2.2 Posterior foraminotomy

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1 Historical perspective

Anterior cervical decompression and fusion (ACDF) has remained the standard surgical procedure for the management of cervical disc herniations since its description by Smith and Robinson in 1958 [1]. This surgical approach was popularized by Cloward for discectomy [2]. The anterior approach facilitates wide access to the spinal cord and bilateral nerve roots through the extensive removal of disc material, which is then replaced by an artificial disc or a fusion device with graft material.

In 1951, Frykholm [3] described the surgical anatomy of the cervical spine, with particular emphasis on the corresponding nerve roots, and provided a detailed account of the dorsal foraminotomy approach. This technique avoids the risk of certain previously reported complications associated with an anterior approach, such as vascular injury, esophageal injury, dysphagia, dyspnea, injury to the recurrent laryngeal nerve, and adjacent segment disease following fusion. With the posterior approach, the preservation of mobility associated with minimal osseous resection is counterbalanced against the risk of postoperative neck pain or spasm. This risk is a consequence of the surgical access required for the foraminotomy, however, the use of a minimally invasive surgical approach may reduce the incidence of postoperative events.

2 Terminology

This chapter focuses on the minimally invasive surgical approach for posterior foraminotomy (MIS-PF), which typically includes surgery performed via microscopic or microendoscopic magnification using tubular retractor systems. This approach was first described by Adamson et al [4] in 2001 and Fessler and Khoo [5] in 2002 using the endoscope, and by Holly et al [6] and Hilton [7] in 2007 using the microscope through tubular retractors. Mention should also be made of alternative approaches, such as microendoscopic foraminotomy, lateral foraminotomy, and transcorporeal foraminotomy, but these will not be discussed in further detail in this chapter.

3 Patient selection

The primary aim of MIS-PF is the foraminal decompression of a cervical nerve. Therefore, the best outcome is achieved for lateral or intraforaminal monosegmental and monolateral radicular pathologies. However, bi- and multisegmental as well as bilateral pathologies can also be treated by this approach.

3.1 Indications

- Cervical radiculopathy refractory to nonoperative management
- Single-level disease with a lateral osteophyte or lateral soft disc herniation causing radiculopathy
- Multilevel disease with radicular pain syndromes
- Bilateral radiculopathy
- Calcified disc herniation.

3.2 Contraindications

- Presence of symptomatic myelopathy in addition to radiculopathy
- Central disc herniation
- Preexisting instability of the cervical spine possibly requiring additional stabilization (relative contraindication)
- Presence of a kyphotic deformity at the approach level (relative contraindication)
- Patients with significant mechanical neck pain could experience exacerbation of their symptoms with the posterior approach, and it may be preferable for them to be treated by anterior stabilization.

4 Pros and cons of posterior foraminotomy

The major advantage of a posterior foraminotomy is that it affords minimally invasive segmental exposure of the target region and the corresponding pathology without the need for additional stabilization (ie, fusion procedures, arthroplasty, etc).

4.1 Pros

- Minimal tissue dissection and reduced morbidity
- Direct visualization of the foramen, allowing accurate assessment of the decompression
- Maintained motion segment
- Comparable outcomes to those for open surgery, with clinical improvement in 90% of cases [8]
- Shorter inpatient stay, with increased cost-effectiveness [5]
- More rapid functional recovery and return to work [9]
- Can be carried out the level adjacent to a fusion or disc arthroplasty (see topic 11 Case example in this chapter).

4.2 Cons

- Not indicated for central disc herniation
- Does not address problems of instability or deformity
- Bilateral surgery and multilevel surgery can both be performed, but these are more complex procedures
- Delayed postoperative instability may develop, requiring further surgery.

