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REVIEW

Cervical disc herniation: which surgery?

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Abstract

Purpose Cervical disc herniation is a common pathology. It can be treated by different surgical procedures. We aimed to list and analyzed every available surgical option. We focused on the comparison between anterior cervical decompression and fusion and cervical disc arthroplasty.

Results The anterior approach is the most commonly used to achieve decompression and fusion by the mean of autograft or cage that could also be combined with anterior plating. Anterior procedures without fusion have shown good outcomes but are limited by post-operative cervicalgia and kyphotic events. Posterior cervical foraminotomy achieved good outcomes but is not appropriate in a case of a central hernia or ossification of the posterior ligament. Cervical disc arthroplasty is described to decrease the rate of adjacent segment degeneration. It became very popular during the last decades with numerous studies with different implant device showing encouraging results but it has not proved its superiority to anterior cervical decompression and fusion. Anterior bone loss and heterotopic ossification are still to be investigated.

Conclusion Anterior cervical decompression and fusion remain the gold standard for surgical treatment of cervical disc herniation.

Keywords Cervical disc herniation · Cervical disc arthroplasty · Anterior cervical decompression

Introduction

Degenerative cervical disc disease is a common pathology, causing neck pain, radiculopathy, and myelopathy [1, 2]. Anterior cervical decompression and fusion (ACDF) is the gold standard in case of symptomatic cervical disc herniation resistant to medical care. It has shown its efficiency and safety in many studies [2–4]. It was first published in 1958 by Smith et al. [5]. Different surgical procedures and devices have been described to achieve bony fusion during the last decades [6–8].

Even though ACDF has been used for decades, other procedures without arthrodesis have been developed to treat cervical disc herniation whether by anterior [9] or posterior approach [10].

Cervical disc arthroplasty (CDA) has first been reported in 1964 by Reitz et al. [11]. Its popularity has been growing constantly since its first use, supported by good clinical results. The preserved range of motion [12, 13] and theoretical prevention of adjacent segment degeneration (ASD) need to be moderated by specific complications such as heterotopic ossification (HO) and anterior bone loss (ABL) [14, 15].

The aim of this study was to review the literature about the available surgical options in case of cervical disc herniation and to focus on comparison between ACDF and CDA.

Available surgical procedures

Posterior approach

Posterior cervical foraminotomy (PCF) is a commonly performed surgery. First described by Scoville et al. in 1944

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[16], it has proven its efficiency and safety. PCF could be performed by endoscopic or open technique [1, 17, 18].

In both cases, patient in a Mayfield three-point head fixation is placed on a semi-sitting position minimizing blood accumulation and allowing an easy use of fluoroscopic control (C-arm). Endoscopic method has been described in several studies [10, 17–19]. A 2-cm incision is made, approximatively 1.5 cm off midline. A K-wire is slowly advanced until being docked in the infero medial side of the lateral mass at the level of interest. Dilatators and retractors with growing diameters are then inserted. The endoscope is attached to the tube. After ligamentum flavum is gently detached from the inferior edge of the superior lamina, a Kerrison or a high-speed drill is used to obtained nerve root decompression with a maximum of 50% facetectomy to minimize post-operative destabilization. The open posterior approach is more aggressive on paraspinal muscles and results in post-operative pain and dysfunction [20]. Endoscopic PCF is an efficient technique and results in 87 to 97% rate of pain relief [17–19]. However, iatrogenic cervical spine instability after bone resection remains a concern when facetectomy is performed without arthrodesis [21], and PCF is not appropriate in case of ossification of the posterior ligament or central hernia.

