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Non fusion options in cervical disc herniations

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Abstract

Cervical disc herniations are common disease encountered by spine surgeon. dISCESCTOMY and fusion have been long regarded as glod standard but non fusion options are gaining ground for speciifc indications. If the pathology is limited to one or two levels in the absence of instability, a limited posterior cervical foraminotomy (PCF) can be useful in decompressing the nerve roots to achieve clinical improvement in radiculopathy. A multilevel pathology with cord compression in the absence of instability can be treated effectively with a skip cervical laminectomy or a laminoplasty. In the presence of instability in two or single level pathology, where in the past a fusion would have been considered a gold standard, non-fusion options such as cervical disc arthroplasty have evolved (ACDR).

Keywords: Cervical dis herniation, foraminotomy, laminectomy, laminoplasty, cervical disc arthroplasty

Introduction

Degenerative changes in the cervical spine can manifest in two broad ways as either biomechanical or neurological problems. The trigger for a dysfunctional cervical spine motion is frequently a single or two-level cervical degenerative changes. A loss of cervical lordosis occurs in the presence of dysfunctional motion. The causes for the loss of cervical lordosis can range from painful paraspinal spasm to multilevel disc degeneration. Biomechanical dysfunction can be treated initially by conservative treatment, failure of which can trigger the need for surgery. A neurological deficit is a compelling indication to consider surgery. These can be secondary to impingement of the spinal cord and/or the nerve roots secondary to the degenerative process resulting in radiculopathy, myelopathy or a combination of the two. Cervical spine mobility is important to the human interaction with the surrounding environment. The important senses, i.e. sight, hearing and smell require the functional use of a mobile cervical spine. Hence in the event of any pathology that restricts cervical motion, we as healthcare providers are expected to return the neck to the "pre-morbid" functional motion. In the face of instability the gold standard surgical solution has been to fuse the motion segments. Anterior cervical discectomy and fusion (ACDF) is considered a gold standard for one or two level cervical degenerate pathology with a loss of disc height and nerve root impingement. Fusion of one or two motion segments does not lead to any loss of functional mobility although biomechanical studies have shown that the motion mechanics in the native segment adjacent to a fused segment are rendered abnormal [1, 2, 3, 4]. These have been noted in several long term and medium term studies and have gained notoriety as "adjacent segment disease". Futhermore, anterior cervical fusion has been linked to a 20% incidence of pseudarthrosis, donor site morbidity [5]. If the pathology is limited to one or two levels in the absence of instability, a limited posterior cervical foraminotomy (PCF) can be useful in decompressing the nerve roots to achieve clinical improvement in radiculopathy. A multilevel pathology with cord compression in the absence of instability can be treated effectively with a skip cervical laminectomy or a laminoplasty. In the presence of instability in two or single level pathology, where in the past a fusion would have been considered a gold standard, non-fusion options such as cervical disc arthroplasty have evolved (ACDR).

Posterior Cervical Foraminotomy

History, rationale and indications

Posterior cervical foraminotomy (PCF) was described in the 1940s and is rightfully considered a reasonable and effective procedure in the appropriately selected patients [6] Posterior cervical foraminotomy allows to achieve direct decompression of the nerve root while maintaining stability and avoiding fusion of a motion segment [7, 8, 9]. It is usually performed in patients with

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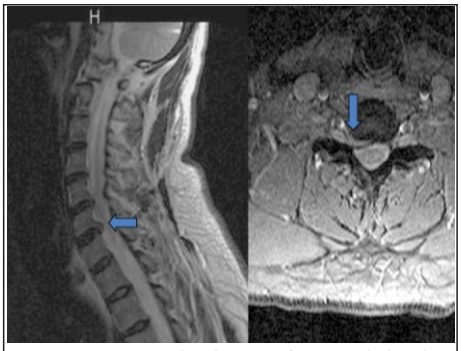
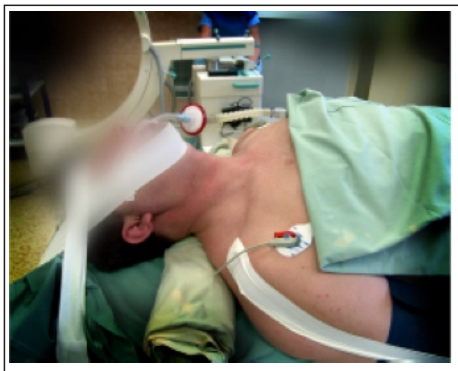


Figure. 1: A typical indication for a single level cervical arthoplasty. 45 year old male with axial neck and right arm pain radiating into the middle finger. MRI shows a soft disc herniation at C67 extending into the right side foramen impinging on the right C7 nerve root.



