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ORIGINAL ARTICLE

Cervical cages placed bilaterally in the facet joints from a posterior approach significantly increase foraminal area

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Abstract
Purpose Foraminal stenosis is a common cause of cervical radiculopathy. Posterior cervical cages can indirectly increase foraminal area and decompress the nerve root. The aim of this study was to assess the influence of bilateral posterior cervical cages on the surface area and shape of the neural foramen.
Methods Radiographic analysis was performed on 43 subjects enrolled in a prospective, multi-center study. CT scans were obtained at baseline and 6- and 12-months after cervical fusion using bilateral posterior cervical cages. The following measurements were performed on CT scan: foraminal area (*A*), theoretical area (TA), height (*H*), superior diagonal (DSI), inferior diagonal (DIS), and inferior diagonal without implant (DISI). Comparisons were performed using R-ANOVA with a significance of $\alpha < 0.05$.
Results Foraminal area, height, TA and DISI were significantly greater following placement of the implant. The mean (SD) A increased from 4.01 (1.09) mm^2 before surgery to 4.24 (1.00) mm^2 at 6 months, and 4.18 (1.05) mm^2 at 12 months after surgery ($p < 0.0001$). Foraminal height (*H*) increased from mean (SD) 9.20 (1.08) mm at baseline to 9.65 (1.06) mm and 9.55 (1.14) mm at 6- and 12-months post-operatively, respectively ($p < 0.0001$). The mean DIS did not change significantly. There was a significant decrease in DSI: 6.18 (1.59) mm pre-operatively, 5.95 (1.47) mm and 5.73 (1.46) mm at 6- and 12-months ($p < 0.0001$).
Conclusions Implantation of bilateral posterior cervical cages can increase foraminal area and may indirectly decompress the nerve roots. Correlation between increase in foraminal area and clinical outcomes needs further investigation.

Keywords Cervical spondylopathy · Cervical radiculopathy · Posterior cervical cage · DTRAX · Foraminal area

Introduction

Cervical foraminal stenosis commonly develops as a result of intervertebral disc degeneration and is a contributing factor to cervical radiculopathy [1]. Nerve root compression manifests with sensorimotor deficits [1]. Although the majority of patients benefit from conservative management, surgical treatment is warranted in select cases [2, 3].

The cervical neural foramen can be decompressed using a direct or indirect approach [4]. Direct decompression can be achieved via anterior cervical discectomy and fusion, transvertebral anterior cervical foraminotomy or posterior foraminotomy [1, 4, 5]. The anterior approach provides both direct and indirect decompression with direct resection of degenerative tissue and disc height restoration [1, 4]. Posterior foraminotomy provides direct decompression, but the degree of which is limited by the amount of bone that may be safely removed [1]. Both anterior and posterior procedures have their own unique challenges, limitations, and complications. Commonly reported complications of

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anterior approach surgeries are dysphagia, dysphonia, neurological complications, vascular complications, implant failure, adjacent segment disease, and esophageal injury [6–8]. Posterior approaches are associated with neck pain secondary to muscle dissection [9]. A slightly higher prevalence of C5 root palsy is observed with posterior laminectomy compared to anterior approach surgery [10].

The recent introduction of posterior cervical cages allows for indirect decompression through a posterior approach. Foraminal area is increased via intervertebral joint facet distraction by placing a posterior cervical cage between the facet joints bilaterally. This surgical approach has been described in both cadaveric [11, 12] and clinical studies [13, 14].

One-year clinical outcomes demonstrated the safety and effectiveness of cervical fusion using bilateral posterior cervical cages in select patients with single level cervical spondylotic radiculopathy [14]. The technique involves bilateral placement of cages between adjacent cervical facet joints, providing both indirect neural foraminal decompression and stabilization of the motion segment [11, 14]. Although the study reported favorable clinical outcomes and a high fusion rate, the effect of cage placement on foraminal area over time was not reported.

The aim of this study was to assess the effect of posterior cervical cages on the surface area and the shape of the cervical neural foramen over time.

Methods

A prospective, multicenter, single-arm study was conducted to evaluate the safety and effectiveness of cervical fusion with posterior cervical cages placed bilaterally between the facet joints in patients with single level cervical spondylotic radiculopathy. Study design and one-year outcomes have been published [14]. As part of the study protocol, subjects were required to undergo CT or MRI imaging pre-operatively and at 6- and 12-months post-operatively. Herein we report changes in the neural foramina over time in subjects with CT imaging at all time points.

