Review Article on Advanced Techniques in Complex Cervical Spine Surgery

Comparison of outcomes following minimally invasive and open posterior cervical foraminotomy: description of minimally invasive technique and review of literature

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Abstract: Although minimally invasive posterior cervical foraminotomy (MIS-PCF) is frequently employed in the treatment of cervical radiculopathy, there are very few studies directly comparing outcomes between MIS-PCF and open posterior cervical foraminotomy and between MIS-PCF and percutaneous endoscopic (full-endoscopic) posterior cervical foraminotomy (FE-PCF). This study includes a description of technique and systematic review of literature and analysis of clinical studies comparing outcomes between MIS-PCF and open posterior cervical foraminotomy and between MIS-PCF and FE-PCF. Six comparative studies, including one randomized controlled trial were included in analysis. Average operative time ranged from 60.5 to 171 minutes in the open group and 77.65 to 115 minutes in the MIS group. Mean intraoperative blood loss ranged from 43.5 to 246 cc in the open group and 42 to 138 cc in the MIS group. Average postoperative length of stay ranged from 58.6 to 304.8 hours in the open group and 20 to 273.6 hours in the MIS group. Two studies reported significantly increased VAS-N (Neck) scores postoperatively in patients undergoing open cervical foraminotomies, however both studies reported that the differences lost statistical significance with longer follow-up. There were no significant differences in complications or reoperations between open and MIS groups. One retrospective cohort study was included in analysis that compared MIS-PCF and FE-PCF. Postoperatively at 24 months, mean NDI and VAS-N were significantly lower after FE-PCF than MIS-PCF. There was no significant change in VAS-A (Arm) between the two groups. Direct comparative studies between MIS-PCF and open cervical foraminotomy are limited in number. Although, there is a significant heterogeneity in studies comparing open and MIS-PCF there appears to be a trend of decreased hospital length of stay and postoperative analgesic usage in the minimally invasive cohort.

Keywords: Cervical radiculopathy; minimally invasive posterior cervical foraminotomy (MIS-PCF); open cervical foraminotomy; percutaneous endoscopic (full-endoscopic) posterior cervical foraminotomy (FE-PCF)

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Introduction

Cervical radiculopathy is a clinical condition resulting from compression of cervical nerve roots (1). Patients can present with a wide range of clinical manifestations including radiating pain, sensory deficits, motor deficits, diminished reflexes, or any combination of the above (1). Cases of cervical radiculopathy that have failed non-operative management can be treated with multiple surgical interventions including from both anterior and posterior approaches. Originally described in two cadaveric studies in 2000, minimally invasive posterior cervical foraminotomy (MIS-PCF) has gained significant traction as a minimally invasive treatment for lateral

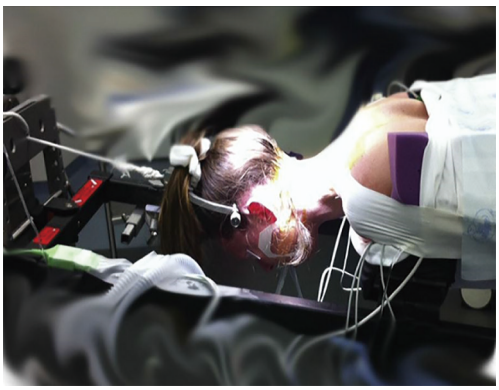

Figure 1 Operative position of patient in Gardner-Wells tongs, prone, on a Jackson table. The neck is in slight flexion. Reprinted from with permission from (26).

spinal canal pathology causing radiculopathy (2,3). Although initial case series focused on minimally invasive endoscopic approaches, the surgeons armamentarium has since expanded to include microscopic and percutaneous endoscopic (full-endoscopic) approaches (4-7).

