2014;81:634–40.
4. Epstein NE. The frequency and etiology of intraoperative dural tears in 110 predominantly geriatric patients undergoing multilevel laminectomy with noninstrumented fusions. J Spinal Disord Tech. 2007;20:380–6.
5. Smith MD, Bolesta MJ, Leventhal M, Bohlman HH. Postoperative cerebrospinal-fluid fistula associated with erosion of the dura. Findings after anterior resection of ossification of the posterior longitudinal ligament in the cervical spine. J Bone Joint Surg. 1992;74:270–7.
6. Hannallah D, Lee J, Khan M, Donaldson WF, Kang JD. Cerebrospinal fluid leaks following cervical spine surgery. J Bone Joint Surg. 2008;90:1101–5.

7. Menon SK, Onyia CU. A short review on a complication of lumbar spine surgery: CSF leak. Clin Neurol Neurosurg. 2015;139:248–51.
8. Salmon B, Martin D, Lenelle J, Stevenaert A. Juxtafacet cyst of the lumbar spine. Clinical, radiological and therapeutic aspects in 28 cases. Acta Neurochir. 2001;143:129–34.
9. Takahashi Y, Sato T, Hyodo H, Kawamata T, Takahashi E, Miyatake N, Tokunaga M. Incidental durotomy during lumbar spine surgery: risk factors and anatomic locations: clinical article. J Neurosurg Spine. 2013;18:165–9.
10. Kalanithi PA, Arrigo R, Boakye M. Morbid obesity increases cost and complication rates in spinal arthrodesis. Spine. 2012;37(11):982–8.
11. Burks CA, Werner BC, Yang S, Shimer AL. Obesity is associated with an increased rate of incidental durotomy in lumbar spine surgery. Spine. 2015;40:500–4.
12. Faraj AA, Webb JK. Early complications of spinal pedicle screw. Eur Spine J. 1997;6:324–6.
13. Vakharia SB, Thomas PS, Rosenbaum AE, Wasenko JJ, Fellows DG. Magnetic resonance imaging of cerebrospinal fluid leak and tamponade effect of blood patch in postdural puncture headache. Anesth Analg. 1997;84:585–90.
14. Kim KD, Wright NM. Polyethylene glycol hydrogel spinal sealant (DuraSeal Spinal Sealant) as an adjunct to sutured dural repair in the spine: results of a prospective, multicenter, randomized controlled study. Spine. 2011;36:1906–12.
15. Desai A, Ball PA, Bekelis K, Lurie J, Mirza SK, Tosteson TD, Weinstein JN. SPORT: does incidental durotomy affect long-term outcomes in cases of spinal stenosis? Neurosurgery. 2015;76:S57–63.
16. Jones AA, Stambough JL, Balderston RA, Rothman RH, Booth RE Jr. Long-term results of lumbar spine surgery complicated by unintended incidental durotomy. Spine. 1989;14:443–6.
17. Cammisa FP Jr, Girardi FP, Sangani PK, Parvataneni HK, Cadag S, Sandhu HS. Incidental durotomy in spine surgery. Spine. 2000;25:2663–7.
18. Adogwa O, Huang MI, Thompson PM, Darlington T, Cheng JS, Gokaslan ZL, Gottfried ON, Bagley CA, Anderson GD, Isaacs RE. No difference in postoperative complications, pain, and functional outcomes up to 2 years after incidental durotomy in lumbar spinal fusion: a prospective, multi-institutional, propensity-matched analysis of 1,741 patients. Spine J. 2014;14:1828–34.
19. Goodkin R, Laska LL. Unintended "incidental" durotomy during surgery of the lumbar spine: medicolegal implications. Surg Neurol. 1995;43(1):4–12; 12–4.
20. Bosacco SJ, Gardner MJ, Guille JT. Evaluation and treatment of dural tears in lumbar spine surgery: a review. Clin Orthop Relat Res. 2001;389:238–47.
21. McCudden CR, Senior BA, Hainsworth S, Oliveira W, Silverman LM, Bruns DE, Hammett-Stabler CA. Evaluation of high resolution gel β(2)-transferrin for detection of cerebrospinal fluid leak. Clin Chem Lab Med. 2013;51(2):311–5.
22. Cain JE Jr, Dryer RF, Barton BR. Evaluation of dural closure techniques. Suture methods, fibrin adhesive sealant, and cyanoacrylate polymer. Spine. 1988;13:720–5.
23. Dafford EE, Anderson PA. Comparison of dural repair techniques. Spine. 2015;15:1099–105.
24. Sawamura Y, Asaoka K, Terasaka S, Tada M, Uchida T. Evaluation of application techniques of fibrin sealant to prevent cerebrospinal fluid leakage: a new device for the application of aerosolized fibrin glue. Neurosurgery. 1999;44:332–7.
25. Jarzem P, Harvey EJ, Shenker R, Hajipavlou A. The effect of fibrin sealant on spinal fusions using allograft in dogs. Spine. 1996;21:1307–12.
26. Jankowitz BT, Atteberry DS, Gerszten PC, Karausky P, Cheng BC, Faught R, Welch WC. Effect of fibrin glue on the prevention of persistent cerebral spinal fluid leakage after incidental durotomy during lumbar spinal surgery. Eur Spine J. 2009;18:1169–74.
27. Epstein NE. Dural repair with four spinal sealants: focused review of the manufacturers' inserts and the current literature. Spine J. 2010;10:1065–8.
28. Narotam PK, Jose S, Nathoo N, Taylon C, Vora Y. Collagen matrix (DuraGen) in dural repair: analysis of a new modified technique. Spine. 2004;29:2861–7.
29. Radcliff KE, Sidhu GD, Kepler CK, Gruskay J, Anderson DG, Hilibrand A, Albert TJ, Vaccaro AR. Complications of flat bed rest after incidental durotomy. Clin Spine Surg. 2016;29:281–4.
30. Allen C, Glasziou P, Del Mar C. Bed rest: a potentially harmful treatment needing more careful evaluation. Lancet. 1999;354:1229–33.

Chapter 29
Minimally Invasive Sacroiliac Joint Fusion

Cristian Gragnaniello, Fadi Sweiss, Crystal Adams, and Jonathan H. Sherman

Introduction

The minimally invasive sacroiliac joint (SIJ) fusion is a surgical procedure to relieve lower back pain that usually radiates below the level of the iliac crests into the buttocks and thighs. Following extensive workup, the SIJ is identified as the pain generator. Isolated SIJ pain can be treated with conservative measures, including medications and physiotherapy, SIJ joint belt, and steroid injections. Those patients that fail these measures and are still severely disabled by the pain related to the SIJ degeneration can be considered for a fusion procedure. The diagnosis of SIJ-related pain is difficult, and the incidence has been underestimated in the past. However, since the development of new minimally invasive fusion techniques, the condition can be treated after conservative measures have failed. Improved postoperative pain scores and quality of life measures have been reported in more than 60% of patients [1–4].

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_29

Preparing for SIJ Fusion

Knowledge of the anatomy and understanding of the relationship of the SIJs with the surrounding structures is of utmost importance for successful surgical procedures in this area.

The SIJ is a joint with very limited movement of gliding and rotating with its main purpose to transfer forces between the axial spine and pelvis-lower extremities complex. The joint consists of different parts and has a large articular surface. It is formed by the auricular surfaces of the sacrum and the iliac auricular surfaces. It is obliquely oriented in the coronal plane. The upper third of the joint is a syndesmosis, a highly fibrous connection, while the lower two-thirds are lined by articular cartilage and only the lower third lined by synovium.

Even though the joint has a capsule, as it is lined by synovium, stability is mainly conferred by ligaments and muscles. Several ligaments, all extracapsular, have a relationship with the joint. These include interosseous sacroiliac (iliac tuberosity to sacral tuberosity), anterior sacroiliac, dorsal sacroiliac (another layer on top of the interosseous), iliolumbar, sacrospinous, and sacrotuberous.

Muscles that stabilize the joint include latissimus dorsi, gluteus and piriformis. Radiological anatomy is especially important when performing minimally invasive fusion of the SIJ as the images used to place and advance the implants are not as familiar to most surgeons.

CT/MRI of the SIJ are used to evaluate and prepare for MIS fusion of the joint and should include specific cuts that are not always available in routine scans. As mentioned earlier, the joint has an oblique coronal orientation and therefore is best seen in para-axial, paracoronal, and parasagittal cuts.

The three x-ray views everybody needs to be familiar with are the AP x-rays of the pelvis, the inlet and outlet views. The inlet view is obtained by aligning the C-arm with the greater axis of the sacrum and ultimately shows a view of the sacrum from the top. An outlet is obtained with the intensifier placed perpendicularly to the major axis of the sacrum and shows the front of the sacrum with the sacral foramens.

The landmarks that should be visible on x-rays prior to surgery must include the ala of the sacrum, the posterior sacral cortex, greater sciatic notches, sacral foramina in outlet view, and S1 endplate. All patients should have x-rays before surgery as some of the features of a dysmorphic sacrum may be difficult to reconcile with the placement of the implants at the time of surgery.

Safe zones for placement of hardware have been described by Miller et al. [5]. The sacral surface available for placement of the hardware is critical as in a dysmorphic sacrum an alar slope that is more acute offers less available surface to accept the hardware. This is well visualized on an inlet view as a cortical indentation, effectively determining the limit for safe placement of the hardware.

Diagnosis

A patient with SIJ pathology will offer clues to his pathology not just from available imaging but also from their clinical history and clinical examination. Although most of the presenting symptoms are common to most of the other pathologies of the spine and hip, some elements of the history seem to be consistently present in patients with SIJ pathology. They include history of trauma, previous surgery of the spine especially lumbar, pain that started or got worse postpartum, and history of worsening pain on one side only when sitting, forcing the patient to sit unevenly putting pressure on the "good side" [6, 7].

For the clinical examination, there are several maneuvers that put pressure on the SIJs and include FABER test (flexion, abduction, external rotation), compression test, thigh thrust, Patrick's test, distraction test, Yeoman's test, sacral thrust, and Gaenslen's test. If three to five of these maneuvers reproduce the patient's pain, it is appropriate to perform confirmatory intra-articular injections with local anesthetic. Injections are considered positive if they relieve at least 50% of the patient's pain [8]. Imaging is then used to rule out other pathology of the hips and lumbar spine and confirm degeneration at the level of the SIJs.

Surgical Technique and Equipment

Patient is placed prone on a radiolucent table with a C-arm to alternate between AP (inlet and outlet) and lateral views. The inlet view shows the sacrum from the top and the outlet view from the front. On a lateral x-ray, the sciatic notches align and are seen as one. This view is very important to determine the safe zone for placement of the implants as it allows for an indirect estimate of the sacral alar slope. In this view, the iliac cortical density (ICD) represents the anterior limit of the SIJs defining the anterior and superior limit of the safe zone for implant placement. This is of utmost importance because any violation of the anterior cortex of the sacrum will increase the risk of injuries to L5 nerve root as it passes just medial to the SIJ, over the anterior cortex of the sacrum.

The skin incision is made along the projection of the posterior cortex of the sacrum on a lateral view for a length of 3 cm, starting where it intersects the alar line. Fascia is incised perpendicularly to the skin incision with blunt dissection carried to the cortex of the ilium.

On a lateral view, the starting point of the first pin is positioned to be 1 cm below the S1 endplate and 1 cm anterior to the posterior sacral cortex, parallel to the ala to be at the midpoint between the endplate and the S1 foramen. The C-arm is then moved to an inlet view to direct the pin toward the middle of the sacrum. Lastly the outlet view is used to confirm that the pin is directed in a parallel direction to S1 endplate.

The pin is then advanced through the SI joint and into the sacrum at about 2–3 mm. A broach is then used and advanced over the same trajectory and finally replaced by the implant. Care must be taken not to violate cortical walls so as to avoid L5 injuries anteriorly and multiple nerve root injuries in the sacral canal [9–12]. Depending on the type of implant and the ICD, this procedure is repeated to place 2–3 implants.

Management of Complications

Intraoperative complications that include nerve root or dural injuries must be addressed with midline open approaches. If vascular or visceral injuries are suspected, direct exploration is mandatory during the same anesthesia.

If patients return complaining of the same preoperative symptoms, the same diagnostic stepwise approach needs to be maintained including SIJ injections and CT/MRI to rule out hardware complications and pseudarthrosis – pseudarthrosis can occur at any place where spinal fusion was attempted and presents as either axial or radicular pain that occurs months to years after any previous lumbar fusion – as well as lumbar spine pathology [13–15].

References

1. Buchowski JM, Kebaish KM, Sinkiv V. Functional and radiographic outcome of sacroiliac arthrodesis for the disorders of the sacroiliac joint. Spine J. 2005;5:520–8.
2. Miller LE, Block JE. Minimally invasive arthrodesis for chronic sacroiliac joint dysfunction using the SImmetry SI joint fusion system. Med Devices (Auckl). 2014;7(7):125–30. https://doi.org/10.2147/MDER.S63575. eCollection 2014.
3. Ledonio CG, Polly DW Jr, Swiontkowski MF, Cummings JT Jr. Comparative effectiveness of open versus minimally invasive sacroiliac joint fusion. Med Devices (Auckl). 2014;7:187–93.
4. Ackerman SJ, Polly DW Jr, Knight T, Holt T, Cummings J Jr. Nonoperative care to manage sacroiliac joint disruption and degenerative sacroiliitis: high costs and medical resource utilization in the United States Medicare population. J Neurosurg Spine. 2014;20(4):354–63.
5. Miller AN, Routt ML Jr. Variations in sacral morphology and implications for iliosacral screw fixation. J Am Acad Orthop Surg. 2012;20(1):8–16.
6. Stark JG. The diagnosis and treatment of sacroiliac joint abnormalities. Curr Orthop Pract. 2010;21:336–48.
7. Wong CK, Johnson EK. A narrative review of evidence-based recommendations for the physical examination of the lumbar spine, sacroiliac and hip joint complex. Musculoskeletal Care. 2012;10:149–61.
8. Vanaclocha V, Herrera JM, Sáiz-Sapena N, Rivera-Paz M, Verdú-López F. Minimally invasive sacroiliac joint fusion, radiofrequency denervation, and conservative management for sacroiliac joint pain: 6-year comparative case series. Neurosurgery. 2018;82(1):48–55.
9. Rudolf L. Sacroiliac joint arthrodesis-MIS technique with titanium implants: report of the first 50 patients and outcomes. Open Orthop J. 2012;6:495–502.
10. Sachs D, Capobianco R. One year successful outcomes for novel sacroiliac joint arthrodesis system. Ann Surg Innov Res. 2012;6:13.

11. Gaenslen FJ. Sacro-iliac arthrodesis: indications, author’s technique and end-results. JAMA. 1927;89:2031–5.
12. Smith-Petersen MN. Arthrodesis of the sacroiliac joint. A new method of approach. J Bone Joint Surg Am. 1921;3-A:400–5.
13. Abbasi H, Hipp JA. The assessment of fusion following sacroiliac joint fusion surgery. Cureus. 2017;9(10):e1787.
14. Dengler JD, Kools D, Pflugmacher R, Gasbarrini A, Prestamburgo D, Gaetani P, van Eeckhoven E, Cher D, Sturesson B. 1-year results of a randomized controlled trial of conservative management vs. minimally invasive surgical treatment for sacroiliac joint pain. Pain Physician. 2017;20(6):537–50.
15. Sachs D, Capobianco R, Cher D, Holt T, Gundanna M, Graven T, Shamie AN, Cummings J Jr. One-year outcomes after minimally invasive sacroiliac joint fusion with a series of triangular implants: a multicenter, patient-level analysis. Med Devices (Auckl). 2014;7:299–304.

Chapter 30
Treatment Considerations for Pyogenic Spinal Infection

Ehab Shiban and Bernhard Meyer

Pathogenesis and Epidemiology

Spondylodiscitis is the most common type of spinal infection [1]. Hematogenous seeding of bacteria from a distant focus is the cause of the inflammation in almost 50% of cases. Thereby skin ulcer, gastrointestinal infections, and endocarditis are the most common foci. In the other 50% of cases, the inflammation is caused by a previous surgical procedure with either hematogenous seeding from a distant focus (i.e., hip replacement surgery) or due to local contamination following a spinal procedure [2, 3].

In western countries, pyogenic spinal infection is the predominant type of spinal infection; thereby *Staphylococcus aureus* is the most common bacteria and is detected in up to 40% of all cases [4]. Other gram-positive cocci are also been commonly found (i.e., *Streptococcus*, *Pneumococcus*, *Enterococcus*). Recently some have reported infection due to gram-negative bacteria as well (i.e., *Escherichia coli*, *Pseudomonas aeruginosa*, *Salmonella*, *Klebsiella*). In the last decade, the emergence of drug multiresistant bacteria has become a relevant problem in all medical fields as well as in spinal infections ([2, 3] II). In developing countries *Mycobacterium tuberculosis* is still a major cause of spinal infection [5].

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_30

Due to the aging population, rise in the rate of immunosuppressed patients, and improvements in the diagnostic possibilities, the incidence of spondylodiscitis has increased in the last years and is estimated within a range from 0.5 up to 10 per 100,000 inhabitants per year in the western countries [6, 7].

Although the absolute number of cases with spondylodiscitis is small in comparison to the volume of spine cases overall, they tend to have a disproportionate impact on both patient outcome and societal cost. Beside the relatively high direct costs of treatment due to the prolonged hospital stay, the indirect costs including lost workdays and income are substantial, especially for patients treated conservatively.

Diagnosis

Most patients with spondylodiscitis present with persisting back pain unresponsive to conservative measures. In contrast to pain due to degenerative disc disease, patients with spondylodiscitis complain of persisting pain also while lying down. Half of the patients will present with fever [2, 3]. C-reactive protein (CRP) is very sensitive and is positive in almost all patients with spondylodiscitis. Leukocyte count is elevated in only half of all cases [2, 3]. The analysis of the sedimentation rate has become obsolete in most western countries.

In every patient with an elevated CRP and persisting back pain, spinal imaging is highly recommended. Thereby magnetic resonance imaging with contrast enhancement has become the gold standard. Spinal surgeons need to ask for a short-TI inversion recovery (STIR) sequence. This special MR sequence is one of the only fat suppression methods available. Thereby the bone marrow fat signals are suppressed, making the diagnosis of spondylodiscitis more clear (Fig. 30.1). In order to appreciate the bone destructions of the vertebral plates, a computer tomogram (CT) is recommended. Moreover, because in 5% of spondylodiscitis cases there will be another spinal infection in a distant part of the spine, imaging of the whole spine should be performed.

With the combination of clinical, laboratory, and image findings, the correct diagnosis of spondylodiscitis can be made in almost all cases. In up to 5% of cases there might still be some amount of uncertainty. In those unclear cases a CT-guided biopsy may be recommended. This diagnostic test has a sensitivity of 52% and a specificity of 99.9% [8]. Also for this diagnostic modality, the spine surgeons need to communicate to the radiologist that the biopsy is to be performed from both the soft tissue and the vertebral body. The microbiological yield is much higher from the soft tissue biopsy (63.5% vs. 39.7%) [9].

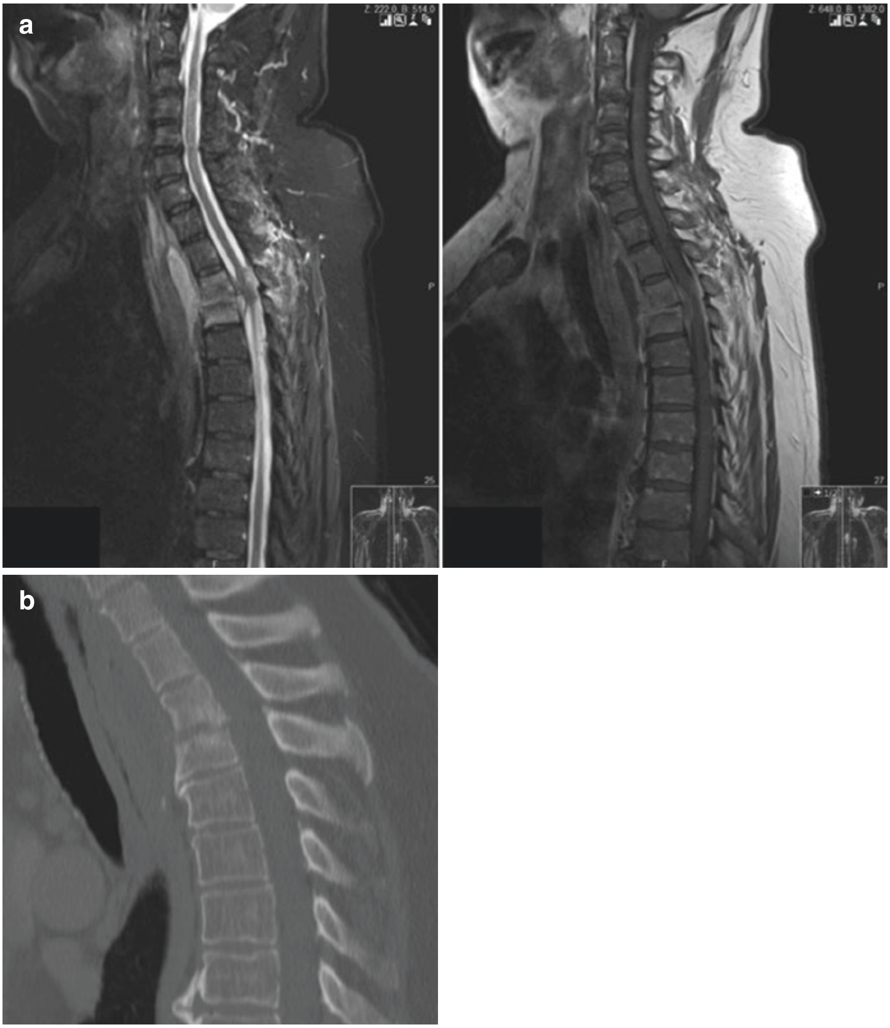

Fig. 30.1 (**a**) (right) MRI- STIR sequense illustrating edema in the vertebral bodies above and below the infected disc as well as epidural emypema. (left) MRT-Contranst enhasment showing the infected Disc. (**b)** CT-scan illustrating the bone distruction of the plates of vertebral bodies

Treatment

Although some therapeutic guidelines are available, treatment of spondylodiscitis is certainly not standardized and is mostly based on local preferences [10–13].

Table 30.1 "Red flags" in patients with spinal infection

Hard indication for surgery treatment
Spinal instability
Spinal deformity
Neurological deficit
Failed conservative treatment
Soft indication
Drug multiresistant bacteria

The treatment of spondylodiscitis is based on the concept of immobilizing the affected spinal segment in combination with prolonged antibiotic treatment. For these two basic treatment principles, there still exists a lot of controversy. The duration of antibiotic treatment was up until recently a matter on intense debate. In a recent French randomized multicenter trial, patients with spontaneous spondylodiscitis were treated conservatively and randomized to either 6 or 12 weeks of antibiotic treatment. Primary outcome was the rate of patients that were cured and alive at 12-month follow-up. The authors found no statistically significant differences between both groups. Approximately 85% of all patients were cured and alive at 12-month follow-up [4].

Immobilizing the affected segment can be done either by bed rest and/or an orthosis for a few weeks or by spinal instrumentation. In the absence of "red flags" (Table 30.1) conservative treatment is still considered the gold standard. However, recently, a paradigm shift has occurred in Western Europe, as most spine surgeons now prefer surgical treatment in most cases in order to avoid prolonged bed rest with its presumed complication in this mostly elderly and fragile patient cohort [2, 3].

Although the French RCT only tackled the controversy of the duration of antibiotic treatment, this RCT sparkled a renewed intense controversy in the spinal community with regard to the need for surgical treatment in patients without the previously mentioned "red flags." The conservative treatment ultimately leads to healing of the inflammation in only 90% of cases, and only 85% were cured and alive at 12-month follow-up [4]. On the other hand, reports of surgical studies demonstrate cured and alive patients in almost all cases [2, 3]. A recent systematic review [14] identified only three studies that compared conservative to surgical treatment [15–17]. All three being retrospective studies. The indications for surgical treatment in the first two studies were neurological deficits, extensive bone destruction, epidural abscess formation, and failure of nonoperative treatment. Although these studies reported about the complications and reoperation rates in detail, no statistical analysis comparing both groups was performed [15, 17]. In contrast to these studies, Nastro et al. [16] offered the patients to choose between an orthosis for 3–4 months or spinal instrumentation (bridging percutaneous pedicle screw constructs) followed by a soft brace for 4 weeks. They found no statistically significant differences after 9 months between both groups with regard to pain or healing rates.

Special Treatment Considerations

Surgical Site Infection

For patients with surgical site infection following thoracolumbar spinal surgery, some different management issues become relevant. At first the degree of infection (superficial vs. deep) as well as the clinical presentation will guide treatment. In the case of a superficial infection without sepsis the patients should be treated conservatively. In case of deep infection, revision surgery is needed. If there are no signs of implant loosening (halo around the implants), the implants should not be removed at first revision. Aim of surgery should be debridement, biopsy, and drainage. If the CRP does not decrease or the patients are still complaining of severe pain, then follow-up imaging followed by implant removal is indicated (Fig. 30.2).

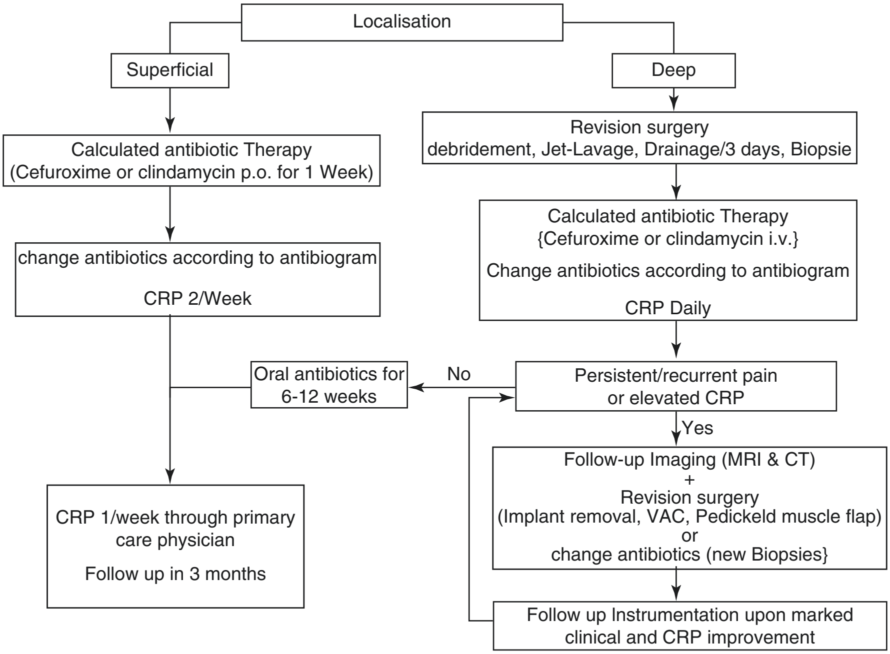

Fig. 30.2 Treatment algorithm for patients with surgical site infection following spinal procedures

References

1. Zimmerli W. Clinical practice. Vertebral osteomyelitis. N Engl J Med. 2010;362:1022–9.
2. Shiban E, Janssen I, Wostrack M, Krieg SM, Ringel F, Meyer B, Stoffel M. A retrospective study of 113 consecutive cases of surgically treated spondylodiscitis patients. A single-center experience. Acta Neurochir. 2014a;156(6):1189–96.
3. Shiban E, Janssen I, Wostrack M, Krieg SM, Horanin M, Stoffel M, Meyer B, Ringel F. Spondylodiscitis by drug-multiresistant bacteria: a single-center experience of 25 cases. Spine J. 2014b;14(12):2826–34.
4. Bernard L, Dinh A, Ghout I, Simo D, Zeller V, Issartel B, Le Moing V, Belmatoug N, Lesprit P, Bru JP, Therby A, Bouhour D, Dénes E, Debard A, Chirouze C, Fèvre K, Dupon M, Aegerter P, Mulleman D. Antibiotic treatment for 6 weeks versus 12 weeks in patients with pyogenic vertebralosteomyelitis: an open-label, noninferiority, randomised, controlled trial; Duration of Treatment for Spondylodiscitis (DTS) study group. Lancet. 2015;385(9971):875–82.
5. Garg RK, Somvanshi DS. Spinal tuberculosis: a review. J Spinal Cord Med. 2011;34(5):440–54.
6. Kehrer M, Pedersen C, Jensen TG, Lassen AT. Increasing incidence of pyogenic spondylodiscitis: a 14-year population-based study. J Infect. 2014;68(4):313–20.
7. Murillo O, Grau I, Lora-Tamayo J, Gomez-Junyent J, et al. The changing epidemiology of bacteraemic osteoarticular infections in the early 21st century. Clin Microbiol Infect. 2015;21(3):254.e1–8.
8. Pupaibool J, Vasoo S, Erwin PJ, Murad MH, Berbari EF. The utility of image-guided percutaneous needle aspiration biopsy for the diagnosis of spontaneous vertebral osteomyelitis: a systematic review and meta-analysis. Spine J. 2015;15(1):122–31.
9. Kim CJ, Kang SJ, Choe PG, Park WB, Jang HC, Jung SI, Song KH, Kim ES, Kim HB, Oh MD, Park KH, Kim NJ. Which tissues are best for microbiological diagnosis in patients with pyogenic vertebral osteomyelitis undergoing needle biopsy? Clin Microbiol Infect. 2015;21(10):931–5.
10. Berbari EF, Kanj SS, Kowalski TJ, et al. 2015 Infectious Diseases Society of America (IDSA) clinical practice guidelines for the diagnosis and treatment of native vertebral osteomyelitis in adults. Clin Infect Dis. 2015;61(6):e26–46.
11. Gasbarrini A, Boriani L, Nanni C, et al. Spinal infection multidisciplinary management project (SIMP): from diagnosis to treatment guideline. Int J Immunopathol Pharmacol. 2011;24(1 Suppl 2):95–100 14.
12. Socie´te´ de pathologie infectieuse de langue franc¸aise (SPLIF). Recommandations pour la pratique clinique Spondylodiscites infectieuses primitives, et secondaires a` un geste intradiscal, sans mise en place de mate'riel. Med Mal Infect. 2007;37:544–72.
13. Sobottke R, Seifert H, Fatkenheuer G, Schmidt M, Gossmann A, Eysel P. Current diagnosis and treatment of spondylodiscitis. Dtsch Arztebl Int. 2008;105(10):181–7.
14. Rutges JP, Kempen DH, van Dijk M, Oner FC. Outcome of conservative and surgical treatment of pyogenic spondylodiscitis: a systematic literature review. Eur Spine J. 2016;25(4):983–99.
15. Karadimas EJ, Bunger C, Lindblad BE, Hansen ES, Høy K, Helmig P, Kannerup AS, Niedermann B. Spondylodiscitis. A retrospective study of 163 patients. Acta Orthop. 2008;79(5):650–9.
16. Nasto LA, Colangelo D, Mazzotta V, Di Meco E, Neri V, Nasto RA, Fantoni M, Pola E. Is posterior percutaneous screw rod instrumentation a safe and effective alternative approach to TLSO rigid bracing for single-level pyogenic spondylodiscitis? Results of a retrospective cohort analysis. Spine J. 2014;14(7):1139–46. pii: S1529-9430(13)01401-0.
17. Valancius K, Hansen ES, Hoy K, Helmig P, Niedermann B, Bunger C. Failure modes in conservative and surgical management of infectious spondylodiscitis. Eur Spine J. 2013;22(8):1837–44.