Radiological evaluation

CT scans were obtained preoperatively, and at 6- and 12-months postoperatively using a multi-slice CT (256 Slice CT Scanner, Philips Inc.) with 1-mm slice thickness at 1 mm intervals. An oblique view at the level of the operated neural foramen was obtained to produce en face images of the medial foramen zone according to methods described by Roberts et al. [15]. Sagittal scans were angled 45° and the plane created after this angulation was set to cross the middle of the two adjacent pedicles [16] (Fig. 1).

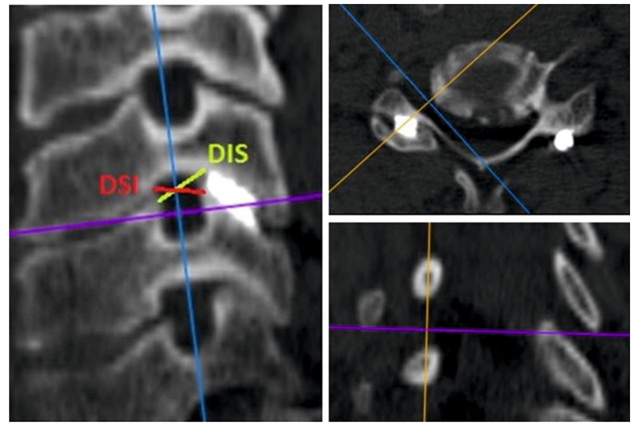

Fig. 1 Multi-planar reconstruction of the foramen. Localization of the measurements. DSI and DIS as described in text

The following measures were performed at the level of the instrumented neural foramina after orthogonal multi-planar reconstruction:

- Height (*H*) was defined as the distance between the middle of superior and inferior pedicles (Fig. 2).
- Foraminal area (*A*) was determined by first manually outlining the cervical neural foramen. The evaluated area was limited by bony structures and the soft tissues according to Tanaka et al. [4]. The bony boundaries were defined superiorly and inferiorly by the proximal and distal pedicles of the adjacent vertebrae, posteriorly by the anterior aspect of the facet joint and the adjacent part of the articular processes, anteriorly by the posteroinferior aspect of the supradjacent vertebrae and by the posterosuperior aspect of the inferior adjacent vertebrae.
  As soft tissue is not adequately visualized on CT imaging, the anterior boundary of the neural foramen was defined by drawing a line connecting the infero-posterior edge of the superior vertebral body and the

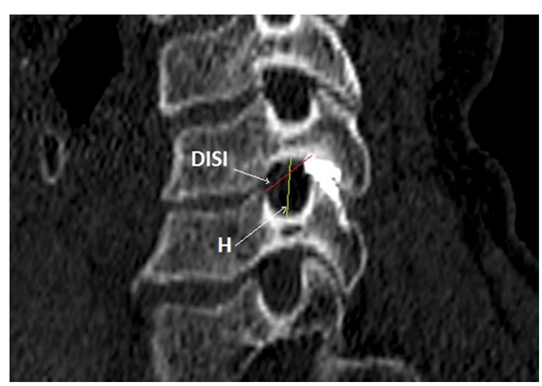

Fig. 2 Height (H), and inferior diameter without implant (DISI) marked at the orthogonal view of the cervical neural foramen

superoposterior edge of the inferior vertebral body. The posterior foraminal boundary was defined as a line connecting the superior margin of the inferior facet and the superior margin of the superior facet. In patients with the implant tip placed inside the foraminal space, the contour of the implant was considered as posterior inter-facet limit (Fig. 3a).

- Theoretical area (TA) was defined as foramen area with bony and soft tissue boundaries described for A, without taking into consideration the influence of the implant tip on the space of the foramen (Fig. 3b).
- Superior diagonal distance (DSI) was defined as the distance between the inferoposterior edge of the superior vertebral body and the superior margin of the inferior facet (Fig. 1).
- Inferior diagonal distance (DIS) was defined as the distance between the superoposterior edge of the inferior vertebral body and the superior margin of the superior facet (Fig. 1). If part of the implant was visible between the joint surfaces, the inferior diameter was defined as the distance between the superoposterior edge of the inferior vertebral body and the tip of the implant (Fig. 1).
- Inferior diagonal without implant (DISI) was defined as the distance between the superoposterior edge of the inferior vertebral body and the superior margin of the superior facet, regardless of whether part of the implant was visible between the joint surfaces (Fig. 2).