Several case series and technique papers have been published describing endoscopic/microscopic MIS-PCF (MIS-PCF) and percutaneous endoscopic (full-endoscopic) posterior cervical foraminotomy (FE-PCF) (8-32). There are, however, very few studies directly comparing minimally invasive to open posterior cervical foraminotomy or MIS-PCF to percutaneous endoscopic(full-endoscopic) posterior cervical foraminotomy. Additionally, the majority of previously published meta-analyses include non-comparative studies and instead use pooled analysis from multiple single-arm case series (33-35). This study includes a description of the current technique employed by the senior author to perform a MIS-PCF and a systematic review of literature and analysis of clinical studies directly comparing outcomes between MIS-PCF and open posterior cervical foraminotomy and between MIS-PCF and FE-PCF. Studies were evaluated for differences in operative/hospital admission metrics, patient-reported outcomes including visual analog scale (VAS) and neck disability index (NDI), complications, and reoperation.

Methods

This study includes a systematic review of literature conducted based on the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement using PubMed, the Cochrane Library, Scopus, and included citations to identify clinical studies comparing MIS-PCF to open posterior cervical foraminotomy or percutaneous endoscopic (full-endoscopic) posterior cervical foraminotomy (FE-PCF). Specific MeSH terms and key words including "cervical radiculopathy" "foraminotomy" "posterior foraminotomy" "minimally invasive cervical foraminotomy" "percutaneous endoscopic foraminotomy" and "full endoscopic foraminotomy" were used to identify studies of interest. Additional manual searches through cited references were performed. Randomized controlled trials, prospective/retrospective cohort and case-control studies were included in further analysis. Non-English publications, editorials, conference abstracts, errata, book chapters, systematic reviews, meta-analyses, case reports, and case series were excluded. Studies that reported outcomes of continuous variables as medians were excluded. Studies were evaluated for differences in operative/hospital admission metrics, patient-reported outcomes (VAS, NDI), complications, and reoperation.

Surgical technique

Following intubation, the patient is placed in Gardner-Wells tongs and placed prone on the surgical table. A radiolucent Jackson frame is used, and the patients head is placed in a slightly flexed position (*Figure 1*). The C-arm is placed beneath or anterior to the patient. An initial image is acquired to confirm visualization of the desired level and to plan the initial entry point. The surgical area is shaved, prepared, and draped in the usual fashion. Preoperative antibiotics are administered. Prior to incision the operative level is re-confirmed on lateral fluoroscopy by placing a Kirschner (K)-wire or another long radiopaque instrument over the lateral side of the patient's neck. Following an injection of local anesthetic, a 2-cm longitudinal incision is made 1.5 cm lateral of the midline. The K-wire is advanced carefully though the musculature under fluoroscopic guidance and docked at the inferomedial edge of the rostral lateral mass of the level of interest. The cervical fascia is incised, not exceeding the length of the skin incision, and the tubular retractors are serially inserted (*Figure 2*). The final tubular retractor, usually 16-mm or 18-mm in diameter, is placed over the dilators and fixed into place using a table-mounted flexible retractor arm. The dilators are then removed and the microscope is brought into position. Monopolar cautery is used to clear the remaining soft tissue from the lamina and lateral mass of interest. The laminotomy and foraminotomy are performed using a high-speed drill and Kerrison rongeur. Once the laminotomy