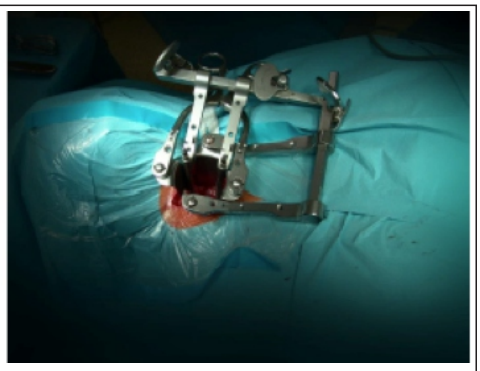


Figure. 2: Accurate assessment of the midline during positioning aids accurate placement of the prosthesis and is crucial in obtaining a good outcome.

unilateral radiculopathy due to posterolateral or foraminal disc herniation or disk/osteophyte complex. Single or double level decompression is normally performed however there are reports of successful decompressions of three consecutive levels as well[10]. In cadaveric studies it has been shown that even bilateral foraminotomy does not increase instability of the motion segment as long as at least half of the joint and joint capsule are being preserved [11, 12] PCF stands for a reasonable option in patients with recurrent or persistent symptoms following anterior cervical discectomy and fusion (ACDF) or disc replacement (ACDR). Whilst revision anterior approach is always an option PCF allows achieving satisfactory decompression omitting the risk of injury to the anterior cervical structures (oesophagus, trachea, recurrent laryngeal nerve) and dysphonia or dysphagia [7, 13, 14] Cervical instability revealed by preoperative flexion-extension plain radiographs stands for the contraindication for PCF. Prior ipsilateral PCF and lateral mass hypoplasia where further decompression may result in iatrogenic instability is another contraindication similarly to scars technical skills and unfamiliarity with this approach.

Technical considerations

The procedure is performed under general anaesthesia with a standard single dose of i.v. antibiotics administered during induction. The patient is positioned in "Condorde" position with the head slightly flexed and fixed using Mayfield clamp. It is advised to keep the skin of the neck horizontal, ideally 10-15 cm above the heart. Sitting position can be used as an alternative in patient who are obese or suffer from severe ventilatory disturbances [15] It is crucial to localize the target level on a lateral fluoroscopic image. It allows planning of the short incision but even more importantly - while using minimally invasive trans-muscular approach - it provides a truly perpendicular track for the blunt splitting of muscles. Skin incision is then performed 10 mm off the midline. After incision of the skin and subcutaneous fat tissue, the superficial fascia of the trapezius muscle appears. The superficial fascia of the trapezius muscle is the first plane to be cut. The fibres are bluntly split with the tip of scissors or with a dissector along their oblique direction. The deep fascia of the trapezius muscle is sharply incised. The deeper muscle layers are opened one by one following the same technique. Having reached the lateral mass, the level of dissection is confirmed with intraoperative XR. Once triangle of the flavum ligament comes into view, an expandable tubular retractor or a miniaturized speculum counter retractor system is placed centred on it. Keeping the direction of the dissection

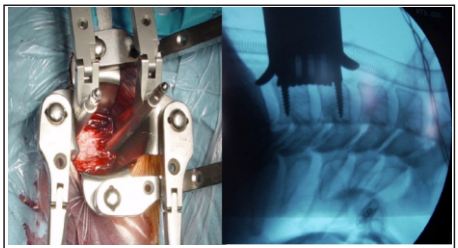


Figure. 3: Accurately placed distraction pins in the midline. These effect a uniform distraction across the disc space that aids in the placement of a 'exact match' disc arthroplasty, after a through decompression.

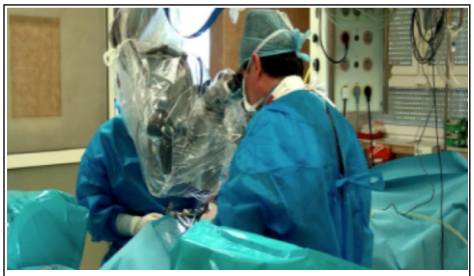


Figure. 4: An important aspect of the procedure is an adequate disc clearance and decompression of the nerve root. This is facilitated microscopically

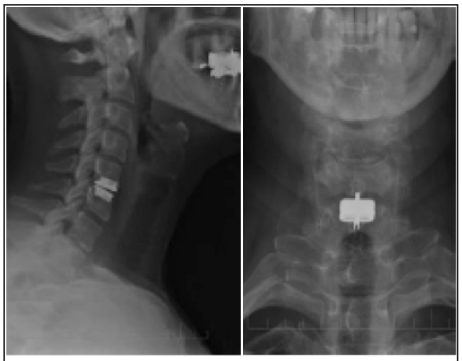


Figure. 5: A post-operative antero-posterior and lateral radiograph confirms adequacy of the spacer height and midline location. This, in tern, has a bearing on the location of the centre of rotation.