5 Preoperative planning and positioning

Preoperative imaging studies comprising MRI and/or CT scans must be undertaken to determine both the localization and suitability of a posterior foraminotomy. Additionally, information should also be obtained on the anatomical relationship or any abnormalities of the vertebral artery, the calcification of disc herniations, and the degree of facetal hypertrophy contributing to the foraminal narrowing. It is essential for these findings to be in agreement with the clinical examination, and electromyogram (EMG) if appropriate. Plain x-ray studies, in addition to lateral flexion and extension lateral views, permit an accurate assessment of instability both at the initial stage and at follow-up.

Shaving of the surgical area is recommended. Further specific patient preparation is not required.

The positioning of the patient depends on the preference of the surgeon and anesthetist, and may either be sitting or prone. Preference is given to general endotracheal anesthesia, in order to secure the airway. The sitting position can improve visualization by minimizing blood loss from the epidural venous plexus and facilitating blood drainage from the surgical field, but involves the increased risk of venous air embolism [10, 11]. However, the prone position is more anatomically familiar and may be preferred, in which case the head should be elevated at a 30° angle to reduce central venous pressure. The head can be held securely in a Mayfield skull clamp or in a horseshoe headrest. Soft padding of the shoulders, lateral chest, and iliac crest/pelvis is performed. Thoracic and abdominal compression should be avoided. Slight flexion of the neck facilitates the skin incision and surgical access; extreme flexion, however, has to be avoided in order to prevent possible anterior compression myelopathy from bony spurs, etc. Mild traction of the arms using tapes could assist in the pre- and intraoperative x-ray identification of the target area, especially when exposing the lower cervical spine or cervicothoracic junction. Intraoperative imaging for determination of the correct target segment and operative magnification for intraforaminal surgery must be ensured. Care should be taken that the anesthesiologist has free access to the endotracheal tube and to all the relevant equipment.

6 Surgical technique

The correct level is determined with a preoperative lateral x-ray to minimize extraneous soft tissue involvement. For minimally invasive surgery with conventional retractors, a midline incision is made with dissection extended to expose the lateral lamina and medial aspect of the facet joint in addition to the lateral mass cranially and caudally. For surgery involving tubular retractors, a paramedian incision is made on the side intended for treatment (Fig 2.2-1). Guide wires should not be used, due to the risk of accidental injury to the spinal cord, nerves, or vascular structures. Instead, the fascia is opened sharply and a blunt dilator is advanced under image intensifier guidance towards the lateral mass at the indicated level. Sequential dilators and a final tubular retractor are inserted and fixed in position. The authors tend to make a more generous incision and fascial opening when compared, for example, to the opening made in the lumbar spine, in order to facilitate dissection through the tense fascia and muscle down to the lamina.

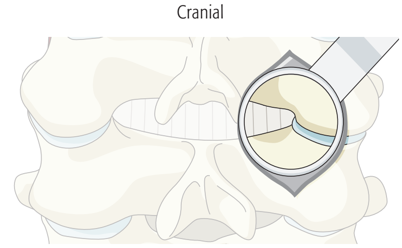

Fig 2.2-1 Surgical approach for tubular retractor.

Magnification with either a microscope or a surgical loupe is required. Partial removal of the hemilamina and medial aspect of the facet is facilitated by a high-speed burr. With care taken to preserve the lateral half of the joint, the bone should be thinned down to its inner plate and then removed with a 1 mm Kerrison punch, or "flicked off" with a 3-O curette [12] (**Fig 2.2-2**). Anatomical studies have shown that a 50% facetectomy exposes approximately 3–5 mm of the nerve root without compromising stability, while the removal of 70% of the facet joint exposes up to 10 mm of nerve root, but is also associated with a higher risk of mechanical failure [13–16].

The pedicle above and below should be palpable with a nerve hook. The nerve should be exposed with care as it remains compressed in the foraminal canal. The ligamentum flavum should be opened, medial to the decompression at its laminar portion, and careful use of bipolar diathermy at this stage will minimize bleeding from the venous plexus. This procedure may be undertaken with a nerve hook, or by incision under direct visualization (**Fig 2.2-3**). Use of the diathermy device with the tips enclosing the ligamentum flavum and venous plexus protect the nerve root at this point, and following cauterization, sharp dissection can be performed to reveal the lateral dura and nerve root.