Measurements were performed manually in OsiriX v5.5.2 software. Images were optimized for evaluation of bony structures using discrete bone window views provided by the viewer software. All measurements were performed twice by two raters in at least 4-week intervals.

Statistical analysis

Inter- and intra-rater reproducibility were tested and quantified by the intraclass correlation coefficient (ICC) and the median error for a single measurement (SEM) [17]. An ICC value of less than 0.40 indicates poor reproducibility, 0.40–0.75 indicates fair to good agreement/reproducibility/reliability, and values greater than 0.75 reflect excellent reproducibility [17].

For each parameter, the mean, standard deviation (SD), and range were calculated. Normal distribution of data was analyzed with the Shapiro–Wilk test. Changes in parameter values were analyzed using repeated measures ANOVA with JMP 10.0.2 software (SAS Institute Inc., Cary, NC). The level of significance was set for $\alpha < 0.05$.

Results

Of the 60 subjects enrolled in the study, 43 had available CT scans for all time points. The mean age was 57.3 ± 8.0 years, 15 subjects were male and 28 were female. A total of 86 foramina were analyzed: 4 at the level of C3–C4, 10 at C4–C5, 60 at C5–C6, and 12 at C6–C7.

All values followed a normal distribution. Statistically significant increases were found for foraminal area, theoretical area and foraminal height (Table 1, Fig. 4). The mean (SD) foraminal area (*A*) increased from 4.01 (1.09) mm^2 pre-operatively, 4.24 (1.00) mm^2 at 6 months, and 4.18 (1.05) mm^2 at 12 months after surgery ($p < 0.0001$) (Table 1). Mean values for theoretical area (TA) were slightly higher: 4.36 (TA) vs 4.24 (A) mm^2 and 4.3 (TA) vs. 4.18 (A) mm^2 at 6- and 12-months, respectively (Table 1). Foraminal height (*H*) increased from mean (SD) 9.20 (1.08) mm at baseline to 9.65 (1.06) mm and 9.55 (1.14) mm at 6- and 12-months post-operatively, respectively ($p < 0.0001$).

A statistically significant decrease was observed in DSI and DISI (Table 1). DSI decreased from 6.18 (1.59) to 5.95 (1.47) and 5.73 (1.46) mm at 6- and 12-months ($p < 0.0001$). DISI decreased from 7.03 (1.66) to 7.99 (1.62) and 7.83 (1.64) mm. DIS declined from 7.03 (1.65) pre-operatively to 7.02 (1.37) and 6.87 (1.34) mm; this change was not significant ($p = 0.1468$). In 60.5 % of measurements, DISI was greater than DIS.

All measurements showed excellent inter- and intra-rater reliability (Table 2).

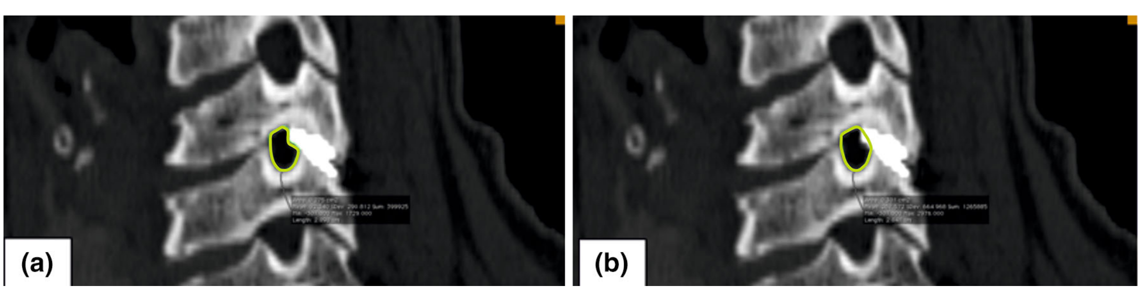

Fig. 3 Cervical neural foramen area measured at orthogonal view: **a** foraminal area (*A*), **b** theoretical area (TA). Explanation in text

Table 1 Foraminal measurements at baseline and 6-months, and 12-months post surgery