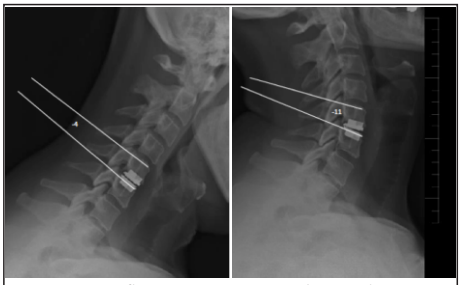


Figure. 6: A flexion extension radiograph at 3 months post-operatively confirms adequate motion at the level of the disc replacement.

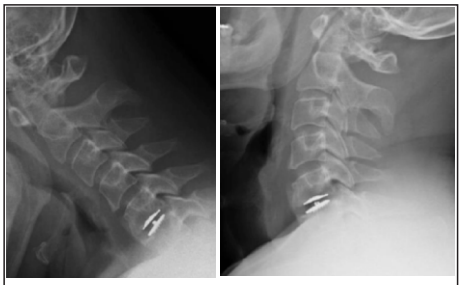


Figure. 7: Flexion extension radiographs 3 years post-operatively in a 54 year old male demonstrates no motion at the level of the disc replacement. There was a good relief of neck and arm pain despite the hypertrophic ossification.

converge 5 to 10 ° towards the midline prevents "lateral bypassing" of the lateral mass, especially in large necks. For orientation purposes, it is important to visualize the medial one-third of the rostral and caudal lateral mass, and the lateral one-third of the rostral and caudal lamina of interest. The classic bony window consisting of the medial quarter of the facet joint, the lower rim of the cranial lamina and the upper rim of the caudal lamina is drilled off with a high-speed burr ('fine-touch' cutting or diamond 3-4 mm tip - depending on the preference and experience. The yellow ligament is detached from the inferior edge at the under surface of the rostral lamina. After visualising the epidural fat, the dura is exposed from the lateral toward the medial aspect of the spinal canal. Low-intensity bipolar haemostasis and readily available haemostatic agents are used in order to control venous epidural bleeding. If needed, dorsal bone overlying the root exiting in the foramen is removed at this point, i. e., before manipulating the root. The root itself is exposed and decompressed, usually the extruded disc fragment is located underneath the root in its axilla. Following the removal of the extruded disc prolapse if the root is not felt to be completely free, exploration of its shoulder becomes mandatory. Before wound closure appropriate haemostasis needs to be assured. Following the removal of retractors, the wound is closed in a multi-layered fashion without a need for drain or external brace.

Table 1: ?????

Ability to tolerate physiological loads without premature fatigue or failure
Superior wear properties and minimal wear debris
Easy secured to the host bone at the time of insertion and incorporated in the long term
Reproduction of the normal disc kinematics with axis of rotation similar to the normal spine and protection of the facets from abnormal stresses

Outcomes and clinical evidence

Based on the available evidence, PCF seems to be another good surgical approach in the treatment of cervical radiculopathy. Liu et al. performed a systematic review including three prospective randomized controlled trails and seven retrospective comparative studies comparing ACDF with PCF. These studies were assessed on risk of bias according to the Cochrane Handbook for Systematic Reviews of Interventions, and the quality of evidence and level of recommendation were evaluated according to the GRADE approach. Clinical outcomes, complications, reoperation rates, radiological parameters, and cost/cost- utility were evaluated [16] No significant difference was found between these two methods with regards to the clinical outcomes (nearly 88% of patients reports significant improvement), complications, and reoperation rates. Meanwhile, postoperative disability was on average shorter for PCF and PCF might have lower medical cost than ACDF not increasing the ROM of the adjacent segment, which might decrease the incidence of adjacent segment disease.