Anterior approach

Anterior cervical decompression and fusion

It is the most commonly used approach when taking care of a cervical disc herniation. ACDF is widely performed and the surgical procedure is well described [1, 3, 5, 8]. The patient is placed in supine position with his arms along him and shoulders taped to allow for C-arm imaging. Left- or right-side approach is decided by surgeon preference however it is advised to perform a left-sided approach if the index-level is lower to C5-C6 to avoid lesion of recurrent laryngeal nerve. Some surgeons would prefer a contralateral approach from the hernia lateralization. A transverse skin incision is performed. Dissection is performed along the anterior edge of the sternocleidomastoid muscle and deeply between the carotid sheath laterally and oesophagus and trachea medially. Discectomy is performed through an incision of the anterior longitudinal ligament. The intervertebral disc is removed with curettes, and the posterior longitudinal ligament should be systematically removed on the hernia side including the removal of osteophytes and posterior part of the uncinate process. A specific distractor could be used such as Cloward's or Caspar's. The endplates are cleaned of the cartilage and finally, the graft or cage is placed in the interspace.

Different methods to achieve bony fusion could be used. Historically, spine fusion was obtained with autologous iliac crest graft. Since tricortical iliac crest graft causes morbidity to the donor site [22], artificial devices filled with autologous cancellous bone or bone substitute are mainly used since the last decade. Bone substitute should have osteoinductive and osteoconductive properties such as tricalcium phosphate [23] or demineralized bone matrix combined with bone morphogenic protein [24]. An allograft is also an option but it has not shown such high fusion rate, and infections have been described [25].

Need for additional osteosynthesis associated with cervical intersomatic cage is debated. The ACDF procedure with additional anterior cervical plating (ACP) has been performed and showed a very high fusion rate with encouraging clinical outcomes [26, 27]. Nevertheless, ACP is associated with specific complications such as screw pull-out, screw breakage, or plate loosening [28] and it may be associated with a higher rate of dysphagia and soft tissue injury [29, 30]. ACP may be used in a single-level procedure by some surgeons but it is mainly used in the case of multi-level ACDF to enhance stabilization. To minimize the ACP procedure complications, self-locking stand-alone cages have been developed. Stand-alone cages have shown good clinical outcomes [7, 31, 32]. Different implant designs (Fig. 1) have been described with anchors [33, 34] or screws going through the cage into the adjacent vertebral bodies. Chen et al. [35] have shown that ACDF multi-level surgery with a stand-alone cage or with ACP achieves the same clinical and radiological outcomes but they warn surgeons to take precautions in the case of multi-level surgery because of non-union and loss of cervical lordosis in the group without ACP.

Anterior discectomy without fusion

Some disadvantages of ACDF have been described in literature such as pseudarthrosis, adjacent segment degeneration, and height loss in intervertebral space [30, 36]. Surgical

Fig. 1 Stand-alone cages with anchors or screws. Axelle, Prosteel, France. Roi-C, LDR, France. Scarlet, SpineArt, France

techniques without fusion have been described, trying to reduce these disadvantages.

In 1995, Pointillart et al. found good clinical and radiological results using a technique of transdiscal cervical discectomy without graft [9]. Their results showed 85.9% of the patients with complete pain relief consistent with the results from other series using a fusion method. The main limitation of this technique was post-operative cervicalgia (56%).

Jho et al. [37] have found good or excellent clinical and radiographic outcomes for 98% of 104 patients with cervical radiculopathy using an anterior microforaminotomy.

Endoscopic methods through an anterior approach have been described [38, 39]. Ruetten et al. [39] found similar and good outcomes at two years' follow-up in both groups (endoscopic decompression without fusion and ACDF). Therefore, the endoscopic method found its limits: limited possibilities to extend operation in case of difficulties, difficult access to the foramen, only mediolateral soft disc herniations accessible, only direct decompression, and a difficult learning curve. Another concern of these techniques without fusion is the risk of kyphosis; however, some studies seem to show no difference for kyphosis between fusion group and non-fusion group until two years of follow-up [9, 39].

Cervical disc arthroplasty

Cervical arthroplasties have been first used by Reitz in 1964 [11] and then by Fernstrom in 1966 [40]. Its use has been constantly increasing during the last decades supported by good clinical results in several studies [12, 13, 41, 42]. The concept of preserving the range of motion on the operating level is seducing. CDA may decrease the rate of ASD and of adjacent level surgery compared to ACDF [12, 43, 44]. Therefore, the debate about the causes of ASD is still an ongoing discussion. Some believe that ASD is mainly caused by the natural history of the degenerative disease, others believe that the fused level is responsible for the accelerated degeneration of adjacent levels.