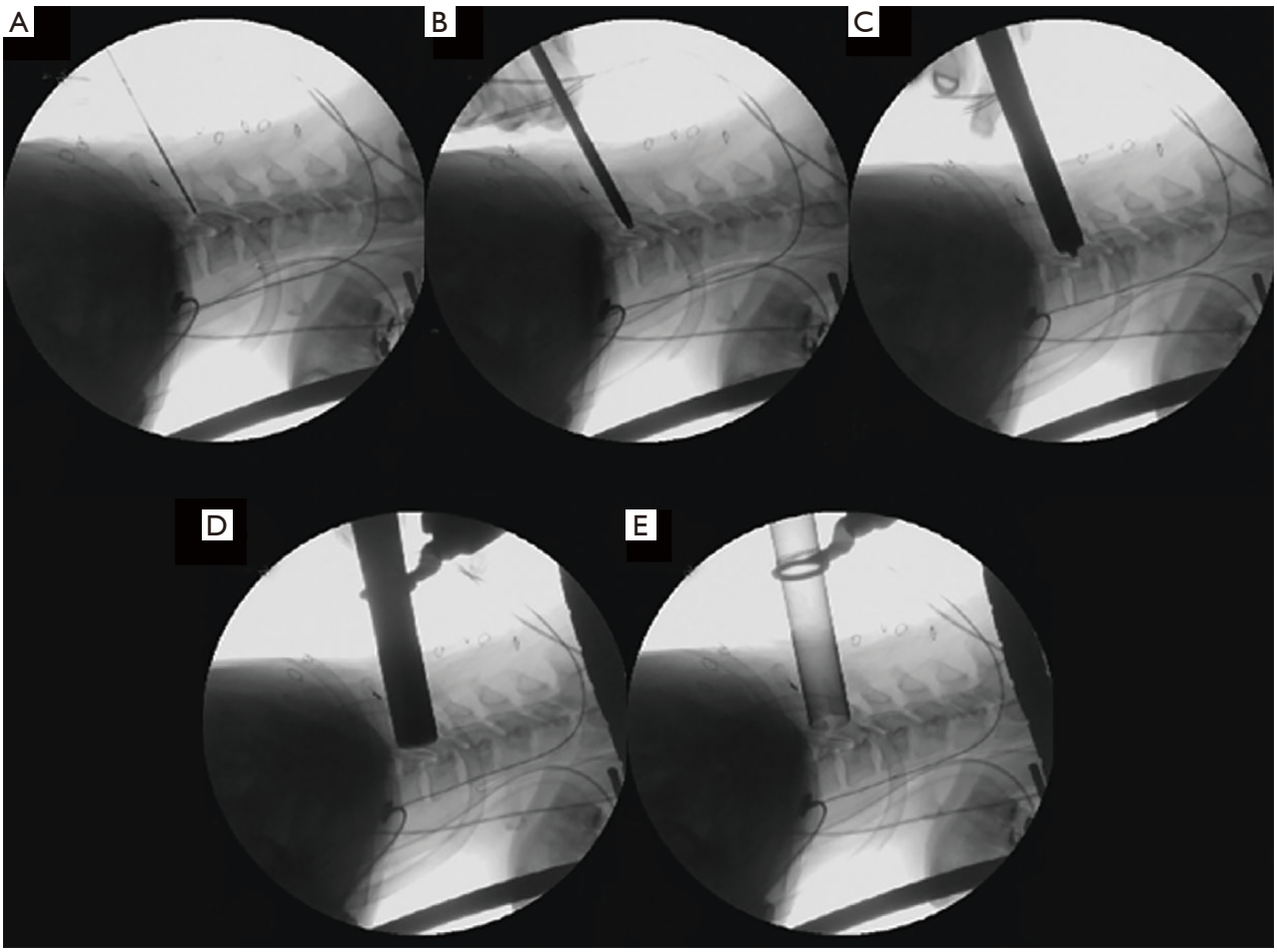

Figure 2 Intraoperative lateral fluoroscopic images demonstrating muscle dilation. (A) K-wire is docked on the laminofacet junction. (B,C) Serial insertion of the first 2 muscle dilators. (D) Progression to largest dilator is complete. (E) An 18-mm tubular retractor is fixed into place and dilators are removed. Reprinted from with permission from (26).

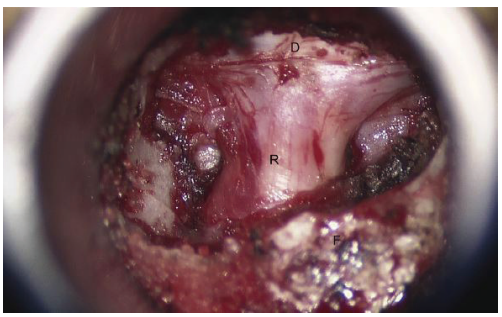

Figure 3 After completion of the laminotomy and removal of less than 50% of the facet, the dura (D) is observed medially, while the nerve root (R) is seen laterally as it exits under the remaining facet (F). The top of the image is medial and the right is cranial. Reprinted from with permission from (26).