Skip Laminectomy

History, rationale and indications

The surgical treatment of cervical myelopathy has been improved significantly using a variety of methods of expansive laminoplasties [17, 18, 19, 20, 21]. However, postoperative problems, such as persistent axial symptoms, marked restriction of neck motion and loss of cervical lordosis, have remained unsolved. This problems are caused by intraoperative damage to the posterior extensor mechanism of the cervical spine cased by the surgical approach and removal of the posterior tension bad[22]. During multilevel posterior decompression (laminectomy or laminoplasty) not only the posterior arches of the decompressed levels but also the muscular attachments to all those spinous processes are affected. The detached deep extensor muscles can no longer act on the spinous processes because their insertions are left unrepaired. That leads to irreversible atrophy of the muscles, loss of function with all the consequences listed above. In 1998 Shiraishi developed skip laminectomy1 to prevent these problems. His techniques, which has gained on popularity significantly over the past few years allows removing posterior anatomic structures compressing the spinal cord such as hypertrophic ligamentum flavum and the cephalad portion of the inferior lamina without damaging the function as well as structure of the posterior tension band itself which has been proved by good short- but also long-term results[23].

Technical considerations

The method described below is based on a four-level decompression between C3–C4 and C6–C7 originally described by Shiraishi in 2002 [24]. The laminae

to be removed are decided from analyses of imaging studies. The procedure is performed under general anaesthesia with a standard single does of i.v. antibiotics administered during induction. The patient is positioned in "Condorde" position with the head slightly flexed and fixed using Mayfield clamp. It is advised to keep the skin of the neck horizontal, ideally 10-15 cm above the heart. Sitting position can be used as an alternative in patient who are obese or suffer from severe ventilatory disturbances[15]. After longitudinally dividing the nuchal fascia in line with the midline skin incision, each interlaminar space between C3–C4 and C6–C7 is exposed using the author's technique for exposure of the cervical spine laminae[24]. The C4 and C6 laminae which are going to be removed are exposed by splitting the spinous processes in half and separating from each posterior arch using a high-speed drill with a fine 3-mm burr. It allows to preserve the attachments of the semispinalis cervicis and multifidus muscles bilaterally. The upper two levels, C3–C4 and C4 –C5, are decompressed by removing the C4 lamina, the cephalad half of C5 lamina and the ligamenta flava at those two levels. The proximal portion of the ligamentum flavum at C3–C4 is removed from the ventral aspect of the C3 lamina using a small curved curette and a fine Kerrison rongeur. The lower two levels, C5–C6 and C6 –C7, are decompressed in the same fashion. In the case where probing under the preserved lower lamina with a fine spatula reveals that only insufficient space has been gained, the ventral surface of the lamina is undercut using a Kerrison rongeur. The four-level decompression is thus achieved preserving the C3, C5, and C7 spinous processes as well as their attaching muscles. The split fragments of the C4 and C6 spinous processes are then reapproximated with a strong non-absorbable suture.

Outcomes and clinical evidence

In 2003 Shiriashi et al. presented their long-term outcomes[23]. They analysed records of 100 patients suffering from cervical myelopathy with nearly 50:50 split between skip laminectomy and open-door laminoplasty as treatment used. They did not observe significant differences in neurological outcomes and postoperative complications in both groups. Postoperative recovery was quicker in the group of skip laminectomy similarly to the better long-term functional and radiological results. Only recently Luo et al. published a meta-analysis comparing results of skip laminectomy and more classic laminoplasty [16]. They presented results of the analysis of four studies comprising 241 patients. Skip laminectomy and laminoplasty were comparable in terms of cervical lordotic curvature and range of motion. The pooled data revealed however that the mean visual analogue scale score for pain of the skip laminectomy group was significantly lower than that of the laminoplasty group and the rate of axial pain was also significantly lower. The atrophy rates of the deep extensor muscles in the skip laminectomy group (14%) were significantly lower than that of the laminoplasty group (60%). In a fairly convincing way this meta-analysis suggested that skip laminectomy is superior to laminoplasty in terms of persistent postoperative paint as well as rates of axial pain and muscle atrophy.

Cervical Disc replacement

Rationale for cervical arthroplasty:

A cervical fusion aims to convert a triple joint complex to a single unit. This is based on the premise that the pain emanates from abnormal motion. Elimination of the abnormal motion should consequently eliminate the pain. However the biomechanical studies have shown that the fusion can lead to abnormal force concentration at the adjacent segment. Intervertebral spacers with innate mobility can be used to prevent this biomechanical consequence. It would allow for more normal force distribution while achieving the decompression of the normal structures, restoring the disc height and allowing facet joints to function normally [25,26]. Biomechanical studies have shown that intervertebral disc replacements can maintain normal cervical spine kinematics [3, 27, 28]. This results in restoring segmental and regional cervical spine alignment and restoring the functional mobility of the cervical spine. Although this has been tested in the biomechanical models as well as in cadaveric experiments [29], the long term clinical results need further assessment.