CDA procedure is not very challenging for surgeons who are used to perform ACDF because the main steps are likely similar. An anterior approach is performed as described above, after discectomy and foraminal decompression are done, the prosthesis is impacted in the end plates.

Different prosthesis has been developed during the last decade with differing materials and degrees of constraint (Fig. 2). Early and long-term results with these different implants seem to be very encouraging [13, 41]. Nevertheless, specific complications of CDA could occur such as implant failure, malposition, dislocation, heterotopic ossifications, and anterior bone loss.

Discussion

ACDF remains the gold standard procedure because of its long clinical history. Lately, CDA became more popular and many studies seem to claim its superiority to ACDF [45, 46].

To our knowledge, diminution of ASD with arthroplasty has not been proven yet in randomized controlled trials. Furthermore, a major part of ASD based on radiological findings are not symptomatic (Fig. 3).

The rate of re-operation is the point to evaluate the safety of a new technology such as cervical arthroplasty.

Hilibrand et al. [47] found 25% re-operation rate for ASD ten years after ACDF. In their work, pre-existing degenerative radiographic evidence on adjacent levels and single-level

Prothesis	Prestige LP	Cervicore	Kineflex	Prodisc-C	PCM	Mobi-C	Secure-C	Bryan	Discocerv
Material	Titanium	Chrome-Cobalt	Chrome-Cobalt-Mo	Chrome-Cobalt-Mo UHMWPE	Chrome-Cobalt-Mo UHMWPE	Chrome-Cobalt UHMWPE	Chrome-Cobalt UHMWPE	Titanium - PU	Titane-Alumine-Zircone
Friction	Titanium - Titanium	Metal - Metal	Metal - Metal	Metal - UHMWPE	Metal - UHMWPE	Metal - UHMWPE	Metal - HMWPE	Metal - PU	Ceramic - Ceramic
Constraint	+	++	+	+++	+	+	+	+/-	++

Fig. 2 Different models of prosthesis with their main characteristics

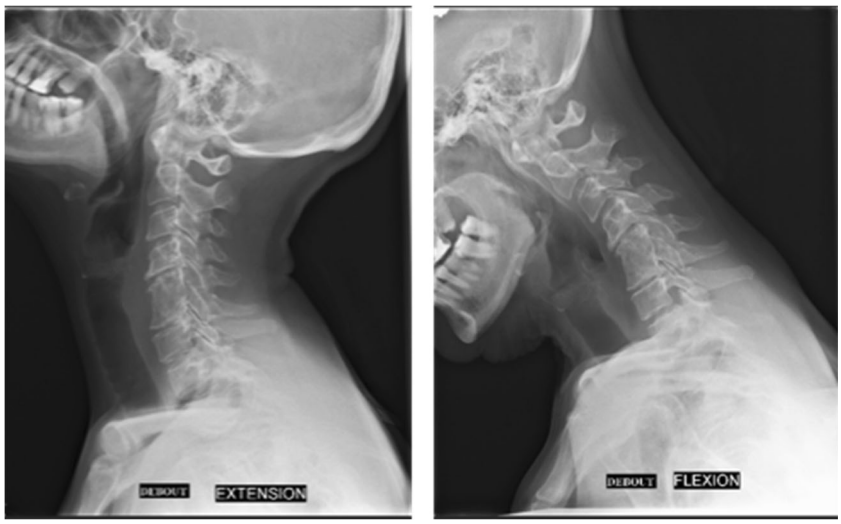

Fig. 3 Radiographic control of a 62-year-old patient who underwent anterior decompression without fusion on C5C6 level 25 years ago. She spontaneously fused and we noticed ASD on the upper and lower level. She has no clinical symptoms, no cervicalgia, and MRI does not show any compression

arthrodesis involving the fifth or sixth cervical vertebra are the greatest risk factors for ASD and re-operation. They suggest that all degenerated levels should be included in the first arthrodesis surgery. Lee et al. [48] found comparable results with 22.2% re-operation rate at ten years. They found that smokers and women had a higher re-operation rate.