Chapter 31
Revision Lumber Decompressions

David Hanscom and Peter Grunert

Overview

There is a significant chance that a given lumbar decompression for disc herniations or stenosis will require future surgery. For soft disc ruptures, the incidence is between 5–11% [1] and 10–17% for stenosis [2]. The outcomes for revision surgery are less predictable than primary surgery, and there is much debate about the indications, pre-op care, and the choice of procedure. This chapter will attempt to highlight the issues, but the topic is not amenable to offering simple solutions, as there are so many variables to consider in a given patient.

Soft Disc Ruptures

There is abundant literature regarding the decision-making process for a primary lumbar decompression for a soft disc rupture. It is clear that a radiculopathy caused by a soft disc has a high chance of spontaneously resolving with the disc often reabsorbing on follow-up MRI scans [3]. A lumbar discectomy, though, will provide faster pain relief with an earlier return to normal activities, and a low complication rate. Clinical decision-making is key in that if the patient is OK with the level of pain and is willing or wanting to wait, then conservative care is the best option. However, it is important for the physician to provide reasonable pain control, so as to not push someone toward surgery that could avoid it. If the pain is intolerable or

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_31

lasting longer than is tolerable, a lumbar discectomy is a good option with a documented acceptable success rate around 85% [4].

Lumbar Stenosis

Lumbar stenosis has a different decision-making process than with soft disc ruptures with the basic difference being that the bony and ligamentous pathology cannot resorb, such as what usually happens with soft disc ruptures. Other differences include:

- Pathology can exist at multiple levels making the diagnosis of the exact source of the pain less clear. Soft disc ruptures rarely occur at more than one level.
- With multiple-level involvement, the symptoms are often vague, again making the exact source of the pain less clear.
- The pathology evolves over time with large variability. Symptom onset is usually gradual over several years.
- If there is an acute onset of pain in the presence of bony pathology, there is often a major life stress that has altered the body's level of adrenaline, cortisol, endorphins, and other stress chemicals. Animal studies show that nerve conduction is increased and therefore the pain threshold is lowered. The preexisting pathology will be the first to become symptomatic [5].

Reasons for ongoing or recurrent radiculitis after a primary lumbar decompression, regardless of the original approach or technique include:

- Inadequate decompression in the form of a retained fragment or inadequate removal of the bony/ligamentous pathology.
- Surgery was performed at the wrong level.
- Wrong surgery – Intra or extra-foraminal nerve root compression can be missed by both the radiologist and the surgeon. A central decompression may have been done when the pathology is more lateral.
- Recurrence of facet capsular hypertrophy resulting in recurrent central or foraminal stenosis.
- Recurrent rupture, which occurs between up to 30% of the time within 10 years [6].
- New rupture or pathology occurring at a different level.
- Infections – superficial, deep, or a discitis.
- Dural tear/nerve damage, which is rare with a primary discectomy and more common in stenosis surgery [7].
- Persistent pain from memorized pain circuits similar to phantom limb pain; 40–60% of the time pain can be induced or worsened when operating in the presence of ongoing chronic pain in any part of the body [8, 9].

All of these possibilities must be taken into account when assessing a patient with recurrent or ongoing radicular pain post lumbar decompression. It should have been made clear to the patient that whatever component of back pain existed prior to surgery rarely resolves and should not have been a factor in deciding on undergoing surgery. Ongoing or recurrent LBP is a separate issue and is not a consideration that will be discussed in this chapter.

A 2011 Medicare database looked at 31,543 patients (>68 years-old) who underwent revision lumbar surgery for stenosis. The greatest predictor of a repeat surgery was a prior operation performed prior to the index procedure (17.2% vs. 10.6% without prior surgery). There is a trend to perform a fusion on the initial stenosis decompression as a "definitive" procedure. The re-operation rate at four-year follow-up was the same for the decompression alone and simple arthrodesis group (10.7%). The re-operation rate (13.5%) was higher in the complex arthrodesis group, which was defined as an anterior/posterior procedure or more than two levels. The incidence of re-operation decreased with increasing age and co-morbidity. This study does not take into account the natural history of progressive disc disease despite surgery or progressive stenosis of adjacent segments [10].

Clinical Scenarios for Recurrent or Persistent Radiculopathy

There are several clinical scenarios that occur after a lumbar decompression and it is important to know into what category your patient falls.

- There was never adequate relief of the radicular pain
- The radicular pain decreased for a short time (days to several weeks) but still persisted
- There was a pain-free interval of several months and the symptoms gradually returned
- There was excellent relief from the index surgery and there is a sudden re-onset of the same pain.

Any one of these scenarios can occur with or without a neurological deficit. This factor will be discussed later in the chapter. If the recurrent symptoms cause a true cauda equine syndrome, then that is beyond the scope of this discussion.

To categorize your patient into one of these categories doesn't take a lot of time, but there are several necessary components: history, clinical evaluation, and a review of all prior and current imaging. You must know the whole story in order to make a thoughtful choice.

History/Clinical Evaluation

It is necessary to understand the starting point; otherwise you cannot accurately move forward with the correct treatment plan. Here are some of the questions that need to be asked to place your patient with recurrent or persistent pain into the correct treatment approach.

It is important to understand the original indications and pathology that necessitated the decompression. Here are a series of concepts to consider:

1. Were there adequate indications for the index operation? If there was minimal pathology or pain, then you are in a difficult spot. You are now trying to solve a problem created by the surgery when it wasn't a surgical issue in the first place. The following questions can help you sort this out.

   - What was the pain pattern prior to the index operation? Was it primarily back pain or leg pain?

     Lumbar decompressions are not effective or indicated for primarily axial pain. There may be a short placebo decrease in LBP, but it is generally not sustained. Patients can usually clearly answer this question. If the leg pain is more severe but of short duration, this is not primarily a radicular problem. Even with a history of neurogenic claudication, it is often the back, not leg pain that causes people stop ambulating and sit down for relief.
   - How long was it presenting before the surgery? Is this a chronic pain situation that had not changed much during the few months prior to the surgery?

     Chronic formerly was defined as pain that persists after the expected healing time. Neuroscience research has demonstrated chronic pain is "that which is memorized and becomes enmeshed with ongoing life experiences. The memory can't be erased" [11]. The classic example is that of phantom limb pain, which can occur in any area of the body. It has been demonstrated that acute pain shifts from the nociceptive areas of the brain to the emotional ones. The nociceptive area becomes dormant. Even if the original source of pain was clearly identifiable, brain can and will memorize the pain. It has been documented to occur within 12 months [12].
   - What was the pattern of the pain? Did it follow a specific dermatome or was it diffuse?

     Pain from an isolated soft disc rupture should follow a specific matching dermatome or myotome. If the original pain was diffuse or not a close match, then the original surgery may not have been a good idea. Surgery is only indicated for a specific identifiable structural problem with matching symptoms.

     Spinal stenosis can present with diffuse symptoms and doesn't have to have an exact match for surgery to be effective. Central stenosis can present with bilateral or unilateral symptoms and often looks like the lesion should be at a lower level of spine. If the pain is in a specific dermatome, then the compression should specifically correlate with the pattern of pain whether proximal to the exiting nerve root level or at the nerve root level.
   - Was it consistently positional?

     Generally soft disc ruptures are worse with sitting and stenosis is worse with standing and walking. This is not an absolute pattern but if a stenosis patient is worse with sitting, that is a warning sign that the scenario is not straightforward. With severe stenosis and a large disc rupture, the pain can be constant regardless of the position. This is frequently the case with disc herniations in the setting of spinal stenosis at the same level, and the disc herniation has been present for longer than a year. Frequently, the initial presentation of a disc herniation in the presence of preexisting spinal stenosis causes dermatomal pain with sitting. However, as the inflammation from the herniated disc resolves, the pain may become more like neurogenic claudication and be more symptomatic with walking or standing.

- How severe was it? Was it bad enough to require surgical intervention?

  Probably the most consistent complaint a spine surgeon will hear is that, "If I just knew how bad my pain could be after surgery, I would never have undergone surgery." If the original pain was relatively mild, then surgery wasn't likely to help and often the persistent or recurrent symptoms are much worse. The current pathology may be similar to the original pathology and more of the same type of surgery won't be helpful. You are also now dealing with a frustrated and often overtly angry patient. Animal studies show that under stress that nerve conduction increases, and the pain will worsen [5].
- Were there any neurological deficits?

  This is critical in that many patients suffer neurological deficits, usually associated with a dural tear. If the deficit was there pre-op, it may or may not improve with the index surgery. If the deficit occurred after the surgery and is persistent, then there is a high likelihood that further surgery won't help improve function. If the neurological deficit is a new presenting complaint, then the whole situation is different, in that improvement might be more of a possibility, although the data is scant. Patients will present with "recurrent radiculopathy" when they really are asking for help in regaining neurological function.

  Of note, bowel and bladder symptoms are rarely caused by chronic lumber spinal canal compression. It is remarkable how tight a lumbar stenosis can be without GI or GU compromise. It is easier to sort out the situation if the onset of true cauda equina symptoms are acute and there is a new compression from any cause. However, without subjective paresthesias or objective sensory changes, bowel and bladders symptoms are unlikely to be from the spine. The classic symptoms include saddle paresthesias/anesthesia, loss of bladder control, bilateral leg weakness, and numbness. This is a true emergency.

  However, patients more often complain of urgency that gets construed by the surgeon as a cauda equina syndrome. Even in the presence of severe, even extreme stenosis, this is not a cauda equine syndrome nor an emergency. It is more likely to be an irritable bladder syndrome, which is associated with chronic pain. By treating the chronic pain, these symptoms will subside [13].
- Were the risk factors that have been documented to be associated with poor outcomes addressed prior to the index operation?

  It has been shown in several different ways that surgeons are not addressing the risk factors for a poor outcome prior to surgery. A 2014 paper showed that only about 10% of surgeons are addressing them prior to recommending surgery [14]. If they weren't addressed, then it shouldn't be surprising when the pain persists after surgery. The risk factors are well-known to all fields of medicine and include: depression, anxiety, catastrophizing, fear avoidance, insomnia, obesity, younger age, female, duration of the pain, level of opioid dependence, disability status, family member on disability, job satisfaction, smoking, illicit substance abuse, excessive ETOH intake, other chronic pain, situational stress, and a history of childhood abuse [15–17].

Additionally, it has been demonstrated that physicians cannot identify the "at-risk" patients in the clinical setting. The ability to pick up a high-risk patient is between 25% and 40%, in spite of the physicians being confident of their general assessment. It doesn't matter whether the physician is a first-year resident or a senior attending. There is too much to assess in a busy clinic [18].

The high-risk patient with recurrent or persistent symptoms will still be at risk and unless these issues are systematically addressed and treated. Otherwise, additional surgery is unlikely to be helpful.

Review of Imaging

It is critical to understand the setting before ordering more tests and then be able to directly compare the presurgical and postsurgical imaging. If the ongoing pain is essentially all back pain, then just lumbar spine x-rays may be adequate to evaluate for post-decompression instability. Without radicular symptoms other advanced imaging won't add much unless there are some clinical "red flags" regarding more severe pathology.

MRI

An MRI is the imaging test of choice if there is radiculopathy. It can reveal or rule out many types of pathology. First of all, is there any mass effect at all? Many recurrent radiculopathies may not have corresponding pathology. If there is no mass effect, then the workup should look at other potential sources of pain. Some of them include:

- Disc at a higher level – including a thoracic disc
- Shingles – Herpes Zoster can be extremely painful with minimal skin lesions
- Diabetic mononeuritis or amyotrophy
- Other peripheral neuropathies
- ALS usually presents with weakness out of proportion to the severity of the stenosis
- Tumor – usually metastatic – 50% of mets to the spine present as a radiculopathy
- Persistent phantom-type pain without compression
- Complex regional pain syndrome affecting the back and or leg

If there is a significant mass effect on the corresponding nerve root with matching symptoms, then the workup is done, and repeat surgery might be considered depending on the intensity of the pain. It is important to evaluate the origin of the compression. Residual scar tissue or granulation tissue is normal following decompression surgery and with few exceptions should not be treated surgically. The pathology could be:

- Retained disc fragment – usually this can be ascertained by comparing the pre- and post-op scans and the use of gadolinium. Gadolinium is the most useful if used for scans within the first year of the index operation. The dye will flow into scar tissue but not the retained or recurrent fragment.

- Recurrent disc rupture – this is also easily identified, as there is usually continuity of the disc fragment in the canal with the disc space. Gadolinium within the first year can be helpful in defining the extent of the mass effect.
- Inadequately decompressed canal:
    - The superior lateral recess wasn't adequately removed.
    - There is still residual ligamentum flavum on the shoulder of the exiting nerve.
    - One of the more common scenarios is that the central canal was decompressed and there is residual intra or extra-foraminal pathology.
- Scar tissue is usually more common with soft disc excisions. There is always scar tissue that forms after any spine surgery but the fibrous tissue from a disc excision seems to create more of it. With primarily bony decompressions, there is less scar and any residual pathology can usually be more readily identified.
- Synovial cyst – occasionally a cyst can rapidly form after a lumbar decompression because of instability. Sometimes the instability cannot be picked up on diagnostic testing, and it is the presence of the cyst that suggests instability. This is usually associated with translation on flexion/extension x-rays as well as fluid in the facet joints on the T2 axial MRI images.

Gadolinium contrast is used within the first year of the index operations for potential recurrent disc ruptures. The dye will flow into the scar tissue and the disc fragment will remain dark. The contrast is not as helpful for recurrent stenosis, as this usually bony pathology.

Myelo/CT

A common scenario is that the pathology is less clear, and the symptoms are vague, but somewhat close to matching the abnormalities. It is critical to continue with the workup. The next logical test is usually the myelogram followed by a CT scan. This is also indicated in the setting of radiculopathy when the patient cannot have an MRI for some unrelated reason. If there is a dye-cutoff that matches the symptoms, then further surgery might be considered. If there is free flow of the contrast, then surgery should not be a consideration. Surgery is a mechanical solution only for a structural problem (Fig. 31.1).

CT Scan

A CT scan without contrast is most useful in assessing radiculopathy after a stenosis decompression. Commonly the pars may be weakened from a foraminal decompression and eventually fracture. Although the foraminal stenosis may be identified on an MRI scan, the pars fracture isn't easily seen. It is important to identify the pars fracture in that it requires a fusion (Fig. 31.2a, b).

Fig. 31.1 A middle-aged male who had undergone two successful L4–5 decompressions – one on each side. He had the gradual re-onset of bilateral L5 pain and spent almost a year working on a structured nonoperative care program. His repeat MRI was difficult to interpret. This myelo/CT showed probable scar tissue impinging the right L5 nerve root. He responded well to an L4–5 TLIF/posterolateral fusion

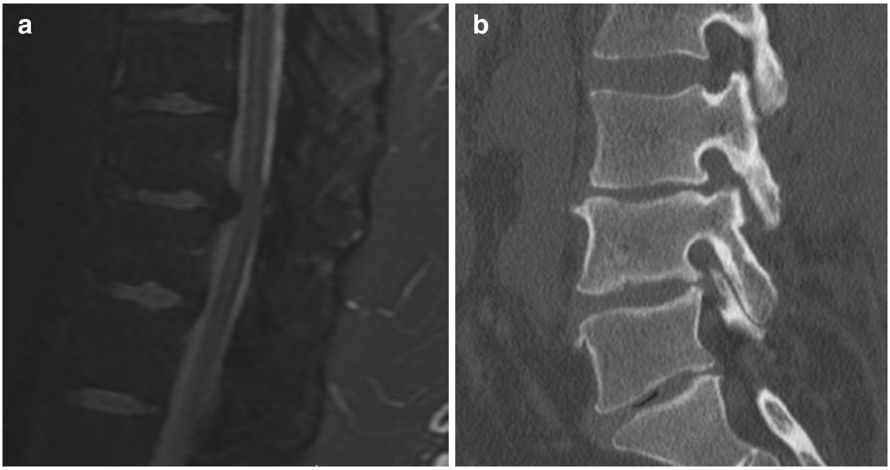

Fig. 31.2 (**a**) A 29-year-old male with stenosis at L4–5 and L5–S1 from large herniated discs documented to present for over a year. New onset of paraparesis. Lumbar decompression considered but workup showed the real problem was the ruptured disc at T10–11. (**b**) A 50-year-old male with two failed right L3–4 decompressions. Had chronic LBP as well and right anterior thigh pain. Under a lot of stress. We spend almost a year on prehab addressing sleep, stress, and anger. Pre-op his back pain had decreased. This CT scan was 1 year prior to his third operation, which was a right L3–4 TLIF/ posterolateral fusion

AP and Flexion/Extension X-Rays

After decompression for a bony stenosis, the facets might be compromised or the pars may fracture, creating instability. Flexion/extension x-rays can identify an instability and guide the surgical treatment toward a fusion. The AP view should include the hips, as hip arthritis can be confused with an L2 or L3 radiculopathy.

EMG/ NCV

An EMG/NCV can be considered as a confirmatory test if there is a question regarding the level. If there are ongoing acute changes, then this nerve is probably the cause of the pain. If it is negative or shows only chronic changes, it doesn’t mean that a compressive lesion isn’t the cause of the pain.

Other etiologies can be considered with an EMG/NCV such as peripheral nerve entrapment, ALS, and diabetic-associated symptoms.

Blocks

A selective nerve block can help confirm the level of the lesion but is not helpful in isolation. Neuritis from other noncompressive causes will also calm down with a corticosteroid injection.

Miscellaneous Diagnostic Considerations

Finally, consider all possibilities. There are many other causes of radicular-type symptoms besides a spinal lesion. In addition to the ones mentioned above, they include:

- Sarcomas of the sciatic notch
- Ganglions of the sciatic nerve
- Ovarian/bladder/uterine cancer
- Hip arthritis
- Chondromalacia of the patella
- Iliotibial band tendonitis
- Trochanteric bursitis
- Intra-dural/medullary thoracic spinal cord tumors
- Thoracic AV malformations
- Lateral femoral cutaneous nerve entrapment
- Peroneal nerve entrapment at the fibular head
- Piriformis syndrome
- Inflammatory sacroiliitis

The main reason to mention these diagnoses is that you should only consider a redo decompression surgery if the spinal pathology is convincing by history, clinical examination, and imaging. Otherwise continue the workup. Radicular pain is a symptom; not a diagnosis.

Clinical Scenarios

Never Adequate Pain Relief

If a patient undergoes surgery without any significant relief of the radicular pain, then there are several possibilities.

- The index operation was not the correct operation because the pathology wasn't convincing to be the cause of the symptoms or the symptoms weren't severe enough to warrant surgical intervention.
- The surgery wasn't technically well-done, or pathology was missed. The technical problems with a discectomy can arise from a retained fragment. Primary disc surgery is not as easy as it might seem. I have felt from the beginning that there is no such thing as a "simple" microdiscectomy. This problem can be minimized by having the diagnostic scans up on the screen and making sure the surgical pathology correlates with the imaging. The disc can often be superior to the disc level and under the dural sac. If there is any feeling of discomfort that the disc material removed is less than you expected, then keep looking. There is also a possibility that the disc has resorbed in the time elapsed since the MRI and the surgery. This should also be considered when operating on an extruded disc fragment, and you find some granulation tissue without residual fragments.
- With spinal stenosis, there are three ways to inadequately decompress the canal. Although the central pathology may be severe, the real problem may be in the foramina. The foramina are best decompressed with an extra-foraminal decompression, which completely opens it up, as well as preserving the pars. A second problem is that it is easy to leave too much flavum on the shoulder of the exiting nerve root. The most common problem is centrally decompressing the canal but leaving too much of the overhanging lateral recess.
- The index operation was performed at the wrong level or on the wrong side. Without going into detail, this occurs more often than you might think. It is one of the main reasons it is critical to view the imaging upon which the index surgical decision was made. It is also critical to perform a time out at the time of intraoperative imaging as well as at the beginning of the operation. Even after placing a needle and making the incision, it is still easy to end up one level above or one level below the desired operative disc level.
- There might be a missed diagnosis and the pain might be emanating from another source. Here are a few examples witnessed by the author:

- An appendectomy being performed for what turned out to be a T11–12 disc rupture.
- Decompressions performed on L3 and/or L4 for what turned out to be hip arthritis. One infamous local case had four spine procedures performed before the correct diagnosis of bilateral hip arthritis was made. It is important to observe the patient's gait and check hip ROM. Routine AP lumbar spine films should always include the hips (Fig. 31.3).
- L5–S1 fusions done for bilateral iliotibial band tendonitis.
- One lumbosacral fusion performed for an isthmic spondylolisthesis resulted in paraplegia. The problem actually was a T5–6 astrocytoma. The clue, in retrospect, was in that the CSF protein from the myelogram was 103. Ironically, the pain pattern was in the L5 distribution.
- L3 decompressions have failed when performed for chondromalacia of the patella. Palpating the patella checking for painful motion takes a few seconds.
- Two patients had significant lumbar stenosis, but the weakness seemed to be out of proportion to the severity and involved too many muscle groups. Fortunately, the diagnosis of ALS was made prior to performing any surgery.

- Chronic pain has now been shown in multiple studies to be an embedded memory that becomes connected to more life situations and cannot be extinguished. Once pain has been memorized, the outcomes of any procedure will be unpredictable. It doesn't matter whether the original pathology was severe enough to warrant surgery or not [11].

The message here is that pain is just a symptom. The history is critical and if there is even a hint of doubt about the source of the pain, then don't do surgery.

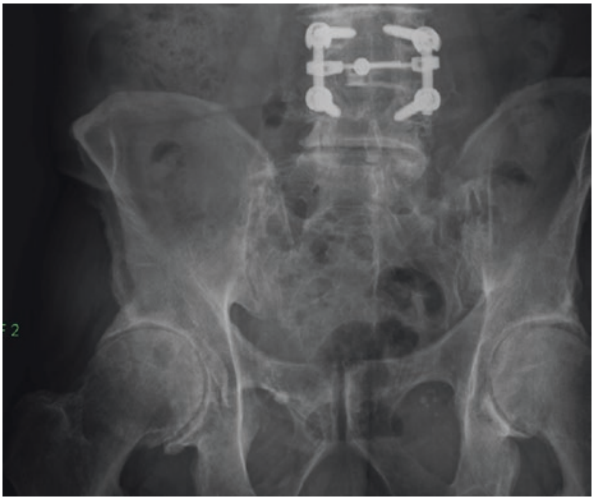

Fig. 31.3 A 70-year-old gentleman who has been followed for 5 years using rehab concepts to improve his function in light of a significant flatback deformity. He had anterior thigh pain, which emanated from his bilateral hip arthritis. His leg pain responded to bilateral total hip arthroplasties and he had a modest improvement in his posture. He has chosen not to pursue a surgical correction of his flatback since he is largely pain free and functioning at an acceptable level

Short-Term Relief of Pain

It seems that almost everyone has relief from surgery for at least a few weeks – even if the surgery was not performed technically well, the surgery was done at the wrong level, or even if it wasn't indicated. There is debate about why this occurs, but the brain is able to downregulate pain [19].

Occasionally, a soft disc may re-rupture within a few days or weeks. Often this is precipitated by a strong Valsalva maneuver associated with post-op constipation from pain meds. Patients may feel so much better that they might return to relatively heavy lifting way too soon. Sometimes an unlucky twist or turn can precipitate a re-rupture.

With stenosis decompressions, enough of a decompression might have been done to give some relief and everyone is optimistic. However, if a lot of pathology was left behind, then it is inevitable that the same preoperative symptoms will return.

Good Relief from Surgery with Gradual Return of Similar Symptoms

This scenario occurs almost always occurs with the gradual re-growth of bone in the scenario of a prior bony decompression. It is unclear why a given patient can and will re-stenose. It is often attributed to instability, which may or not be clear on flexion/extension x-rays. Or bone may just re-grow back into the surgical field. It can occur centrally, at the lateral recess, in the foramen or out in the far-lateral area.

Other causes may include unilateral collapse of the interspace causing foraminal stenosis and a corresponding radiculopathy. There may also be residual medial facet capsule that hypertrophies and causes recurrent lateral recess stenosis.

Almost by definition, a gradual re-onset cannot be caused be a re-herniation [20]. A given disc will either re-rupture or not. It rarely works itself out slowly.

Good Relief from Surgery with Sudden Return of Pre-op Symptoms

After a discectomy, a sudden re-onset of the pre-op symptoms can be just two choices. Either there is a disc re-rupture or prior pain circuits have been re-activated. It is critical to obtain as accurate a history as possible because the pain almost has to be in the same pre-op distribution. A high percent of the time what the patient is complaining about is mostly back pain with some hint of pain in the old distribution. This just should be treated as a lumbar strain. Often you can just treat the symptoms and not do further imaging unless the radicular pain is severe or there some worrisome symptoms suggesting another more severe problem. For example, a new disc rupture can occur at the level above but be large enough to create symptoms in the prior nerve root distribution. A repeat MRI with Gadolinium will quickly clarify the diagnosis.

When people are under severe personal stress, the body's stress chemicals are elevated and may be sustained. Animal studies show that there is an increase in nerve conduction and the pain threshold is lower [5]. Residual pathology will be the first to become symptomatic. Also, pain circuits are linked to anxiety/anger circuits, and at a certain stress level, these prior patterns can become symptomatic. It is important to note that surgeons are unable to accurately identify patients under stress in the clinic setting. The chances of accurately assessing a patient at risk range from 25% to 43% [18]. Interestingly, the level of training or years of experience do not improve the diagnostic accuracy. It is critical to ask or obtain the information from a questionnaire. The pain is often at the same intensity and can resolve quickly given the correct treatment paradigm for chronic pain. Doing further surgery in the presence of unresolved chronic pain can induce or worsen chronic pain between 40% and 60% of the time [8].

In the scenario of a sudden re-onset of symptoms after a laminectomy/laminotomy, there is the possibility of a post-laminectomy instability. Rarely, there might be a primary disc rupture at the level of the decompression. The instability may be unilateral or bilateral. The unilateral symptoms may be caused by a pars fracture or both pars can fracture resulting in post-laminectomy translational instability.

Possible Overall Pathologies

Soft disc

- Retained fragment
- Re-rupture
- Scar tissue
- Re-activated pain circuits

Laminectomy, laminotomy

- Pars fracture – unilateral or bilateral
- Facet instability
- Inadequate decompression
    - Lateral recess
    - Shoulder of the nerve root
    - Intraforaminal
- Re-growth of bone
- Re-activated pain circuits

The Decision to Undergo Revision Surgery

Is there a lesion that is amenable to surgery? This is always the primary question and has already been discussed in detail. Surgery should only be considered if there is a distinct identifiable structural problem with matching symptoms along the path of the nerve in question. If this isn't the situation, then a complete workup is indicated to rule out other pathology. Axial back pain is rarely a reason to undergo any surgery, much less revision surgery.

The second question is whether the radicular pain is severe enough to warrant the risk of surgery. Often patients are actually more frustrated with their back pain and the leg pain of little importance. One key question is, "If you could get rid of your leg pain but still had a similar intensity of back pain, would you consider the surgery successful?"

There is also a lot of confusion regarding what constitutes a true radiculopathy. Commonly, the leg pain is a quick shooting pain that will last minutes to seconds. It may or not be positional, especially if it is arising from another source, such as a tendonitis. This pattern doesn't represent a radiculopathy. Radicular pain should closely follow the nerve root pathway, is commonly relatively severe and lasts for hours. Often it is consistently positional. For example, an L5–S1 foraminal stenosis will reliably worsen with standing and walking, as the foramina closes down. If the L5 pain is worse while sitting, then another source of pain should be considered.

The nature of the pain is important. If the main concern is tingling or decreased sensation, that isn't a reason to perform surgery. Paresthesias are unlikely to improve and probably are not worth the surgical risk.

Painless weakness is a controversial issue without any real way to document surgical outcomes versus nonoperative care. It is confusing with both primary decompressions and revisions. It is unclear whether surgical decompression improves the chances of neurological recovery with soft disc ruptures, since most improve without surgery. The neurological deficits in stenosis are usually more of a gradual onset and the prognosis for motor recovery is poor regardless if there is surgical intervention.

Any elective operation, especially revision spinal surgery should be avoided in the presence of severe personal stress, regardless of the patient's psychological profile. Even with relatively severe pathology, caution should be exercised regarding the surgical decision. Sustained stress causes profound changes in the body's chemistry and increases nerve conduction [4]. Every effort should be made to help the patient through the unpleasant circumstances. When the pain threshold drops, the areas of impingement will be the first to become symptomatic. As the situational stress resolves, it is surprising how many times the symptoms will disappear. Conversely, it is well-documented that operating in the presence of anxiety, depression, fear avoidance, anger, disability, younger age, female will produce poor surgical outcomes. Only about 10% of surgeons address these factors prior to proceeding with a procedure [14].

Choice of Procedure

Redo's for a Prior Soft Disc Rupture

The general trend is to simply re-excise the disc on the first trip back to the OR. There are some exceptions where the re-rupture is large and extensive bony removal is needed to safely remove the disc. A disc may re-rupture a second time, and on the third trip to the OR, the trend is more toward performing a fusion, although just redoing the discectomy is a reasonable choice.