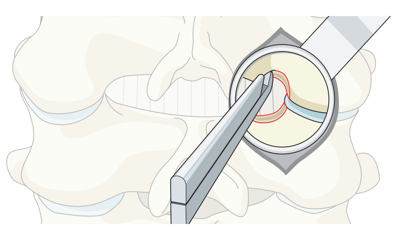

Fig 2.2-2 Removal of the thinned-out hemilamina utilizing a Kerrison punch.

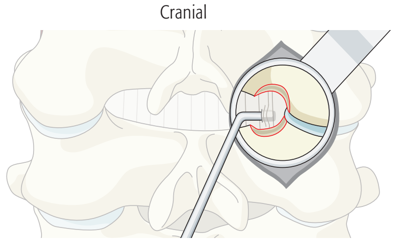

Fig 2.2-3 The ligamentum flavum may be divided over a nerve hook under direct visualization.

The pedicle above and below should be palpable with a nerve hook (**Fig 2.2-4**). If the indication for surgery is a soft disc herniation, it is now necessary to find the disc and perform a partial discectomy. The nerve must be retracted cranially (**Fig 2.2-4**)—both the motor and sensory portions that might be present in separate dural sheaths—with care not to mobilize the cord itself. Identification of the ruptured annulus fibrosus with the detection of extruded fragments may be possible, otherwise, a micro-blade may be used to incise the posterior longitudinal ligament, following which the disc material is removed with a micro-pituitary rongeur. Sometimes an extruded disc fragment can also be found cranial to the nerve root.

Hemostasis is ensured with the use of bipolar diathermy as required, and an antibiotic wash is undertaken prior to removal of the retractors. The muscle is carefully inspected and bleeding is controlled with bipolar coagulation. The fascia is then closed in a watertight fashion, and the skin is closed up in the usual manner.

The use of computer-assisted surgical navigation in MIS-PF has not been reported to date; image intensification and direct visual observation are the standard means of visualizing the surgical field. Instrumentation is not required for this type of surgery, unless there is significant destabilization of the joint with more than 70% facetectomy [15, 16].

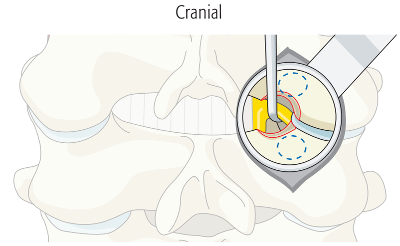

Fig 2.2-4 Cranial retraction of the nerve root. The pedicle above and below should be palpable with a nerve hook. The position of the pedicles is indicated.

7 Postoperative care

Most patients can be discharged and sent home within 24 hours, with the expectation of surgical-site pain and muscle spasms during the immediate postoperative period. Wound inspection is performed at dressing changes, with care being taken to exclude the presence of infection. Standard antiinflammatory medication and analgesics are routinely prescribed, but if required, muscle relaxants or opioid treatment for pain control may be administered. Rapid mobilization is encouraged, and physical therapy may be initiated once the wound has healed in cases where more extensive surgical intervention is required. The use of a soft collar is optional and depends on the surgeon's preference, but is not part of the present authors' routine. No further follow-up imaging is generally required. Return to work is as individually tolerated, but is usually rapid.

8 Evidence-based results

There is no high-grade evidence reported in the literature on MIS-PF. The majority of studies include retrospective case series, or compare anterior to posterior procedures rather than minimally invasive to open procedures. Generally, these studies note a resolution of symptoms in around 90% of cases, with a low rate of neurological injury, further disc degeneration, or instability [7, 17–19]. A systematic review sponsored by the American Association of Neurological Surgeons/Congress of Neurological Surgeons [20], which included data up to 2007, concluded that only Class III evidence was available in support of posterior laminoforaminotomy for the treatment of cervical radiculopathy resulting from soft lateral cervical disc displacement or cervical spondylosis with resulting narrowing of the lateral recess. The most relevant papers included a review carried out in 1983 of 846 posterior foraminotomy cases in which 92% of patients rated their outcome as good or excellent [21], and a 2006 study of 292 posterior foraminotomy patients with a mean 6-year follow-up, and good or excellent outcomes in 85% of cases [22].