Design – types, evolution and salient features:

Whilst a cervical fusion can be fraught with the problems of pseudarthrosis, donor site morbidity, the design of the arthroplasty is the potential limiting factor. Our experience from lower limb arthroplasty is that there are three classes of constraint that can be built into a device. A fully constrained device is one where a mechanical stop is built into the mechanism within the physiological range of motion, a semi-constrained device has a mechanical stop outside the normal range of motion while an unconstrained device does not have a mechanical stop [30]. Whilst the constrained prosthesis provides for greater stability it has a fixed axis of rotation and has the ability to minimise the shear stresses on the facet joint. In order to get the best out of a fully constrained prosthesis it is imperative to get the precise placement and accurate reproduction of the natural axis of rotation. The other end of the spectrum of arthroplasty design is an

unconstrained prosthesis that allows for translation and provides for a lower stress concentration at any point along the articulating surface. Although these are more forgiving with accuracy of placement, they have a much lower innate stability and expose the facet joints to greater and shear torsional loads[31,32]. Design considerations are central to the function of the cervical arthroplasty. The device kinematics are affected by the bio-materials used, prosthesis shape, dimensions, methods of anchorage to the host bone and the type of the articulation. Though several articulation types are available in the market, the commonest generic types are a ball and socket articulation and a saddle type of articulation. Whilst the ball and socket articulation provides for a purely rotational motion, the saddle type of a joint has much less constraint and allows for rotation and translation. The basic premise in material consideration for articulation is to recreate normal motion while minimising wear. The bearing surfaces should have the ability to distribute load with minimal or low friction and a high wear resistance. Stainless steel bearing surfaces lead to corrosion and have a high fatigue failure. On the other hand cobalt chromium and titanium exhibit better bio-compatibility, resistance to corrosion and have superior biomechanical properties. Titanium scores above all of the materials in being MRI compatible [33,34]. Anchorage of the prosthesis to the host bone should be considered microscopically and macroscopically, both at the time of the insertion and in the longer term. Spikes, keels and screws can provide an effective endplate fixation. However, screws have largely been replaced in newer designs although were common in the earlier prototypes.
Macroscopically the surface texture alteration and porosity provide additional features for immediate and long term stability. Surface coatings such as plasma sprayed titanium, titanium mesh, aluminium oxide, porous cobalt chromium and bioactive materials such as hydroxyapatite and calcium phosphate have all been explored in different arthroplasty designs. 34 At the microscopic level the ability of the surface to allow for biological incorporation provides for long term stability of the prosthesis. An important consideration for longevity of the fixation is the wear property of the bearing surfaces. The wear particles can incite an inflammatory reaction and produce cytokines. Besides the failure of the bearing surfaces by the wear process the cytokines that are produced secondarily can lead to bone resorption leading to loosening of the anchorage and further mechanical failure[35]. In summary, the ideal prosthesis should be able to tolerate physiological loads without premature fatigue and consequent failure, have superior wear properties and generate minimal wear debris, are easily secured to the host bone and protect the facet joints from biomechanical stress while reproducing the kinematics of the normal spine.
Table

Patient selection indications and surgical considerations:

One or two level degenerative changes with instability and symptoms of neck and arm pain are typical clinical situations that would benefit from cervical arthroplasty. In the absence of a robust long term outcome, multilevel pathology or skip pathology are not recommended for treatment by cervical arthroplasty except if under a clinical trial. Clinical and radiological concordance with the level and side of pathology and the symptoms of radiculopathy should be confirmed. The typical indication would be a one or a two level soft disc prolapse with concordant symptoms and MRI findings. (Figure 1) A cervical arthroplasty in the presence of myelopathy is not recommended. Similarly cervical arthroplasty is contraindicated in the presence of a tumour, infection, significant deformity, reduced preoperative range of motion, osteopenia and pre-existing facet joint disease. The primary goal of surgery is to restore the disc height, segmental motion and remove the degenerative compression of the neural structures. Secondary goals of treatment include preservation of global spinal biomechanics and alignment and restoration of functional motion of the rest of the cervical spine and consequently allowing for reduction in the incidence of adjacent level pathology. While counselling and selecting patients it is imperative to consider the long term goals of the prosthesis in achieving incorporation into the host bone. Bone health should be considered. Established osteoporosis and smoking should be mitigated against and the patient should be counselled appropriately. Surgical considerations should include a full appraisal of the device being implanted by the surgeon and good understanding of the biomechanics of the design. The procedure is performed through a routine Smith Robinson approach. An important aspect in positioning, is to maintain the head and neck in the neutral position. This facilitates intra-operative identification of the midline. This is critical in accurate placement of the spacer to reproduce the centre of motion of the replaced disc. (Figure 2) Identification of the midline with bi-planar imaging is undertaken at the time of placement of the distractor pins. The distractor pins are placed to provide a uniform disc height and lordosis reconstruction. It is imperative to prevent "over-stuffing" of the disc or placement of an implant in a "lax mode" without due soft tissue tensioning. (Figure 3) It should be recognised that the device is merely a spacer. As with anterior cervical discectomy and fusion

