Current Concepts of Anterior Cervical Discectomy and Fusion: A Review of Literature

Kyung-Jin Song¹, Byeong-Yeol Choi²

¹Department of Orthopedic Surgery, Chonbuk National University Hospital, Research Institute of Clinical Medicine, Biomedical Science Institute, Chonbuk National University Medical School, Jeonju, Korea
²Department of Orthopedic Surgery, Presbyterian Medical Center, Jeonju, Korea

Anterior cervical discectomy and fusion (ACDF) is a safe and effective procedure for degenerative cervical spinal disease unresponsive to conservative management and its outstanding results have been reported. To increase fusion rates and decrease complications, numerous graft materials, cage, anterior plating and total disc replacement have been developed, and better results were reported from those, but still there are areas that have not been established. Therefore, we are going to analyze the treatment outcome with the various procedure through the literature review and determine the efficacy of ACDF.

Keywords: Cervical vertebrae; Pathology; Fusion; Complications

Introduction

Anterior cervical discectomy and fusion (ACDF) has been accepted as an effective treatment on a various spinal cervical abnormality such as spondylosis, herniated discs, fractures, neoplastic lesion. It has excellent clinical results and relatively safe so that it has been the one of the most common procedure for degenerative spinal cervical disease and more than 5 million operations have been conducted in the United States between the period of 1990–1999 [1]. A various trials and experiments have been carried out in the last decades to get better results from the procedure, and it was essential to develop new graft materials and implants for this, but these changes could not always guarantee the better results. The authors identified the historical importance of ACDF in disease of cervical spine and have conducted a literature review on the development of clinical results through the changes in operative techniques and instruments.

Historical Review

Anterior cervical approach which is familiar to the spine surgeon was initially described by Lahey and Warren [2] to expose esophageal diverticula. Smith and Robinson [3] first applied this approach to cervical spine and reported the result of anterior cervical interbody fusion by using a horseshoe-shaped graft harvested from iliac crest in 14 patients suffering from radiculopathy. At that time there was no attempt to remove the structure compressing neural structure and simply disc was removed and autologous bone graft was filled in the hollow space to conduct the fusion. They expected that the inserted graft will indirectly decompress nerve root by recovering the disc height, and it was thought that existing osteophytes would regress with stabilization of the involved...
motion segment. Consequently, 9 patients had excellent and 4 patients had good or fair results. The reason that anterior cervical fusion came to the fore, was that the effort for overcoming the limitation of the current posterior approach. Laminectomy was often not effective when posterior osteophytes compress the nerve root in the intervertebral foramen. Furthermore if the radicular pain was bilateral, bilateral facet excision was necessary to adequately decompress the nerve roots by a posterior approach, often leading to instability. They reported the following benefits of ACDF for the treatment of radiculopathy that this operation: 1) has less morbidity than laminectomy, 2) can remove disc pathology without disturbing spinal canal, 3) allows interbody fusion of the cervical spine at the specific intervertebral level from which symptom arise. In November of the same year, Cloward [4] reported interbody arthrodesis by using dowel type graft. It applied Wiltberger’s lumbar interbody dowel fusion technique on cervical spine, and unlike Smith-Robinson technique, it removed not only discs but also all lesions that compressing the neural structure anteriorly under direct visualization, and used a large drill to prepare the area for bone graft. They showed the result that 42 cases out of 47 cases had a complete relief, and 5 cases had a partial relief, and more rapid symptomatic recovery was achieved than in cervical laminectomy. Bailey and Badgley [5] reported the technique with slot or trough type graft. This technique was originally attempted to remove tumor on cervical spine. They did not attempt to decompress neural structure directly or restore the disc height, instead they only conducted fusion with an onlay graft. They recommend 6 weeks of postoperative traction on a Stryker frame followed by immobilization in a brace for 4–6 months. This technique is not used today for single level disease, but this concept led to the development of the grafting technique after the corpectomy. In 1969, Simmons and Bhalla [6] reported anterior fusion by using keystone graft, and in 1981, Bloom and Raney [7] modified Smith-Robinson technique and inserted the horseshoe type graft in the reversed way so that cortical portion headed to disc space, so it could be stronger to resist compressive force. Since then a numerous modifications were introduced by many surgeons, and subsequent excellent results were reported so that anterior approach became the treatment of choice for cervical radiculopathy (Fig. 1).

**Autograft versus Allograft**

The history of modification in ACDF is the effort to obtain stable fusion. The ideal graft should have all potentials of osteogenesis, osteoinduction and osteoconduct, and currently the only graft that fulfills all of three properties is autologous bone graft. So far the fusion using autobone graft has been a gold standard with a high
fusion rate. Smith and Robinson’s horseshoe type tricortical iliac bone graft was found to be much more resistant to compressive forces than the other graft shapes and has been used as the most popular technique in autograft graft [8]. The height of the graft should be a minimum of 7 mm and at least 2 mm higher than the original disc height. The graft should be countersunk into disc space and location which slightly posterior to the anterior surface of the adjacent vertebral body is the best position [9,10].