Parameter	Baseline	6 months	12 months	P value[a]	Baseline vs 6 months[b]	Baseline vs 12 months[b]	6 vs 12 months[b]
A (mm^2)							
Mean ± SD	4.01 ± 1.09	4.24 ± 1.00	4.18 ± 1.05	**<0.0001**	**0.0003**	**0.0210**	0.3542
Range	2.03–7.27	2.11–6.66	1.81–7.33				
TA (mm^2)							
Mean ± SD	4.01 ± 1.09	4.36 ± 1.06	4.30 ± 1.07	**<0.0001**	**<0.0001**	**<0.0001**	0.3985
Range	2.03–7.27	2.14–6.83	1.81–7.36				
H (mm)							
Mean ± SD	9.20 ± 1.08	9.65 ± 1.06	9.55 ± 1.14	**<0.0001**	**<0.0001**	**<0.0001**	0.1046
Range	6.41–11.5	6.88–12.4	6.77–12.1				
DSI (mm)							
Mean ± SD	6.18 ± 1.59	5.95 ± 1.47	5.73 ± 1.46	**<0.0001**	0.0375	**0.0001**	0.0287
Range	2.80–9.58	2.99–9.41	2.48–8.98				
DIS (mm)							
Mean ± SD	7.03 ± 1.65	7.02 ± 1.37	6.87 ± 1.34	0.1468	1	0.4404	0.1316
Range	2.85–10.7	3.60–10.4	3.68–10.0				
DISI (mm)							
Mean ± SD	7.03 ± 1.66	7.99 ± 1.62	7.83 ± 1.64	**<0.0001**	**<0.001**	**<0.001**	0.1789
Range	2.85–10.7	3.95–12.4	4.19–12.0				

Bolded values with $p < 0.05$

H height, *A* foraminal area, *TA* theoretical area, *DSI* superior diameter, *DIS* inferior diameter, *DISI* inferior diameter without implant

[a] Repeated ANOVA

[b] Post-hock tests with Bonferroni correction

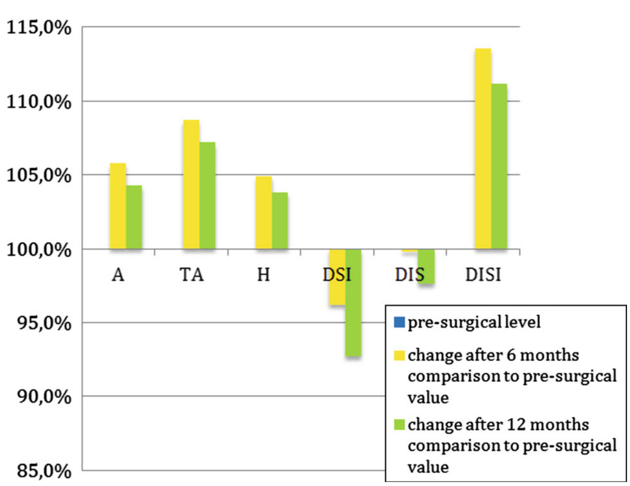

Fig. 4 Graphical analysis of the percentage changes of the evaluated parameters measured 6 and 12 months after surgery in pre-surgically

Table 2 Inter- and intra-rater reliability of measurements quantified with ICC and SEM

	Inter-rater		Intra-rater	
	ICC	SEM	ICC	SEM
A	0.9216	0.0292 mm^2	0.9322	0.0271 mm^2
TA	0.7988	0.0479 mm^2	0.9122	0.0316 mm^2
H	0.8644	0.0408 mm	0.9256	0.0302 mm
DSI	0.8783	0.0528 mm	0.8669	0.0552 mm
DIS	0.8693	0.0526 mm	0.8680	0.0529 mm
DISI	0.7813	0.0788 mm	0.8071	0.0740 mm

H height, *A* foraminal area, *TA* theoretical area, *DSI* superior diameter, *DIS* inferior diameter, *DISI* inferior diameter without implant, *ICC* intraclass correlation coefficient, *SEM* median error for a single measurement

Discussion

This study reports the effects of posterior cervical cage placement on cervical foraminal area at 6- and 12-months after fusion with bilateral posterior cervical cages. The concept of indirect decompression is based on described clinical observations; cervical extension aggravates symptoms in patients with cervical radiculopathy and flexion often relieves them [18]. These observations can be explained by motion dependent foraminal size changes as demonstrated in a cadaveric study performed by Yoo et al. [19]. The authors reported that foraminal diameter decreased with cervical extension and increased with flexion. Indirect decompression provided by facet distraction is achieved by increasing foraminal height. The distance between the facet joints and bony structures (vertebral body, pedicle and articular processes) of the adjacent vertebrae work as a lever arm with the axis of rotation at the level of the intervertebral disc. This mechanism was previously described in cadaveric studies. Leasure and Buckley described increased foraminal area after implantation of posterior cervical cages. Tan et al. reported an increase in foraminal height and area immediately after interfacet placement of machined bone graft [11, 12].