a thorough disc clearance and decompression of the neural structures is the primary surgical goal. This should lead to the creation of a rectangular space for placement of the arthroplasty. While achieving the disc clearance the integrity of the bony endplate should be ensured with a thorough removal of the cartilaginous endplate. The creation of a rectangular gap with surgical carpentry allows for soft tissue tensioning for the the placement of the 'optimal' spacer. This allows for the best milieu for prosthesis incorporation at the time of insertion and in the long term. (Figure 4) Post-operative immobilisation is not required. The antero-posterior radiographs provide confirmation of the restoration, normalisation of the disc height and a symmetrical placement of the 'spacer'. (Figure 5) Postoperative flexion/extension radiographs aid in confirming the achievement of the surgical goals. (Figure 6)

Outcomes and clinical evidence:

Clinical studies have lent credence to the presence of adjacent level disease. Hillibrand reviewed 374 patients undergoing anterior cervical discectomy and fusion between 1973 and 1992, with a maximum 21 year follow up. He reported adjacent level disease over a 10 year period with symptomatic disease in 2.9% per year and 25.6% of the cohort being affected at 10 years. This was more likely to occur at C5/6 and C6/7 as well as in older patients (relative risk 4.9), though was less in multilevel pathology. This suggested that the findings may be influenced by the natural history as also by the biomechanical factors[1]. The evolution of cervical arthroplasty has been slow and has been guided by early FDA clinical trials. The gold standard has been a competitive group comprising of anterior cervical discectomy and fusion. A large RCT noted that the clinical and quality of life results were similar between arthroplasty and fusion groups. However, 3.4% in the fusion group required adjacent level surgery as compared with 1.1% in the arthroplasty group[36]. Another study reported a meta-analysis of four prospective randomised controlled FDA/IDE clinical trials on 1608 patients across 98 sites over 24 months. They reported a statistically significant treatment effect favouring arthroplasty as compared to ACDF. Several studies have reported cervical arthroplasty to be a safe and effective option to anterior cervical fusion [37,38,39,40]. However a distinct disconnect has been reported between clinical outcomes and biomechanical studies[3, 41, 42]. This may be due to a variety of causes. The design of the prosthesis is a significant variable. The Bryan disc has been reported as demonstrating good functional motion at five years though this does not automatically establish the device's longevity in the long term[35]. It has been suggested that some of the reported adjacent level disease may be radiological finding and over-diagnosis rather than symptomatic problem[43]. Variations in the design can affect variations in wear, facet joint loading, bone modelling and implant incorporation [43]. Safety and efficacy in single level cases have been reported with good 30 day outcomes with the patients being treated as outpatients [44,45]. Multi-level disc replacements has been reported with good clinical and radiological results, though should be considered as a part of clinical trials and a part of future prospective studies [46]. Some series have reported hybrid combination of fusion and disc replacements with good results. However, the adjacent level motion is higher with fusion than disc replacements suggesting that the arthoplasty may be protective for the un-operated segments[47]. Some series have reported hetrotopic ossification. It has been suggested that this can be minimised by surgical technique. However, some series have reported a high incidence of this complication. Its presence is not linked to a poor outcome, though defeats the purpose of maintaining mobility. Poor technique and design flaws can lead to dislocation. Achieving an adequate soft tissue tension during the operation allows for a good primary stability. Some keel-less designs that are unconstrained have a higher incidence of dislocation [48,49]. The jury is still out and longer term studies with consistent cervical arthroplasty designs will be required for accurate literature validation in the future.