Zhong et al. [49] in a meta-analysis including 12 randomized controlled trials found a re-operation rate of 6% for CDA (4% index level, 3% adjacent levels) and 12% in ACDF (8% index level, 8% adjacent levels). They admit taking these results with caution because there are limitations. The allograft was used, instead of autograft known to have better fusion rate, in 11 studies and eight different types of the prosthesis were tested. Most of the revision in the ACDF group were for pseudarthrosis.

A very interesting and critical review of the literature about cervical arthroplasty from Alvin et al. published in 2014 [50] stratified the analysis based on conflict of interest status (COI). Those studies without a COI reported adjacent segment disease (ASDI) and adjacent segment degeneration (ASD) rates of 6.3% and 14.2% CDA and 6.2% and 0% ACDF, respectively. In contrast, the reverse was reported by studies with a COI, for which the ASDI and ASDG were 2.5% and 24.3% CDA and 6.3% and 36.5% ACDF, respectively. COI impacted the results in favour of arthroplasty.

A recent Norwegian study from Sundseth et al. [51] showed that the rate of index level re-operations was higher and the duration of surgery longer with arthroplasty. In this randomized and single-blinded prospective study, they found excellent clinical outcomes and no significant differences between arthroplasty and fusion.

Heterotopic ossification (HO) is a well-known adverse event in the field of knee and hip total arthroplasty. Only a few studies have reported risk factors for HO in CDA. Yi et al. [52] found a high rate of HO (from 21 to 71.4%, depending on the device type). Male gender and type of implant were reported as predisposing factors. Guerin et al. [53] found that HO did not seem to affect clinical outcomes. Alvin et al. [50] showed that HO was associated with COI. In the studies with COI, the rate of HO was 22%, in the studies without COI this rate was 46%.

The anterior bone loss is a common event after CDA. Mainly causes by stress shielding it occurs early in the first 3 months. Kieser et al. [14] found 57.1% in a cohort of 146 patients during five years of follow-up. The clinical implication of ABL remains unclear.

Conclusion

Surgical options for cervical disc herniation are numerous. CDA is now an established and validated option because it has shown its safety and efficiency with good clinical outcomes. Despite of its great debut, CDA has not proved yet its superiority to ACDF in the surgical treatment of cervical disc herniation. Adverse events can occur with cervical arthroplasty with a high rate of HO and ABL. ACDF remains the most reliable option.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