As far as ACDF versus MIS-PF is concerned, a recent study on early in-hospital outcomes found improved clinical outcome for the ACDF procedure versus MIS-PF, however, this was a retrospective study and no later outcomes were reported [23]. A retrospective review of 38 cases in which patients underwent either ACDF or MIS-PF for unilateral cervical radiculopathy showed an overall cost benefit for posterior surgery, shorter length of hospital stay, earlier return to work—with no differences in blood loss or surgery times [9]. A retrospective study from Germany [22] comparing anterior discectomy with polymethylmethacrylate (PMMA) interbody stabilization to posterior cervical foraminotomy in a total of 292 patients concluded that the overall clinical success rate based on the Odom scale was higher in the anterior surgery group, but that the complication rates were also higher (96.6% versus 85.0% and 6.5% versus 1.8%, respectively).

Recent studies [8, 24, 25] have reported little difference between MIS-PF and open posterior surgery in terms of duration of hospitalization, outcome, or complications. Kim and Kim's study [18] is the only reported randomized clinical trial comparing open to MIS-PF. In 41 patients randomized to either an open or tubular retractor approach, the only significant differences in outcomes were related to incision length, duration of hospital stay, and initial analgesic use, which favored the tubular retractor approach, but no medium- or long-term differences were observed, although this may have been due to the low power of this study. The largest study included a 5-year follow-up [26], and reported on 162 patients that underwent MIS-PF. In these patients, the Neck Disability Index improved in 93% of cases, and 95% of patients experienced improvement in their radiculopathy. Three percent of patients underwent additional cervical spine surgery, with one patient requiring posterior stabilization. The authors found that age > 60 years, previous posterior surgery, and < 10° of lordosis preoperatively were predictive of delayed sagittal misalignment, and close follow-up of these at-risk patients was recommended. These findings reflect the previous results of a long-term study investigating same-segment and adjacent-segment disease after posterior cervical foraminotomy [27], in which a 6.7% rate of symptomatic adjacent-segment disease and a 5.0% rate of same-segment disease at 10 years was reported. Treatment of multilevel disease has also been reported, with no perioperative complications encountered. During the 2-year follow-up period, the complete resolution of symptoms was achieved in 90% of patients [6].

9 Complications and avoidance

The complications associated with MIS-PF are primarily related to surgical error. One of the major challenges can be the accurate localization of the correct surgical level in the lower cervical spine. The sitting position may offer advantages in this respect. However, taping the patient's shoulders and the use of intraoperative image intensification can facilitate localization of the correct level with the patient in the prone position.

Injury to the nerve root can occur as a result of it being mistaken for a disc (especially in cases of duplicated nerve roots), or due to the insertion of surgical instruments that compress the nerve within the stenotic foramen. To avoid these risks, utmost care must be taken to fully visualize the nerve and decompress it, with an accompanying awareness that the nerve may be divided into separate branches, which could inadvertently be mistaken for disc material.

Patients with calcified discs or disc/osteophytes may not be ideal candidates for this approach as extensive retraction of the neural elements is required to remove the osteophytes. Simple decompression without an attempt of removing the osteophyte may be preferable.

Incidental durotomy can generally be managed by tamponade with dural sealant materials, but persistent leakage may require a lumbar drain, when required, in conjunction with a direct repair.

Careful use of bipolar diathermy, both to minimize excessive bleeding from the venous plexus and to avoid neural injury, is an important consideration. The high-speed burr may cause local thermal injury, and careful irrigation must be ensured, particularly when the patient is in the sitting position.

Air embolism constitutes a serious complication in the sitting position, therefore, vigilant intraoperative monitoring and careful surgical techniques are essential in this regard. Intraoperative Doppler cardiac monitoring may be considered.