There is debate regarding the decision to simply re-excise the disc versus performing a fusion. The argument in favor of a fusion is that more bone can be removed in order to more safely decompress the nerve root. A repeat discectomy is a smaller operation with a lower complication rate and less chance of adjacent segment breakdown. A prospective study was done assigning one group to a fusion with the first re-rupture and the other just to a re-excision. The re-operation rate was the same in both groups with a higher complication rate in the fusion cohort. The conclusion was that re-excising the disc was the procedure of choice [21].

Several smaller studies have documented the effectiveness of a fusion for a redo disc excision. However, there are not any comparison groups within the series [22]. One large retrospective study showed a much lower re-operation rate with fusion being performed for a re-rupture (5.0% versus 25%). There is a documented higher complication rate with a fusion and the re-operation rate for an instrumented fusion is around 20% within the first year [2]. Unless there are compelling anatomical considerations, a simple discectomy should be considered the procedure of choice.

When the problem is scar that is obstructing the flow of the myelogram dye, then it may be a better idea to perform a complete facetectomy with a fusion to definitively free up the nerve. Often the clinical symptoms are vague where the problem is primarily from scar tissue. Even with a distinctly abnormal myelogram, outcomes for scar tissue removal are unpredictable. You want to make sure that the anatomical issues are definitively solved.

Repeat Surgery for Recurrent Bony Stenosis

Repeat surgery for stenosis is fraught with unpredictable scenarios. The most common one is that the bone is thick, and a wider bony exposure is needed to safely free up the nerves. There is a significant chance of creating an unstable segment, which would require you to return yet a third time for a fusion. By working in too small of a space, you also may not be able to safely perform a decompression. With a revision surgery, you want to be definitive and often going right to a fusion with wide decompression and facetectomies is a better choice. However, as mentioned above a fusion doesn't decrease the chances of needing another revision surgery [2]. Another registry study out of Sweden prospectively looked at decompressions with or without a fusion in patients older than 50 years. At two-year follow-up, there was no significant difference in outcomes and re-operation rate. So, if the spine is stable or you can decompress the canal without destabilizing it, then a fusion is not indicated [23].

If there is any concern for potentially doing a fusion, then the preoperative consent should cover this possibility. The instability may not be discovered until the time of surgery.

If there is instability because of compromised facet joints or a fractured pars, then a fusion is the procedure of choice. The method employed by the surgeon will depend on the number of levels and the surgeon's comfort level.

If there is a synovial cyst after a prior surgery, then one must assume that the segment is unstable. Although simply excising the cyst is the procedure of choice for a primary occurrence, a resection of the diseased facet joint that creates the cyst, followed by fusion, is usually the better choice on a revision procedure. The anatomy is always challenging with a cyst and is more difficult with the presence of scar tissue from the index operation. After resecting the facet joint from which the cyst occurs, the part of the cyst attached or scarred to the dura can be left alone. With the facet joint being resected, there will be no recurrence of the facet cyst.

Technical Considerations

The technical issues are the similar for redo surgery regardless whether a disc has re-ruptured, there was inadequate bony decompression, a new instability has developed or there has been re-growth of bone.

Redo Discectomy

The first principle of redo surgery is to work from normal anatomy into the plane of the pathology. A redo discectomy is particularly challenging compared to a revision laminotomy/laminectomy because the traversing nerve is adherent to the prior annulotomy. It is critical to get well above and below the disc as well as definitively identifying the anatomy.

The re-operation of a soft disc rupture will be described first, as it is more complex and fraught with pitfalls. The left L4–5 level will be the basis of the discussion.

The initial incision should be significantly longer than the one of the index operation. It allows you to find the normal plane on the posterior part of the laminae above and below. A large Cobb elevator will minimize the chances of inadvertently entering the spinal canal and tearing the dura. You are able dissect off the scar tissue almost to the dural sac on the first pass. Any unilateral retractor will suffice, and the tissues should be retracted to the facet joint and the L4 and L5 pars identified. The left L4 laminae should be almost completely exposed and the inferior edge of L4 cleanly defined with a curette. A high-speed drill is used to extend the prior laminotomy above the scar tissue or remnants of flavum. Removing some of the laminae medially and anterior to the spinous process takes a couple of extra minutes but creates more space to retract the nerves. Using a microscope facilitates identification of structures.

Phase 2 involves releasing the scar tissue from the superior border of L5 and the laminae is removed to about half way down the level of the pedicle of L5. The most important landmark to identify is the pedicle of L5 before any nerve root dissection is attempted. The visualization goes down to the anterior border of the pedicle where it intersects with the vertebral body. The L5 nerve root can be slightly mobilized distally to finish the definitive identification of the landmarks. The nerve dissection is carried to the superior edge of the L5 pedicle and then laterally over the L4–5 disc. This is perhaps the most important step. By identifying normal disc lateral to the pedicle, you are ensured of being in the correct plane and can sequentially mobilize the L5 nerve root. It is helpful to remove some of the bone that is superior and lateral to the L5 pedicle so as to have more working room.

Then the attention is paid to the area cephalad to the shoulder of the L5 nerve above the disc space. The lateral aspect of the L4 laminae is further defined and the dural sac superior to the scar can be freed up. By working back and forth superiorly and inferiorly, the scar along the length of the L5 nerve root is connected and the nerve is mobilized medially. If the disc has migrated distally, it is difficult to mobilize the nerve over the disc. Dissection should be focused superior to the disc and quite a bit of space can be created, as well as being able to safely retract the dural sac. Then the re-ruptured disc can be approached from the cephalad direction. If the disc has migrated proximally then the reverse sequence is used. It is helpful to first mobilize the nerve over normal tissue. Tension will be created at the junction of the normal dura and scar. The angle created allows you to make a more precise dissection.

At this point, surgeons approach the problem from several different mindsets, depending on their training and experience. If it is possible, the scar can be stripped off the dural sac and nerve root, essentially turning the case into a primary discectomy. However, if the scar doesn't strip easily, then mobilizing nerve with the scar is the only option. Either way it is helpful to approach the dissection as a "sculpting" event, where all of the anatomy is clearly defined, and the disc removal is almost the last step. Again, make sure the pathology being removed correlates with the pathoanatomy on the scan.

Redo Laminotomy/Laminectomy

There are marked differences in approaching a redo decompression versus discectomy. With the disc scenario, the nerve is adherent to the prior annulotomy site and mobilizing the nerve is challenging. Although a redo decompression doesn't have the adherent nerve root problem, there is often thick bone that has re-formed and the dural is usually adherent to the bone. Both procedures have a higher chance of incurring a dural tear than the primary surgery. Therefore, there is also a greater chance of a neurological injury.

The initial sequence for a redo decompression is the same as described above for a repeat discectomy. It is critical to first identify the lower pedicle (L5 for a continuing example) but to slide the Penfield four toward the floor and onto the vertebral body for a definitive identification. It is easy to be too superficial and many structures feel like they might be the pedicle. The L5 nerve is able to be easily mobilized over the intact disc. Enlarging the L4 laminotomy medially and anterior to the spinous process creates more working space.

In the first stage of enlarging the prior L4 laminotomy, take note of the L4 pars and keep as much bone intact as possible, so as to avoid a delayed pars fracture. Make sure the cephalad exposure is well above the scar and any residual flavum is removed. When exposing the superior border of the L5 laminae, begin medially and go distally 3–5 mm so as to be below the level of the scar tissue. Then go 90° and remove the lamina to the L5 pedicle. Once you hit the pedicle then you stay laterally on the shoulder of L5 nerve. Staying as lateral and anteriorly as possible minimizes the possibility of a dural tear. Occasionally, it may be easier to remove the lamina of L5 and work toward the previously dissected area.

Often bone has to be thinned down with a burr before using a punch. Some surgeons who are comfortable with the matchstick burr can burr off the bone down to the dura. The key is to have a strong identification of the anatomy and again treat the case as a "sculpting" event. Don't try to dig out the pathology.

The corollary of taking a "sculpting" approach to a revision is that you may have to remove an amount of bone that will destabilize the level. If that seems like a possibility on pre-op planning, then discussing the possibility of doing fusion should be part of the preoperative conversation with the patient.

Complications with Revision Surgery

The outcomes of a revision surgery should be close to that of the index operation if all of the concepts outlined in this chapter are followed, including the technical suggestions. That being said there is a higher complication rate with repeat surgery [24]. Some of them include:

- Dural tears
- Nerve root damage
- Infection
- Poorer outcomes

Outcomes

There is not a good way to determine specific outcomes with revision surgery. The problem with the current literature is that all the known risk factors associated with poor outcomes have not been consistently documented and addressed prior to surgery. Surgery is only one part of the solution and indicated when there is a specific structural problem with matching symptoms in the distribution of that specific nerve. What makes revision surgery more problematic is that interpretation of the pain switches over to the emotional center within 12 months after the onset of pain and repeat surgeries are usually done in the context of long-standing pain [12]. It is even more important that the known variables that affect surgical outcomes be systematically addressed in revision surgery.

Outcomes will be predictably good if:

- The symptoms match the identified lesion.
- Expectations are set regarding what symptoms can be reliably relieved with surgery. Spine surgery, with or without a fusion, will not decrease back pain.
- Patient is getting adequate sleep for at least 6 weeks [25, 26].
- Medications are defined and stabilized. Narcotics should be tapered down prior to surgery if the dose is above 80 mg of Morphine equivalents per day. Higher doses cause upregulation and sensitize the nervous system [27].
- Patient's stress levels are defined and addressed [28, 29].
  - Anxiety, fear avoidance
  - Anger/catastrophizing
  - Depression
  - Situational stresses are noted, and support provided. Don't operate in the presence of a patient's severe personal crises [30].
  - A post-op plan is created in the context of a work injury. A pain clinic assessment preoperatively is helpful.
- Education regarding the nature of chronic pain. The neuroscience research centers are coming to a common definition. "Chronic pain is an imbedded memory that becomes increasingly associated with other life events and the memory can't be erased" [11]. It is a solvable problem by simultaneously addressing all of the issues relevant to that patient. A "prehab" process should be implemented prior to any surgery, especially in revision surgery.
- Some type of physical activation is implemented.

Outcomes of revision surgery will be unpredictable if all of the abovementioned variables aren't addressed. Additional factors include:

- The source of the pain is not clear even after extensive diagnostic testing.
- The wrong diagnosis has been made. See the above list regarding hip arthritis, chondromalacia, etc.
- The overall situation hasn't been assessed. Operating in the presence of untreated chronic pain can induce chronic pain at the new surgical site 40–60% of the time. Five to 10% of the time it can become permanent [31].

- The revision operation must be technically performed well. Even if the patient does poorly, the anatomical variables must be defined and solved. It is surprising the number of poorly performed index operations that happen, and the revisions are more complicated. If you aren't used to routinely performing revision spine surgery, you should refer the patient to a complex spine surgeon you trust.
- The problem was actually a re-activation of prior pain circuits because of situational stress. It would be logical that the pain would be in the same pattern as addressed by the index operation. This problem is avoided by not performing elective surgery in the presence of extreme situational stress [28, 29, 32].

References

1. Malter AD, McNeney B, Loeser JD, Deyo RA. 5-year reoperation rates after different types of lumbar spine surgery. Spine (1976). 1998;23:814–20.
2. Deyo RA, Martin BI, Kreuter W, Jarvik JG, Angier H, Mirza SK. Revision surgery following operations for lumbar stenosis. JBJS. 2011;93:1979–86.
3. Macki M, Hernandez-Hermann M, Bydon M, Gokaslan A, McGovern K, Bydon A. Spontaneous regression of sequestrated lumbar disc herniation: literature review. Clin Neurol Neurosurg. 2014;120:136–40.
4. Weinstein JN, Tosteson TD, Lurie JD, et al. Surgical vs nonoperative treatment for lumbar disk herniation: the spine patient outcomes research trial (SPORT): a randomized trial. JAMA. 2006;296:2441–50.
5. Chen X, et al. Stress enhances muscle nociceptor activity in the rat. Neuroscience. 2011;185:166–73.
6. Frymoyer JW, Matteri RE, Hanley EN. Failed lumbar disc surgery requiring second operation. A long-term follow-up study. Spine. 1978;3:7–11.
7. Cammisa FP Jr. Incidental durotomy in spine surgery. Spine. 2000;25:2663–7.
8. Ballantyne J, et al. Chronic pain after surgery or injury. Pain Clin Updates. IASP. 2011;19:1–5.
9. Schug SA, et al. Chronic pain after surgery or injury. Pain Clin Updates. 2011;19:1–5.
10. Deyo R, et al. Revision surgery following operations for lumbar stenosis. JBJS. 2011;93:1979–86.
11. Mansour AR, et al. Chronic pain: the role of learning and brain plasticity. Restor Neurol Neurosci. 2014;32:129–39.
12. Hashmi JA, et al. Shape shifting pain: chronification of back pain shifts brain representation from nociceptive to emotional circuits. Brain. 2013;136:2751–68.
13. Abbass A, Lovas D, Purdy A. Direct diagnosis and management of emotional factors in chronic headache patients. Cephalalgia. 2008;28(12):1305–14.
14. Young AK, et al. Assessment of pre-surgical psychological screening in patients undergoing spine surgery. J Spinal Disord Tech. 2014;27:76–9.
15. Edwards RR, Cahalan C, Mensing G, Smith M, Haythornthwaite JA. Pain, catastrophizing, and depression in the rheumatic diseases. Nat Rev Rheumatol. 2011;7(4):216–24.
16. Linton SJ. A review of psychological risk factors in back and neck pain. Spine (Phila Pa 1976). 2000;25(9):1148–56.
17. Felitti VJ, et al. The relationship of adult health status to childhood abuse and family dysfunction. Am J Prev Med. 1998;14:245–58.
18. Daubs MD, Patel AA, Willick SE, et al. Clinical impression versus standardized questionnaire: the spinal surgeon's ability to assess psychological distress. J Bone Joint Surg Am. 2010;92(18):2878–83.

19. Basbaum AI, Fields HL. Endogenous pain control mechanisms: review and hypothesis. Ann Neurol. 1978; https://doi.org/10.1002/ana410040511.
20. McGirt MJ, Eustacchio S, Varga P, Vilendecic M, Trummer M, Gorensek M, Ledic D, Carragee EJ. A prospective cohort study of close interval computed tomography and magnetic resonance imaging after primary lumbar discectomy: factors associated with recurrent disc herniation and disc height loss. Spine. 2009;34:2044–51.
21. White AH, von Rogov P, Zucherman J, Heiden D. Lumbar laminectomy for herniated disc: a prospective controlled comparison with internal fixation fusion. Spine. 1987;12:305–7.
22. Abd El-Kader HEA. Transforaminal lumbar interbody fusion for management of recurrent disc herniation. Asian Spine J. 2016;10:52–8.
23. Forsth P, Michaelsson K, Sanden B. Does fusion improve the outcome of decompressive surgery for lumbar stenosis? Bone Joint J. 2013;95-B:960–5.
24. Fandino J, Botana C, Viladrich A, Gomez-Bueno J. Reoperation after lumbar disc surgery: results in 130 cases. Acta Neurochir. 1993;122:102–4.
25. Zarrabian MM, et al. Relationship between sleep, pain and disability in patients with spinal pathology. Arch Phys Med Rehabil. 2014;95:1504–9.
26. Agmon M, Armon G. Increased insomnia symptoms predict the onset of back pain among employed adults. PLoS One. 2014;8:e103591. pp. 1–7.
27. Liang D, et al. Chronic morphine administration enhances nociceptive sensitivity and local cytokine production after incision. Mol Pain. 2008;4:7.
28. Chaichana KL, Mukherjee D, Adogwa O, Cheng JS, McGirt MJ. Correlation of preoperative depression and somatic perception scales with postoperative disability and quality of life after lumbar discectomy. J Neurosurg Spine. 2011;14(2):261–7.
29. Main CJ, Wood PL, Hollis S, Spanswick CC, Waddell G. The distress and risk assessment method. A simple patient classification to identify distress and evaluate the risk of poor outcome. Spine (Phila Pa 1976). 1992;17(1):42–52.
30. Rahe RH, et al. Social stress and illness onset. J Psychosomatic Res. 1964;8:35.
31. Perkins FM, Kehlet H. Chronic pain as an outcome of surgery. Anesthesiology. 2000;93:1123–33.
32. Block AR, Ohnmeiss DD, Guyer RD, Rashbaum RF, Hochschuler SH. The use of presurgical psychological screening to predict the outcome of spine surgery. Spine J. 2001;1(4):274–82.

Chapter 32
Revision Pedicle Screw Strategies

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Preoperative Imaging

Preoperative x-rays will enable the surgeon to have an understanding of the levels and location of the hardware. It is also important to understand if there are any broken screws that may not be able to be fully removed. If unable to remove a screw due to the shaft of the screw being broken inside the bone, this level may or may not be able to have a screw replaced. Sometimes the screw trajectory can be modified intraoperatively to a new start point and/or a new trajectory such that a new screw may be placed with good purchase in spite of the residual broken screw in the bone. Breaks in the screw-tulip head interface may be difficult to identify on x-ray. A CT may be more beneficial when looking to perform a revision surgery, as usually CT is obtained to evaluate for pseudoarthrosis [1].

The CT is helpful to evaluate haloing around each screw so that the surgeon can understand the magnitude of the loosening of the hardware. This CT can help the surgeon predict the size of screw that will be needed as well. Significant haloing around pedicle screws may preclude the patient from being able to have a screw replaced at that level. Some revisions require going up in size to 10.5 mm screws. Even sizing up to this size screw, with significant loosening of hardware, this size may not be large enough to achieve solid purchase in the bone.

When removing screws and then replacing them, it is customary to size up the screw about 1 mm or more if needed. Also, it is important to review preoperative CTs to see if the screws may be extended in length, which will facilitate more purchase in the bone. Screw length should be extended to the appropriate depth into the vertebral body if shorter screws have been placed previously to maximize screw pullout resistance.

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_32

Identification of Hardware

Obtaining operative reports can be important in determining the type of hardware or vendor used in the prior surgeries. Finding out the vendor and the types of screws, set screws, and any connectors that are utilized can be key to successful and efficient removal of the hardware. Removal of screws can be accomplished by simply pulling them out with a Kocher or Leksell if the screws have been loosened significantly. If the screw is not loose enough, it is not best to pull the screw out. The screw should be engaged with the appropriate screwdriver from the vendor or from a universal screw removal system. If the appropriate screwdriver is not available, then a shorter rod should be cut and used to helicopter out the screw.

As each screw is removed, the length and width of the screw should be recorded in preparation for sizing up each screw that is removed. The surgeon should also take note of the contour of the threads in the shaft.

From the preoperative imaging, the surgeon should take care to notice if there is any fracture through the pedicles that could cause fragments to violate the foramen or canal. If there is concern for fracture through the pedicle, the surgeon should use caution in sizing up as the pedicle could be expanded too aggressively and cause impingement on a traversing or exiting nerve root of the level below.

Adjuncts to Screw Revisions

In challenging cases where the screws are very loose, or the pedicles are obliterated, it may be useful to have a handful of tools in the surgeon's armamentarium that could serve as an adjunct to the revision fusion. One of these could be utilizing cement augmentation for the screws. It is important to scrutinize the preoperative CT to ensure that there is no violation of the pedicle or no fracture through the pedicle that could result in extravasation of the cement. As long as the pedicle appears intact and the cortex of the vertebral body is not violated, using cement to augment the revision screw can be useful [2].

Other screw options in revision surgery include facet screws; however, these tend to be narrower in diameter and less robust in their purchase. Sublaminar hooks are another option if the pedicles have been fractured or are too small for screw placement.

The most important concept in revision work is understanding where to start and where to finish. It is prudent to remove all of the screws that are definitely loose and then feel the screws that appeared stable on CT. Obviously if using a different vendor, all screws should be replaced. The surgeon may take a Kocher or Leksell and pull up on the tulip head of the screw to ensure that the purchase feels solid. As long as the screw feels solid, it may be retained. If there is concern for screw pullout or loosening, the screws should also be replaced and upsized.

Whatever the reason of the necessity for revision surgery in thoracolumbar fusions, it is imperative to achieve maximum stability with the revision work. The more revisions that have to be done, the more concern for less bone mass in which to obtain purchase in the future.

Screw Design

The other aspect to consider when replacing screws is the design of the threads. Research has been done over the past few decades to design screw threads to resist pullout. With so many designs now, surgeons must be attentive not only to the width and length of the screw removed but also to the actual pattern of the threads. If a mixed threaded screw is used, the surgeon should take note of the thread angle, pitch, and inner and outer diameters. The surgeon should replace with a screw that will maximize each of the dimensions of the screw [3].

Misplaced Screws

On the preoperative imaging, the surgeon should take care to notice any misplaced hardware or screws that have fractured out of their prior trajectory. If the screws have moved or if they were misplaced to begin with, they may be abutting or violating a foramen and impinging the nerve root or be in the canal. Special care must be taken when removing these screws to minimize trauma to the adjacent neural structures. If the screws are going to be replaced with new trajectories, image guidance systems may be beneficial to gain the most purchase of the screw [4]. If good purchase through the old tract or new trajectory is not possible, the surgeon should skip the level because a loose screw attached to the new rod/screw construct is suboptimal.

Pearls

- Obtain imaging to know the levels of hardware to be removed, vendor of hardware if possible, fractures of the vertebral bodies or pedicles, and broken rods or screws.
- Develop a plan for the revision construct. Know the anatomy of new levels to be instrumented.
- Strategize with plan A, B, C, and D.

Summary

Revision spine surgery is one of the most gratifying parts of the field. Many surgeons do not prefer to embark upon revision work due to the longer surgery time and arduous nature of the surgeries. Revision spine surgery is like a 2000-piece puzzle in which you were handed a box full of pieces that you have to put together to form a final work of art. Sometimes it is easy to lose sight of the final goal when working in a small area. It is easy to get frustrated when a piece does not fit where it seemed it would. In these moments during the surgery, it is important to step back and take a look at the surgical objectives that were established with the patient preoperatively. There are many ways to work a puzzle. Some opt to start at the outside and establish a framework for the inner pieces. Some prefer to piece together small parts of the inside of the puzzle and then put everything together at the end. Regardless, all of the pieces come together to form a final picture. In spine surgery, whatever the method to the end is used, the important thing is that the final product is consistent with the goal of the revision surgery.

References

1. Wu X, Shi J, Wu J, Cheng Y, Peng K, Chen J, Jiang H. Pedicle screw loosening: the value of radiological imagings and the identification of risk factors assessed by extraction torque during screw removal surgery. J Orthop Surg Res. 2019;14:6.
2. Renner SM, Lim TH, Kim WJ, Katolik L, An HS, Andersson GB. Augmentation of pedicle screw fixation strength using an injectable calcium phosphate cement as a function of injection timing and method. Spine (Phila Pa 1976). 2004;29(11):E212–6.
3. Seng WRD, Chou SM, Siddiqui SS, Oh JYL. Pedicle screw designs in spinal surgery: is there a difference? A biomechanical study on primary and revision pull-out strength. Spine (Phila Pa 1976). 2019;44(3):E144–9.
4. Mason A, Paulsen R, Babuska JM, Rajpal S, Burneikiene S, Nelson EL, Villavicencio AT. The accuracy of pedicle screw placement using intraoperative image guidance systems. J Neurosurg Spine. 2014;20(2):196–203.

Chapter 33
Revision Strategies for Cervical Spine Surgery

Anthony Conte and Faheem A. Sandhu

Introduction

Between 2002 and 2011, over 300,000 cervical spine operations were performed in the United States. The volume of cervical spine operations, along with cost, has risen significantly on a year-to-year basis [24]. A study by Liu et al. estimated approximately 420,000 cervical spine operations performed for cervical degenerative disease between 2001 and 2013, with the volume of cases increasing yearly [19]. The mean age of a patient undergoing a cervical spine procedure in the United States is 52 years while the average U.S. life expectancy increased to 78 years with advances in health-care technology. Concomitantly, there has been an increased rate of cervical spine revision surgery. In the same time period between 2002 and 2011, over 3500 revision 1–2 level anterior cervical discectomies and 250 revision total disc replacements took place [25]. Multiple studies observed these trends in revision rates for cervical spine surgery, with rates of ACDF revision quoted at 9–10% in 2 years versus 15% at 31 months [32, 33]. Revisions of posterior approaches to the cervical spine are equally prevalent, with a 2-year revision rate for posterior cervical foraminotomy observed between 6.7% and 9.9% [1, 23]. In today's medical landscape, surgeons must be adept in the indications and techniques for revision surgery in the previously reconstructed cervical spine to achieve successful outcomes for their patients.

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_33

Indications for Revision Surgery

Adjacent Segment Disease

Adjacent segment disease (ASDI) describes the development of symptoms of cervical spondylosis at the level adjacent to a previously fused level whereas adjacent segment degeneration (ASDG) describes the radiographic evidence of cervical spondylosis without clinical symptoms. Reports vary per study on the incidence of adjacent segment disease following ACDF, with a likelihood of 3% per year to anywhere between 25% at 10 years, 15.3% at 31-month average, and 11.99% at an average of 9 years [5, 14, 32]. Carrier et al. found a rate of adjacent level degeneration of 47.33% at an average of 9 years following ACDF [5]. ASDI is not limited to anterior procedures. One study found a 4.9% rate of adjacent segment disease at an average of 7 years following posterior cervical foraminotomy [6].

A major controversy in cervical spine surgery has been whether adjacent segment disease can be attributed primarily to the biomechanical stress placed on adjacent disc spaces from the index fusion level or the natural development of degenerative changes of the spine. The answer may, in fact, be both. Biomechanical studies have shown that by eliminating normal disc motion with fusion, intradiscal pressures and load-bearing increase with normal range of motion at adjacent levels [9]. This increased intradiscal pressure may ultimately lead to early disc degeneration. However, in a study by Bydon et al., increased length of the anterior cervical construct, which would translate to higher levels of stress to adjacent levels, did not translate into a higher rate of adjacent segment disease when compared to 1–2 level constructs [2]. Additionally, researchers have not observed a correlation between index level of fusion and incidence of adjacent segment disease, indicating that the natural history of degeneration plays a major role in adjacent segment disease.

Pseudoarthrosis

Pseudoarthrosis is a common problem following cervical spine fusion procedures, despite advances in instrumentation and grafting material over the last two decades. One meta-analysis calculated the current pseudoarthrosis rate for anterior cervical fusions at 2–3% in 2 years [28]. Multilevel anterior fusions carry a higher risk of pseudoarthrosis when compared with single-level fusions and most often occur at the caudal level. Pseudoarthrosis rates for posterior laminectomy and fusion have varied in the literature, with rates of 1–8% observed [37]. Smoking, poor nutrition, prolonged steroid use, and medical comorbidities including diabetes and renal failure increase the relative risk of pseudoarthrosis following cervical spine surgery. Patients with pseudoarthrosis following ACDF or posterior cervical fusion typically present with a combination of axial neck pain, radiculopathy, myelopathy, and recurrence of preoperative symptoms. Evidence of these symptoms at 6 months following surgery should initiate an investigation for pseudoarthrosis with dynamic imaging [18]. For asymptomatic patients with evidence of pseudoarthrosis, monitoring may be employed if no signs of instability are present. Direct current stimulation with the use of an external bone growth stimulator may also be used, as it has shown efficacy in promoting bony fusion.

Recurrent Symptoms/Residual Stenosis/Poor Index Indication

For patients presenting with recurrent symptoms following a cervical spine surgery, a detailed history must be obtained to localize the exact pathology correlating with their pain. Important questions to ask the patient are "what symptoms he/she was having prior to their surgery?" Did these symptoms ever resolve for a period of time or did they remain the same postoperatively? Were there any perioperative/postoperative complications? Although cervical decompression and fusion has yielded excellent results in treating cervical radiculopathy and myelopathy, the resolution of chronic axial neck pain is less clear. Multiple studies cite a positive outcome of 70–85% following ACDF for chronic axial neck pain [36]. It is recommended to exhaust all conservative measures and radiographic investigation prior to performing a fusion for axial neck pain. Lack of a sufficient workup can lead to the fusion of the wrong index level and exacerbation of chronic neck symptoms.

Within the patient's history may lie clues to the initial extent of decompression and whether an adequate surgical decompression was achieved with the initial procedure. MRI or CT myelograms are the studies of choice when evaluating for persistent stenosis in the setting of previously implanted hardware. Failure to achieve any improvement following the index surgery points to an area of residual stenosis that warrants decompression. Initial improvement, followed by a period of worsening neurological symptoms indicates an alternative pathology including graft or hardware failure/subsidence, pseudoarthrosis, or adjacent segment disease.

Infection

Postoperative infection in the cervical spine is seen at a higher frequency in posterior procedures than anterior procedures, secondary to increased length of incision, extensive anatomical dead space, and higher blood loss. Patients with diabetes, obesity, multiple medical comorbidities, immunocompromised states, and history of prior infections are at an increased risk of developing surgical site infections following cervical spine surgery. Early infections typically present with drainage from the incision site, along with local erythema, fevers, and an elevated leukocyte count. Late infections may be more indolent, and not as easily identifiable. The most common red flag sign for late infection is worsening pain and neurologic symptoms following a period of improvement. CT scan may show loosening and "haloing" around previously implanted hardware, whereas MRI may reveal rim-enhancing lesions indicative of an abscess in the surgical bed. Radiographic and clinical signs of infection often necessitate a return to the operating room, where surgical site cultures are obtained and the wound thoroughly debrided with the placement of a wound vacuum and multiple surgical drains. Hardware is evaluated intraoperatively for loosening, and every effort is maintained to preserve hardware to aide in bony fusion. Typically, an intravenous antibiotic course of a minimum of 8 weeks is recommended following debridement.

Kyphosis/Deformity

Postlaminectomy cervical kyphosis is a common cause of neck pain and neurologic disability following posterior cervical laminectomy. Cervical kyphosis may also occur de novo, usually in elderly patients with severe degenerative changes. Cervical kyphosis leads to a positive increase in sagittal alignment. This anterior shift in alignment, accelerated by laxity in the tension band following detachment of muscle and ligaments, leads to excess strain on the supporting musculature. This increased workload leads to worsening axial neck and back pain. Often, patients maintain a stooped posture to maintain line of sight, which further exacerbates their pain and fatigue. Also, with worsening kyphosis, the spinal cord may drape over the vertebral bodies leading to neurologic compromise and myelopathy over time. Surgery is meant to correct this kyphosis and restore a balanced sagittal alignment as well as prevent further neurologic decline.