References

1. Yamano Y (1985) Soft disc herniation of the cervical spine. Int Orthop 9:19–27. https://doi.org/10.1007/BF00267033

2. Herkowitz HN, Kurz LT, Overholt DP (1990) Surgical management of cervical soft disc herniation. A comparison between the anterior and posterior approach. Spine 15:1026–1030
3. Liao J-C, Niu C-C, Chen W-J, Chen L-H (2008) Polyetheretherketone (PEEK) cage filled with cancellous allograft in anterior cervical discectomy and fusion. Int Orthop 32:643–648. https://doi.org/10.1007/s00264-007-0378-x
4. Xie Y, Li H, Yuan J et al (2015) A prospective randomized comparison of PEEK cage containing calcium sulphate or demineralized bone matrix with autograft in anterior cervical interbody fusion. Int Orthop 39:1129–1136. https://doi.org/10.1007/s00264-014-2610-9
5. SMITH GW, ROBINSON RA (1958) The treatment of certain cervical-spine disorders by anterior removal of the intervertebral disc and interbody fusion. J Bone Joint Surg Am 40–A:607–624. https://doi.org/10.2106/00004623-195840030-00009
6. Ipsen BJ, Kim DH, Jenis LG et al (2007) Effect of plate position on clinical outcome after anterior cervical spine surgery. Spine J Off J North Am Spine Soc 7:637–642. https://doi.org/10.1016/j.spinee.2006.09.003
7. Chin KR, Pencle FJR, Mustafa LS et al (2018) Sentinel sign in standalone anterior cervical fusion: outcomes and fusion rate. J Orthop 15:935–939. https://doi.org/10.1016/j.jor.2018.08.027
8. Spallone A, Marchione P, Li Voti P et al (2014) Anterior cervical discectomy and fusion with "mini-invasive" harvesting of iliac crest graft versus polyetheretherketone (PEEK) cages: a retrospective outcome analysis. Int J Surg 12:1328–1332. https://doi.org/10.1016/j.ijsu.2014.11.003
9. Pointillart V, Cernier A, Vital JM, Senegas J (1995) Anterior discectomy without interbody fusion for cervical disc herniation. Eur Spine J 4:45–51
10. Ruetten S, Komp M, Merk H, Godolias G (2007) A new full-endoscopic technique for cervical posterior Foraminotomy in the treatment of lateral disc herniations using 6.9-mm endoscopes: prospective 2-year results of 87 patients. Minim Invasive Neurosurg 50:219–226. https://doi.org/10.1055/s-2007-985860
11. Reitz H, Joubert MJ (1964) Intractable headache and cervico-brachialgia treated by complete replacement of cervical intervertebral discs with a metal prosthesis. South Afr Med J Suid-Afr Tydskr Vir Geneeskd 38:881–884
12. Cheng L, Nie L, Zhang L, Hou Y (2008) Fusion versus Bryan cervical disc in two-level cervical disc disease: a prospective, randomised study. Int Orthop 33:1347. https://doi.org/10.1007/s00264-008-0655-3
13. Bertagnoli R, Yue JJ, Pfeiffer F et al (2005) Early results after ProDisc-C cervical disc replacement. J Neurosurg Spine 2:403–410. https://doi.org/10.3171/spi.2005.2.4.0403
14. Kieser DC, Cawley DT, Fujishiro T et al (2018) Risk factors for anterior bone loss in cervical disc arthroplasty. J Neurosurg Spine 29:123–129. https://doi.org/10.3171/2018.1.SPINE171018
15. Luo J, Gong M, Huang S et al (2015) Incidence of adjacent segment degeneration in cervical disc arthroplasty versus anterior cervical decompression and fusion meta-analysis of prospective studies. Arch Orthop Trauma Surg 135:155–160. https://doi.org/10.1007/s00402-014-2125-2
16. Scoville WB (1945) Recent developments in the diagnosis and treatment of cervical ruptured intervertebral discs. Proc Am Fed Clin Res 2:23
17. Song Z, Zhang Z, Hao J et al (2016) Microsurgery or open cervical foraminotomy for cervical radiculopathy? A systematic review. Int Orthop 40:1335–1343. https://doi.org/10.1007/s00264-016-3193-4
18. O'Toole JE, Sheikh H, Eichholz KM et al (2006) Endoscopic posterior cervical foraminotomy and discectomy. Neurosurg Clin N Am 17:411–422. https://doi.org/10.1016/j.nec.2006.06.002