References

1. Hillibrand AS, Carlson GD, Palumbo MA, Jones PK, Bohlman HH. Radiculopathy and myelopathy at segments adjacent to the site of a previous anterior cervical arthrodeisis. JBJS Am 1999; 81: 519 – 528
2. Wigfield CC, Skrypiec D, Jackowski A, Adams MA. Internal stress distribution in cervical intervertebral discs: the influence of an artificial cervical joint and simulated anterior interbody fusion. J Spianl Disord Tech 2003; 16: 44 – 49
3. Puttlitz CM, Rousseau MA, Xu Z, Hu S, Tay BK, Lotz JC. Intervertebral disc replacement maintains cervical spine kinetics. Spine 2004; 29: 2809 – 2814
4. Powell JW, Sasso RC, Metcalf NH, Anderson PA, Hipp JA. Quality of spinal motion with disc arthoplasty: computer-aided radiographic analysis. J Spinal Disord Tech 2010; 23: 89-95
5. Sekhon LH, Ball JR. Artificial cervical disc replacement: principles, type and techniques. Neurol India 2005; 53: 445 – 450
6. Scoville WB. Recent developments in the diagnosis and treatment of cervical ruptured intervertebral discs. Proc Am Fed Clin Res. 1945; 2:23.
7. Woods BI, Hilibrand AS. Cervical radiculopathy: epidemiology, etiology, diagnosis, and treatment. J Spinal Disord Tech. 2015;28: E251–E259.
8. Church EW, Halpern CH, Faught RW, et al. Cervical laminoforaminotomy for radiculopathy: symptomatic and functional

out- comes in a large cohort with long-term follow-up. Surg Neurol Int. 2014;5(suppl 15):S536–S543.