Our results demonstrated that both foraminal area and height significantly increased after posterior cervical cage implantation. This increase was maintained at 6- and 12-months after surgery, and despite a small, insignificant decrease in measurement values between the 6- and 12-month follow-up interval. The observed increase in foraminal area was smaller than expected based on cadaveric results reported in the literature. Yoo et al. reported increases in foraminal diameter at the levels C5–C6 and C6–C7 of 8 and 10 % for cervical spine flexion of 20° and 30°, respectively [19]. Leasure and Buckley reported a 33 % increase in foraminal area in a neutral position after posterior cage implantation [11]. Tan et al. described an 18.4 % (0.2 mm^2) increase in foraminal area immediately after placement of a machined bone implant in a cadaveric study [12]. Foraminal area in the current study increased by 5.8 % at 6 months (0.23 mm^2). The discrepancy between studies may be explained by several factors. First, the implant configurations for both Tan et al. and Leasure and Buckley were slightly different than that used in the current study. Second, the study reported herein assessed changes in foraminal area in vivo over time versus previously reported cadaveric data. Some subsidence as a result of axial loading is expected [20]. Third, the subjects in the current study had degenerative changes, possibly limiting the mobility of the soft tissues. The surgical procedure described in this study was tissue sparing, with preservation of all surrounding muscles and ligaments, whereas in both cadaveric studies these elements were removed, potentially reducing the restraints to over-distraction. Finally, the implant tip entered the foraminal space in 21.1 % of cases (Fig. 3a, b). However, this is accounted for in the calculation of theoretical foraminal.

Although the neural foramen of the cervical spine has an almost elliptical shape [18], we found that additional space was created posteriorly at the level of intervertebral joint in 61.1 % of cases (Fig. 5). The impact of this on foraminal pressure is unclear. However, accounting for this space increases total foraminal volume.

When evaluating the neural foramen in patients with radiculopathy, it is crucial to identify the location of nerve compression. Anatomically, the neural foramen is divided into three parts. The pedicle (medial) zone is believed to play an important role in the etiology of cervical radiculopathy [4]. Roberts et al. suggest reformatting standard axial CT images of the cervical spine in an oblique plane perpendicular to the long axis of the neural foramen to produce en face images to improve demonstration of anatomic relationships and enable accurate measurements [15]. They also described excellent observer agreement by evaluating cervical foraminal stenosis using oblique reformation of cervical CT images. In addition to nerve compression location, the type of location must also be taken into consideration. In a study of 1085 foraminotomy cases, Church et al. found that radiculopathy due to soft disc subtypes may be associated with a better prognosis compared to osteophyte disease [21]. Further investigation is needed to understand if there are any differences in success rates when using posterior cervical cages.

Measurements of the cervical foramina are often performed using the narrowest image of the foramen [12, 14]. The current study used the plane passing the mid-point of two adjacent pedicles. We assumed that after posterior cervical cage implantation, the localization of the narrowest part of the foramen could change, but the mid-point of the pedicle would remain as a constant anatomical landmark. The narrowest point typically corresponded to the mid point of the pedicle [18]. Although the anatomical foraminal axis angle differs by level [22, 23], sagittal scans were always angled at 45° to avoid possible error due to a

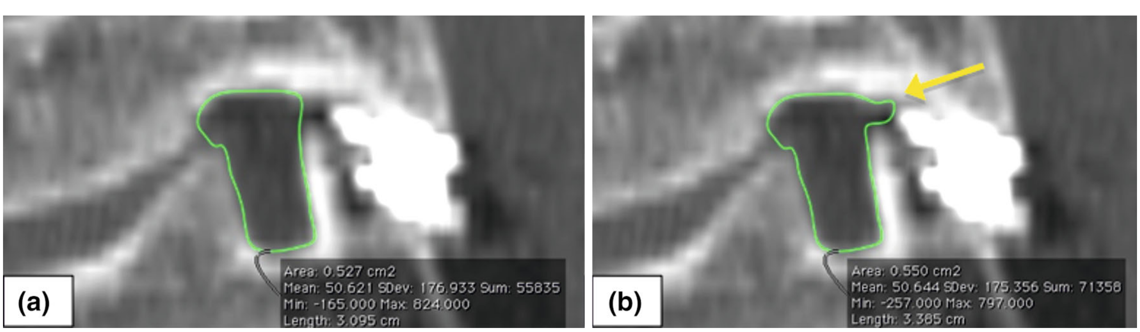

Fig. 5 Foraminal area: **a** standard measurement, **b** measurement with additional interfacetal area

difference in sagittal plane angulation. To avoid possible image distortion from brightness and contrast, measurements were performed using discrete bone window views provided by the viewer software.