19. Gala VC, O'Toole JE, Voyadzis J-M, Fessler RG (2007) Posterior minimally invasive approaches for the cervical spine. Orthop Clin N Am 38:339–349. https://doi.org/10.1016/j.ocl.2007.02.009
20. Hosono N, Yonenobu K, Ono K (1996) Neck and shoulder pain after laminoplasty. A noticeable complication. Spine 21:1969–1973
21. Zdeblick TA, Zou D, Warden KE et al (1992) Cervical stability after foraminotomy. A biomechanical in vitro analysis. J Bone Joint Surg Am 74:22–27
22. Epstein NE, Schwall G, Reillly T et al (2011) Surgeon choices, and the choice of surgeons, affect total hospital charges for single-level anterior cervical surgery. Spine 36:905–909. https://doi.org/10.1097/BRS.0b013e3181e6c4d8
23. Topuz K, Çolak A, Kaya S et al (2009) Two-level contiguous cervical disc disease treated with peek cages packed with demineralized bone matrix: results of 3-year follow-up. Eur Spine J 18:238–243. https://doi.org/10.1007/s00586-008-0869-5
24. Dickerman RD, Reynolds AS, Morgan B (2008) Polyetheretherketone (PEEK) cage filled with bone morphogenic protein and demineralised bone matrix in anterior cervical discectomy and fusion. Int Orthop 32:717–717. https://doi.org/10.1007/s00264-007-0450-6
25. Young WF, Rosenwasser RH (1993) An early comparative analysis of the use of fibular allograft versus autologous iliac crest graft for interbody fusion after anterior cervical discectomy. Spine 18:1123–1124
26. Park J-B, Cho Y-S, Riew KD (2005) Development of adjacent-level ossification in patients with an anterior cervical plate. J Bone Jt Surg 87:558–563. https://doi.org/10.2106/JBJS.C.01555
27. Wang JC, McDonough PW, Kanim LE et al (2001) Increased fusion rates with cervical plating for three-level anterior cervical discectomy and fusion. Spine 26:643–646-647
28. Das K, Couldwell WT, Sava G, Taddonio RF (2001) Use of cylindrical titanium mesh and locking plates in anterior cervical fusion. Technical note. J Neurosurg 94:174–178
29. Fraser JF, Härtl R (2007) Anterior approaches to fusion of the cervical spine: a metaanalysis of fusion rates. J Neurosurg Spine 6:298–303. https://doi.org/10.3171/spi.2007.6.4.2
30. Suk K-S, Kim K-T, Lee S-H, Park S-W (2006) Prevertebral soft tissue swelling after anterior cervical discectomy and fusion with plate fixation. Int Orthop 30:290–294. https://doi.org/10.1007/s00264-005-0072-9
31. Zhou J, Li J, Lin H et al (2018) A comparison of a self-locking stand-alone cage and anterior cervical plate for ACDF: minimum 3-year assessment of radiographic and clinical outcomes. Clin Neurol Neurosurg 170:73–78. https://doi.org/10.1016/j.clineuro.2018.04.033
32. Kapetanakis S, Thomaidis T, Charitoudis G et al (2017) Single anterior cervical discectomy and fusion (ACDF) using self- locking stand-alone polyetheretherketone (PEEK) cage: evaluation of pain and health-related quality of life. J Spine Surg 3:312–322. https://doi.org/10.21037/jss.2017.06.21
33. Grasso G, Giambartino F, Tomasello G, Iacopino G (2014) Anterior cervical discectomy and fusion with ROI-C peek cage: cervical alignment and patient outcomes. Eur Spine J 23:650–657. https://doi.org/10.1007/s00586-014-3553-y
34. Grasso G, Landi A (2018) Long-term clinical and radiological outcomes following anterior cervical discectomy and fusion by zero-profile anchored cage. J Craniovertebral Junction Spine 9:87–92. https://doi.org/10.4103/jcvjs.JCVJS_36_18
35. Chen Y, Lü G, Wang B et al (2016) A comparison of anterior cervical discectomy and fusion (ACDF) using self-locking stand-alone polyetheretherketone (PEEK) cage with ACDF using cage and plate in the treatment of three-level cervical degenerative spondylopathy: a retrospective study with 2-year follow-up. Eur Spine J 25:2255–2262. https://doi.org/10.1007/s00586-016-4391-x