Imaging

AP, lateral, and flexion-extension radiographs should be the first images obtained when evaluating recurrent pain following cervical spine surgery. AP and lateral radiographs examine previously placed instrumentation in the cervical spine and regional alignment, whereas flexion-extension films assess for instability or translation at an adjacent level or pseudoarthrosis at the index level(s) of prior surgery. Flexion-extension films should be obtained no earlier than 3–6 months postoperatively in a patient if pseudoarthrosis is suspected. An angulation of two degrees or greater of the C2–C7 Cobb angle on flexion-extension radiographs is indicative of potential pseudoarthrosis [3]. A recent systemic review by Rhee et al. suggested that motion of greater than one millimeter in the interspinous distance at the index level on flexion-extension films was a more accurate means of assessing fusion [27].

Flexion-extension radiographs and standing scoliosis films are obtained to assess cervical spine deformity and sagittal alignment. Patients with a cervical kyphotic deformity should undergo flexion-extension films to determine if the deformity is fixed or reduces with a change in position. Recent literature has focused on parameters in full-length radiographs defining cervical kyphosis/deformity with overall sagittal alignment, and its correlation with a patient's pain and quality of life. The C2–C7 Cobb angle has been consistently shown to average approximately 10 degrees in normal patients [10, 13], whereas global cervical lordosis (O-C7) typically averages 40° [13]. Global sagittal alignment can be assessed with a sagittal vertical axis (SVA), a plumb line drawn from the anterior tubercle of C1, center of C2, or posterior C7 vertebral body, measuring how far anteriorly this vertical line is from the posterosuperior corner of S1. Increasing distance has correlated with worse pain and neurologic disability scores in patients. For assessment of regional deformity, the sagittal vertical axis can be measured from plumb lines dropped from the center of C2 and posterosuperior corner of C7. A distance greater than 4 cm between the two lines has correlated with worse pain and disability scores in patients with cervical deformity. Measuring the difference between the T1 slope, the angle created by a horizontal line and a line across the T1 endplate, and cervical lordosis gives insight into regional alignment and deformity. A mismatch of over 15–20° is indicative of higher neurologic disability in patients. Lastly, the chin-brown to vertical angle, an angle between a line from the patient's chin to brow and a vertical line, may be measured to assess horizontal gaze, with an angle of 10° typically considered normal.

Noncontrast computed tomography (CT) is another valuable tool in assessing cervical spine pathology. Fusion mass following anterior or posterior cervical fusion may be accurately assessed using a CT scan. Bony detail is most accurately observed with CT, detailing fusion mass, lytic endplate changes caused by infection or screw haloing or pullout. The size of the neural foramen may be measured and uncovertebral osteophytes causing neuroforaminal stenosis identified. To confirm residual stenosis, CT myelogram may be more efficient than an MRI in the setting of previously placed hardware and to evaluate osseous stenosis.

MRI of the cervical spine is the gold standard for evaluation of the soft tissue and discoligamentous complex. Adjacent segment degeneration and neural element compression is easily identifiable. T2 hyperintensity within the spinal cord is a sign of irreversible myelomalacia that may be the cause of continued symptoms following cervical decompression. Additionally, syringomyelia from cord compression or tension may be identified and monitored. Gadolinium contrast is administered to evaluate for enhancement in the soft tissue for signs of subfascial infection. Contrast enhancement also delineates compression from residual scar tissue, compared to recurrent disc herniation, which does not enhance with gadolinium administration.

Further Testing

When considering the need for revision surgery following a cervical spine procedure, a host of clinical and laboratory testing must be considered to identify the nature of a patient's symptom. Electromyography and nerve conduction studies should be performed in patients with extremity symptoms without a clear source of compression on cervical spine imaging. A peripheral neuropathy can often mimic symptoms of central compression, or contribute to a part of the patient's overall symptomatology.

Patients must be counseled regarding the lower chances of recovery from symptoms if cord myelomalacia is present. If imaging and nerve conduction studies are unrevealing, consultation with a neurologist and further laboratory testing should be undertaken. A lumbar puncture to assess for oligoclonal bands diagnostic of multiple sclerosis or hyperproteinemia seen in Guillan-Barre is often indicated. ALS or a chronic demyelinating polyneuropathy must also be taken into consideration.

Underlying infection is difficult to conclude in patients with persistent pain and neurologic symptoms in the setting of inconclusive imaging and blood work. Leukocyte levels may be increased secondary to the physiologic stress and inflammation following surgery, and does often not elevate greater than 10×10^3/ml, even in the setting of deep infection. Erythrocyte sedimentation rate, another marker of systemic inflammation, is elevated over 6–8 weeks following surgery and is not sensitive in identifying underlying infection. C-reactive protein, an acute phase reactant synthesized in hepatocytes, is more sensitive in identifying infection in the postoperative state. Kang et al. found a daily rise in CRP in the 3 days following spine surgery, to an average value of 15 mg/L [17]. This value should begin to normalize following a week after surgery. A continued rise in CRP levels indicates the possibility of underlying or indolent infection.

Recurrent laryngeal nerve injury and esophageal perforation are complications of anterior cervical spine surgery that must be taken into consideration when a revision surgery is planned. Recurrent laryngeal nerve injury causes vocal cord paralysis, hoarseness, dysphagia, and aspiration. These symptoms may be permanent or as temporary as several weeks. Rates of recurrent laryngeal nerve injury and vocal cord paralysis following anterior cervical spine surgery vary from 2% to 24% [30]. Prior to revision surgery, the patient should consult with an otolaryngologist and undergo direct laryngoscopy to evaluate for vocal cord paralysis. Dysfunction of the vocal cord contraindicates a contralateral approach to the anterior cervical spine. The approach to the anterior cervical spine should be made from the ipsilateral side, with the assistance of an ENT surgery if necessary. If no vocal cord dysfunction is seen, a surgeon may elect to avoid scar tissue and approach the anterior cervical spine via a contralateral approach.

Esophageal perforation is a rare, but highly morbid complication following anterior cervical spine surgery. Esophageal injury is seen in less than 0.1% of cases, and occurs perioperatively or secondary to hardware migration up to several years postoperatively [22]. If a patient complains of persistent dysphagia and swallowing difficulties following an anterior cervical procedure, an evaluation of the hardware along with esophagoscopy should be undertaken to evaluate for graft failure, erosion into the esophagus, or esophageal fistula.

Revision Strategies

The increasing occurrence of cervical spine surgery in our current society requires the neurosurgeon to be adept in revision strategies and reconstruction approaches. Different approaches and surgical techniques, some used in combination, are applied based on the cause of initial failure and the current radiographic features of the cervical spine. Using a combination of flexion-extension radiographs, CT with myelography, and MRI, along with a detailed history, spinal surgeons can identify kyphotic deformity, pseudoarthrosis, neural compression, and instability. The goal of any revision surgery should be to address and correct these findings via an anterior, posterior, or combined approach.

Revision surgery for pseudoarthrosis is dictated by the prior approach taken. For patients with previous anterior cervical discectomy and fusion, a dissection through scar tissue may be challenging and a contralateral approach places the patient at risk for bilateral vocal cord dysfunction. The status of the fusion mass may be directly visualized with an anterior approach; however, removal of graft material and hardware is challenging. Anterior revision surgery for previous ACDF in the setting of pseudoarthrosis has proven less successful than posterior revision strategies, with pseudoarthrosis rates as high as 44% observed [5]. Conversely, the rate of fusion with posterior instrumentation following pseudoarthrosis with ACDF ranges from 98% to 100% [4, 20]. It is recommended that a posterior approach be taken in cases of pseudoarthrosis following an anterior fusion procedure, unless a moderate-severe kyphotic deformity is present. Laminoforaminotomy should be performed in conjunction with posterior instrumentation and fusion for any remaining area of neural compression seen on follow-up imaging. Pseudoarthrosis is rare following posterior reconstruction, with nonfusion rates as low as 1% observed [11]. If a patient is symptomatic from pseudoarthrosis following a posterior approach, an anterior approach is preferred to limit the incidence of durotomy and neurologic injury with a repeat posterior approach. Anterior reconstruction provides access to the neuroforamina and decompression of residual stenosis to the nerve roots following the posterior approach.

Similar to pseudoarthrosis, revision surgery for adjacent segment disease is dictated by the index procedure and radiographic details. Following ACDF, a repeat anterior approach may be utilized for ASDI. Performing an additional ACDF at the level of ASDI is useful in cases of junctional kyphosis and significant ventral compression. Revision with extension of ACDF requires significant dissection through scar tissue with removal and replacement of hardware, placing the patient at increased risk of injury to vascular and soft tissue structures. To limit the need for aggressive dissection and removal of hardware, stand-alone cage/plate constructs have been increasingly utilized for cases of ASDI over the last several years. Discectomy and fusion is performed similarly with stand-alone cages as with standard cage/plating systems. With stand-alone spacers, however, the graft is implanted and cervical anchoring screws or anchors are placed through the anterior portion of the cage into the superior and inferior endplates, obviating the need for hardware removal. Use of stand-alone spacers has been associated with similar postoperative pain improvement when compared with standard cage/plates, in addition to shorter operative times, less blood loss, and lower rates of dysphagia [21, 35].

Motion-preserving techniques and cervical disc arthroplasty are emerging tools currently being studied for their use in adjacent segment disease. Multiple studies have shown one- and two-level cervical disc arthroplasty is as efficacious as ACDF for the improvement of neck pain and disability while reducing rates of adjacent segment disease and degeneration over 5–7 years from index surgery [7, 8, 15, 16].

Little attention has been given, however, to the use of cervical disc arthroplasty for the treatment of ASDI following ACDF. Though an off-label use, disc replacement at the level of adjacent segment disease has shown similar improvements in neck and arm pain and disability, with lower rates of adjacent segment degeneration and less range of motion in adjacent segments. Motion-preserving techniques are certainly an area requiring further study, but show promise in limiting further development of adjacent segment degeneration.

When discussing adjacent segment disease in the cervical spine, one must be aware that this pathology is not limited to anterior procedures. Clarke et al. observed a 10-year symptomatic adjacent-segment disease rate of 6.7%, with a same-segment rate of 5.0% following posterior cervical foraminotomy [6]. Bydon et al. observed a 9.9% reoperation rate in patients at an average of 2.5 years after undergoing posterior cervical foraminotomy. This rate increased to 18.3% and 24.3% in patients with a follow-up of 2 and 10 years respectively [1]. This data indicates revision surgery is undertaken after posterior cervical foraminotomy, not only for adjacent segment degeneration but for residual stenosis, disc herniation, and progression of degenerative spondylosis at the index level. In cases of adjacent or same-segment disease, anterior discectomy and fusion has been employed with success [34]. The anterior approach avoids posterior dissection through scar tissue and potential injury to the cervical cord or nerve roots.

Postsurgical cervical kyphosis with sagittal/coronal imbalance is an increasingly studied subject as spine surgeons look to the global alignment of the spinal column to address their patient's long-term pain relief and recovery. Using a detailed history and physical, along with the application of deformity parameters to flexion-extension radiographs, CT, and MRI, one can formulate a treatment strategy to restore alignment and prevent worsening kyphosis. The ultimate goal of revision surgery for kyphotic deformity is the correction of malalignment with long-term stabilization, decompression of the neural elements, and prevention of onset/worsening neurologic deterioration. By lengthening the anterior column and shortening the posterior column of the cervical spine, traction on the spinal cord is limited, hence reducing spinal cord compression and stretch.

The first step in realigning the postsurgical, kyphotic cervical spine is to determine if the kyphotic deformity is fixed or reducible. A kyphotic cervical spine that reduces with extension may be approached via either an anterior or posterior approach. Anterior decompression and fusion is favored in patients with ventral compression, no evidence of bony fusion, and a kyphotic deformity spanning less than 2–3 levels. Interbody lordotic graft placement, corpectomy with cage placement, or a hybrid construct are options to restore sagittal alignment. Obtaining up to 10–30° of lordosis has been observed in anterior-only procedures [26, 29, 31]. An anterior-only approach should be limited to up to three-disc space levels due to the increased frequency of graft displacement with an increasing amount of vertebral body corpectomies and increased risk of pseudoarthrosis with lengthening anterior constructs. A posterior-only approach is favored for a mild-moderate kyphotic deformity that spans three or more levels, with evidence of dorsal compression, prior posterior cervical constructs, and no signs of bony fusion. Intraoperative traction with Gardener-Wells tongs is used to restore sagittal alignment to the cervical spine, followed by stabilization with lateral mass screws and rods. Selective lamino-foraminotomies may be carried out at any areas of suspected stenosis. Lastly, a combined anterior-posterior approach is favored for patients with moderate-severe kyphotic deformity with evidence of ventral and dorsal decompression. By combining both techniques, one can achieve greater decompression and lordotic correction than with an anterior-only approach. Although this technique is more time-consuming with a higher rate of blood loss, pseudoarthrosis and graft complication rates are lower when compared with anterior-only approaches [29].

Fixed kyphotic deformities often require a more involved operation due to the presence of bony fusion and inability to reduce the deformity with preoperative traction. In cases of fixed deformity without evidence of bony fusion, an anterior discectomy/fusion or corpectomy with plating may be used to restore lordosis. In cases where a fixed deformity shows evidence of bony fusion, the site of fusion will often dictate the surgical approach. Fixed deformities with evidence of fusion along the anterior column may be corrected with anterior osteotomies followed by multi-level interbody fusion or corpectomy with graft placement to achieve correction of kyphosis. Fixed deformities with evidence of posterior column or circumferential fusion often require correction with a combined posterior-anterior-posterior approach with posterior osteotomies. In these cases, posterior osteotomies followed by lateral mass and pedicle screw instrumentation will allow for mobility and correction of lordosis. Anterior interbody fusion or corpectomy with graft placement further helps to restore lordosis. Following anterior fusion, the posterior construct is again accessed for insertion of rods and stabilization of the final construct. In cases of chin-brow deformity centered at the cervicothoracic junction, a pedicle subtraction osteotomy is undertaken at C7 or T1 to restore lordosis [12].

Complications

Complication rates increase drastically for revision procedures, for both anterior and posterior approaches alike. There is an average infection rate in revision ACDF surgery of approximately 1.3% [25]. Posterior revision surgeries are associated with a significantly higher rate of infection, secondary to extensive dissection through scar tissue and an increased amount of anatomical dead space. Revision anterior surgery may place the patient at up to four times greater risk for recurrent laryngeal nerve injury and vocal cord paralysis [30]. Hoarseness, dysphonia, and swallowing difficulties are all at a higher likelihood with anterior revisions. Though rare, esophageal perforation and vascular injury are at an increased risk in revision surgery due to dissection through scar tissue and blurring of normal, soft tissue planes. Revision posterior approaches place the cervical spinal cord at risk of incidental durotomy or neurologic injury as dissection through scar tissue is a challenging undertaking. C5 palsy and transient radiculopathies may occur in both anterior and posterior approaches without a clear increase in revision surgeries.

References

1. Bydon M, Mathios D, Macki M, Garza-Ramos R, Sciubba D, Witham T, Wolinsky JP, Gokaslan Z, Bydon A. Long-term patient outcomes after posterior cervical foraminotomy: an analysis of 151 cases. J Neurosurg Spine. 2014;21:727–31.
2. Bydon M, Xu R, Macki M, Garza-Ramos R, Sciubba D, Wolinsky JP, Witham T, Gokaslan Z, Bydon A. Adjacent segment disease after anterior cervical discectomy and fusion in a large series. Neurosurgery. 2014;74:139–46.
3. Cannada L, Scherpin S, Yoo J, Jones P, Emery S. Pseudoarthrosis of the cervical spine: a comparison of radiographic diagnostic measures. Spine. 2003;28(1):46–51.
4. Carreon L, Glassman S, Campbell M. Treatment of anterior cervical pseudoarthrosis: posterior fusion versus anterior revision. Spine J. 2006;6:154–6.
5. Carrier C, Bono C, Lebl D. Evidence-based analysis of adjacent segment degeneration and disease after ACDF: a systematic review. Spine J. 2013;13:1370–8.
6. Clarke M, Ecker R, Krauss W, McClelland R, Dekutoski M. Same-segment and adjacent-segment disease following posterior cervical foraminotomy. J Neurosurg Spine. 2007;6:5–9.
7. Davis R, Kim K, Hisey M, Hoffman G, Bae H, Gaede M, Rashbaum R, Nunley PD, Peterson D, Stokes J. Cervical Total disc replacement with the Mobi-C cervical artificial disc compared with anterior discectomy and fusion for treatment of 2-level symptomatic degenerative disc disease: a prospective, randomized, controlled multicenter clinical trial. J Neurosurg Spine. 2013;19:532–45.
8. Davis R, Nunley PD, Kim K, Hisey M, Jackson R, Bae H, Hoffman G, Gaede S, Danielson G, Gordon C, Stone M. Two-level total disc replacement with Mobi-C cervical artificial disc versus anterior discectomy and fusion: a prospective, randomized, controlled multicenter clinical trial with 4-year follow-up results. J Neurosurg Spine. 2015;22:15–25.
9. Eck J, Humphreys C, Lim TH, Jeong ST, Kim J, Hodges S, An H. Biomechanical study on the effect of cervical spine fusion on adjacent level intradiscal pressure and segmental motion. Spine. 2002;27(22):2431–4.
10. Gillis C, Kaszuba M, Traynelis V. Cervical radiographic parameters in 1-2 level anterior discectomy and fusion. J Neurosurg Spine. 2016;25:421–9.
11. Guppy K, Harris J, Chen J, Paxton E, Alvarez J, Bernbeck J. Reoperation rates for symptomatic nonunions in posterior cervical fusions with and without bone morphogenetic protein in a cohort of 1158 patients. J Neurosurg Spine. 2016;24:556–64.
12. Hann S, Chalouhi N, Madineni R, Vaccaro A, Albert T, Harrop J, Heller J. An algorithmic strategy for selecting a surgical approach in cervical deformity correction. Neurosurg Focus. 2014;36(5):E5.
13. Hardacker J, Shuford R, Capicotto P, Pryor P. Radiographic standing cervical segmental alignment in adult volunteers without neck symptoms. Spine. 1997;22(13):1472–80.
14. Hilibrand A, Carlson G, Palumbo M, Jones P, Bohlman H. Radiculopathy and myelopathy at segments adjacent to site of a previous anterior cervical arthrodesis. J Bone Joint Surg. 1999;81(4):519–27.
15. Jackson R, Davis R, Hoffman G, Bae H, Hisey M, Kim K, Gaede S, Nunley PD. Subsequent surgery rates after cervical total disc replacement using a Mobi-C cervical disc prosthesis versus anterior cervical discectomy and fusion: a prospective randomized clinical trial with 5-year follow-up. J Neurosurg Spine. 2016;24:734–45.
16. Janssen M, Zigler J, Spivak J, Delamarter R, Darden B, Kopjar B. ProDisc-C total disc replacement versus anterior cervical discectomy and fusion for single-level symptomatic cervical disc disease. J Bone Joint Surg Am. 2015;97:1738–47.
17. Kang BU, Lee SH, Ahn Y, Choi WC, Choi YG. Surgical site infection in spinal surgery: detection and management based on serial C-reactive protein measurements. J Neurosurg Spine. 2010;13:158–64.

18. Koerner J, Kepler C, Albert T. Revision surgery for failed cervical spine reconstruction. HSSJ. 2015;11:2–8.
19. Liu C, Zygourakis C, Yoon S, Kliot T, Moriates C, Ratliff J, Dudley RA, Gonzales R, Mummaneni P, Ames C. Trends in utilization and cost of cervical spine surgery using the National Inpatient Sample Database, 2001-2013. Spine. 2017;42(15):906–13.
20. Liu H, Ploumis A, Schwender J, Garvey TA. Posterior cervical lateral mass screw fixation and fusion to treat pseudoarthrosis of anterior cervical fusion. J Spinal Disord Tech. 2012;25(3):138–41.
21. Liu Y, Wang H, Li X, Chen J, Sun H, Wang G, Yang H, Jiang W. Comparison of a zero-profile anchored spacer and the PEEK cages with an anterior plate in anterior cervical discectomy and fusion for multilevel cervical spondylotic myelopathy. Eur Spine J. 2016;25:1881–90.
22. Lu X, Guo Q, Ni B. Esophagus perforation complicating anterior cervical spine surgery. Eur Spine J. 2012;21:172–7.
23. Lubelski D, Healy A, Silverstein M, Abdullah K, Thompson N, Riew KD, Steinmetz M, Benzel E, Mroz T. Reoperation rates after anterior cervical discectomy and fusion versus posterior cervical foraminotomy: a propensity-matched analysis. Spine J. 2015;15:1277–83.
24. Marquez-Lara A, Nandyala S, Fineberg S, Singh K. Current trends in demographics, practice, and in-hospital outcomes in cervical spine surgery: a National Database Analysis between 2002-2011. Spine. 2014;39(6):476–81.
25. Nandyala S, Marquez-Lara A, Fineberg S, Singh K. Comparison of revision surgeries for one to two-level cervical TDR and ACDF from 2002-2011. Spine J. 2014;14:2841–6.
26. Park Y, Riew K, Cho W. The long-term results of anterior surgical reconstruction in patients with postlaminectomy cervical kyphosis. Spine J. 2010;10:380–7.
27. Rhee J, Chapman J, Norvell D, Smith J, Sherry N, Riew KD. Radiological determination of postoperative cervical fusion: a systematic review. Spine. 2015;40(13):974–91.
28. Shriver M, Lewis D, Kshettry V, Rosenbaum B, Benzel E, Mroz T. Pseudoarthrosis rates in anterior cervical discectomy and fusion: a meta-analysis. Spine J. 2015;15:2016–27.
29. Song KJ, Johnson JS, Choi BR, Wang JC, Lee KB. Anterior fusion alone compared with combined anterior and posterior fusion for the treatment of degenerative cervical kyphosis. J Bone Joint Surg Br. 2010;92:48–52.
30. Tan TP, Govindarajulu A, Massicotte E, Venkatraghavan L. Vocal cord palsy after anterior cervical spine surgery: a qualitative systematic review. Spine J. 2014:1332–42.
31. Uchida K, Nakajima H, Sato R, Yayama T, Mwaka E, Kobayashi S, Baba H. Cervical spondylotic myelopathy associated with kyphosis or sagittal sigmoid alignment: outcome after anterior or posterior decompression. J Neurosurg Spine. 2009;11:521–8.
32. Van Eck C, Regan C, Donaldson W, Kang J, Lee J. The revision rate and occurrence of adjacent segment disease after anterior cervical discectomy and fusion: a study of 672 consecutive patients. Spine. 2014;39(26):2143–7.
33. Veeravagu A, Cole T, Jiang B, Ratliff J. Revision rates and complication incidence in single and multilevel anterior cervical discectomy and fusion procedures: an administrative database study. Spine J. 2014;14:1125–31.
34. Wang T, Lubelski D, Abdullah K, Steinmetz M, Benzel E, Mroz T. Rates of anterior cervical discectomy and fusion after initial posterior cervical foraminotomy. Spine J. 2015;15:971–6.
35. Wang Z, Jiang W, Li X, Wang H, Shi J, Chen J, Meng B, Yang H. The application of zero-profile anchored spacer in anterior cervical discectomy and fusion. Eur Spine J. 2015;24:148–54.
36. Wieser E, Wang J. Surgery for neck pain. Neurosurgery. 2007;60:51–6.
37. Woods B, Hohl J, Lee J, Donaldson W, Kang J. Laminoplasty versus laminectomy and fusion for multilevel cervical spondylotic myelopathy. Clin Orthop Relat Res. 2011;469:688–95.

Chapter 34
Metastatic Tumor Stabilization

Rod J. Oskouian Jr., Emre Yilmaz, and Tamir A. Tawfik

Introduction

Metastatic Spine Tumors

In the United States there are about 1.2 million new cancer cases and about 550,000 deaths per year. Major cause of death is complication due to metastatic disease. Skeletal system is the third most common site of metastases after the lung and liver. The spine is the most common site of skeletal metastases [1, 2]. As many as 70% of cancer patients will have spinal metastases on autopsy studies. 10–30% of cancer patients will suffer from symptomatic spinal metastases [3].

The impact of spine metastases is ranging from pain, loss of mobility, bone fractures, and instabilities to paralysis due to spinal cord compression. The concepts for surgical treatment include decompression of neural elements, segmental fixation, and bone grafts. The main goals of surgical treatment in metastatic spine tumor are to restore/protect neurologic function, improve pain, and improve the quality of life [4]. The understanding of the spinal tumors biology is critical in defining the goals of treatment and determining the most appropriate therapeutic approach.

The Cancer Patient

The typical cancer patient is in 85% older than 55 years of age. The immune status is often compromised with decreased WBC (high risk of infections, lack of fever response), weight loss greater than 80%, increased catabolic state, decreased intake,

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_34

low serum albumin less than 3–4 mg/dl, increased infection rate, decreased wound healing, chemo−/radiation/steroids, coagulopathy, thrombocytopenia, increased DVT, low platelet count, high rate of wound complications, increased age, altered immune system, cachexia, radiation/chemotherapy, and plastic surgery/flap closure. Therefore, patient evaluation is crucial for right decision-making. Before thinking about a surgical treatment, the medical fitness, the clinical presentation, the oncologic status, and the feasibility of surgical plan have to be taken into consideration in a multidisciplinary approach [5, 6].

Treatment Considerations

Regardless of the various therapeutic treatment options, a knowledge about the tumor entity is absolutely critical for an optimal treatment. In addition to the radiological diagnostic tools, a biopsy is often needed for correct diagnosis. Biopsies can be taken from a fine needle aspiration (FNA), a CT-guided core biopsy, or an open biopsy.

Preparative chemotherapy can be considered in patients with Ewing's sarcoma, osteogenic sarcoma, high-grade chondrosarcoma, and dedifferentiated chordoma [7, 8].

Radiation before surgery can be reasonable in patients with a high risk of recurrence. However, Ghogawala et al. reported in their study an increased rate of major complications in patients with radiation before vs. de novo surgical decompression (32% vs.12%, $p < 0.05$) [9]. Planning/timing is very important to transfer the patient to the right treatment. Spine metastasis patients with "radio-resistant" tumors like melanoma, renal cell carcinoma, and sarcoma do not benefit from radiation, whereas myeloma and lymphoma present a high sensitivity for radiation.

Preoperative embolization is another treatment option which should be considered. Taking into account that 60% of all spinal metastasis are hypervascular, preoperative embolization "may help identify regional vascular supply of the spinal cord, decrease intraoperative blood loss, decrease local recurrence, and even provide palliative pain relief. Hypervascular lesions can be encased by the regional arterial supply making surgical excision extremely difficult and risky without embolization" [10].

Indications for Surgical Treatment

The current surgical treatment options range from limited decompression, invasive vertebroplasty/kyphoplasty to a radical en bloc resection with anterior and/or posterior stabilization and complex reconstructions techniques [11]. The most common goal of surgical treatment in metastatic spine is pain relief. Furthermore, a gross excision or en bloc resection may improve patients' survival. Instability of vertebral metastases is an important indication for surgical treatment. The SINS score (spinal instability neoplasia score) is a comprehensive classification system for neoplastic instability in order to support the decision-making process for patients with spine tumors [12]. Risk factors for collapse in lumbar spine are pedicle destruction the percentage of involved vertebral body. The criteria for an impending collapse are fulfilled in cases of 35–40% body involvement alone or 25% body involvement with pedicle or posterior element destruction. Risk factors in thoracic spine are costovertebral joint destruction and the percentage of involved vertebral body. The criteria for an impending collapse are fulfilled in cases of 50–60% body involvement alone or 25–30% body involvement with costovertebral involvement [13]. Neurologic symptoms are important criteria for surgery including cord compression/myelopathy, nerve root compression/radiculopathy, and intractable pain.

The management options range from intra-lesional or en bloc resections, adjuvant chemo- or/and radiation-therapy to minimally invasive vertebroplasty/kyphoplasty. Indications for minimally invasive surgery include axial spine pain due to pathologic compression fractures and cases of multiple myeloma where bone quality limits surgical options, combined with radiosurgery as a primary treatment for painful metastatic vertebral collapse.

Surgical Considerations/Operation Planning

The surgery should be performed before radiation (if possible), before pathologic fractures occur, and while the patient is still neurologically intact. The technical feasibility, adequate approach, and exposure should be planned carefully before surgery. Most cases of metastatic spine tumors require a rigid posterior segmental instrumentation. Nevertheless, the surgical strategy for en bloc resection and stabilization should be defined, and if necessary, options for a soft tissue coverage should be discussed with plastic surgery.

Outcome/Prognosis

Choi et al. reported in their prospective multicenter cohort study for predictors of long term survival are the tumor type, the number of spinal metastasis, and the presence of visceral metastasis are and the preoperative Karnosky, Frankel and EQ-5D score is the best predictor for postoperative quality of life [14]. Surgery and radiation are superior to radiation alone in the treatment of spinal cord compression caused by metastasis [4]. Fehlings et al. showed in a prospective multicenter study that surgical intervention in patients with focal symptomatic metastatic epidural spinal cord compression and at least 3-month survival prognosis improve the pain level, the neurologic function, and the health-related quality of life [15]. Patients with vertebral collapse and spinal cord compression from metastatic malignancy improved in 67.7% from an anterior decompression and stabilization as shown by Harrington et al. [16]. Yang et al. showed in their systematic review comparing minimally invasive and open spine surgery in the treatment of painful spine metastasis that both achieved improvement of pain and neurological dysfunction. Open surgery had more major complications, a trend of lower survival rates and higher recurrence rates compared to MIS [17]. MIS is able to provide safe and uncomplicated treatment of metastatic spine disease [18].