Inter- and intra-rater analysis showed that measurements were reliable and repeatable. Therefore, the method used in the current study is applicable to measuring changes of foraminal area on CT scans after surgical foraminal volume augmentation.

When evaluating foraminal size after posterior cervical cage implantation, the influence of the implant on both regional and global sagittal alignment should be taken into consideration. It is important to note that all measurements in this study were performed in the supine position, thus proper cervical sagittal parameters could not be evaluated. McCormack et al. reported a 1.6° loss of segmental lordosis on standing lateral radiographs at the treated level at 1 year [14]. The clinical significance of this needs to be further evaluated. In their study of 14 subjects who underwent single-level cervical disc arthroplasty and 28 case-matched ACDF subjects, Lee et al. reported that restoration of cervical lordosis was an important factor in anterior cervical spine surgery [24].

There are limitations to this study. A correlation between change in foraminal area and clinical outcome was not performed due to the small sample size. Measurements were performed on the virtual orthogonal reconstruction of the actual images. However, this was performed using a reliable and widespread method.

The current study did not evaluate foraminal size past the 12-month follow-up interval. However, neither foraminal area nor foraminal height are expected to change after solid spondylodesis, which was shown for this study population at 1 year. McCormack et al. reported that 93 % of subjects had intrafacet bridging trabecular bone on CT scans, 100 % had translational motion <2 mm and 83 % had angular movement $<5°$ at 1 year [14].

Although there was a small, non-statistically significant decrease in foraminal size between the 6- and 12-month follow up intervals, favorable clinical results were maintained [14]. It appears that both motion elimination (via fusion) and increasing foraminal area are critical for successful outcomes in patients treated for cervical spondylotic radiculopathy.

Conclusions

Cervical fusion using bilateral posterior cervical cages can increase foraminal area and may indirectly decompress the nerve roots. Correlation between increase in foraminal area and clinical outcomes needs further investigation.

Compliance with ethical standards

Conflict of interest Kris Siemionow is on the scientific advisory board of Providence Medical Technologies.

References

1. Caridi JM, Pumberger M, Hughes AP (2011) Cervical radiculopathy: a review. HSS J Musculoskelet J Hosp Spec Surg 7:265–272. doi:10.1007/s11420-011-9218-z
2. Carrier CS, Bono CM, Lebl DR (2013) Evidence-based analysis of adjacent segment degeneration and disease after ACDF: a systematic review. Spine J Off J North Am Spine Soc 13:1370–1378. doi:10.1016/j.spinee.2013.05.050
3. Jiang H, Zhu Z, Qiu Y et al (2012) Cervical disc arthroplasty versus fusion for single-level symptomatic cervical disc disease: a meta-analysis of randomized controlled trials. Arch Orthop Trauma Surg 132:141–151. doi:10.1007/s00402-011-1401-7
4. Tanaka N, Fujimoto Y, An HS et al (2000) The anatomic relation among the nerve roots, intervertebral foramina, and intervertebral discs of the cervical spine. Spine 25:286–291
5. Umebayashi D, Hara M, Nakajima Y et al (2013) Transvertebral anterior cervical foraminotomy: midterm outcomes of clinical and radiological assessments including the finite element method. Eur Spine J Off Publ Eur Spine Soc Eur Spinal Deform Soc Eur Sect Cerv Spine Res Soc 22:2884–2890. doi:10.1007/s00586-013-2974-3
6. Frempong-Boadu A, Houten JK, Osborn B et al (2002) Swallowing and speech dysfunction in patients undergoing anterior cervical discectomy and fusion: a prospective, objective preoperative and postoperative assessment. J Spinal Disord Tech 15:362–368
7. Veeravagu A, Cole T, Jiang B, Ratliff JK (2014) Revision rates and complication incidence in single- and multilevel anterior cervical discectomy and fusion procedures: an administrative database study. Spine J Off J North Am Spine Soc 14:1125–1131. doi:10.1016/j.spinee.2013.07.474
8. Cole T, Veeravagu A, Zhang M, Ratliff JK (2014) Surgeon procedure volume and complication rates in anterior cervical discectomy and fusions: analysis of a national longitudinal database. J Spinal Disord Tech. doi:10.1097/BSD.0000000000000238
9. Witzmann A, Hejazi N, Krasznai L (2000) Posterior cervical foraminotomy. A follow-up study of 67 surgically treated patients with compressive radiculopathy. Neurosurg Rev 23:213–217
10. Shou F, Li Z, Wang H et al (2015) Prevalence of C5 nerve root palsy after cervical decompressive surgery: a meta-analysis. Eur Spine J Off Publ Eur Spine Soc Eur Spinal Deform Soc Eur Sect Cerv Spine Res Soc 24:2724–2734. doi:10.1007/s00586-015-4186-5
11. Leasure JM, Buckley J (2014) Biomechanical evaluation of an interfacet joint decompression and stabilization system. J Biomech Eng. doi:10.1115/1.4026363
12. Tan LA, Gerard CS, Anderson PA, Traynelis VC (2014) Effect of machined interfacet allograft spacers on cervical foraminal height and area. J Neurosurg Spine 20:178–182. doi:10.3171/2013.11.SPINE131
13. Goel A, Shah A (2011) Facetal distraction as treatment for single- and multilevel cervical spondylotic radiculopathy and myelopathy: a preliminary report. J Neurosurg Spine 14:689–696. doi:10.3171/2011.2.SPINE10601
14. McCormack BM, Bundoc RC, Ver MR et al (2013) Percutaneous posterior cervical fusion with the DTRAX Facet System for