is complete, the ligamentum flavum can be removed from medial to lateral to identify the proximal nerve root and lateral dura. Bony resection of the medial facet is carried out to expose the proximal foraminal course of the nerve root, however, careful attention should be paid to not resect greater than 50% of the facet. This limits the risk of iatrogenic instability. After the root is well visualized (*Figure 3*) a fine-angled dissector can be used to palpate ventral to the nerve root and confirm the root is adequately decompressed. To allow removal of any osteophytes or disc fragments additional drilling of the superomedial quadrant of the caudal pedicle can be carried out to allow greater access without excessive retraction of the nerve root. The foramen is inspected one last time for adequacy of decompression prior to hemostasis, antibiotic-impregnated irrigation, and multi-layer closure (*Figure 4*).

Results

In total 178 abstracts were reviewed of which 99 were excluded; 79 full text articles were assessed of which 39 were excluded. Several articles were excluded if they did not include minimally invasive procedures, if it was unclear from the manuscript whether or not minimally invasive techniques were performed, or if they included open or "mini-open" cervical foraminotomies within a posterior cervical cohort (36-46). Articles were excluded if they included laser-mediated decompressions (47-49). or if they included anterior endoscopic approaches (50). Overall 5 comparative studies, including one randomized controlled trial, were included in analysis comparing open to MIS-PCF (5,51-54). One study was included in analysis that compared minimally invasive tubular retractor based posterior cervical foraminotomy to percutaneous endoscopic cervical foraminotomy and discectomy ("full-endoscopic") (55). A flow chart of study inclusion and exclusion is shown in *Figure 5* (56).

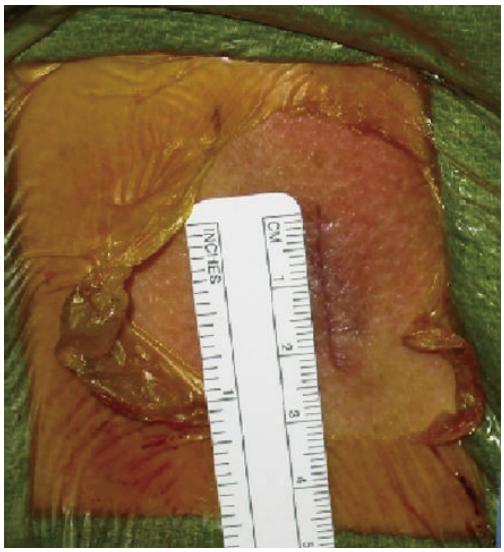

Figure 4 Incision is closed with absorbable sutures and topical skin adhesive. Reprinted from with permission from ref. (26).

Five studies were included comparing minimally invasive cervical foraminotomy to open cervical foraminotomy (5,51-54). Fessler *et al.* included a prospectively collected, retrospectively analyzed cohort series whereas Kim *et al.* (in 2009) consisted of a randomized controlled trial (5,51). The remainder of series were retrospective cohort series (*Table 1*).

Average operative time was reported in 5 studies which ranged from 60.5 to 171 minutes in the open group and 77.65 to 115 minutes in the minimally invasive group (5,51-54). Eicker *et al.* was the only study to find a statistically significant decrease in operative time in the MIS