References

1. Cole JS, Patchell RA. Metastatic epidural spinal cord compression. Lancet Neurol. 2008;7(5):459–66.
2. Prasad D, Schiff D. Malignant spinal-cord compression. Lancet Oncol. 2005;6(1):15–24.
3. Galasko CS. Skeletal metastases. Clin Orthop Relat Res. 1986;210:18–30.
4. Patchell RA, Tibbs PA, Regine WF, Payne R, Saris S, Kryscio RJ, et al. Direct decompressive surgical resection in the treatment of spinal cord compression caused by metastatic cancer: a randomised trial. Lancet. 2005;366(9486):643–8.
5. Choi D, Bilsky M, Fehlings M, Fisher C, Gokaslan Z. Spine oncology-metastatic spine tumors. Neurosurgery. 2017;80(3S):S131–S7.
6. Curtin M, Piggott RP, Murphy EP, Munigangaiah S, Baker JF, McCabe JP, et al. Spinal metastatic disease: a review of the role of the multidisciplinary team. Orthop Surg. 2017;9(2):145–51.
7. Benjamin RS, Wagner MJ, Livingston JA, Ravi V, Patel SR. Chemotherapy for bone sarcomas in adults: the MD Anderson experience. Am Soc Clin Oncol Educ Book. 2015:e656–60.
8. Wagner MJ, Livingston JA, Patel SR, Benjamin RS. Chemotherapy for bone sarcoma in adults. J Oncol Pract. 2016;12(3):208–16.
9. Ghogawala Z, Mansfield FL, Borges LF. Spinal radiation before surgical decompression adversely affects outcomes of surgery for symptomatic metastatic spinal cord compression. Spine (Phila Pa 1976). 2001;26(7):818–24.
10. Ghobrial GM, Chalouhi N, Harrop J, Dalyai RT, Tjoumakaris S, Gonzalez LF, et al. Preoperative spinal tumor embolization: an institutional experience with onyx. Clin Neurol Neurosurg. 2013;115(12):2457–63.
11. Laufer I, Sciubba DM, Madera M, Bydon A, Witham TJ, Gokaslan ZL, et al. Surgical management of metastatic spinal tumors. Cancer Control. 2012;19(2):122–8.
12. Fisher CG, DiPaola CP, Ryken TC, Bilsky MH, Shaffrey CI, Berven SH, et al. A novel classification system for spinal instability in neoplastic disease: an evidence-based approach and expert consensus from the Spine Oncology Study Group. Spine (Phila Pa 1976). 2010;35(22):E1221–9.
13. Taneichi H, Kaneda K, Takeda N, Abumi K, Satoh S. Risk factors and probability of vertebral body collapse in metastases of the thoracic and lumbar spine. Spine (Phila Pa 1976). 1997;22(3):239–45.
14. Choi D, Fox Z, Albert T, Arts M, Balabaud L, Bunger C, et al. Prediction of quality of life and survival after surgery for symptomatic spinal metastases: a multicenter cohort study to determine suitability for surgical treatment. Neurosurgery. 2015;77(5):698–708; discussion.
15. Fehlings MG, Nater A, Tetreault L, Kopjar B, Arnold P, Dekutoski M, et al. Survival and clinical outcomes in surgically treated patients with metastatic epidural spinal cord compression: results of the prospective multicenter AOSpine Study. J Clin Oncol. 2016;34(3):268–76.
16. Harrington KD. Anterior decompression and stabilization of the spine as a treatment for vertebral collapse and spinal cord compression from metastatic malignancy. Clin Orthop Relat Res. 1988;(233):177–97.

17. Yang Z, Yang Y, Zhang Y, Zhang Z, Chen Y, Shen Y, et al. Minimal access versus open spinal surgery in treating painful spine metastasis: a systematic review. World J Surg Oncol. 2015;13:68.
18. Kumar N, Malhotra R, Zaw AS, Maharajan K, Naresh N, Kumar A, et al. Evolution in treatment strategy for metastatic spine disease: presently evolving modalities. Eur J Surg Oncol. 2017;43(9):1784–801.

Chapter 35
Intradural Tumor Resection

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Intradural spinal tumors can be subdivided into intra- and extramedullary lesions. Intramedullary tumors are notable for cord expansion on imaging, may or may not show enhancement, and can be associated with a syrinx [1].

Spinal cord tumors overall have an annual incidence of 2–10/100,000. Intradural tumors account for 4–10% of all primary tumors [2, 3]. The most common spinal cord tumors include astrocytoma, meningioma, ependymoma, hemangioblastoma, and nerve sheet tumors such as neurofibroma and schwannoma [4]. The differential diagnosis may include vascular malformations, multiple sclerosis, infection, other inflammatory conditions (sarcoid, granulomatous angiitis, Guillain-Barré), spinal cord infarction, or lipoma [1]. In pediatric patients, approximately 40% of all spinal cord tumor are intradural intramedullary, 10% are intradural extramedullary, and the remaining 50% are extradural. In the adult population, 60% of tumors are intradural extramedullar, while the remaining tumors are split evenly between intradural intramedullary and extradural locations.

Up to 30% of all spinal cord tumors are astrocytomas. This is the most common spinal cord tumor in children [2]. The mean age at presentation is the third decade with an equal gender distribution. Astrocytomas are usually eccentric, show variable enhancement, and are T1 hypointense and T2 hyperintense on MRI. The tumor size and the level of occurrence are variable, as is the presence of cysts [1].

Hemangioblastomas are often associated with a large syrinx despite a typically smaller size. Due to their rich vascularity, they are robustly contrast-enhancing. Ninety percent of hemangioblastomas are located in the cervico-thoracic area [1].

Neurofibromas, schwannomas, and meningiomas account for 80% of intradural, extramedullary tumors [5]. Most nerve sheath tumors are benign. Malignant peripheral nerve sheath tumors are a rare variant and may show ill-defined borders and/or heterogeneous contract enhancement. Meningiomas show a female preponderance

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_35

and are most commonly located in the thoracic spine and they typically have a broad base with dural tail and are contrast-enhancing on imaging.

Schwannomas are slow-growing, benign tumors with an incidence of 0.3–0.05/100,000 people per year [6]. The diagnosis is often made based on incidental imaging findings, but the condition may also present with symptoms such as radicular pain, paresthesias, back pain, or weakness. Schwannomas commonly demonstrate extraforaminal extension. They often present in between the fourth and sixth decades of life [7]. Schwannomas can be found anywhere along the spinal column and typically grow as a peripheral appendage to the parent nerve [8, 9]. Schwannomas often demonstrate patchy T2 hyperintensity on MRI or may be cystic, in differentiation to meningiomas.

Ependymomas are the most common intramedullary tumor in adults, commonly presenting in the fourth decade. Imaging characteristics include a well-circumscribed and homogeneous tumor with contrast enhancement. The rule of Cs is a helpful mnemonic to describe the main characteristics of ependymomas: cervical, contrast-enhancing, cavity (syrinx), cap (hemosiderin), and central location [1, 10].

Myxopapillary ependymomas are a variant typically located at the conus medullaris and associated with the cauda. They are discrete, contrast-enhancing, and often lobulated and may be hyperintense on T1-weighted imaging.

The clinical presentation of spinal cord tumors is often non-specific. It varies from pain (65%), weakness (40%), sensory deficits (40%), gait abnormalities (30%), spinal deformity (15%), and urinary dysfunction (5%). The symptoms are often indolent and may be mild, which may explain why many patients present after a long period with mild sensory disturbances.

Surgical Treatment

Treatment options include observation, surgical resection, and radiation. Prior to surgical consideration, appropriate imaging is crucial for operative planning. Preoperative MRI is the gold standard and can help narrow the differential diagnosis and guide the surgical resection. CT is important to assess for any bony remodeling and is helpful if instrumentation is planned. Plain x-rays are important in children who present with deformity. Angiography may be useful if there is suspicion for vascular malformation or if embolization is being considered [11].

The goals of surgical resection include tissue diagnosis, relief of mass effect, and definitive cure for select lesions. Intraoperative issue diagnosis is vital to determine the extent of resection. Neuromonitoring allows for safe resection of tumors while continuously monitoring spinal cord function.

From a technical standpoint, laminectomies above and below the lesion are performed to allow for wide dural exposure without obstruction. Depending on the level, a wide laminectomy may necessitate instrumentation to avoid postoperative instability. Utilization of the microscope is important for a detailed view of the anatomy. The dura is often opened in the midline but may be lateralized depending on tumor location. Meticulous hemostasis is required to keep the field dry. Dural tack-ups are placed after dural incision. Extramedullary lesions can be resected away from the spinal cord by finding the plane with micro-instruments. Intramedullary lesions require a midline myelotomy to avoid creating sensory deficits [12]. Intraoperative ultrasound is an important adjunct to visualize the lesion prior to making the myelotomy [13, 14]. Intramedullary tumors such as ependymomas may have a resection plane, while diffuse astrocytomas may invade into the surrounding parenchyma. After resection, hemostasis is mandatory as is a watertight dural closure.

Outcome

Benign spinal cord tumors have a good prognosis with careful surgical technique and complete resection. Close follow-up is needed to monitor for recurrence. Factors associated with poorer surgical outcomes include preoperative neurologic deficits, longer duration of symptoms, and thoracic location. Preoperative functional status is the best predictor of postoperative functional status. Many intradural tumors can be resected completely while minimizing risk to the patient, while intrinsic lesions often require subtotal resection to avoid significant neurologic deficit.

Bibliography

1. Ahlhelm FJ, Fries P, Nabhan A, Reith W. Spinal tumors. Radiologe. 2010;50(2):165–78; quiz 179-180.
2. Chamberlain MC, Tredway TL. Adult primary intradural spinal cord tumors: a review. Curr Neurol Neurosci Rep. 2011;11(3):320–8.
3. Stein BM, McCormick PC. Intramedullary neoplasms and vascular malformations. Clin Neurosurg. 1992;39:361–87.
4. Tobin MK, Geraghty JR, Engelhard HH, Linninger AA, Mehta AI. Intramedullary spinal cord tumors: a review of current and future treatment strategies. Neurosurg Focus. 2015;39(2):E14.
5. Traul DE, Shaffrey ME, Schiff D. Part I: spinal-cord neoplasms-intradural neoplasms. Lancet Oncol. 2007;8(1):35–45.
6. Seppälä MT, Haltia MJ, Sankila RJ, Jääskeläinen JE, Heiskanen O. Long-term outcome after removal of spinal schwannoma: a clinicopathological study of 187 cases. J Neurosurg. 1995;83(4):621–6.
7. Sharifi G, Mortaz M, Parsaei B. Multiple intradural extramedullary tumours presenting with paraplegia after trauma. Acta Neurochir. 2009;151(6):697–8.
8. Conti P, Pansini G, Mouchaty H, Capuano C, Conti R. Spinal neurinomas: retrospective analysis and long-term outcome of 179 consecutively operated cases and review of the literature. Surg Neurol. 2004;61(1):34–43; discussion 44.
9. Parmar HA, Ibrahim M, Castillo M, Mukherji SK. Pictorial essay: diverse imaging features of spinal schwannomas. J Comput Assist Tomogr. 2007;31(3):329–34.
10. Kahan H, Sklar EM, Post MJ, Bruce JH. MR characteristics of histopathologic subtypes of spinal ependymoma. AJNR Am J Neuroradiol. 1996;17(1):143–50.
11. Pinter NK, Pfiffner TJ, Mechtler LL. Neuroimaging of spine tumors. Handb Clin Neurol. 2016;136:689–706.

12. Tredway TL, Santiago P, Hrubes MR, Song JK, Christie SD, Fessler RG. Minimally invasive resection of intradural-extramedullary spinal neoplasms. Neurosurgery. 2006;58(1 Suppl):ONS52–8; discussion ONS52-58.
13. Epstein FJ, Farmer JP, Schneider SJ. Intraoperative ultrasonography: an important surgical adjunct for intramedullary tumors. J Neurosurg. 1991;74(5):729–33.
14. Sciubba DM, Liang D, Kothbauer KF, Noggle JC, Jallo GI. The evolution of intramedullary spinal cord tumor surgery. Neurosurgery. 2009;65(6 Suppl):84–91; discussion 91-82.

Chapter 36
Cervical Spine Trauma

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Basic Principles

Introduction

The basic three tenants of cervical spine injury management are (1) recognition of potentially dangerous injuries, (2) appropriate classification of cervical spine trauma under use of currently accepted and validated systems to understand and predict the stability of the injury, and (3) neurologic injury prevention or most effective possible treatment thereof. Effective application of these three principles is paramount to achieving the best possible recovery for patients. Understanding the relevant normal anatomy and awareness of strengths and weaknesses of imaging modalities are prerequisites for successful management beyond the implementation of sound surgical and nonoperative principles. The appreciation of classifications and our understanding of the essential differentiation of stability and instability of the cervical spine has been an evolving concept. Use of more comprehensive integrated classification systems, which include descriptive anatomic and biomechanical features as well as the neurologic injury status of the patient, has been globally validated among stakeholder medical specialties; these more severity-oriented systems hopefully will allow for spine providers to arrive at a more consistent understanding of the nature and relevant variables of cervical spine injuries. The following chapter will review in progression basic concepts of cervical trauma assessment and primary management and then address the more level-specific concerns separated into an upper and a lower cervical spine subsection.

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https://doi.org/10.1007/978-3-030-20847-9_36

Epidemiology

There is a generally biphasic occurrence of cervical spine injuries, with a traditionally male predisposition in the age group of 20–30-year-olds and a more gender-neutral distribution affecting patients over 65 years old. Interestingly, the morbidity and mortality of the latter group are considerably higher than in the younger peak group and fare more commonly associated with low-level energy mechanisms such as ground-level falls, rather than motor vehicle crashes and more violent injury mechanisms [1, 2]. One of the greatest emerging challenges in cervical spine trauma care has been the accurate diagnosis and management of serious neck injuries affecting aging patients with significant comorbidities and/or presence of considerable nontraumatic cervical spine disorders. Along with an increasingly aging population, there has been an increased incidence of significant comorbidities, which significantly alter diagnostic pathways and/or management [3]. For instance, presence of therapeutic anticoagulations, implanted electromagnetic devices, and oversized patients substantially alter diagnostic algorithms. Presence of ankylosing disorders and spinal deformities affects everything from emergency retrieval to choice of imaging modalities as well [4]. Considerable decision-making challenges also arise in the care of patients with advanced age and impaired mental capacities, where therapeutic intervention decision areas of medicine traditionally are not associated with spine care such as geriatric medicine, medical ethics, and palliative care. From a treatment perspective, severe ankylosing disorders, osteoporosis, and use of immune-suppressive and anti-inflammatory therapies will affect the choice of surgical care and complication rates. Increasing awareness of such and including them in the assessment and treatment pathway considerations a priori are increasingly desirable features of spine care in general and certainly include cervical spine trauma care. Pediatric injuries to the subaxial spine are fortunately relatively rare and thankfully seem to be decreasing in incidence but remain fearsome due to the potential for missed injuries. This risk potential arises out of the mismatch of more elastic ligaments and not yet matured boney joint contours that could offer protective injury restraints [5].

Emergency Retrieval and Resuscitation

The basic tenants of the ATLS have not changed since their inception in the early 1970s [6]. Pertinent to the cervical the ATLS principles propose to assume a cervical spine injury provided there is a mechanism for such and the patient either is neurocognitively impaired or exhibits focal mechanical pain and neurologic deficits. Under this premise immobilization of the cervical spine with a rigid neck collar and supine placement of an injured party on a rigid backboard at earliest feasible point of contact has become a mainstay of emergency retrieval providers. Exceptions to this rule present under few circumstances:

- Placement of younger pediatric patients on a conventional rigid emergency medical services backboard should preferably be done on a specialized stretcher which features a cranial recess to avoid inadvertent flexion of the head/neck caused by the proportionally larger head size relative to the torso in the very young patients [7]. For patients with known cervical spinal deformities and/or ankylosing disorders who are neurologically intact, supportive positioning in their presenting deformity position is preferable over a closed reduction attempt prior to having the benefit of neuroimaging available in order to avoid shearing or pithing of the spinal cord during an attempt at flat recumbent positioning. Such supportive neck immobilization can be created out of pillows, sand sacks, and tape around the forehead and retrieval board [4].
- Patients in need of emergent airway access can usually be safely intubated with manual in-line-traction applied by an assistant to minimize manipulation of the cervical spine, which is usually incurred during conventional endotracheal intubation. More recent alternatives include fiber-optic endotracheal intubation and "glide"-type endoscopes featuring combined tongue and pharyngeal depressor with a built-in rigid video camera [8].
- Patients with penetrating neck trauma also require local hemostatic control, in addition to getting airway control established as soon as possible. In such situations a circumferential neck collar is not feasible for obvious reasons; sand sacks on either side of the head and a retaining tape across the forehead attached to either side of the backboard can serve as a suitable neck restraint during the transport of such patients.

Diagnostic Tools

Cervical tomography (CT) has replaced conventional imaging as a preferred first-line diagnostic tool. Most centers will routinely add a spiral/helical to a head CT or have a low threshold to add this test if there is an even remote suspicion based on mechanisms, symptoms, and findings. This modality has consistently been shown to be less time-consuming and better in detecting cervical injuries compared to conventional radiology and is also superior in delineating bone injuries compared to magnetic resonance imaging (MRI) [9].

CT angiography for detection of vertebral artery injuries is usually added if there is any involvement with even minor displacement of a transverse foramen.

Magnetic resonance imaging is a desirable modality for any cervical spine patients with new-onset manifest or suspected neurologic deficits. This imaging technology also enhances our ability to look for soft tissue abnormalities such as epidural or paraspinal hematoma, disc and ligament injuries, and severity of spinal cord injury by assessment of nature and size of cervical cord signal changes. Increasingly, however, patients present with contraindications to MRI due to body size, neck deformity stimulators, pumps, and pacemakers. While there are efforts made by manufacturers to make these devices, MRI-compatible providers need to be aware of the need to adjust their workup algorithm to accommodate for patients who are MRI-incompatible. In these patients, consideration for contrast-enhanced CT scans should be given, such as *CT myelography* or at least an intravenous contrast-enhanced CT [9].

Other diagnostic modalities such as *radionuclide scans* or *electrodiagnostics* usually have no role in the workup of acute neck injuries, but certainly serve an important role in the postprimary scenario. For patients with suspected spinal cord injuries who offer limited examinability due to other accompanying circumstances, baseline motor and sensory evoked potentials may offer valuable initial insights into presence, distribution, and severity of neurologic injury.

Plain radiographs of the cervical spine in the assessment of trauma continue to play an important role in several regards:

- Alignment checks, especially in the postprimary phase, are most effectively performed with upright radiographs.
- When used as a simple screening tool using lateral radiographs offer an above 90% chance to detect clinically meaningful images. Well-known limitations arise out of the limited visualization of the cervicothoracic junction in larger patients [10].
- Stability assessment can be very effectively performed with a voluntary upright patient-controlled flexion-extension effort, provided the patient is neurologically intact and has no known unstable cervical spine injury. Given common circumstances, this type of test is usually best performed in a postprimary setting outside of an emergency room to assure best possible validity of the study and minimize risk to the patient [10].
- Traction tests have been described as a simple alternative to flexion-extension radiographs for patients to determine stability of a known cervical spine injury. For upper cervical spine injury, physician-supervised traction fluoroscopy studies with weighs of not more than 2 pounds have been reported to be sufficient to detect occult or unclear osseo-ligamentous injuries of the upper cervical spine [11].

Emergent Interventions

Cervical spine trauma offers the challenge as well as opportunity to positively affect the neurologic outcome of certain injuries by timely and properly applied closed reduction of a neck dislocation at earliest clinically safe time point. The enduring controversy surrounding this concept lies in the question if it is necessary to get a MRI scan to detect a potential disc herniation in front of the spinal cord prior to performing a reduction of the fracture-dislocation. As such a disc herniation could potentially lead to spinal cord compression with adverse neurologic outcome following a closed reduction, the detection of such a disc herniation might change management plans in favor of performing an anterior decompression first. On the other hand, leaving a neck dislocated for a prolonged time will likely adversely affect chances for neurologic improvement and expose an intact patient to secondary neural deterioration induced by ongoing compression and propensity for swelling and further cord manipulation. It is difficult to provide general recommendations as each center has different response times for emergent MRIs and operating rooms [12]. In places with near immediate MRI and operation room availability, closed reduction efforts prior to surgical intervention might seem anachronistic. Realistically, however, most centers have some limits of accessibility on these two modalities which makes it desirable to consider emergent closed reduction for patients presenting with cervical fracture/dislocation. Basic principles that have stood the test of time include:

- It is preferable to decompress a newly compromised spinal cord as soon as medically feasible to minimize or even reverse neural injury.
- Closed reduction prior to getting an MRI scan is preferable in a patient with manifest spinal cord injury to decompress the spinal cord at the earliest possible time point.
- Such closed reduction is preferably carried out in a controlled setting with fluoroscopy, skeletal traction, if integrity of the skull has been evaluated, and is applied in a controlled progressive fashion under adequate sedation, muscle relaxation, pain control, and vital sign monitoring while performing regular interval neurologic examinations [13].
- In a neurologically intact patient presenting with a dislocated neck closed reduction is a treatment option provided regular interval neurologic examinations are performed.
- Leaving a neck dislocated without meaningful efforts at deformity reduction subjects the cord to potential further damage induced by swelling, bleeding, and malperfusion.
- If an MRI is performed first and a disc herniation of sufficient size with potential to impact the spinal cord following reduction is detected, anterior surgical decompression is the first treatment choice to be performed on an urgent/emergent basis. Adequate stabilization with an anterior and/or posterior procedure follows such a procedure [12].

For patients with spinal cord injuries a number of additional considerations arise. These urgent interventions consist of a resuscitation and a pharmaceutical component [14].

For resuscitation considerations, the main emphasis has focused on improving spinal cord blood perfusion as early and as safely as possible. Supportive measures in this regard include the following three parts [14]:

- Increasing the mean arterial pressure (MAP) above 80 mm Hg
- Assuring adequate oxygenation
- Keeping the hematocrit as close to or above 30%

Other measures, such as cooling the cord or the entire patient are being investigated actively and due to their potential for adverse impact on general patient physiology have to be approached with caution.

Intravenous high-dose steroids remain the predominant pharmaceutical agent considered for the treatment of acute spinal cord injuries. Continued controversy surrounds the efficacy and safety of intravenous methylprednisolone. More recent reevaluations of early high-dose administration of this drug, which is not FDA-approved for this purpose, have shown some potential of improved neurologic outcomes [15]. Concerns of increased complications revolving around gastrointestinal bleedings, pulmonary deterioration, and wound infections have been raised in case of prolonged administration exceeding 24 hours [16]. Adjuvant preventative management, such as tight glucose control, antacid management, respiratory therapy, and comprehensive incision care, should minimize these adverse events. At this time the use of intravenous high-dose steroids in acute spinal cord injury care remains a management option but does not rise to the level of a treatment recommendation. There are a number of additional pharmaceutical trials under way as well, which may change current treatment recommendations in the future, but are presently not applicable outside of an investigative setting.

Timing of Surgery

Safety and improved outcomes in terms of neurologic injury recovery, intensive care unit stay, and decreased mortality and complication rates have been attributed to early surgical intervention in spine trauma [16, 17]. Limitations of the formal scientific analysis remain in the lack of a consistently applied definition of the timeline of "early" and "urgent" versus "emergent" in this context and the variability of patient conditions and comorbidities [18].

There appears to be a general trend in support of early decompression and surgical stabilization of unstable spine fractures. Desirable features of such early interventions are to avoid secondary hypotension as much as possible to avoid a "second hit" to neural elements, to minimize blood loss, and to limit the duration of surgery as much as feasible while providing a meaningful immediate decompression and stabilization of the injured spinal column and impaired neural structures [19, 20].

A number of conditions have been reported to benefit from such "early" surgical interventions, again with the caveat that there are no clearly accepted strict definitions of what the actual time limits are. As a concept, the term "emergent" in this context would apply to surgeries brought to an operating room within hours of the injury event but not much beyond 8 hours. The term "urgent" in this concept may be understood as surgery taking place within 24 hours of an injury event, while the term "early" would encompass an intervention taking place within a time period of 48–72 hours [15–22].

- *Fracture-dislocations*: for patients with such injuries, early surgery seems to offer generally improved outcomes without increasing complications. As discussed earlier closed reduction offers a reasonable temporizing option, but is not a preferred definitive treatment option due to complications generally associated with prolonged recumbent treatment.
- *Vertebral artery injuries (VAI)*: some form of anticoagulation for intimal VAI patients with or without stenting will affect the ability of surgeons to intervene decisive early stabilization is preferable over taking a delayed intervention

approach, which could take weeks to months. As much as possible the least invasive and the most expedient surgical approach is desirable in such a situation and postoperative drain management should take the need for postoperative anticoagulation into consideration.

- *Penetrating neck trauma*: similar principles to the VAI situation apply in the patients. In the cervical spine early surgical stabilization of an unstable rendered at the time of the emergent surgical site care is usually clearly preferable over delayed care for many reasons.
- *Ankylosing spondylitis and other ankylosing diseases*: Patients with a stiffened neck from underlying inflammatory pathology who present with a fracture of their cervical spine pose a number of special challenges. Many if not most of these injuries are actually unstable Type B2 hyperextension or outright Type C fracture-dislocations. Impaired general patient health status, concurrent significant neck deformities, complex fracture patterns, poor bone stock, and the potential for epidural hematomas as well as the more remote potential for fracture-induced esophageal injury from a sharp fracture end all contribute to a significant morbidity and even mortality burden for the patient and impose difficult management challenge for treating providers. In general—and if medically feasible—early surgical stabilization has been reported to show decreased complications and potential for better outcomes in this very vulnerable patient population. Consideration may be given to use an anterior decompression and stabilization of the subaxial cervical spine first to provide an initial decompression and stabilization prior to performing the usually necessary secondary multilevel posterior surgical stabilization in a secondary or even delayed fashion [23, 24].
- *Polytrauma/multiply injured patient*: Similar to the principles discussed above, early stabilization of unstable cervical spine fractures is generally desirable to facilitate mobilization and extubation. For subaxial injuries an initial anterior surgery offers a number of advantages over the more invasive posterior surgeries, despite a number of considerable biomechanical shortcomings. Usually anterior surgeries are less invasive and atraumatic compared to posterior cervical surgery and can be performed with the patient supine. If deemed necessary, a secondary more definitive posterior surgery can be added later [25, 26].
- *Cranio-cervical dislocations*: These injuries will be discussed later. In general, recognition of a dislocation or “dislocatable” cranio-cervical junction is a serious and potentially life-threatening condition. Urgent or even emergent surgical stabilization usually provided in the form of a posterior decompression and fusion is desirable if compatible with the patient condition. A halo vest has been described as a temporizing form of external immobilization but is obviously limited by the need for torso purchase supplied by the vest and the inherent biomechanical that this device is primarily a traction modality and does not offer a genuine compression effect. Since traction in cranio-cervical injuries is generally contraindicated this limits the use of such devices significantly. Temporary external stabilization prior to definitive surgery may be best facilitated by sand sacks on either side of the head taped to forehead and bed affixed with a visible

warning sign to other providers as to the instability of this patient's neck. As can be gathered from these preceding descriptions, there is a strong preference to provide earliest possible definitive posterior occipito-cervical or upper cervical stabilization once a patient has been medically stabilized to allow for mobilization of the patient [27].

Nonsurgical Care

Most cervical spine injuries can be effectively treated nonsurgically. Some circumstances where surgery is a preferable intervention have been described above together with others which will be further expanded upon below. Basic principles to help differentiate preferable nonsurgical from surgical care include the presence of bone injury versus discoligamentous trauma (the prior having a much better prognosis for healing), presence of serious neurologic injury including axial and appendicular pain, and more general patient factors. Of course, patients with significant cervical spine deformities are usually not amenable for meaningful orthotic care.

In general, nonsurgical care ranges from simple observation, use of adjuvant modalities, activity restrictions as applicable, and mobilization to use of some external orthotic device with or without head and/or torso adaption feature. There are few if any clear guidelines as to duration of device use.

Any and all external immobilization device hold some inherent drawbacks aside from being *biomechanically limited* in its capacity to truly "immobilize" the cervical spine. These limitations of orthotic used in the neck include:

- *Muscle atrophy*. This can be expected to worsen with prolonged time of immobilization.
- *Skin breakdown*. This is of particular concern in neurocognitively impaired patients and in patients at prolonged bedrest. Note that skin breakdown may also include skin superinfections brought on by the moist environment and colonization of padding elements inside collars and vests.
- *Dysphagia*. As the normal act of swallowing necessitates some head tilting a neck collar may increase the risk of aspiration in an at-risk patient.
- *Airway obstruction and aspiration*. In predisposed patients' airway patency may be adversely affected by a circumferential neck collar.
- *Patient compliance*. Any and all of the orthotics described require a modicum of patient compliance and adherence to self-care. Therefore, these devices are of limited value and could be viewed to be dangerous to patients who are clearly noncompliant [28].

To assess stability inferred upon an injured cervical spine by any of these external devices, a simple upright lateral radiograph obtained with the patient wearing the device in conjunction with a repeat patient assessment and comparison with previous alignment studies may provide helpful early reassurance. To ensure minimal bone healing of a fracture, usually a 3–6-week immobilization period may suffice at the lower end, 3 months will provide a high reassurance that bone healing and remodeling have reached an advanced stage, and longer durations of 4 or even more months bracing would be rarely—if ever—necessary. Final stability assessment—similar to surgically treated spinal fractures—is then provided with a combination of clinical assessment and flexion-extension lateral radiographs together with an anteroposterior and neutral upright lateral cervical radiograph.

In the following, a brief review of some general device-inherent features and considerations is provided. Note that all of these devices may also play a role in serving in an adjuvant role to cervical spine surgery.

- *Soft neck collars* are usually considered to provide little more than being a patient reminder to limit activities and limit posterior neck muscle activity. In this capacity, these low-cost devices provide a simple mainstay for sprains and management of some very simple stable bony injuries.
- *Rigid neck collars* offer various degrees of stiffness depending upon the padding used and the effective mandibular and torso fit. Some of this fit can be improved by applying a cranial bar and skull band rostrally and/or a thoracic vest extension. These adaptations would be primarily considered for patients with upper cervical and cervicothoracic fractures. Especially, the headband adaptions such as featured in the SOMI models are generally poorly tolerated by patients. Thoracic extensions in the form of a “cervicothoracic” orthosis are a far more tolerable modification, but rely on integrity of the chest wall and a suitable body physiognomy [28].
- *Halo vests* have undergone a general decline in popularity due to perceived problems primarily with pin tracts, aspiration risk with subsequent pulmonary deterioration, and perceived lack of efficiency brought on by the “snaking” of the mid-cervical spine, which is allowed to move between the locked-in upper cervical spine and the “bulwarked” cervicothoracic junction. In principle, halo vests offer the best overall propensity for external immobilization of any orthotic device used for cervical spine fracture management [29]. Over 75% of well-selected patient with cervical spine trauma can be expected to heal their injuries between 8 and 12 weeks, assuming adherence to a diligent pin care and torso pad maintenance protocol [30]. Attention to detail in pin placement, number of pins used, and retightening as well as regular follow-up are foundations for success. As can be gathered, patient cooperation and support is essential to avoid aspiration and pulmonary complications. A sound fit of the vest to the patient torso is the leading biomechanical predictor for success. Most failures of halo vest fixation occur within the first 2 weeks after application, which allows for a much-improved success prediction if patients are able to follow-through beyond this initial time window. As can be seen from these preceding sentences, halo vest management of cervical spine fractures is an involved process, which requires both effective patient engagement and participation to provider follow-through. For these reasons and more, this over 50-year-old care modality has progressively fallen out of favor.