Postoperative instability is limited by rigorous preoperative patient selection, avoidance of bilateral surgery and careful preservation of the lateral aspect of the facet joint. Patients with a straight or kyphotic spine may be better treated via an anterior approach and/or fusion. The authors aim to resect up to 50% of the joint, as resection greater than this may lead to fracture and instability [15, 16].

Vertebral artery injury may manifest as significant intraoperative hemorrhaging, either as a consequence of a dissection that has been extended too far laterally or due to an abnormal or aneurysmal artery. Films should be carefully reviewed at the preoperative stage in order to detect any anatomical abnormalities of the vertebral artery.

New onset symptoms or recurrence of radiculopathy should be worked up aggressively, as they may be indicative of nerve injury or the presence of a postoperative epidural abscess. Chronic regional pain syndrome associated with MIS-PF has recently been reported [28].

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10 Tips and tricks

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- Even if more than 50% of the facet is removed, it is unlikely that instability will develop because the midline structures and the opposite facets are intact.
- It often is necessary to remove part of the pedicle to decompress the nerve root. This can be done under magnification by drilling into the pedicle with a high-speed diamond drill and then cracking the inferior wall of the pedicle with a microcurette.
- After a soft-disc herniation has been removed, extensive venous bleeding can occur. Such bleeding is normal and can usually be contained by the use of hemostatic agents.
- To expose the interspace, it is preferable to retract the root rostral and remove the disc or drill down the osteophyte in the axilla between the nerve root and the dural sac. Occasionally, depending on the site of the abnormality, the nerve root has to be retracted caudally.
- If the operation is performed to treat a hard-disc herniation, the surgeon must judge whether only a decompression is indicated, or whether removal of the bone spurs should also be considered. If the latter is pursued, it should be done under magnification using the diamond-drill bit.
- Intraoperative imaging should be performed as close as possible to the interspace. The surgeon should not be misled by the oblique facets or abnormal osteophytes.
- After posterior foraminotomy and discectomy, an external orthosis is unnecessary.
- The posterior-motor portion can have its own dural sheath and be mistaken for herniated disc material. The application of electrical stimulation and performing the operation under magnification will help the surgeon to differentiate disc material from the nerve root.
- Use of the posterior approach avoids complications associated with anterior surgery, such as dysphagia and dysphonia.
- This operation can be performed with the patient in the sitting or prone position. The sitting position reduces bleeding, but increases the risk of air embolism. Conversely, the prone position reduces the risk of air embolism but increases the chances of bleeding.
- This operation can be performed with the surgical microscope or loupe magnification. This author prefers the microscope because the assistant has a clearer view, and the magnification and lighting are better.

11 Case example

A 42-year-old man presented with neck pain and right C6 and C7 radiculopathy with biceps and triceps weakness. No other symptoms were present, and the patient was unresponsive to nonsurgical treatment. Preoperative MRI showed a broad disc herniation at C5/6, causing spinal cord compression; in addition, a lateral disc herniation at C6/7 was apparent on the right side, with an osteophyte arising from the uncovertebral joint (**Fig 2.2-5**). The surgical technique consisted of an anterior discectomy at C5/6 with a cervical disc arthroplasty, followed by minimally invasive C6/7 posterior foraminotomy. The surgical procedure was uneventful, and postoperatively the patient experienced excellent symptomatic relief from the radiculopathy (**Fig 2.2-6**, **Fig 2.2-7**).

12 Key learning points

- Single-level radiculopathy associated with soft lateral disc herniation is most appropriately treated via posterior cervical foraminotomy. Osteophytes can be removed in this manner, but care must be taken to avoid irritation of the nerve root during surgery (**Fig 2.2-8**)
- Patients should be carefully selected. Mechanical neck pain, deformity, central disc herniation, and symptomatic myelopathy are contraindications for this type of surgery, and may respond better to anterior decompression with or without stabilization
- Postoperative instability is an uncommon occurrence in appropriately selected patients, and most surgeons recommend removing less than 50% of the facet joint.