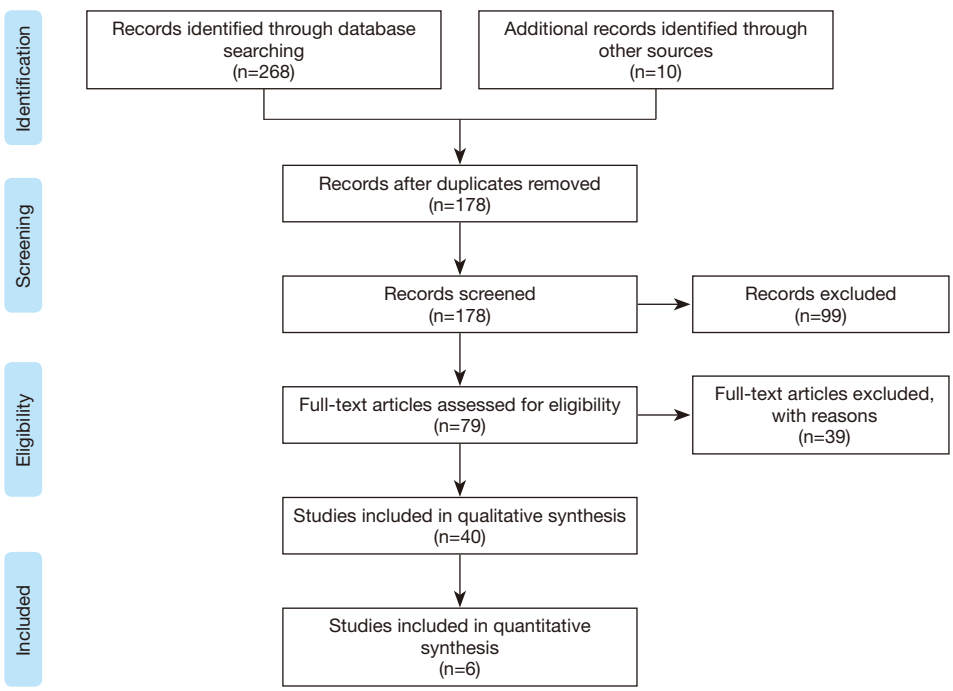

Figure 5 A flow chart of study inclusion and exclusion.

Table 1 Included studies comparing open and MIS-PCF

Study	Study type	Intervention (# of patients)	Follow-up (months)	Operative time (minutes)	Estimated blood loss (cc)	Postoperative length of stay (hours)
Fessler *et al.*, 2002	PCS	Open (n=26); MIS/ endoscopic(n=25)	15.2; 4.6	171^; 115^	246^; 138^	68^; 20^
Kim *et al.*, 2009	RCT	Open (n=22); MIS/ microscopic (n=22)	34.2; 33.1	76.5; 78.5	NR	160.8*; 98.4*
Winder *et al.*, 2011	RCS	Open (n=65); MIS/ microscopic (n=42)	NR	103.25; 100.74	233.20*; 96.10*	58.60*; 26.86*
Uehara *et al.*, 2015	RCS	"Mini-open" (n=10); MIS/ microscopic (n=10)	33.0; 41.8	60.5*; 86.2*	43.5; 42.0	304.8; 273.6
Eicker *et al.*, 2016	RCS	Open (n=23); MIS/ microscopic (n=17)	66.4; 23.3	104*; 77.65*	NR	178.32*; 115.68*

*, P<0.05; ^, significance not reported. PCS, prospective cohort series; RCT, randomized controlled trial; RCS, retrospective cohort series; NR, not reported; MIS, minimally invasive surgery; MIS-PCF, minimally invasive posterior cervical foraminotomy.

group (53).Kim *et al.* (in 2009) and Winder *et al.* failed to find a statistically significant difference in operative time between the two groups, and Uehara *et al.* found operative time to be significantly increased in the minimally invasive tubular retractor group (51,52,54). Mean intraoperative estimated blood loss was reported in 3 studies which ranged from 43.5 to 246 cc in the open group and 42 to 138 cc in the MIS group (5,52,54). Winder *et al.* was the only included comparative study to show a statistically significant decrease in estimated blood loss in the MIS group (52). Five studies reported postoperative length of stay which ranged from 58.6 to 304.8 hours in the open group and 20 to 273.6 hours in the MIS group (5,51-54). Eicker *et al.*, Winder *et al.*, and Kim *et al.* (in 2009) all found significant decreases in postoperative length of stay in patients undergoing MIS posterior cervical foraminotomy (51-53) (*Table 1*). Regarding postoperative analgesia, Winder *et al.* and Eicker *et al.* found significantly decreased dosages of pain medication in the minimally invasive group, whereas Kim *et al.* (in 2009) found that patients in the minimally invasive group had a significantly decreased duration of pain medication usage (51-53). Both Kim *et al.* (in 2009) and Eicker *et al.* found significantly decreased skin incision lengths in the MIS group (51,53).