Summary

It is helpful to follow a relatively simple triage-based ten-question algorithm when approaching a patient with a cervical spine fracture/dislocation.

- ABCs—all checked out?
- Is there a new-onset neurologic injury?
- Decide intact versus spinal cord +/− root/complete/incomplete.
- Is this an isolated or a multisystem injury?
- What is the general health status of the patient?
- Is there a preexistent nonacute spinal condition (i.e., deformity, ankylosis, osteoporosis, spinal stenosis)?
- Is there any dislocation of the spine?
- Is it a bony, ligamentous, or combined injury?
- Is this a stable or an unstable injury?
- Could the vertebral artery be injured?

In the following anatomic review will describe newer general all-encompassing injury classification systems and use case examples to illustrate the pertinent injuries.

Definitive Care of Upper Cervical Spine Trauma

Cranio-cervical Injuries

Keys to Diagnosis

Cranio-cervical injuries, such as atlantooccipital dislocation (AOD), are typically associated with high forces of flexion-extension or rotational forces. Patients may present with neck pain or, in severe cases, sensorimotor deficit and cardiorespiratory instability due to injury of the cervicomedullary spinal cord.

Pure bony injuries are usually limited to fractures of the occipital condyle. These were first classified by Anderson and Montesano and are typically stable injuries (AO Spine OC Type A, Fig. 36.1) when occur without significant displacement [31]. In contrast, purely ligamentous injuries without displacement (OC Type B) are often unstable and require a high degree of clinical suspicion with evidence of disruption on MRI.

The occipital condyle-C1 interval is used to measure the distance between the occipital condyle and the lateral mass of C1 and has the highest sensitivity and specificity for diagnosing AOD with ligamentous injury (OC Type C) [32, 33]. A normal measurement is less than 2.5 mm on each side, while anything greater suggests dissociation. There are additional means of radiographic interpretation helpful in diagnosing AOD with the use of X-ray, CT, or MRI:

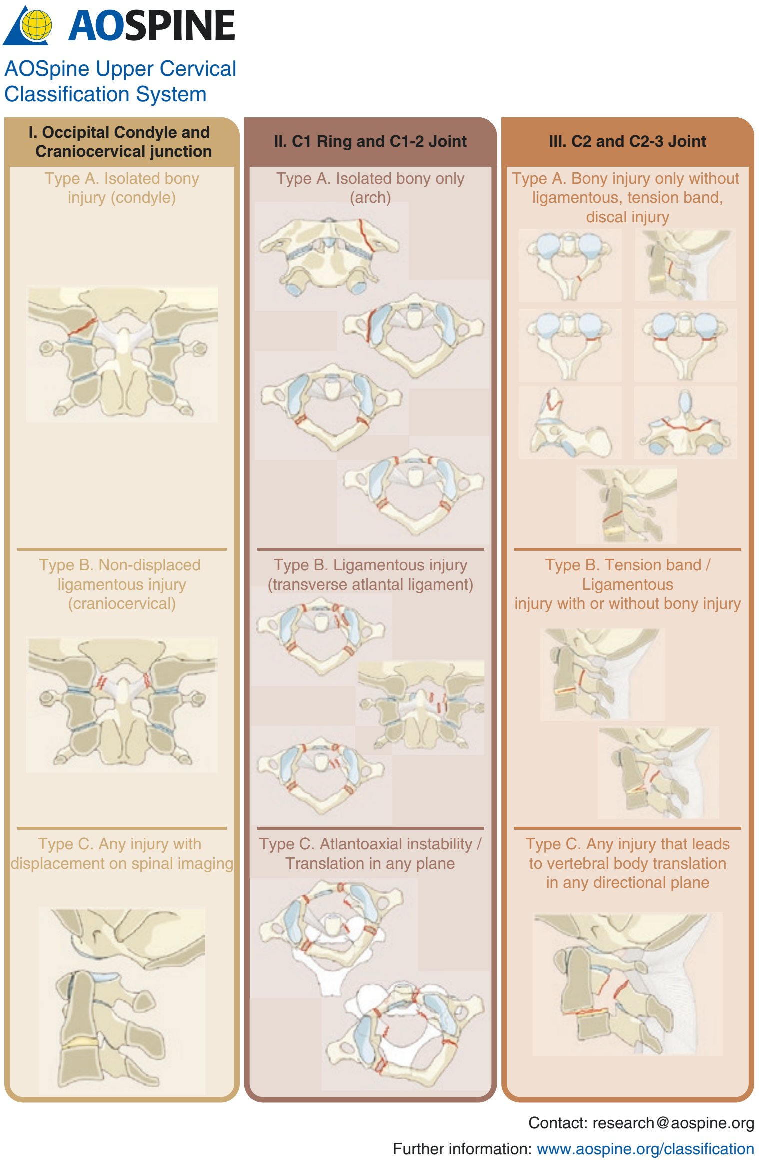


Fig. 36.1 AOSpine upper cervical spine injury classification algorithm and nomenclature, including neurological and facet injury modifiers

- Powers ratio (measurement of the distance from basion to posterior ring of C1 over distance from opisthion to anterior ring of C1; if >1 signifies subluxation). This ratio is of limited value as it only applies to vertical distraction injuries and not to translational ones. It is of largely historical relevance, but included here for completeness sake [34].

- Harris Rule of 12 (the distance from basion to tip of the dens >12 mm suggests dislocation) [35, 36].
- Wackenheim Line (line extending down the posterior aspect of the clivus; if in front of the dens, it suggests anterior subluxation; if behind the dens, there may be posterior dislocation) [37].

Key Concept

The occipital-atlanto-axial unit should be viewed as one highly integrated motion system. This region is responsible for roughly half of cervical axial rotation (about 45–50°), approximately 45° of flexion-extension, and 15° of lateral bending [38]. With this in mind, selecting a surgical approach requiring occiput-cervical fusion for Type B and C injuries should be carefully considered due to its morbidity associated with restricting range of motion.

Role of Nonoperative Care

Rigid cervical collars can be safely used for OC Type A injuries. The use of halos is largely outdated for severe occipito-cervical injuries (Types A, B) due to being primarily ligamentous in nature. Halo vests may be used initially in order to stabilize the patient in preparation for internal fixation. However, treatment with a halo vest alone is associated with a 10% risk of neurologic decline and is not currently recommended [33].

Surgical Care

In most cases of diagnostically proven AOD and/or ligamentous disruption, posterior surgical fixation is required (Fig. 36.2a–d). Spanning the injured segment thus providing adequate reduction necessitates fusing from the occiput to the upper cervical spine [39]. Subaxial cervical spine injuries are not uncommonly associated with AOD, and care should be taken to include those injured segments within the surgical construct if necessary.

Atlas Injuries

Keys to Diagnosis

Both open-mouth radiographs and CT scans are used in the initial diagnostic workup of C1 traumatic injuries. Determining the integrity of the transverse atlantal ligament (TAL) is of paramount importance and can be best confirmed with MRI,

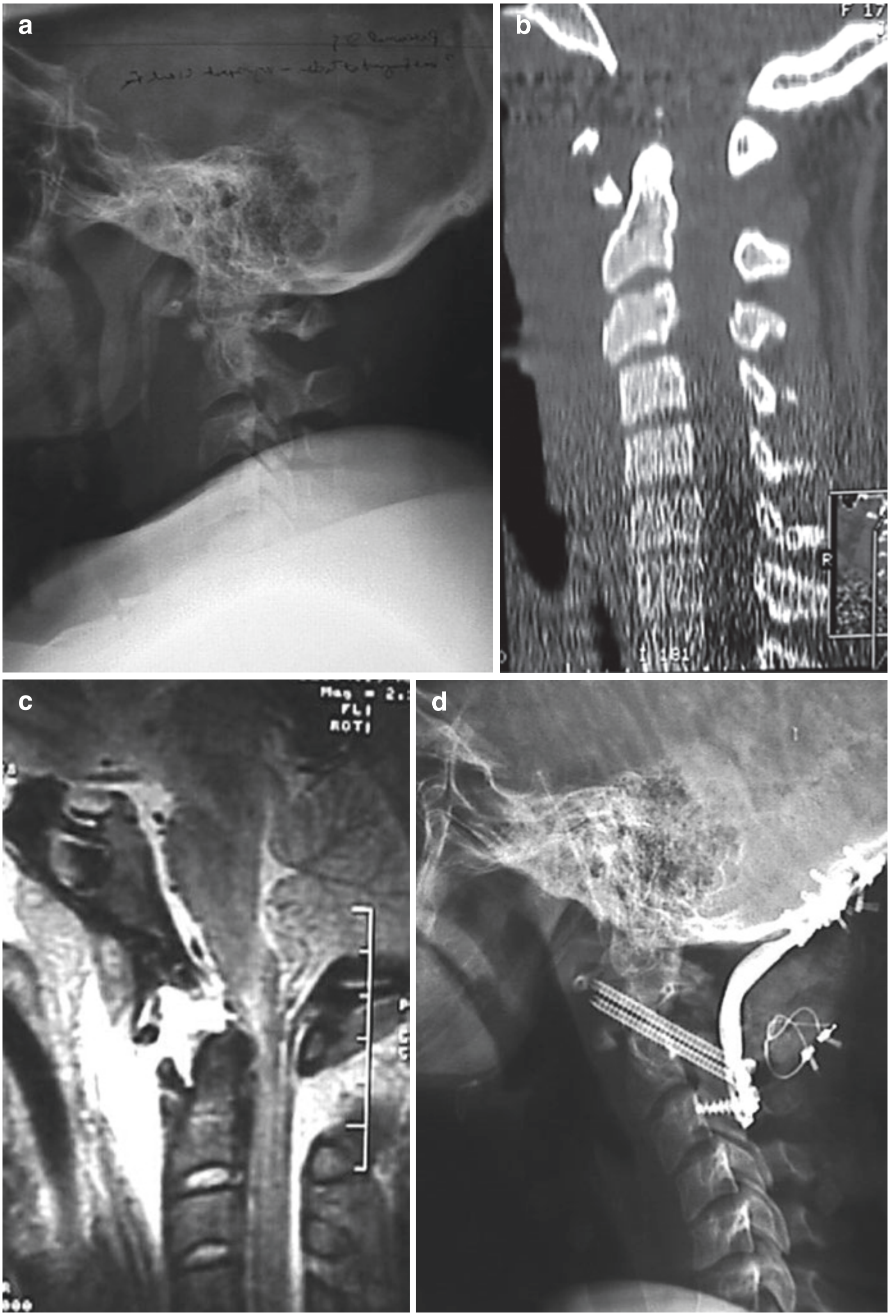


Fig. 36.2 A 17-year-old female presented after high-speed MVC complaining of severe headache and right shoulder weakness. Preoperative X-ray, CT, and MRI demonstrate AOD, C1–2 dislocation, and fracture of anterior ring of C1 with severe ligamentous injuries (**a**–**c**). She underwent ORIF from occiput to C3 and made a full recovery (**d**)

although the Rule of Spence (bilateral overhang of C1 lateral mass on C2 >7 mm) is still commonly employed [40]. There are two types of TAL injuries according to Dickman et al., with one being purely ligamentous and the other accompanied by medial tubercular avulsion [41].

Key Concept

The TAL is one of the major sources of stability at the atlantoaxial junction with a tensile strength of around 350N and keeps the anterior ring of C1 adhered to the odontoid [42]. Therefore, atlas injuries are classified according to this principle. C1 isolated bony injuries (C1 Type A), such as frequently encountered Jefferson fractures, are often stable injuries. Isolated TAL injuries without concomitant fractures (C1 Type B) may render the upper cervical spine highly unstable and must be considered in trauma patients complaining of unexplained neck pain with movement and/or positional upper extremity dysesthesias (Fig. 36.3a–d). Similarly, C1 fractures with TAL injury resulting in translation and atlantoaxial instability (C1 Type C) are highly unstable lesions, and one should immediately immobilize the cervical spine after diagnosis.

Role of Nonoperative Care

Most atlas bony fractures, including Jefferson fractures, may be treated conservatively with rigid external immobilization such as a cervical collar or halo when there is no suspected TAL compromise [43]. Type B and C injuries contain an unstable ligamentous component, which will not heal using halo immobilization and should therefore only be used if in preparation for surgery.

Surgical Care

In cases of TAL disruption with or without an associated fracture, internal surgical fixation is the preferred method of treatment. This is usually performed with C1–2 instrumentation and fusion and may be carried down more inferiorly if necessary. Because of the resulting restriction in the range of motion, fusing to the occiput should be avoided if at all possible.

C1 lateral mass screws may be traditionally placed with a starting point in the middle of the lateral mass; however, this is sometimes not possible due to fracture. Posterior arch lateral mass (PALM) screws can be placed in this circumstance with a starting point in line with the middle of the C1 lateral mass while entering on the inferior portion of the posterior ring of C1. Special care should be taken to avoid a superior trajectory when using this technique in order to prevent vertebral artery injury.

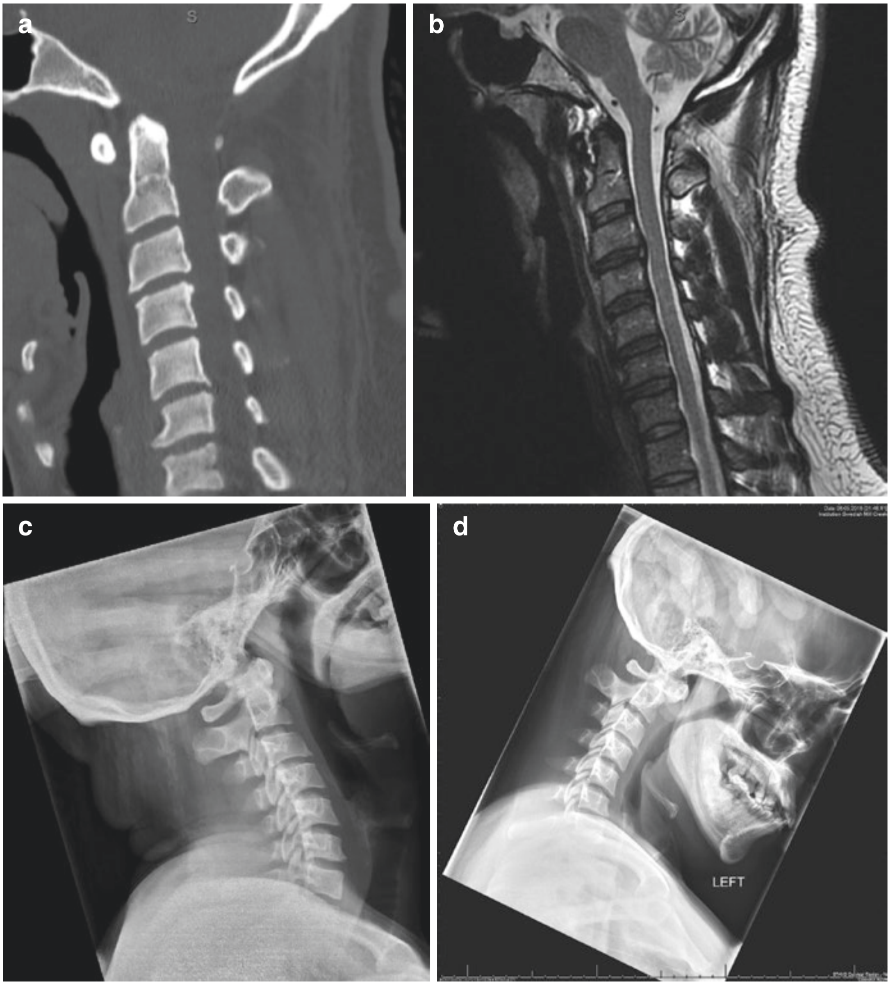


Fig. 36.3 A 36-year-old male presented to the ED with neck pain and positional upper extremity paresthesias. CT (**a**) and MRI (**b**) of the cervical spine showed no obvious fracture but an atlanto-dental interval of >2 mm. Flexion and extension plain films (**c**, **d**) show blatant translation of the atlas relative to the dens, confirming a C1 Type B injury

Odontoid Injuries

Keys to Diagnosis

Uncomplicated bony odontoid fractures (C2 Type A) are one of the most common injuries in the elderly and should always be suspected in an older patient with neck pain after sustaining a fall resulting in hyperextension and/or hyperflexion. It is uncommon for these fractures to present with ligamentous injury or neurologic deficit, which is a common reason for their diagnosis to be missed, although severely posterior angulated fractures may impinge the cervicomedullary spinal cord resulting in severe neurologic injury.

As in most instances of suspected trauma to the spinal column, CT scan should be the initial diagnostic test for suspected dens fracture. Coronal and sagittal views are most helpful since most odontoid fractures tend to be oriented in the axial plane. The most commonly used classification system has been that devised by Anderson and D'Alonzo [44]:

- Type I (fracture at the tip of the dens; unstable)
- Type II (fracture at the base of the dens; usually stable, but relatively high risk for nonunion, especially in the elderly)
- Type III (fracture extending into the body of C2; usually stable)

Key Concept

The odontoid acts as the anchor of the upper cervical spine and is thus prone to pivot failure in flexion and extension, especially in the elderly with atlantal-odontoid arthropathy, while the C1–2 facets remain intact. Ground-level falls in the elderly, particularly when falling face-first, are notably common mechanisms for such injuries, with low to moderate energy rotational forces placing the odontoid at risk for fracture [45, 46].

Role of Nonoperative Care

Odontoid injuries, particularly Type II and III fractures, can successfully be managed with nonoperative measures but is not without risk. Halo vests are largely outdated for external immobilization, especially in the elderly where the morbidity and mortality are unacceptably high [47]. If conservative treatment is elected, a rigid cervical collar is the usual preferred method of immobilization. However, nonoperative management is associated with a roughly 20% rate of nonunion in Type II fractures, which may or may not be clinically significant [48]. Further, mortality rates have been shown to be higher in the elderly treated conservatively in this population [49]. Therefore, nonoperative management of C2 Type A, M1 fractures at the base of the dens should be reserved for younger patients with a relatively low risk of nonunion or for the elderly patient whose comorbidities preclude tolerating surgery.

Surgical Care

The surgical treatment of odontoid injuries remains an area of continuous debate. While those fractures associated with TAL disruption are a relatively clear indication for surgery (Type C2 C), most others can be managed either conservatively or surgically. In those undergoing surgery for odontoid injury with or without ligamentous compromise, a posterior C1–2 Harms fusion is the preferred method of fixation (Fig. 36.4a–d). Anterior odontoid screw placement remains an option, but complication rates and nonunion in the elderly for treatment of Type A, M1 fractures remain high [50]. Thus, posterior internal fixation and reduction, if necessary, is preferred and is the workhorse for odontoid fractures associated with ligamentous injury and those with a high suspicion for nonunion.

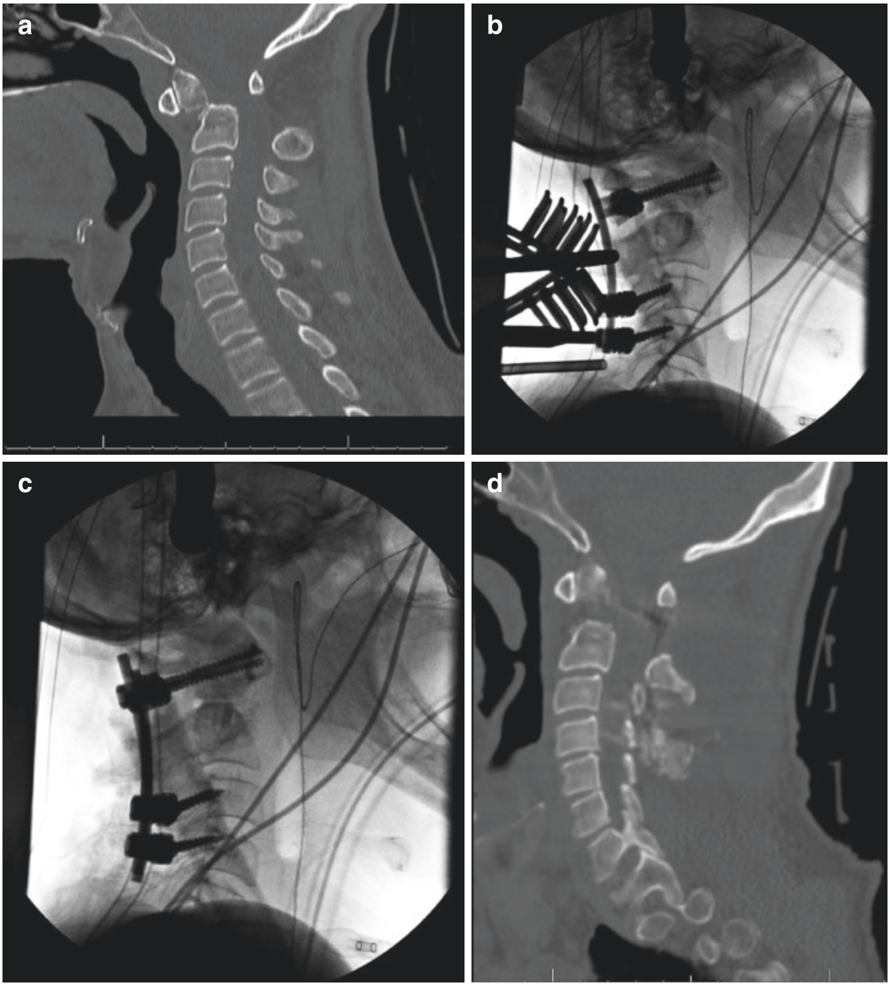


Fig. 36.4 A 57-year-old male presented with a history of falls, neck pain, and progressive cervical myelopathy. CT shows a severely anteriorly displaced dens fracture causing upper cervical stenosis (**a**). Intraoperatively, the fracture was partially reduced before final placement of the rod (**b**). Final reduction with the rod allowed adequate fracture reduction (**c**, **d**)

Hangman's Fractures

Keys to Diagnosis

Despite its moniker, Hangman's fractures usually result from high-energy trauma. As opposed to classifications such as that by Levine/Effendi and Edwards [51], the stability of Hangman's fractures mainly lies within the presence or absence of tension band/ligamentous injury, which when present may occur with or without bony injury (C2 Type B) or with any degree of vertebral body translation +/− angulation (C2 Type C). These are hallmark features of these injuries and are key in identifying which fractures are stable or unstable thus dictating conservative versus operative management. Fractures that are limited to osseous involvement without tension band disruption are stable (C2 and C2–3 joint Type A).

Key Concept

Identifying tension band and ligamentous failure in C2 fractures can be arduous and not always easily identifiable on MRI. Surrogates for tension band failure such as previously mentioned translation and downward C2 angulation can be reliable indicators of ligamentous failure and instability. Classic principles suggest any form of translation/spondylolisthesis >3 mm or downward angulation of C2 >11° signifies instability [51]. These have been reliable gauges of Hangman's fractures instability and should act as a guide in determining tension band failure.

Treatment

For C2 Type A injuries, rigid external fixation should be considered with a cervical collar or halo in younger patients felt to be at risk for nonunion. Operative management is indicated in Type B and C injuries. C2–3 ACDF is a notably valid option in discal injuries of C2–3 or in Type B and C injuries with unfavorable foramen transversarium anatomy for placement of a C2 pedicle screw, although fusion from C1 to the subaxial cervical spine is also an option in this case.

Open reduction and internal fixation (ORIF) is a powerful tool for Type C injuries with substantial translation. This can be attempted via reduction of the screw head during placement of the rod or by manually reducing the fracture fragment with the patient securely in a skull clamp. Whatever method of ORIF chosen, near anatomic alignment should be achieved to maximize construct durability and reduce the risk of worsening neurologic impairment.

Definitive Care of the Subaxial C-spine C3-T1

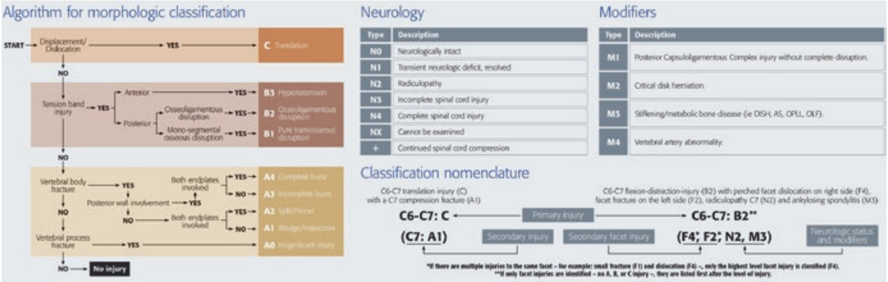
Introduction

There have been many cervical spine injury classification schemes published over the years [52–54] with one of the most recent being the AOSpine Subaxial Cervical Spine Classification System (algorithmic classification shown in Fig. 36.5) [55]. This classification scheme was initially devised as a comprehensive way of classifying subaxial cervical spine injuries while being simple enough for clinical use. This classification system was created with the goal of simplifying communication between providers and patients, as well as being conducive to cervical spine injury research. A recent study demonstrated its utility with it having been found to have high inter- and intra-rater reliability [55]. Here, it will be used and applied to the most common subaxial cervical spine injuries including burst fractures, ligamentous injuries, facet complex injury (unilateral and bilateral), as well as complex fracture-dislocations, respectively.

Burst Fractures

General Features

Burst fractures are, by definition, any injury involving the vertebral body that extends into the spinal canal. These usually result from a flexion-compression type of mechanism resulting in axial loading of the vertebral body and causing vertebral body fracture without disruption of the posterior ligamentous complex (PLC). These injuries are classified as a Type A injury according to the AOSpine system, as shown in Fig. 36.6 [55]. Depending on their morphology, they can be further subclassified as being A2 (coronal split or pincer fracture involving both endplates without involvement of the posterior aspect of the vertebral wall, Fig. 36.6A2), A3 (burst fracture involving a single endplate and the posterior vertebral wall, Fig. 36.6A3), or A4 (burst fracture or sagittal split injury involving both endplates,



Type	Description
N0	Neurologically intact
N1	Transient neurologic deficit, resolved
N2	Radiculopathy
N3	Incomplete spinal cord injury
N4	Complete spinal cord injury
NX	Cannot be examined
+	Continued spinal cord compression

Type	Description
M1	Posterior Capsuloligamentous Complex injury without complete disruption.
M2	Critical disk herniation.
M3	Stiffening/metabolic bone disease (ie DISH, AS, OPLL, OLF).
M4	Vertebral artery abnormality.

C6-C7 translation injury (C) with a C7 compression fracture (A1)

C6-C7 flexion-distraction-injury (B2) with perched facet dislocation on right side (F4), facet fracture on the left side (F2), radiculopathy C7 (N2) and ankylosing spondylitis (M3)

*If there are multiple injuries to the same facet – for example: small fracture (F1) and dislocation (F4) –, only the highest level facet injury is classified (F4).
**If only facet injuries are identified – no A, B, or C injury –, they are listed first after the level of injury.

Fig. 36.5 AOSpine subaxial cervical spine injury classification algorithm and nomenclature, including neurological and facet injury modifiers

Fig. 36.6 AOSpine subaxial cervical spine Type A compression injury classification, including subclassifications A0 to A4

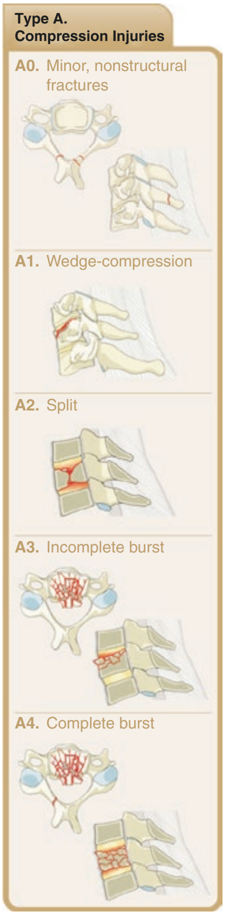


Fig. 36.6A4). Of note, although Type A1 (Fig. 36.6A1) fractures also may result from a flexion-compression mechanism, as they do not extend into the middle spinal column and are restricted to the anterior column, they will not be considered here.

Diagnosis

An important point in diagnosing this type of injury is ensuring that there is no concomitant injury to the PLC. With coincident PLC injury, the injury then becomes classified as a complex fracture subluxation/dislocation, or a AOSpine Type C injury. Injury to the PLC can be determined a number of different ways, including for example interspinous process widening on plain radiograph (XR) or computed tomography scan (CT), facet joint widening or subluxation on XR or CT, ligamentous signal abnormality on magnetic resonance imaging (MRI), among others. On radiographic imaging, these injuries will consist of fracture through the anterior and middle vertebral body column, have variable involvement of its endplates, and a variable amount of bony retropulsion into the spinal canal. Because of the loss of anterior column support, often angular cervical kyphosis will be seen at the site of injury either acutely, or in a delayed fashion during follow-up.

Patients with this type of injury can have a variable presentation ranging from being neurologically intact (N0 or N1 modifier according to the AOSpine system) to having a complete (AOSpine classification modifier N4) spinal cord injury (SCI). The severity of neurological deficit is dependent on, among other things, the degree of vertebral body bony retropulsion into the spinal cord that may be seen. Originally described by Schneider and Khan, these types of injuries are commonly termed teardrop fractures and quadrangular fractures [56].

Treatment

Similar to their presentation, treatment of burst fractures can also be quite varied. Depending on the severity of injury, management may consist of nonoperative treatment with rigid external orthosis or operative treatment. Primary treatment goals consist of reduction of any deformity (if present), decompression of the spinal cord (if necessary), and cervical spine stabilization and fusion. These goals can be accomplished a number of different ways. If spinal cord decompression is necessary (depending on the presence and degree of bony retropulsion) due to ongoing compression (AOSpine modifier "+"), open surgical decompression is often the best method to do so. Closed reduction with traction may also result in spinal decompression (although this is also somewhat dependent on the integrity of the posterior longitudinal ligament, PLL). With nonoperative treatment, rigid external immobilization with a collar or halo vest is then required for up to 12 weeks, followed by static and dynamic (flexion-extension XR) cervical spine radiographs. As mentioned, for more severe injuries operative intervention is usually required. Operative treatment for this type of injury usually requires anterior column reconstruction via an anterior cervical discectomy and/or corpectomy (ACDF and ACCF, respectively) with anterior cervical plating and unicortical or bicortical locking screws.