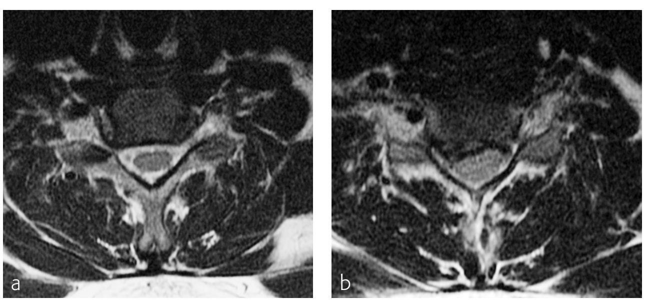

Fig 2.2-5a–b
a Preoperative axial T2 MRI at C6/7 showing right foraminal narrowing.
b MRI of the level C5/6 showing large disc herniation with spinal cord compression.

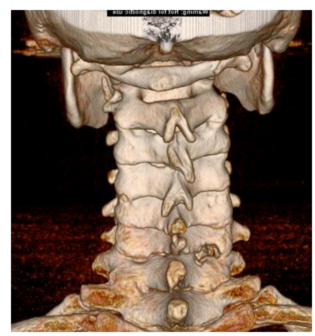

Fig 2.2-7 CT scan reconstruction demonstrating right-sided C6/7 foraminotomy.

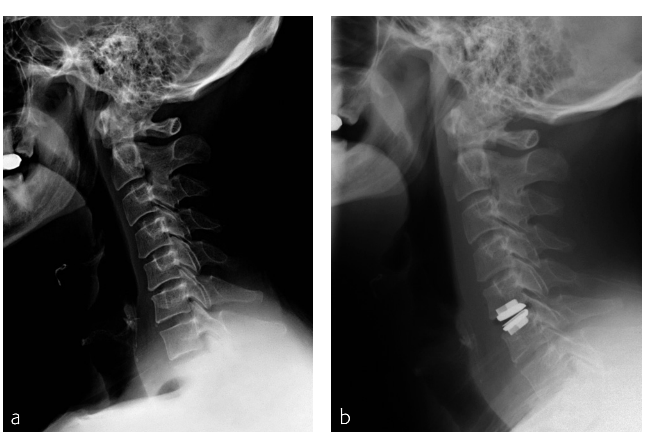

Fig 2.2-6a–b Preoperative (**a**) and postoperative (**b**) lateral x-rays. Foraminotomy was performed at C6/7 below the cervical disc arthroplasty at C5/6.

Fig 2.2-8 Foraminal compression due to lateral osteophyte causing monoradiculopathy. This nerve can be decompressed via a posterior cervical foraminotomy. Care must be taken to mechanically minimize irritation of the nerve during microsurgery.

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14 Evidence-based summaries

Kim KT, Kim YB (2009) Comparison between open procedure and tubular retractor assisted procedure for cervical radiculopathy: results of a randomized controlled study. *J Korean Med Sci;* 24(4):649–653.

Study type	Study design	Class of evidence
Therapy	Randomized controlled trial	II

Purpose

To compare the clinical parameters and surgical outcomes of open foraminotomy/discectomy and tubular-retractor assisted foraminotomy/discectomy in the treatment of cervical radiculopathy.

P	Patient	Cervical radiculopathy (N = 41)
I	Intervention	Tubular-retractor assisted foraminotomy/discectomy (group 2, n = 22)
C	Comparison	Open foraminotomy/discectomy (group 1, n = 19)
O	Outcome	Clinical parameters, surgical outcomes

Authors' conclusion

Tubular-retractor assisted foraminotomy/discectomy is as clinically effective as the open foraminotomy/discectomy.

Korinth MC, Krüger A, Oertel MF, et al (2006) Posterior foraminotomy or anterior discectomy with polymethyl methacrylate interbody stabilization for cervical soft disc disease: results in 292 patients with monoradiculopathy. *Spine;* 31(11):1207–1214; discussion 15–16.