single-level radiculopathy: results in 60 patients. J Neurosurg Spine 18:245–254. doi:10.3171/2012.12.SPINE12477

15. Roberts CC, McDaniel NT, Krupinski EA, Erly WK (2003) Oblique reformation in cervical spine computed tomography: a new look at an old friend. Spine 28:167–170. doi:10.1097/01.BRS.0000041581.18401.A7
16. Panjabi MM, Maak TG, Ivancic PC, Ito S (2006) Dynamic intervertebral foramen narrowing during simulated rear impact. Spine 31:E128–E134. doi:10.1097/01.brs.0000201243.81745.ba
17. Shrout PE, Fleiss JL (1979) Intraclass correlations: uses in assessing rater reliability. Psychol Bull 86:420–428
18. Kitagawa T, Fujiwara A, Kobayashi N et al (2004) Morphologic changes in the cervical neural foramen due to flexion and extension: in vivo imaging study. Spine 29:2821–2825
19. Yoo JU, Zou D, Edwards WT et al (1992) Effect of cervical spine motion on the neuroforaminal dimensions of human cervical spine. Spine 17:1131–1136
20. Brenke C, Dostal M, Scharf J et al (2015) Influence of cervical bone mineral density on cage subsidence in patients following stand-alone anterior cervical discectomy and fusion. Eur Spine J Off Publ Eur Spine Soc Eur Spinal Deform Soc Eur Sect Cerv Spine Res Soc 24:2832–2840. doi:10.1007/s00586-014-3725-9
21. Church EW, Halpern CH, Faught RW et al (2014) Cervical laminoforaminotomy for radiculopathy: symptomatic and functional outcomes in a large cohort with long-term follow-up. Surg Neurol Int 5:S536–S543. doi:10.4103/2152-7806.148029
22. Simpson AK, Sabino J, Whang P et al (2009) The assessment of cervical foramina with oblique radiographs: the effect of film angle on foraminal area. J Spinal Disord Tech 22:21–25. doi:10.1097/BSD.0b013e3181639b62
23. Marcelis S, Seragini FC, Taylor JA et al (1993) Cervical spine: comparison of 45 degrees and 55 degrees anteroposterior oblique radiographic projections. Radiology 188:253–256. doi:10.1148/radiology.188.1.8511307
24. Lee SE, Jahng T-A, Kim HJ (2015) Correlation between cervical lordosis and adjacent segment pathology after anterior cervical spinal surgery. Eur Spine J Off Publ Eur Spine Soc Eur Spinal Deform Soc Eur Sect Cerv Spine Res Soc 24:2899–2909. doi:10.1007/s00586-015-4132-6