Key Concepts

- Vertebral body fracture with no concomitant posterior column disruption
- Variable clinical presentation from patients being neurologically intact to complete SCI
- Variable treatment options depending on severity:
  - Mild: no bony retropulsion, minimal to no kyphotic deformity, and neurologically intact may be treated with rigid external immobilization via collar or halo vest with close clinical and radiological follow-up.
  - Moderate: minimal to no bony retropulsion or kyphosis that reduces with traction and neurologically intact may be treated via traction and halo vest with close clinical and radiological follow-up.

- Severe: moderate to severe bony retropulsion or kyphosis with any neurological deficit should be treated (with or without brief trial of preoperative closed reduction via traction) via open surgical decompression, reduction and internal fixation via anterior cervical discectomy and/or corpectomy with anterior plating, and close postoperative clinical and radiological follow-up.

Posterior Ligamentous Injury

General Description

Posterior ligamentous injuries are classified as a Type B injury according to the AOSpine Subaxial Cervical Spine Classification System, as shown in Fig. 36.7. Although these injuries can be further subclassified into bony and/or ligamentous (B1, Fig. 36.7B1, vs B2, Fig. 36.7B2, respectively), here we will only consider purely ligamentous injury. Purely ligamentous injuries can then be categorized as

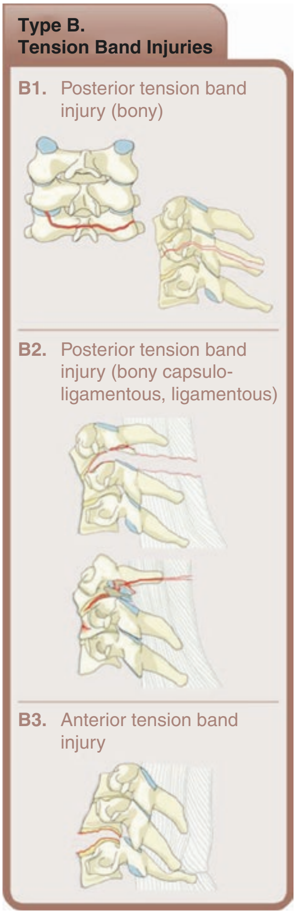


Fig. 36.7 AOSpine subaxial cervical spine Type B tension band injury classification, including subclassifications B1 to B3

anterior only with tethering of the posterior elements, or posterior with/without anterior involvement (B3, Fig. 36.6B3, vs B2, respectively). Ligamentous injuries in the cervical spine can occur as a result of either a flexion or extension mechanism, often accompanied by a distracting force on the segment in question. For the purposes of this section, we will consider these injuries together.

Diagnosis

Diagnosis of a pure ligamentous injury is predicated on the absence of concomitant bony injury being visualizing on XR, CT, or MRI. Diagnosis of a patient having sustained a ligamentous injury can be made on XR or CT by there being PLC disruption resulting in interspinous process widening, facet capsule disruption and joint widening, intervertebral disc space widening, angulation, or listhesis. That being said, any resultant vertebral body translation or distraction relative to one another would result in an escalation of injury grade classification to an AOSpine Type C accompanied by a Type B description [55]. Ligamentous cervical spine injury can oftentimes be difficult to diagnose in circumstances in which no obvious deformity is present. MRI is helpful in such circumstances as ligamentous and disc space signal abnormality subsequent to the traumatic injury is indicative of this injury pattern (classified under the “M” modifier in the AOSpine classification system). However, the clinical utility of an MRI showing signal abnormality is still unclear in such circumstances [57] and considered by many to be overly sensitive and lacking specificity in directing clinical management. A limited role for dynamic cervical spine XR exists in such trauma patients who are neurologically intact and have substantial neck pain with no obvious bony injury or deformity present.

Patients with a purely ligamentous injury may present with a variety of signs and symptoms. These patients may be neurologically intact and complaining of only neck pain, they may have transient neurological deficits that subsequently resolve (AOSpine N1 modifier), and they may also have a more severe spinal cord injury (N3 modifier for incomplete SCI or N4 modifier for complete SCI). Of note, although patients presenting with a central cord syndrome pattern of injury are classified as an A0 according to the AOSpine classification system, as this is a clinical syndrome and not diagnosed morphologically, patients with a purely ligamentous injury may present in such a manner. Furthermore, although described in the pre-MRI era, patients with a spinal cord injury without radiographic abnormality (SCIWORA) may also have a ligamentous injury (however, as this is much more common in pediatric patients, this is to be considered in other sections of this book).

Treatment

Management of patients having sustained a purely ligamentous injury is primarily surgical treatment. The goal of treatment, depending on the specific case and presence of spinal cord compression, consists primarily of stabilization and fusion. In the absence of a bony fracture, the likelihood of successful stabilization without fusion is low. This argues for upfront surgical stabilization upon diagnosis (although surgical stabilization in a delayed fashion for patients who are neurologically intact, without deformity, and showing instability after being initially treated in external orthosis is also advocated by some). Open surgical stabilization and fusion for purely ligamentous injuries can be accomplished via anterior or posterior approach. As these injuries more commonly involve disruption of the posterior tension band with intact anterior column support, a posterior approach is typically taken involving fixation and fusion via a lateral mass screw-rod construct (posterior spinal instrumented fusion, PSIF). However, anterior cervical discectomy and fusion is also considered an acceptable alternative (with many advocating for its use) upon careful consideration of its advantages and disadvantages versus a PSIF.

Key Concepts

- Purely ligamentous injury with diagnosis precluding a concomitant bony injury and diagnosis being made via XR, CT, MRI, and in a limited number of patient flexion-extension XR
- Variable patient presentation from patients being neurologically intact, having transient deficits, to varying degrees of spinal cord injury
- Management in patients with deformity, deficit, or instability (acute or delayed) consists primarily of open surgical reduction and fixation via PSIF, with a limited role for anterior approaches

Facet Injury (Unilateral or Bilateral) With/Without Fracture

General Description

Facet injuries have a special classification or modification descriptor in the context of the AOSpine classification system. This is a relatively broad category of injury and may consist of unilateral or bilateral injury, capsuloligamentous injury resulting in facet subluxation, perch or dislocation, as well as facet complex fracture. The AOSpine classification system categorizes these injuries as F1 if the injury results in a nondisplaced fracture (either superior or inferior articular facet processes in which the fracture fragment is <1 cm and <40% of the lateral mass), F2 if the injury results in a potentially unstable fracture (either superior or inferior articular facet processes in which the fracture fragment is >1 cm and >40% of the lateral mass or displaced), BL designating bilateral facet injury (with the right facet fracture being noted first and left second), and any facet subluxation, perch, or dislocation due to a flexion-distraction type mechanism being classified as a Type C injury pattern followed by the appropriate F designation. Because of the heterogeneity within this group of injuries, there is a plethora of different mechanisms and combinations thereof that may cause them. For example, an extension-compression type of mechanistic force will typically result in a (potentially isolated) facet fracture, whereas flexion-distraction mechanism (in which the instantaneous axis of rotation is located within the anterior or middle spinal column) will typically result in a vertebral body fracture with accompanying facet capsuloligamentous disruption (and potential fracture of the articular processes). Although many different facet injuries may be possible due to the different mechanisms causing them, for simplicity sake, we will organize this section into unilateral and bilateral facet injury with/without fracture.

Diagnosis: Unilateral Facet Injury (With/Without Fracture)

Identification and diagnosis of a unilateral facet injury may be accomplished via XR, CT, or MRI. On XR, depending on the severity of injury, simple distraction with nonoverlapping facets may be seen, a fracture line may be visualized if one exists, interspinous widening may be seen (although this usually necessitates bilateral injury), or occlusion of the neural foramen may be seen on an oblique view. In the case of a unilateral dislocated facet, on a lateral projection XR a "bow-tie sign" [58] may be seen in which both facets can be visualized side-by-side instead of superimposed. An anteroposterior (AP) projection will reveal the ipsilateral lateral mass to be slightly larger, and the spinous process superiorly will be rotated ipsilaterally to the facet injury). Although there is still a role for XR, CT scan has largely become the gold standard in diagnosing these types of injuries. In a unilateral facet injury, varying degrees of asymmetric widening of the facet complex and joint space will be seen, with or without accompanying facet fracture, and in the case of a dislocated facet a "naked facet sign" or "reverse hamburger bun sign" may be visualized in which the articular process surfaces are unopposed [59, 60]. Although it is possible to diagnose these injuries with MRI alone, its diagnostic strength in this context is mainly directed at visualizing the discoligamentous complex and rule out traumatic disc herniation to aid in planning a management strategy and surgical approach, if necessary.

Depending on the severity of injury, patients with a unilateral facet injury may present with neck pain, to radicular symptoms, to spinal cord injury. In the case of a unilateral dislocated or "jumped" facet, patients will usually present with a unilateral radiculopathy, and depending on the magnitude of the traumatic force, may present with either complete or incomplete SCI. Previous studies have shown that 25% of all unilateral dislocated facets will be neurologically intact, 37% will have a radiculopathy, 22% will have an incomplete SCI, and 15% will have a complete SCI [58]. Unlike bilateral facet capsule injury, these injuries can sometimes present a diagnostic challenge if patients are not initially investigated with CT or present in a delayed fashion, which can then result in controversy regarding best treatment options.

Diagnosis: Bilateral Facet Injury (With/Without Fracture)

Bilateral facet injury is usually a much more straightforward diagnosis than its unilateral counterpart. Although possible to diagnose on XR, CT has largely supplanted XR and is considered to be the gold standard in identifying this injury. In the case of subtle facet capsuloligamentous distraction injury, upright cervical XR may help in the diagnosis (as well as determining stability) by identifying patients who go on to develop a kyphotic deformity. On CT, bilateral injury will result in a similar injury pattern to that seen with unilateral facet injury, with the exception that a translational deformity is often also seen. Bilateral facet capsule will oftentimes result in anterolisthesis and/or angulation of the superior vertebral body relative to the inferior with both inferior articular processes of the level above dislocating and locking anterior to the superior articular processes of the level below. Although likely less common in unilateral facet dislocation, with bilateral facet dislocation, it is important to recognize the risk of vertebral artery injury (VAI) and investigate it accordingly with vascular imaging (angiogram or CT-angiogram (CTA)) [61]. The facet capsuloligamentous structures impart a large stabilizing force within the cervical spine [62, 63], and in order to injure and/or dislocate both facet capsules, a large traumatic force is necessary. It is not surprising then that these patients are much more likely to have an accompanying spinal cord injury [64].

Treatment: Unilateral Facet Injury (With/Without Fracture)

Management of patients with a unilateral facet injury may vary depending on the extent of injury. Patients with a minor injury (unilateral facet capsuloligamentous distraction, with or without a small, nondisplaced fracture (F1)) may be treated in rigid cervical orthosis (with the risk of instability being commonly accepted as much higher, the fracture fragment is >40% of the lateral mass or 1 cm) [65]. Although patients with a neurological deficit are typically treated surgically, this is still not necessarily a standard of care. Many argue that in the event of radiculopathy in the context of a facet fracture, nonoperative immobilization will result in bony fusion and facet remodeling and subsequent improvement of the patient's radiculopathy. In the case of a unilateral jumped facet, controversy again exists as to the best treatment for these patients. Not infrequently patients with this injury pattern will present in a delayed fashion complaining of neck pain due to a missed diagnosis at the time of injury. Many use this point in arguing the stability of this type of injury. Although previous studies exist supporting both surgical and nonsurgical approaches in managing these injuries, it is likely that surgical treatment of these injuries results in both more predictable and favorable patient outcomes [66].

In the event of either operative or nonoperative management, a closed reduction may be attempted first in the case of a unilateral jumped facet (although relatively contraindicated in the presence of an acute disc herniation). However, if attempted, it is the authors' opinion that only a brief period of traction be attempted with a low threshold for surgical intervention as this particular type of injury has been shown to be quite difficult to reduce with traction alone (again, arguing the mechanical stability of the injury). The goals of surgical treatment for these patients include reduction, decompression if warranted, and stabilization and fusion. Much like other aspects of these types of injuries, the optimal approach is controversial. Both anterior (ACDF with plating) and posterior approaches (usually PSIF) have been advocated and reported [67–69]. In the absence of discoligamentous injury or a traumatic disc herniation, the authors would advocate a posterior approach with facet reduction, nerve root decompression if necessary, and stabilization and fusion using a screw-rod construct.

Treatment: Bilateral Facet Injury (With/Without Fracture)

Management of patients with a bilateral facet injury is largely confined to surgical treatment. Similarly to unilateral facet injury, surgical goals consist of reduction, decompression if necessary, and stabilization and fusion. The majority of these patients present with a spinal cord injury, and as such decompression as soon as safely possible is warranted [70]. This may be via closed traction-reduction (again, usually in the absence of acute traumatic disc herniation) or surgically [69, 71]. Although most agree that bilateral facet injury warrants surgical stabilization (with the role of halo vest external immobilization being mainly historical), many groups argue the merit of anterior, posterior, and combined approaches [67–69]. Although the technical description of each surgical treatment option and its respective advantages and disadvantages are beyond the scope of this chapter, the authors advocate that the optimum approach for these injuries is likely going to depend on each case's unique injury pattern (e.g., facet subluxation or dislocation, accompanying unilateral or bilateral facet fractures, and vertebral body endplate fractures, among others).

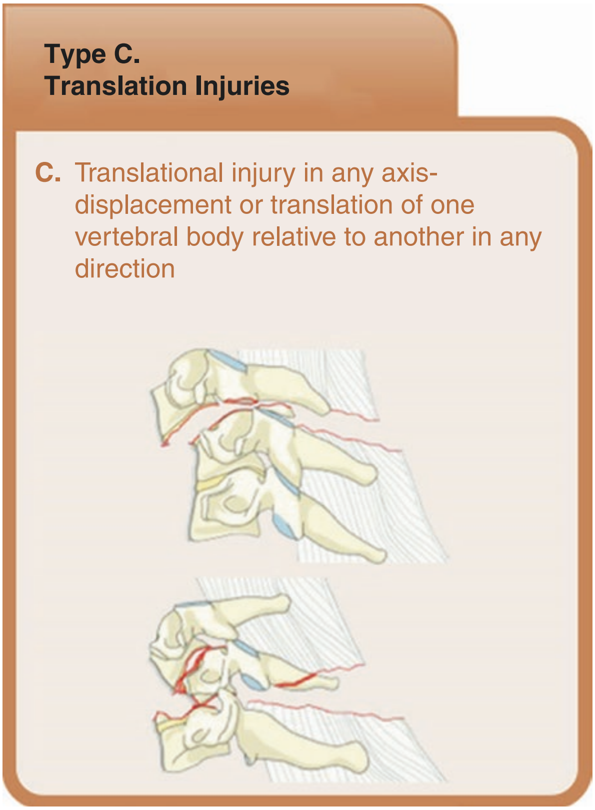
Key Concepts

- Injury to the subaxial cervical spine facet complexes, either unilaterally or bilaterally, is common with a unique AOSpine classification system modifier.
- Diagnosis is primarily made via CT scan, with limited role of cervical spine XR and MRI.
- Depending on the severity of injury, a broad range of clinical patient presentations may be seen: patients with unilateral facet complex dislocation classically present with ipsilateral radiculopathy (either acutely or in a delayed fashion), whereas those with bilateral facet dislocation classically present with SCI.
- Management of these injuries is dependent on presence of unilateral or bilateral facet injury and associated fracture patterns:
  - Unilateral: controversy exists as to best treatment, whether surgical or nonsurgical (although surgical likely portends more predictable and better patient-reported outcomes long-term) as well as the surgical approach (anterior or posterior).
  - Bilateral: surgical treatment warranted with external halo vest immobilization now primarily an antiquated option; best surgical approach (anterior, posterior, or combined) remains controversial with best approach likely dependent on accompanying injuries and patient factors.

Complex Fracture-Dislocation

General Description

Complex fracture-dislocations are classified as a Type C injury according to the AOSpine classification, as shown in Fig. 36.8. As the name implies, this injury pattern results in a complex combination of spinal column fracture and injury. In a similar pattern to that described above with bilateral facet dislocation, Type C fracture-dislocations typically result in translation and anterolisthesis of the superior vertebral body relative to the inferior level, other vertebral body fractures (Type A or B AOSpine injury), ligamentous injury (Type B AOSpine injury), and unilateral and/or bilateral facet capsuloligamentous injury with/without fracture (Type F AOSpine modifier). As would be expected, these injuries can result from a complex interaction and combination of mechanistic forces during the traumatic event, though the predominant mechanism being a flexion-distraction force.



C. Translational injury in any axis-displacement or translation of one vertebral body relative to another in any direction

Fig. 36.8 AOSpine subaxial cervical spine Type C translation injury classification

Diagnosis

Diagnosis of this pattern of complex cervical spine fracture-dislocation is relatively straightforward. Although it is possible to diagnose this injury on XR, as in the case of facet injuries, CT has largely replaced XR as the diagnostic investigation of choice for complex fracture-dislocations. As mentioned above, patients may have a various types of bony and ligamentous injuries, including for example vertebral body fractures, facet fracture-dislocations, discoligamentous injury, among others. Similarly to facet dislocations, there is a significant risk of VAI with this injury pattern. It is recommended that this be investigated with vascular imaging (usually CTA) as diagnosis may alter management. Furthermore, MRI is recommended in these patients to examine ongoing spinal cord compression. Clinically, patients suffering complex fracture-dislocation cervical spine injury will typically present with a SCI. Although the degree of SCI may vary from injury to injury, it is important to recognize the high likelihood of a SCI being present as often these patients can be difficult to examine due to concomitant traumatic brain injury (being designated with an "NX" modifier as per the AOSpine classification) and the necessity of SCI management that follows according the clinical guidelines.

Treatment

Management of these patients can often be difficult and requires a multidisciplinary team in an intensive care unit (ICU) setting. Although the medical treatment of SCI is beyond the scope of this chapter, it is of note that management and treatment of these patients is likely best accomplished in large tertiary care, level-1 trauma centers and in accordance with institutional and established SCI guidelines. The surgical treatment of these injuries should be achieved as quickly as safely possible, [70] and goals should include reduction, decompression, and stabilization and fusion. Although somewhat controversial, complex fracture-dislocations often require a combined anteroposterior instrumented fusion in order to achieve adequate stability. More controversial yet is the order and manner in which surgical decompression and stabilization occurs. Many prefer an anterior first approach with decompression via discectomy and/or corpectomy, followed by a posterior approach for instrumented stabilization (and possible decompression if still necessary), and return to the front for definitive graft fixation. Others argue the merit of performing a posterior first approach acutely with reduction, long posterior decompression to accommodate for potential spinal cord swelling and instrumented fusion, followed by a delayed and supplemental anterior approach if necessary, once the patient is no longer in the acute SCI time window. Much like bilateral facet dislocations, the advantages and disadvantages of each approach are debatable, although the optimal outcome is likely going to depend on the specific complex radiological fracture characteristics, patient factors, and surgeon- and institution-related factors, among others.

Key Concepts

- Complex fracture-dislocation injury is typically a Type C AOSpine classification system injury with potential A, B, F, N, M, and “+” modifiers.
- Diagnosis for this type of injury is relatively straightforward with CT and MRI and vascular imaging to rule out VAI being necessary.
- Patients typically present with a SCI of varying severity and should be treated in an ICU at a tertiary care, level-1 trauma center according to established SCI management guidelines.
- Management is surgical, usually consisting of a combined anteroposterior approach, the order and timing of which remain controversial.

Case

A 29-year-old male was brought to the emergency room by ambulance after being extricated from his vehicle that had been involved in a motor vehicle collision at approximately 60 miles per hour. After initial stabilization and resuscitation, he has a Glasgow Coma Scale score of 15, and his clinical examination revealed him to have a spinal cord injury AIS A, neurological level C7. Initial CT exam of his cervical spine revealed a complex fracture-dislocation with bilateral jumped facets, a vertebral body fracture, and a unilateral fractured facet complex (Fig. 36.9) (AOSpine classification C6–7: Type C (C7 Type A3, C6–7 B2, F4, F4, N4)). After

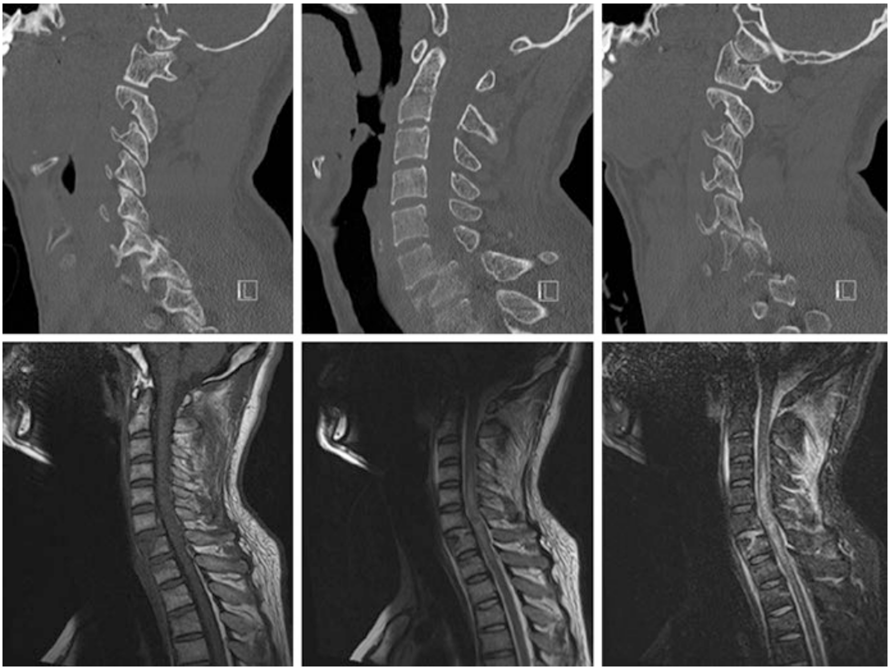


Fig. 36.9 A 29-year-old male involved in a motor vehicle collision. CT exam of his cervical spine revealed a complex fracture-dislocation with bilateral jumped facets, a vertebral body fracture, and a unilateral fractured facet complex. MRI demonstrates realignment after closed reduction and was eventually treated with combined anterior and posterior decompression and fusion

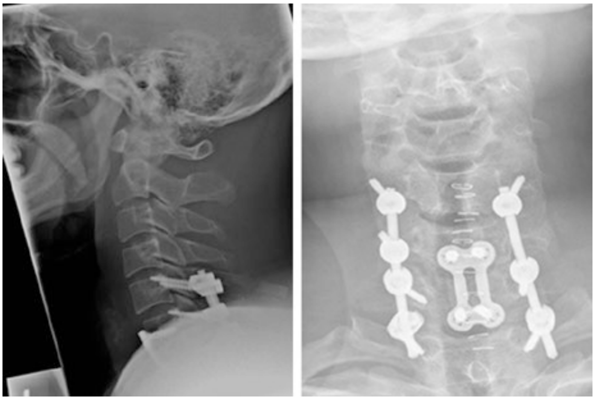


Fig. 36.9 (continued)

initial closed traction-reduction (postreduction MRI below), the patient underwent definitive surgical decompression, open reduction, and internal fixation and fusion via a combined anteroposterior approach with postoperative XR.

References

1. Chapman J, Smith JS, Kopjar B, et al. The AOSpine North America Geriatric Odontoid Fracture Mortality Study: a retrospective review of mortality outcomes for operative versus nonoperative treatment of 322 patients with long-term follow-up. Spine (Phila Pa 1976). 2013;38:1098–104.
2. Bliuc D, Nguyen ND, Milch VE, Nguyen TV, Eisman JA, Center JR. Mortality risk associated with low-trauma osteoporotic fracture and subsequent fracture in men and women. JAMA. 2009;301:513–21.
3. Vos T, et al. Global, regional, and national incidence, prevalence, and years lived with disability for 301 acute and chronic diseases and injuries in 188 countries, 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013. Lancet. 2015;386(9995):743–800.
4. Rustagi T, Drazin D, Oner C, York J, Schroeder GD, Vaccaro AR, Oskouian RJ, Chapman JR. Fractures in ankylosing disorders: a narrative review of disease and injury types, treatment techniques, and outcomes. J Orthop Trauma. 2017;31:S57–74.
5. Avellino AM, Mann FA, Grady MS, Chapman JR, Ellenbogen RG. The misdiagnosis of acute cervical spine injuries and fractures in infants and children: the 12-year experience of a level I pediatric and adult trauma center. Childs Nerv Syst. 2005;21(2):122–7.
6. Tchorz KM. Advanced trauma life support (ATLS®): the ninth edition. J Trauma Acute Care Surg. 2013;74(5):1363.
7. Curran C, Dietrich AM, Bowman MJ, Ginn-Pease ME, King DR, Kosnik E. Pediatric cervical-spine immobilization: achieving neutral position? J Trauma: Inj Infect Crit Care. 1995;39(4):729–32.
8. Manoach S, Paladino L. Manual in-line stabilization for acute airway management of suspected cervical spine injury: historical review and current questions. Ann Emerg Med. 2007;50(3):236–45.
9. Pekmezci M, Theologis AA, Dionisio R, Mackersie R, McClellan RT. Cervical spine clearance protocols in Level I, II, and III trauma centers in California. Spine J. 2015;15(3):398–404.

10. Hoffman JR, Wolfson AB, Todd K, Mower WR, For the NEXUS Group. Selective cervical spine radiography in blunt trauma: methodology of the National Emergency X-Radiography Utilization Study (NEXUS). Ann Emerg Med. 1998;32(4):461–9.
11. Child Z, Rau D, Lee MJ, Ching R, Bransford RJ, Chapman JR, Bellabarba C. The provocative radiographic traction test for diagnosing craniocervical dissociation: a cadaveric biomechanical study and reappraisal of the pathogenesis of instability. Spine J. 2016;16(9):1116–23.
12. Grauer JN, Vaccaro AR, Lee JY, Nassr A, Dvorak MF, Harrop JS, Dailey AT, Shaffrey CI, Arnold PM, Brodke DS, Rampersaud R. The timing and influence of MRI on the management of patients with cervical facet dislocations remains highly variable: a survey of members of the Spine Trauma Study Group. J Spinal Disord Tech. 2009;22(2):96–9.
13. Grant GA, Mirza SK, Chapman JR, Winn HR, Newell DW, Jones DT, Grady MS. Risk of early closed reduction in cervical spine subluxation injuries. J Neurosurg Spine. 1999;90(1):13–8.
14. Hurlbert RJ. Strategies of medical intervention in the management of acute spinal cord injury. Spine. 2006;31(11S):S16–21.
15. Fehlings MG, the Spine Focus Panel Summary Statement. The use of methylprednisolone in acute spinal cord injury. Spine. 2001;26(24S):S55.
16. Hurlbert RJ. The role of steroids in acute spinal cord injury: an evidence-based analysis. Spine. 2001;26(24S):S39–46.
17. Mirza SK, Krengel WF III, Chapman JR, Anderson PA, Bailey JC, Grady MS, Yuan HA. Early versus delayed surgery for acute cervical spinal cord injury. Clin Orthop Relat Res. 1999;359:104–14.
18. Fehlings MG, Perrin RG. The timing of surgical intervention in the treatment of spinal cord injury: a systematic review of recent clinical evidence. Spine. 2006;31(11S):S28–35.
19. Furlan J, Noonan V, Cadotte DW, Fehlings DW. Timing of decompressive surgery of spinal cord after traumatic spinal cord injury: an evidence-based examination of pre-clinical and clinical studies. Spine. 2001;26(24S):S39–46.
20. Fehlings MG, Vaccaro AR, Wilson JR, Singh A, Cadotte DW, Harrop JS, Aarabi B, Shaffrey CI, Dvorak M, Fisher C. Early versus delayed decompression for traumatic cervical spinal cord injury: results of the Surgical Timing in Acute Spinal Cord Injury Study (STASCIS). PLoS One. 2012;7:e32037. https://doi.org/10.1371/journal.pone.0032037.
21. Bliemel C, et al. Early or delayed stabilization in severely injured patients with spinal fractures? Current surgical objectivity according to the Trauma Registry of DGU: treatment of spine injuries in polytrauma patients. J Trauma Acute Care Surg. 2014;76(2):366–73.
22. Carreon LY, Dimar JR. Early versus late stabilization of spine injuries: a systematic review. Spine. 2011;36(11):E727–33.
23. Westerveld LA, van Bemmel JC, Dhert WJ, Oner FC, Verlaan JJ. Clinical outcome after traumatic spinal fractures in patients with ankylosing spinal disorders compared with control patients. Spine J. 2014;14(5):729–40.
24. Caron T, Bransford R, Nguyen Q, Agel J, Chapman J, Bellabarba C. Spine fractures in patients with ankylosing spinal disorders. Spine (Phila Pa 1976). 2010;35(11):E458–64.
25. Gelb DE, et al. Treatment of subaxial cervical spinal injuries. Neurosurgery. 2013;72:187–94.
26. Wiseman DB, Bellabarba C, Mirza SK, Chapman JR. Anterior versus posterior surgical treatment for traumatic cervical spine dislocation. Curr Opin Orthop. 2003;14(3):174–81.
27. Reis A, Bransford RJ, Penoyar T, Chapman JR, Bellabarba C. Diagnosis and treatment of craniocervical dissociation in 48 consecutive survivors. Evid Based Spine Care J. 2010;1(2):69–70.
28. Ivancic PCS. Do cervical collars and cervicothoracic orthoses effectively stabilize the injured cervical spine? A biomechanical investigation. Spine. 2013;38(13):E767–74.
29. Mirza SK, Moquin RR, Anderson PA, Tencer AF, Steinmann J, Varnau D. Stabilizing properties of the halo apparatus. Spine (Phila Pa 1976). 1997;22(7):727–33.
30. Bransford RJ, Stevens DW, Uyeji S, Bellabarba C, Chapman JR. Halo vest treatment of cervical spine injuries: a success and survivorship analysis. Spine. 2009;34(15):1561–6.
31. Anderson PAULA, PASQUALE X. Montesano. Morphology and treatment of occipital condyle fractures. Spine. 1988;13(7):731–6.