Regarding patient reported outcomes (PRO's), Kim *et al.* (in 2009) found no significant differences in VAS-A scoring however VAS-N was significantly increased in the open group from 1 day to 4 weeks postoperatively. There was no significant difference in VAS-N from 3 to 24 months postoperatively (51). Eicker *et al.* reported VAS-N was significantly reduced in the minimally invasive group compared to the open group on the first postoperative day and day of discharge however was not significant at 6 weeks postoperatively. VAS-A scores were not significantly different between groups (53). Uehara *et al.* found no significant differences in PRO's (NDI, VAS-A, VAS-N) postoperatively (54). Regarding complications, Fessler *et al.* reported three overall complications in the minimally invasive group including two CSF leaks and one partial thickness dural violation (5). There were no reported complications in the open group. Kim *et al.* (in 2009) reported no complications in either group (51). Total complications were not statistically different between groups in Winder *et al.* and were not specified by group in Eicker *et al.* (52,53). Three of five studies did not include reoperations (51,52,54). Fessler *et al.* reported no cases of reoperations within either cohort and Eicker *et al.* did not specify reoperations by group (5,53).

One study was included in analysis that compared minimally invasive tubular retractor based posterior cervical foraminotomy (MIS-PCF) to percutaneous endoscopic (full endoscopic) cervical foraminotomy (FE-PCF). Kim *et al.* (in 2015), a retrospective cohort study, compared 24 consecutive patients who underwent percutaneous endoscopic cervical foraminotomy and discectomy to 34 patients who underwent minimally invasive tubular assisted microscopic cervical foraminotomy (55). Mean follow up times were not reported although all patients were followed for >2 years. Postoperatively at 24 months, the mean NDI and VAS-N were significantly lower after percutaneous endoscopic cervical foraminotomy than minimally invasive tubular assisted microscopic cervical foraminotomy. There was however no significant change in VAS-A between the two groups.

Discussion

Five studies were included comparing minimally invasive cervical foraminotomy to open cervical foraminotomy (5,51-54). All of these studies were retrospective cohorts except Kim *et al.* (in 2009) and Fessler *et al.* All five of the studies had significant limitations including small sample sizes and relatively short follow-up periods. There was significant heterogeneity in the study designs. Four of the five studies involved minimally invasive tubular assisted microscopic cervical foraminotomy, however Fessler *et al.* included an endoscopic series in the minimally invasive group. Fessler *et al.* also contained an operative technique change as the first 12 cases in the minimally invasive group were done in prone position and the final 13 cases were done in sitting position. Uehara *et al.* further compared minimally invasive tubular assisted microscopic cervical foraminotomy to a "mini-open" retractor based foraminotomy. Given the significant heterogeneity between studies a meta-analysis was not performed.

Operative time was found to be decreased in Eicker *et al.* and Fessler *et al.*, however, a level of significance was not reported in the latter study (5,53). Kim *et al.* (in 2009), and Winder *et al.* failed to find a statistically significant difference in operative time between the two groups, and Uehara *et al.* found operative time to be significantly increased in the minimally invasive group (51,52,54). This discrepancy may be related to an increased learning curve that occurs with using the tubular retractor or endoscopic system leading to increased operative time. Fessler *et al.* found decreased operative blood loss and surgical duration when switching from prone to sitting position (5). None of the other studies were performed in the sitting position which may have led to increased operative time compared to open procedures.