36. Fountas KN, Kapsalaki EZ, Nikolakakos LG et al (2007) Anterior cervical discectomy and fusion associated complications. Spine 32: 2310–2317. https://doi.org/10.1097/BRS.0b013e318154c57e
37. Jho HD (1996) Microsurgical anterior cervical foraminotomy for radiculopathy: a new approach to cervical disc herniation. J Neurosurg 84:155–160. https://doi.org/10.3171/jns.1996.84.2.0155
38. Ahn Y, Lee SH, Chung SE et al (2005) Percutaneous endoscopic cervical discectomy for discogenic cervical headache due to soft disc herniation. Neuroradiology 47:924–930. https://doi.org/10.1007/s00234-005-1436-y
39. Ruetten S, Komp M, Merk H, Godolias G (2008) Full-endoscopic anterior decompression versus conventional anterior decompression and fusion in cervical disc herniations. Int Orthop 33:1677. https://doi.org/10.1007/s00264-008-0684-y
40. Fernström U (1966) Arthroplasty with intercorporal endoprothesis in herniated disc and in painful disc. Acta Chir Scand Suppl 357: 154–159
41. Pointillart V, Castelain J-E, Coudert P et al (2018) Outcomes of the Bryan cervical disc replacement: fifteen year follow-up. Int Orthop 42:851–857. https://doi.org/10.1007/s00264-017-3745-2
42. Chen Y, He Z, Yang H et al (2013) Clinical and radiological results of total disc replacement in the cervical spine with preoperative reducible kyphosis. Int Orthop 37:463–468. https://doi.org/10.1007/s00264-012-1754-8
43. Zhu Y, Tian Z, Zhu B et al (2016) Bryan cervical disc arthroplasty versus anterior cervical discectomy and fusion for treatment of cervical disc diseases: a meta-analysis of prospective, randomized controlled trials. [miscellaneous article]. Spine 41:E733–E741. https://doi.org/10.1097/BRS.0000000000001367
44. Zheng B, Hao D, Guo H, He B (2017) ACDF vs TDR for patients with cervical spondylosis – an 8 year follow up study. BMC Surg 17:113. https://doi.org/10.1186/s12893-017-0316-9
45. Lei T, Liu Y, Wang H et al (2016) Clinical and radiological analysis of Bryan cervical disc arthroplasty: eight-year follow-up results compared with anterior cervical discectomy and fusion. Int Orthop 40:1197–1203. https://doi.org/10.1007/s00264-015-3098-7
46. Zou S, Gao J, Xu B et al (2017) Anterior cervical discectomy and fusion (ACDF) versus cervical disc arthroplasty (CDA) for two contiguous levels cervical disc degenerative disease: a meta-analysis of randomized controlled trials. Eur Spine J 26:985–997. https://doi.org/10.1007/s00586-016-4655-5
47. Hilibrand AS, Carlson GD, Palumbo MA et al (1999) Radiculopathy and myelopathy at segments adjacent to the site of a previous anterior cervical arthrodesis. J Bone Joint Surg Am 81: 519–528
48. Lee JC, Lee S-H, Peters C, Riew KD (2015) Adjacent segment pathology requiring reoperation after anterior cervical arthrodesis: the influence of smoking, sex, and number of operated levels. Spine 40:E571–E577. https://doi.org/10.1097/BRS.0000000000000846
49. Zhong Z-M, Zhu S-Y, Zhuang J-S et al (2016) Reoperation after cervical disc arthroplasty versus anterior cervical discectomy and fusion: a meta-analysis. Clin Orthop 474:1307–1316. https://doi.org/10.1007/s11999-016-4707-5
50. Alvin MD, Abbott EE, Lubelski D et al (2014) Cervical arthroplasty: a critical review of the literature. Spine J 14:2231–2245. https://doi.org/10.1016/j.spinee.2014.03.047
51. Sundseth J, Fredriksli OA, Kolstad F et al (2017) The Norwegian cervical arthroplasty trial (NORCAT): 2-year clinical outcome after single-level cervical arthroplasty versus fusion—a prospective, single-blinded, randomized, controlled multicenter study. Eur Spine J 26:1225–1235. https://doi.org/10.1007/s00586-016-4922-5
52. Yi S, Shin DA, Kim KN et al (2013) The predisposing factors for the heterotopic ossification after cervical artificial disc replacement. Spine J 13:1048–1054. https://doi.org/10.1016/j.spinee.2013.02.036
53. Guérin P, Obeid I, Bourghli A et al (2012) Heterotopic ossification after cervical disc replacement: clinical significance and radiographic analysis. A prospective study. Acta Orthop Belg 78:80–86