32. Gire JD, et al. The utility and accuracy of computed tomography in the diagnosis of occipito-cervical dissociation. Spine J. 2013;13(5):510–9.
33. Walters BC, et al. Guidelines for the management of acute cervical spine and spinal cord injuries: 2013 update. Neurosurgery. 2013;60(CN_suppl_1):82–91.
34. Powers B, et al. Traumatic anterior atlanto-occipital dislocation. Neurosurgery. 1979;4(1):12–7.
35. Harris JH Jr, Carson GC, Wagner LK. Radiologic diagnosis of traumatic occipitovertebral dissociation: 1. Normal occipitovertebral relationships on lateral radiographs of supine subjects. AJR Am J Roentgenol. 1994;162(4):881–6.
36. Harris JH Jr, et al. Radiologic diagnosis of traumatic occipitovertebral dissociation: 2. Comparison of three methods of detecting occipitovertebral relationships on lateral radiographs of supine subjects. AJR Am J Roentgenol. 1994;162(4):887–92.
37. Wackenheim A. Roentgen diagnosis of the craniovertebral region. Berlin/New York: Springer; 1974.
38. Benzel EC. Biomechanics of spine stabilization. 3rd ed. New York: Thieme Medical Publishers; 2015.
39. Hall GC, et al. Atlanto-occipital dislocation. World J Orthop. 2015;6(2):236.
40. Spence JR, Kenneth F, Decker S, Sell KW. Bursting atlantal fracture associated with rupture of the transverse ligament. JBJS. 1970;52(3):543–9.
41. Dickman CA, Greene KA, Sonntag VKH. Injuries involving the transverse atlantal ligament: classification and treatment guidelines based upon experience with 39 injuries. Neurosurgery. 1996;38(1):44–50.
42. Dvorak J, et al. Biomechanics of the craniocervical region: the alar and transverse ligaments. J Orthop Res. 1988;6(3):452–61.
43. Hadley MN, et al. Acute traumatic atlas fractures: management and long term outcome. Neurosurgery. 1988;23(1):31–5.
44. Anderson LD, D'Alonzo RT: Fractures of the odontoid process of the axis. J Bone Joint S. 1974;56(8):1663–74.
45. Malik SA, et al. Evaluation of morbidity, mortality and outcome following cervical spine injuries in elderly patients. Eur Spine J. 2008;17(4):585–91.
46. Ryan MD, Henderson JJ. The epidemiology of fractures and fracture-dislocations of the cervical spine. Injury. 1992;23(1):38–40.
47. Tashjian RZ, et al. Halo-vest immobilization increases early morbidity and mortality in elderly odontoid fractures. J Trauma Acute Care Surg. 2006;60(1):199–203.
48. Fehlings MG, et al. Predictors of treatment outcomes in geriatric patients with odontoid fractures: AOSpine North America multi-centre prospective GOF study. Spine. 2013;38(11):881.
49. Chapman J, et al. The AOSpine North America Geriatric Odontoid Fracture Mortality Study: a retrospective review of mortality outcomes for operative versus nonoperative treatment of 322 patients with long-term follow-up. Spine. 2013;38(13):1098.
50. Andersson S, Rodrigues M, Olerud C. Odontoid fractures: high complication rate associated with anterior screw fixation in the elderly. Eur Spine J. 2000;9(1):56–9.
51. Levine AM, Edwards CC. The management of traumatic spondylolisthesis of the axis. J Bone Joint Surg (Am Vol). 1985;67(2):217–26.
52. Allen BL Jr, Ferguson RL, Lehmann TR, O'Brien RP. A mechanistic classification of closed, indirect fractures and dislocations of the lower cervical spine. Spine (Phila Pa 1976). 1982;7(1):1–27.
53. Harris JH Jr, Edeiken-Monroe B, Kopaniky DR. A practical classification of acute cervical spine injuries. Orthop Clin North Am. 1986;17(1):15–30.
54. Vaccaro AR, Hulbert RJ, Patel AA, Fisher C, Dvorak M, Lehman RA Jr, et al. The subaxial cervical spine injury classification system: a novel approach to recognize the importance of morphology, neurology, and integrity of the disco-ligamentous complex. Spine (Phila Pa 1976). 2007;32(21):2365–74.
55. Vaccaro AR, Koerner JD, Radcliff KE, Oner FC, Reinhold M, Schnake KJ, et al. AOSpine subaxial cervical spine injury classification system. Eur Spine J. 2016;25(7):2173–84.

56. Schneider RC, Kahn EA: The significance of the acute flexion or “tear-drop” fracture dislocation of the cervical spine. JBJS. 1956;38(5):985–97.
57. Como JJ, Diaz JJ, Dunham CM, Chiu WC, Duane TM, Capella JM, et al. Practice management guidelines for identification of cervical spine injuries following trauma: update from the eastern association for the surgery of trauma practice management guidelines committee. J Trauma. 2009;67(3):651–9.
58. Andreshak JL, Dekutoski MB. Management of unilateral facet dislocations: a review of the literature. Orthopedics. 1997;20(10):917–26.
59. Daffner SD, Daffner RH. Computed tomography diagnosis of facet dislocations: the “hamburger bun” and “reverse hamburger bun” signs. J Emerg Med. 2002;23(4):387–94.
60. Gomes S, Rudkin S, Tsai F, Lotfipour S. Bilateral cervical spine facet fracture-dislocation. West J Emerg Med. 2009;10(1):19.
61. Harrigan MR, Hadley MN, Dhall SS, Walters BC, Aarabi B, Gelb DE, et al. Management of vertebral artery injuries following non-penetrating cervical trauma. Neurosurgery. 2013;72(Suppl 2):234–43.
62. Nadeau M, McLachlin SD, Bailey SI, Gurr KR, Dunning CE, Bailey CS. A biomechanical assessment of soft-tissue damage in the cervical spine following a unilateral facet injury. J Bone Joint Surg Am. 2012;94(21):e156.
63. Rasoulinejad P, McLachlin SD, Bailey SI, Gurr KR, Bailey CS, Dunning CE. The importance of the posterior osteoligamentous complex to subaxial cervical spine stability in relation to a unilateral facet injury. Spine J. 2012;12(7):590–5.
64. Sonntag VK. Management of bilateral locked facets of the cervical spine. Neurosurgery. 1981;8(2):150–2.
65. Spector LR, Kim DH, Affonso J, Albert TJ, Hilibrand AS, Vaccaro AR. Use of computed tomography to predict failure of nonoperative treatment of unilateral facet fractures of the cervical spine. Spine (Phila Pa 1976). 2006;31(24):2827–35.
66. Kepler CK, Vaccaro AR, Chen E, Patel AA, Ahn H, Nassr A, et al. Treatment of isolated cervical facet fractures: a systematic review. J Neurosurg Spine. 2016;24(2):347–54.
67. Jack A, Hardy-St-Pierre G, Wilson M, Choy G, Fox R, Nataraj A. Anterior surgical fixation for cervical spine flexion-distraction injuries. World Neurosurg. 2017;101:365–71.
68. Kwon BK, Fisher CG, Boyd MC, Cobb J, Jebson H, Noonan V, et al. A prospective randomized controlled trial of anterior compared with posterior stabilization for unilateral facet injuries of the cervical spine. J Neurosurg Spine. 2007;7(1):1–12.
69. Gelb DE, Aarabi B, Dhall SS, Hurlbert RJ, Rozzelle CJ, Ryken TC, et al. Treatment of subaxial cervical spinal injuries. Neurosurgery. 2013;72(Suppl 2):187–94.
70. Fehlings MG, Vaccaro A, Wilson JR, Singh A, Cadotte DW, Harrop JS, et al. Early versus delayed decompression for traumatic cervical spinal cord injury: results of the Surgical Timing in Acute Spinal Cord Injury Study (STASCIS). PLoS One. 2012;7(2):e32037.
71. Gelb DE, Hadley MN, Aarabi B, Dhall SS, Hurlbert RJ, Rozzelle CJ, et al. Initial closed reduction of cervical spinal fracture-dislocation injuries. Neurosurgery. 2013;72(Suppl 2):73–83.

Chapter 37
Anterior Approach to the Lumbosacral Spine

Joseph C. Babrowicz Jr.

Introduction

Retroperitoneal exposure of the lumbosacral spine may be accomplished via an anterior approach, thus enabling anterior lumbar interbody fusion (ALIF). This approach to the lumbosacral spine represents a special and valuable skill for a surgeon. These operations require knowledge of vascular, general, and spine surgery anatomy and techniques. In most cases, these operations are accomplished by the joint efforts of a general or vascular surgeon working with a spine surgeon. The importance of this teamwork has been long recognized. Sacks, in a 1965 report of anterior lumbar interbody fusion of the lumbar spine, emphasized that "The best results are obtained by teamwork between an orthopedic and general surgeon." He went on to declare that "Undoubtedly the patients are benefitted by saving of time and the increased safety produced by this cooperation." [1]. It continues today that when done well, retroperitoneal exposure enhances the quality, efficiency, and safety of lumbosacral spinal interbody fusion.

Historical Perspective

Retroperitoneal approach to the lumbar spine appears to have been borne out of the need to treat tuberculous spondylitis of the lumbar spine and Pott's disease. Traditionally, Pott's disease of the lumbar spine was treated by immobilizing procedures designed to provide rest and relief of weight bearing on the diseased vertebra.

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J. R. O'Brien et al. (eds.), *The Resident's Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9_37

In 1933, Ito et al. reported 10 cases of a new radical operation for Pott's disease [2]. Extrapolating from abundant experience with retroperitoneal approach to the sympathetic chain for lower extremity revascularization, they hypothesized that "the vertebral column could be reached with remarkable ease." They went on to report 10 successful approaches to the lumbar spine for resection of diseased bone via a left pararectal incision and retroperitoneal dissection to the lumbar spine. They concluded that "For Pott's disease involving the lumbar vertebrae below and including the second, our pararectal incision with extraperitoneal approach is advantageous, in that the resection of the body is comparatively easy and danger of contamination of the peritoneum is obviated."

The earliest reports of ALIF were performed via transabdominal approach to the retroperitoneum as reported separately by Carpenter and Burns in 1932 and 1933, respectively [1]. According to Syed and Foley, in the 1980s, a simultaneous combined posterior and anterior approach to the lumbar spine was developed but quickly fell into disfavor due to the large incision and significant blood loss [3]. By 1991, Obenchain reported on the use of laparoscopy for lumbar discectomy [4]. Throughout the 1990s, laparoscopic-assisted ALIF was in favor. A report by Regan et al. in 1999 suggested that the laparoscopic approach offered shorter hospital stay and reduced blood loss with similar complication rates as open ALIF [5]. However, more recent studies suggest that there is a higher complication rate with the laparoscopic technique compared to mini-open retroperitoneal approach to the lumbar spine [5]. In 2002, Brau published his technique and results for 686 mini-open retroperitoneal approaches for ALIF [6]. Since then, Brau's techniques have been popularized and adopted as the mainstay of ALIF approaches.

Preoperative Evaluation

The need for teamwork for ALIF cannot be overemphasized. It is recommended that the access surgeon evaluate the patient in his or her office prior to the planned surgery. He or she should perform a full history and physical, as well as a review of pertinent imaging. The access surgeon's findings and any concerns should be discussed with the spine surgeon as an operative plan is finalized.

During the history and physical, certain key points should be assessed. These include patient age and general comorbidities. The advancing age of many patients will likely play a role in the future of ALIF surgery. Bae et al. portend a significant increase in the number of spinal fusion patients in the coming years [7]. Advances in anesthesia and critical care techniques have made it possible to offer ALIF to elderly patients with comorbidities.

Specific patient history questions relate mostly to prior abdominal, pelvic, or retroperitoneal surgery. Prior abdominal or pelvic surgery may be a factor in these cases, but rarely prohibits performing retroperitoneal exposure. Studies have shown that retroperitoneal exposure for lumbar interbody fusion can be safely accomplished in patients with prior surgery [8, 9]. In general, patients with prior sigmoid colon disease, such as diverticulitis, or resections can have the retroperitoneum exposed with little difficulty. Cesarean section and hysterectomy present little or no problem exposing the retroperitoneum as the approach starts more lateral to the scarring generally caused by these operations. The presence of a colostomy in the left lower quadrant presents a contraindication to retroperitoneal approach. This is not because the retroperitoneum cannot be accessed, but is more because of the considerable risk of infection presented by operating in proximity to a dirty source.

Certain prior operations may be absolute or relative contraindications to retroperitoneal exposure of the lumbosacral spine. Aortobifemoral bypass and undescended testicle surgery cause extensive scarring and fibrosis in the retroperitoneum. Retroperitoneal approach to the lumbar spine should be avoided in these patients. Intravascular stent placement, for instance, iliac artery stenting, causes inflammation around the outside of the vessel and may make retroperitoneal dissection more difficult.

The access surgeon must also be aware of prior mesh placement for abdominal wall repair or certain laparoscopic inguinal hernia repair techniques. While an incision may look midline on the abdominal wall, ventral hernia repair techniques often employ underlay or overlay mesh placement, such that the mesh product extends well lateral along the abdominal wall. These procedures cause scarring that may make entrance to the retroperitoneum difficult and should be considered relative contraindications to retroperitoneal approach. Rectus muscle harvest for procedures such as TRAM flap or DIEP flap breast reconstruction also tends to heavily scar the rectus sheath area.

Obesity may make the conduct of lumbar spine exposure more taxing and somewhat physically demanding for the access surgeon, but in and of itself is not prohibitive of successful lumbar spine exposure. Studies have found that ALIF can be successfully accomplished in the obese patient [8, 10]. For these cases, the access surgeon should anticipate additional time for the exposure as the cases tend to take longer.

During physical examination of potential ALIF patients, special attention should be paid to the following key points as well as the general physical findings for all surgery candidates. The presence and location of surgical scars on the abdominal wall should be noted. In general, it is preferable if the left lower quadrant has not been previously violated. A full arterial exam of the lower extremities is mandatory to verify that the patient has palpable pedal pulses. For one, a patient's claudication may be arterial or neurogenic in origin. If pedal pulses are not palpable it may be reasonable to send the patient for noninvasive vascular testing to determine if arterial insufficiency may be a contributing factor to their claudication. Second, it is essential to recognize any pulse changes that may occur due to vessel manipulation and retraction during the lumbar spine exposure. Preexisting leg edema should be noted. While infrequent, retroperitoneal exposure may disrupt lymphatic structures potentially leading to leg swelling.

Preoperative Imaging Evaluation

As with many types of surgery, key to successful and safe retroperitoneal lumbar spine exposure is a detailed review of preoperative imaging. This is another opportunity where teamwork between an access surgeon and spine surgeon cannot be overemphasized. Together, an access surgeon and spine surgeon should study the axial and sagittal views of a lumbar MRI side by side with scout line marking. The location of and morphology of the major vascular structures in relation to the lumbar disc levels should be noted.

At the L5-S1 disc level, the relationship of the left common iliac vein to the anterior portion of the disc should be noted. In an unfavorable situation, a more medial and possibly midline vein may require extensive mobilization and retraction to expose the underlying disc. When the vessels, in particular the left common iliac vein, are well lateral to the midline of the disc, a favorable situation, little or no manipulation of the vessels may be needed (Fig. 37.1). Regarding vessel morphology, a plump round vein in cross section is favorable. An oval or flat appearance to the vein as it crosses the disc suggests tethering or tension on the vein, thus presenting a challenge to mobilizing that vein. The presence of fat tissue between the vein and disc is beneficial. If there is no fat between the vein and the disc, the vein may be relatively adherent to the disc and thus difficult to mobilize.

Additional information gained from the lumbar MRI may include the presence of various anatomical anomalies. The possibility of left-sided vena cava or duplicate bilateral vena cava must be kept in mind. Transitional pelvic anatomy can be accompanied by aberrant venous anatomy. The location and number of iliolumbar veins can sometimes be seen on MRI. Pelvic kidney with associated vascular aberrations can occur and should be recognized preoperatively. Any of these anatomic variations could significantly negatively impact retroperitoneal exposure of the lumbosacral spine.

Plain anterior-posterior and lateral lumbar x-rays can be helpful. In particular, the relationship of the lumbar discs to the iliac crests is helpful for determining incision placement and extent. Also, it is crucial to recognize the angle of incidence of the L5-S1 disc. A steeply angled L5-S1 disc will require low placement of the skin incision so that a parallel approach may be made to the disc space. Finally, the presence of osteophytes and spondylolisthesis is best seen on plain films. Such changes can provoke inflammatory reaction anterior to the disc. The resulting rind of fibrotic tissue can adhere to the vessels often making them more difficult to mobilize.

Operative Considerations

For ALIF the patient is placed in the supine position. After the induction of general endotracheal anesthesia, a bump is placed under the sacrum to help reduce the downward angulation of the L5-S1 disc. The knees are raised on pillows such that the hips are flexed at least 30° which relaxes and allows more excursion of the iliac

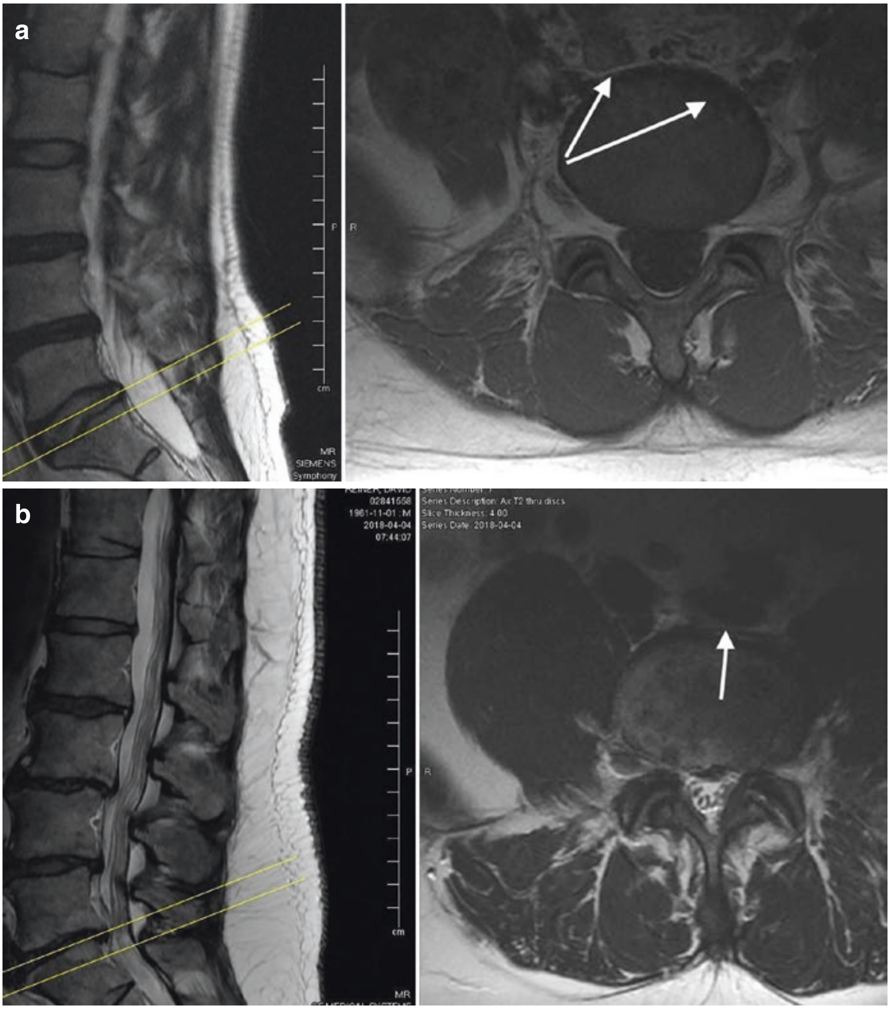

Fig. 37.1 (**a**) demonstrates favorable venous anatomy at the L5/S1 disc level with common iliac veins (white arrows) well lateral to the anterior portion of the disc. (**b**) demonstrates unfavorable venous anatomy at the L5/S1 disc level with a midline vein (white arrow) with minimal fat layer behind the vein

vessels and the psoas muscles. The abdomen and groins are prepped and draped widely to allow ample room for conversion to a larger incision if a vascular mishap occurs. Some programs place a pulse oximeter on the left great toe to monitor for decreased perfusion to the left leg as the left iliac vessels are retracted.

The use of a table-mounted retractor system is key to obtaining and maintaining clear and safe exposure of the lumbar spine. Several variations of these retractors exist. They can be wishbone configuration like the Thompson Surgical lumbar spine system or circular like the Globus and SynFrame systems.

Incision placement is dependent upon the lumbar level or levels to be fused. For single-level L5-S1 ALIF, the incision can be transverse (partial Pfannenstiel) or longitudinal in the left lower quadrant. For two or more levels, the incision should be longitudinal and paramedian on the left to allow more cranial-caudal exposure of the lumbar spine as needed. The location of the skin incision, whether transverse or longitudinal, is determined from the lateral lumbar plain x-ray. The level of the iliac crests in relation to the intended lumbar disc is noted. The crests normally align with the L4-L5 disc. At the time of surgery, the top of the iliac crests are palpated and then marked with a skin marker. A line is drawn from crest to crest, usually crossing the L4-L5 level. This line is then used to determine the position of the incision. For L5-S1 the incision is normally three fingerbreadths below the L4-L5 level. For steeply angled L5-S1 discs, the incision may need to be placed even lower than three fingerbreadths below the L4-L5 level. The intention is to approach the disc such that the surgical instruments enter parallel to the disc space. At higher disc levels, angulation is less of an issue and the incision should generally be centered over the appropriate level.

After the skin is incised, the subcutaneous tissues are divided with electrocautery down to the anterior rectus sheath. The anterior rectus sheath is opened along the length of the wound with electrocautery. The rectus muscle is then encountered. For single-level L5-S1 discectomy via a transverse incision, the rectus muscle is mobilized and retracted medially. Raising flaps of the anterior rectus sheath cranially and caudally by dividing small perforator vessels exiting the rectus muscle will allow easier mobilization of the rectus muscle. If the incision is well placed and low enough, once the rectus muscle is retracted, one should be caudal to the arcuate line (*linea semicircularis*) of the posterior rectus sheath. Thin fibers of the transversalis fascia will be directly over the peritoneum at this position. The retroperitoneum can be easily entered by blunt dissection in the lateral recess of the exposure. An endoscopic Kittner dissector may be helpful for this part of the dissection.

For L4-L5 disc or higher levels, the posterior rectus sheath is deep to the rectus muscle. When encountered, sharp incision of the posterior rectus sheath down to the peritoneum is necessary. Adequate length of the transversalis should be opened longitudinally as it can restrict retraction and deeper exposure if not adequately divided. If multiple disc levels are being addressed through a longitudinal incision, the rectus muscle should be retracted from medial to lateral to preserve innervation of the muscle that comes from the laterally based T7 to T11 thoracoabdominal nerves.

Entry into the retroperitoneum is usually confirmed when yellow retroperitoneal fat is encountered. The peritoneum is mobilized by further blunt dissection, often aided by use of endoscopic Kittner dissectors. Care is taken to bring the left ureter along with the peritoneum. The left psoas muscle is identified and followed medially. At the medial edge of the psoas, the left iliac vessels are identified and the arterial pulse can be palpated. To approach the L5-S1 disc, the soft tissues are mobilized and retracted superiorly and to the right from within the region of the aortic bifurcation and proximal iliac vessels. The proper disc level is then verified by means of a lateral lumbar x-ray. The median sacral artery and vein, normally coursing anterior to the L5/S1 disc, should be ligated and divided with bipolar cautery, surgical clips, or suture material. In most L5-S1 cases, it will be necessary to mobilize the medial edge of the left common iliac vein. This should be done by dividing the adventitial attachments between the vein and disc with bipolar cautery in a longitudinal fashion. Dissection in this region should be done with bipolar cautery in a longitudinal direction, in an attempt to limit damage to the sympathetic chain and the superior hypogastric plexus. Injury to the sympathetic chain can result in a "warm" ipsilateral leg, thus raising concern for a "cool" contralateral leg. Superior hypogastric plexus injury may result in retrograde ejaculation in men. After the adventitial attachments are divided, the vein can be mobilized bluntly with endoscopic Kittner dissectors. If there is an inflammatory rind anterior to the disc, bipolar cautery in the midline over the disc is performed until the striated shiny fibers of the disc are identified. Once under the edge of the rind, the inflammatory tissue along with the vein is mobilized and retracted. Attempting to dissect the vein free from the inflammatory tissue increases the risk of a venous injury.

Approach to the L4-L5 level and higher is done to the left side of the aorta. The psoas muscle is followed medially to the spine and the left margin of the large vessels. In order to provide adequate retraction of the left common iliac vein during exposure of L4-L5, it is highly suggested to prophylactically identify and divide the iliolumbar vein or veins. If the left iliac vein cannot be adequately mobilized and retracted, it may be safer to leave the vein visible in the field. A tethered vein that has been effaced to the disc tissue by retraction may not be visible and is at increased risk for injury.

Even with today's excellent retractor systems, it is necessary to reposition the blades as each disc level is addressed. Care should be taken to avoid vessel injury anytime the retractors are positioned or repositioned.

Upon completion of the discectomy and instrumentation for fusion, the retroperitoneum is explored and checked for hemostasis. The vessels are palpated to ensure that they remain pliable and that the artery continues to pulsate. One should consider breaking scrub to verify that there has not been a change in the lower extremity pulse exam. The peritoneum and contents are returned to the left retroperitoneal space and the abdominal incision is closed in layers.

Outcomes and Complications

One of the largest series of mini-open approaches for ALIF was reported by Salvador Brau in 2000 [6]. Six hundred and eighty-six approaches were performed in 684 patients over a two-and-a-half year period ending in December 2000. Of these cases, the majority ($n = 563$) were single-level L5-S1, single-level L4-L5, or both L4-L5 and L5-S1. The remaining cases included L3-L4 and were often multiple-level procedures. The average time of exposure ranged from 18.7 minutes for a single-level L5-S1 to 38.4 minutes for L4 to S1. In this series only four procedures were aborted. One case was aborted after thrombectomy of a thrombosed iliac artery. Two cases were aborted in obese patients when venous bleeding was encountered and there was difficulty mobilizing the aorta during exposure of L2-L3. The fourth patient suffered significant bleeding from a left common iliac vein injury and developed shock and a myocardial infarction despite aggressive resuscitation. He was later found to have preexisting coronary artery disease. All of these patients made full recoveries. One patient went into cardiogenic shock immediately after surgery, resulting in the single mortality of the series.

Overall rates were low for all other complications in Brau's series [6]. Arterial thrombosis or major venous injury each occurred in six patients (0.8%). DVT occurred in 7 patients (1.0%), while retrograde ejaculation happened for 1 out of 345 male patients (0.28%). Ileus requiring nasogastric tube drainage lasting 3 days occurred in six patients (0.8%).

More contemporary reports continue to show that ALIF can be done safely with relatively low complication rates. Garg et al. investigated vascular complications during ALIF performed by a vascular surgeon and spine surgeon in 212 patients [11]. The major findings of the study were that there was a significant correlation between increasing BMI and estimated blood loss. However, overall the mean blood loss for all cases was only 143 milliliters. Thirteen (6.1%) of patients had vascular injuries, about two-fifths of which were considered major requiring multiple suture repair. Only one of the major vascular injuries was arterial. There was an increased risk of vascular injury when bilevel exposures at L4/L5 and L5/S1 were performed. In conclusion, Garg states that "ALIF can be performed safely with a team approach that includes a vascular surgeon."

The effects of prior surgery and obesity on ALIF exposure have been studied. In general, neither prior surgery nor obesity need be considered an absolute contraindication to ALIF approach. Mogannam et al. noted 23.3% vascular injury rate (3.8% major) in 476 patients undergoing ALIF [8]. Prior abdominal surgery had no effect on time to exposure, vascular injury, and perioperative complications. These investigators did find that BMI of 30 or greater and exposures involving L4-L5 independently increased the risk of vascular injury (30.8% vs 19.7%, $P = 0.007$ and 29.7% vs 13.1%, $P < 0.001$, respectively). They conclude that "caution is warranted in obese patients and exposures of L4-5."

References

1. Sacks S. Anterior interbody fusion of the lumbar spine. J Bone Joint Surg. 1965;47B(2):211–22.
2. Ito H, Tsuchiya J, Asami G. A new radical operation for pott's disease: report of ten cases. J Bone Joint Surg. 1934;16(3):499–515.
3. Syed O, Foley K. History and evolution of minimally invasive spine surgery. In: Phillips F, Lieberman I, Polly D, editors. Minimally invasive spine surgery. New York: Springer; 2014.
4. Obenchain TG. Laparoscopic lumbar discectomy: case report. J Laparoendosc Surg. 1991;1(3):145–9.
5. Thongtrangan I, Le H, Park J, Kim D. Minimally invasive spine surgery: a historical perspective. Neurosurg Focus. 2004;16(1):1–9.
6. Brau S. Mini-open approach to the spine for anterior lumbar interbody fusion: description of the procedure, results and complications. Spine J. 2002;2:216–23.

7. Bae H, Rajaee S, Kanim L. Nationwide trends in the surgical management of lumbar spine stenosis. Spine. 2013;38(11):916–26.
8. Mogannam A, Bianchi C, Chiriano J, Patel S, Teruya T, Sharon L, Abou-Zamzam A Jr. Effects of prior abdominal surgery, obesity, and lumbar spine level on anterior retroperitoneal exposure of the lumbar spine. Arch Surg. 2012;147(12):1130–4.
9. Smith M, Rahn K, Shugart R, Belschner C, Stout K, Cheng I. Comparison of perioperative parameters and complications observed in the anterior exposure of the lumbar spine by a spine surgeon with and without the assistance of an access surgeon. Spine J. 2011;11:389–94.
10. Lucas F, Emery E, Dudoit T, Berger L. Influence of obesity on access-related complications during anterior lumbar spine interbody fusion. World Neurosurg. 2016;92:229–33. https://doi.org/10.1016/j.wneu.2015.12.104.
11. Garg J, Woo K, Hirsch J, Bruffey J, Dilley R. Vascular complications of exposure for anterior lumbar interbody fusion. J Vasc Surg. 2010;51:946–50.

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J. R. O’Brien et al. (eds.), *The Resident’s Guide to Spine Surgery*,
https://doi.org/10.1007/978-3-030-20847-9