9. Albert TJ, Murrell SE. Surgical management of cervical radiculopathy. J Am Acad Orthop Surg. 1999;7:368–376.
10. Skovrlj B, Gologorsky Y, Haque R, et al. Complications, outcomes, and need for fusion after minimally invasive posterior cervical foraminotomy and microdiscectomy. Spine J. 2014;14:2405–2411
11. Bevevino AJ, Lehman RA Jr, Kang DG, et al. The effect of cervical posterior foraminotomy on segmental range of motion in the setting of total disc arthroplasty. Spine. 2014;39:1572–1577.
12. Zdeblick TA, Abitbol JJ, Kunz DN, et al. Cervical stability after sequential capsule resection. Spine. 1993;18:2005–2008.
13. Lubelski D, Healy AT, Silverstein MP, et al. Reoperation rates after anterior cervical discectomy and fusion versus posterior cervical foraminotomy: a propensity-matched analysis. Spine J. 2015;15: 1277–1283.
14. Caridi JM, Pumberger M, Hughes AP. Cervical radiculopathy: a review. HSS J. 2011;7:265–272.
15. Papavero L, Kothe R. Minimally invasive posterior cervical foraminotomy for treatment of radiculopathy : An effective, time-tested, and cost-efficient motion-preservation technique. Oper Orthop Traumatol. 2018 Feb;30(1):36-45. doi: 10.1007/s00064-017-0516-6.
16. Luo W, Li Y, Zhao J, Zou Y, Gu R, Li H. Skip Laminectomy Compared with Laminoplasty for Cervical Compressive Myelopathy: A Systematic Review and Meta-Analysis. World Neurosurg. 2018 Sep 8. pii: S1878-8750(18)32040-0. doi: 10.1016/j.wneu.2018.08.231.
17. Hidai Y, Ebara S, Kamimura M, et al. Treatment of cervical myelopathy with a new dorsolateral decompressive procedure. J Neurosurg 1999;90:178–85.
18. Ishihara A. Roentgenological investigation on the cervical lordosis of normal subjects. J Jpn Orthop Assoc 1968;42:1033–44.
19. Itoh T, Tsuji H. Technical improvements and results of laminoplasty for compressive myelopathy in the cervical spine. Spine 1985;10:729–46.
20. O'Brien MF, Peterson D, Casey AT. A novel technique for lamino-plasty augmentation of spinal canal area using titanium miniplate sta-bilization: a computerized morphometric analysis. Spine 1996;21: 474–84.
21. Yoshida M, Otani K, Shibasaki K, Ueda S. Expansive laminoplasty with reattachment of spinous process and extensor musculature for cervical myelopathy. Spine 1992;17:491–7.
22. Shiraishi T. Skip laminectomy—a new treatment for cervical spondylotic myelopathy, preserving bilateral muscular attachments to the spinous pro- cesses: a preliminary report. Spine J. 2002;2:108 –115.
23. Shiraishi T, Fukuda K, Yato Y, Nakamura M, Ikegami T. Results of skip laminectomy- minimum 2-year follow-up study compared with open-door laminoplasty. Spine (Phila Pa 1976). 2003;28:2667-2672.
24. Shiraishi T. A new technique for exposure of the cervical spine laminae: technical note. J Neurosurg. 2002;96(Spine 1):122–126.
25. Pickett GE, Mtsis DK, Sekhon LH, Sears WR, Duggal N. Effects of cervical disc prosthesis on segmental and cervical spine alignment. Neurosurg Focus 2004; 17: 30 – 35
26. Wigfield C, Gill S, Nelson R, et al. Influence of an artificial cervical joint compared with fusion on adjacent level motion in the treatment of degenerative cervical disc disease. J Neurosurg Spine 2002; 96: 17 – 21.
27. Eck JC, Humphreys SC, Lim TH, et al. Biomecahnical study on the effect of cervical spine fusion on adjacent-level intra-discal pressure and segmental motion. Spine 2002; 27 : 2431 – 4.
28. Matsunaga S, Kabayama S, Yamamoto T, et al. Strain on inter-vertebral discs after anterior cervical decompression and fusion. Spine 1999; 24: 670 – 5
29. Kotani Y, Cunningham BW, Abumi K, et al. Multidirectional flexibility analysis of cervical artificial disc reconstruction: in vitro human cadaveric spine model. J Neurosurg Spine 2005; 2: 188 – 194.
30. Phillips FM, Garfin SR. Cervical disc replacement. Spine 2005; 30: 527 – 533.
31. McAfee PC, Cunningham B, Dmitriev A, et al. Cervical disc replacement porous coated motion prosthesis: a comparative biomechanical analysis showing the key role of the posterior longitudinal ligament. Spine 2003; 28: S176 – S185
32. Dooris AP, Goel VK, Grosland NM, et al. Load sharing between anterior and posterior elements in a lumbar motion segment implanted with an artificial disc. Spine 2001: 26: E122 – E129
33. Anderson PA, Sasso RC, Hipp J, Norvell DC, Raich A, Hashimoto R. Kinematics of the cervical adjacent segments after disc arthoplasty compared with anterior discectomy and fusion: a systematic review and meta-analysis. Spine 2012; 37 (22 Suppl): S85 – S95
34. Takasali S, Graeur JN, Vaccaro A. Material considertaions for intervertebral disc replacement implants. The Spine Journal 4 (2004); 231S – 238S
35. Anderson PA, Rouleau JP, Bryan VE, Carlson CS. Wear analysis of the Bryan Cervical Disc Prospthesis. Spine 28 (20S); 2003: S186 – S194
36. Mummaneni PV, Burkus JK, 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: 198 – 209
37. McAfee PC, Reah C, Gilder K, Eisermann L, Cunningham B. A meta-analysis of comparative outcomes following cervical arthroplasty or anterior cervical fusion. Spine 37 (11); 2012: 943 – 952
38. Ryu WH, Kowalczyk I, Duggal N. Long term kinematic analysis of cerbical spine after single level implantation of Bryan cervical disc prosthesis. The Spine Journal 13 (2103): 628 – 634
39. Hisey MS, Bae HW, Davis R, et al. Multi-centre, prospective, randomized, controlled investiogational device exemption clinical trail 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 Surgery 2014, 8
40. Harrod CC, Hillibrand AS, Fischer DJ, Skelly AC. Adjacent segment pathology following cervical motion-sparing procedures or devices compared with fusion surgery: a systematic review. Spine 2012; 37 (22 Suppl): S96 – S112
41. Goel VK, Faizan A, Palepu V, Bhattacharya S. Parameters that effect spine biomechanics following cervical disc replacement. Eur Spine J 2012; 21 (5): S688 – 699
42. Zhao Y, Du C, at al. Does rotation centre in artificial disc affect cervical biomechanics? Spine 40 (8); 2015: E469 – E475
43. Goffin J, Geusens E, Vantomme N, et al. Long term follow-up after interbody fusion of the cervical spien. J Spinal Disord Tech 2004; 17: 79 - 85
44. Bovouratwet P, Fu, Ondeck NT, et al. Safety of artificial single level cervical total disc replacement: A propensity matched multi-institution study. Spine 2018, sept 21
45. Segal DN, Wilson JM, Staley C, Yoon TS. Outpatient and Inpatient single level cervical total disc replacement: A comparison of 30 day outcomes. Spine June 11, 2018
46. Li Y, Shen H, Khan KZ, et al. Comparison of multi-level cervical disc replacement and multi-level anterior discectomy and fusion: A systematic review of biomechanical and clinical evidence. World Neurosurgery Aug 2018; 116: 94 – 104
47. Wu TK, Meng Y, Wang BY, et al. Is the behaviour of disc replacement adjacent to fusion affected by the location of the fused level in hybrid surgery? Spine J 2018, Aug 27.
48. Mehren C, Heider F, Sauer D, et al. Clinical and radiological outcome of a new total cervical dsic replacement design. Spine July 2018
49. Sasso RC, Anderson PA, Riew KD, Heller JG. Results of cervical arthoplasty compared with anterior discectomy and fusion: four-year clinical outcomes in a prospective, randomized controlled trial. J Bone Joint Surg Am 2011; 93: 1684 – 1692

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