Of only two studies that analyzed estimated blood loss for statistical significance, Winder *et al.* was the only study to show MIS-PCF had significantly lower blood loss than Open-PCF (52). Uehara *et al.* did report decreased blood loss in the MIS group however it was not statistically significant. This may be related to the open cohort in Uehara *et al.* actually being a "mini-open" cohort and thus the blood loss may be closer to a MIS approach than an open approach (54). Kim *et al.* (in 2009), Winder *et al.*, and Eicker *et al.* all reported statistically significant decreases in hospital length of stay and postoperative analgesic usage in the minimally invasive group (51-53). Regarding PRO's both Kim *et al.* (in 2009) and Eicker *et al.* reported significantly increased VAS-N scores postoperatively in patients undergoing open cervical foraminotomies. Both studies also reported that the differences lost statistical significance with longer follow-up. This is likely related to a longer incision and increased muscle dissection in the open approach. There was not enough data included in the above studies to suggest a difference in complication rate and reoperation rate between minimally invasive and open cervical foraminotomy.

This analysis has some advantages and similar limitations over previously published meta-analyses. McAnany *et al.* included 8 studies in meta-analysis however only one study, Kim *et al.* (in 2009), was comparative in nature (33). The remainder of studies were either case series of minimally invasive (both endoscopic and microscopic) or open procedures which were pooled for analysis. The meta-analysis found that there was no statistically significant difference in the pooled clinical success rate for either procedure (33). Clark *et al.* included 18 publications of which 3 were directly comparative [Kim *et al.* (in 2009), Fessler *et al.*, Winder *et al.*] (57). Given the degree of heterogeneity the authors did not perform a meta-analysis. Similar to this analysis, in data aggregated from the included publications they found that patients undergoing minimally invasive cervical foraminotomy have less inpatient analgesic use, and shorter hospital stays. Aggregate data from Clark *et al.* also showed patients undergoing minimally invasive cervical foraminotomy have lower blood loss and shorter surgical time compared with patients undergoing open procedures (57).

Only one study was found in systematic review that compared minimally invasive tubular retractor based posterior cervical foraminotomy to percutaneous endoscopic cervical foraminotomy and discectomy and thus meta-analysis was not able to be performed. Although the study was limited by short follow-up and low sample size, the authors showed that percutaneous endoscopic cervical foraminotomy had significantly lower mean NDI and VAS-N scores postoperatively (55). It is unclear why the scores would be different between the two procedures. According to the surgical methods the difference in the incisions is 1.2 cm and muscular dissection should be minimized in both procedures. Postoperative differences would likely normalize by 24 months as they were in the minimally invasive vs open foraminotomy studies. Two meta-analyses have been done that compare MIS-PCF to percutaneous endoscopic cervical foraminotomy (34,35). Both studies include Kim *et al.* (in 2015) as the only directly comparative study within their meta-analysis. Wu *et al.* (in 2018) evaluated total complications, complications

for single level radiculopathy, dural tear, transient root palsy, and superficial wound infection and found only a statistically increased rate of transient root palsy in the full-endoscopic group (35). The meta-analysis was however significantly limited by heterogeneity, included only one directly comparative study, and included multiple series that were excluded from this analysis including a case series of patients undergoing open cervical foraminotomy (35,46). Wu *et al.* (in 2019) compared the clinical success rate, total complication rate, and reoperation rate between MIS-PCF and percutaneous endoscopic cervical foraminotomy and found no statistically significant difference (34). It is limited by many of the same limitations as the previous study.

Limitations

There are several limitations to this study. Following systematic review only 6 studies were included that met inclusion/exclusion criteria. Although all studies were directly comparative in nature there were several key differences between the studies that limited the ability to perform meta-analysis. A majority of studies did not include or did not stratify reoperation or complications. Follow-up time and cohort size were additionally limited. Regarding studies comparing minimally invasive to percutaneous (full-endoscopic) approaches only one directly comparative paper was found.

Conclusions

Direct comparative studies between MIS-PCF and open cervical foraminotomy are limited in number. Although, there is a significant heterogeneity in studies comparing open and MIS-PCF there appears to be a trend of decreased hospital length of stay and postoperative analgesic usage in the minimally invasive cohort. There is not enough data currently to suggest a difference in complication rate and reoperation rate between minimally invasive and open cervical foraminotomy. There is not enough data to currently compare MIS-PCF and FE-PCF in a meaningful manner.

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Footnote

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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