Study type	Study design	Class of evidence
Therapy	Cohort	III

Purpose

To evaluate the long-term outcome after two different surgical procedures in the treatment of cervical radiculopathy, compare them with each other and with previous data from other surgical techniques, and outline the indications, advantages, and disadvantages of each procedure.

P	Patient	Cervical radiculopathy (N = 292)
I	Intervention	Ventral microdiscectomy and PMMA stabilization (n = 124) (group A)
C	Comparison	Posterior foraminotomy (n = 168) (group B)
O	Outcome	Success rate, complications

Authors' conclusion

A higher success rate appears to result after anterior microdiscectomy with PMMA interbody stabilization for treatment of degenerative cervical monoradiculopathy than after posterior foraminotomy. Although statistically significant differences in clinical data were found in both groups, both approaches seem to have equivalent value in individual indications.

Schebesch KM, Albert R, Schödel P, et al (2011) A single neurosurgical center's experience of the resolution of cervical radiculopathy after dorsal foraminotomy and ventral discectomy. *J Clin Neurosci;* 18(8):1090–1092.

Study type	Study design	Class of evidence
Therapy	Retrospective cohort study	III

Purpose

To evaluate the neurological outcomes after surgical treatment with dorsal foraminotomy and sequestrectomy (Frykholm's method), or ventral discectomy and intervertebral cage (modified Cloward's method).

P	Patient	Cervical radiculopathy (N = 100)
I	Intervention	Ventral discectomy and intervertebral cage (Cloward group, n = 49)
C	Comparison	Dorsal foraminotomy and sequestrectomy (Frykholm group, n = 51)
O	Outcome	Neurological outcomes

Authors' conclusion

Complete removal of the affected cervical disc via a ventral approach and segmental fusion results in a superior neurological performance in the short-term compared to a dorsal foraminotomy and nerve root decompression by sequestrectomy.

Tumialán LM, Ponton RP, Gluf WM (2010) Management of unilateral cervical radiculopathy in the military: the cost effectiveness of posterior cervical foraminotomy compared with anterior cervical discectomy and fusion. *Neurosurg Focus;* 28(5):E17.

Study type	Study design	Class of evidence
Therapy	Retrospective cohort study	III

Purpose

To identify the difference in time to return to active duty between a posterior cervical foraminotomy (PCF) and anterior cervical discectomy and fusion (ACDF) in military personnel and to examine the cost effectiveness and clinical outcomes in those patients.

P	Patient	Unilateral cervical radiculopathy (N = 38)
I	Intervention	PCF (n = 19)
C	Comparison	ACDF (n = 19)
O	Outcome	Time to return to active duty, cost effectiveness, clinical outcomes

Authors' conclusion

In the management of unilateral posterior cervical radiculopathy for military active-duty personnel, PCF offers a benefit relative to ACDF in immediate short-term direct and long-term indirect costs. The indirect cost of time away from duty was the more significant contributor to difference in cost effectiveness.

Winder MJ, Thomas KC (2011) Minimally invasive versus open approach for cervical laminoforaminotomy. *Can J Neurol Sci;* 38(2):262–267.

Study type	Study design	Class of evidence
Therapy	Retrospective cohort study	III

Purpose

To determine any appreciable differences between the use of microscopic tubular assisted posterior foraminotomies (MTPF) compared with traditional open foraminotomies and to compare results of MTPF with the reported results of microendoscopic posterior foraminotomies.

P	Patient	Cervical radiculopathy (N = 107)
I	Intervention	MTPF (n = 42)
C	Comparison	Traditional open laminoforaminotomy (n = 65)
O	Outcome	Clinical parameters, surgical outcomes

Authors' conclusion

The results suggest that MTPF is comparable to endoscopic posterior foraminotomy and enables shorter hospital stays, while minimizing analgesic requirements, with similar complication rates when compared to open procedures performed.

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