Despite of excellent clinical outcome from ACDF with autograft, there were continuous modifications in surgical technique. One of the most important reasons is a fatal complication of donor site morbidity. The donor site complication due to the use of host bone led to the morbidity rate of 20% or higher [11], and it is presented as pain in the donor site, seroma, hematoma, infection, hip fracture, and meralgia paresthetica. To resolve those problems the use of allogenic bone graft and synthetic devices were suggested, and there was development various new surgical techniques and synthetic materials.

Iliac bone or fibula is used in allograft usually and fibula allograft has been reported to be more effective in maintaining the disc height [12,13]. Although allograft has advantages over autograft in terms of donor site morbidity and surgical time, it is expensive and outcomes of fusion rate, maintenance of disc height and lordosis are worse than autograft. Also the issue with disease transmission cannot be neglected [14]. However when it is used with the addition of cervical plate fixation, the fusion rates become comparable with autograft and has been reported that the patient was able to return to work faster [15,16]. Demineralized bone matrix (DBM) is an allograft with a varying degree of osteoinduction, and it cannot support the disc space on its own, so that it require being used with mineralized allograft or synthetic cage [17].

Bovine bone or calf bone was used as animal allograft (Xenograft). Despite of some favorable datas [18,19], its use has declined due to problems like poor biocompatibility and increased re-operation rates [20,21].

**Other Bone Graft Substitutes**

A various synthetic materials have been introduced which can substitute autograft (Fig. 2). The use of cage has advantages of shorter operation time, maintenance of intervertebral disc height and lordotic angle and when it is used with cancellous autograft that is packed into the cage, it can reduce the donor site complications and obtain comparable fusion rate to autogenous tricortical iliac bone [22,23]. On the other hand, some reports indicated that the cage itself appeared to have stress shielding onto inserted bone graft so that it reduced the fusion rate, and caused delay in fusion, nonunion and kyphosis due to the cage migration, subsidence and loss of lordosis [24]. Although cortical allograft can be manufactured as a cage, the materials generally used for cage are plastic and metal. Polyetheretherketone cage which is a kind of plastic cage is popularized due to its physical property that has similar rigidity to the normal bone, and it is feasible in radiological fusion analysis [22,25,26]. Usually it is made in a box type which cancellous autograft, DBM or ceramics can be packed. Stainless steel, Ti (titanium), Ta (tantalum) are used for metal cage, and mainly Ti is used. Titanium cage is generally packed with autogenous bone from iliac crest, and there are provided as a variety of form such as mesh type, thread type, box type, etc, and it showed low donor site morbidity, high fusion rates [27,28], but in case of mesh cage, the combination with anterior cervical plate was recommended due to the risk of subsidence [27]. The cage with carbon fiber showed satisfactory results [29], but this device is currently not...
available in the United States.

Ceramics are attractive graft option as they avoid donor site morbidity, demonstrate biocompatibility, present no risk of infection or disease transmission. And their supply is virtually limitless and it can be manufactured into a various sizes and shapes. Hydroxyapatite or tricalcium phosphate are most widely investigated for use in the cervical spine. Although there were problems like slippage or fracture in the beginning, but with continuous development ceramics are now showing relatively favorable clinical outcomes and fusion rates [30-32]. On the other hand, the use of biocompatible osteoconductive polymer or polymethylmethacrylate showed poor outcomes [33,34].

Bone morphogenic proteins (BMPs) was first introduced by Urist [35] and was suggested as an innovative material to increase the fusion rate, and the outcome of use in lumbar spine was promising [36,37]. However, in cervical spine, the serious complications such as serious postoperative edema, dysphagia, and ectopic bone formation were reported [38,39] and eventually Food and Drug Administration announced the warning of using BMP in anterior cervical spinal surgery [40]. Currently the use of BMP in cervical spine is an off label, and additional studies are warranted for adequate dosage and delivery method in the future.

1. Cervical plating

Anterior cervical plate was developed in early 1980 and it was first developed for use in cervical spinal trauma like fracture or dislocation. With successes in trauma, anterior plate fixation has spread to use in degenerative cervical spinal diseases. There are theoretical benefits with additional fixation with anterior plating such as initial stability, early mobilization and minimizing external bracing, prevention of bone graft collapse or extrusion, improved bone fusion and maintenance of sagittal alignment. Although anterior plating in long cervical fusion (two or more levels) with high pseudoarthrosis rate can be justified [16,23,41], the routine use in single-level fusion is still controversial due to the additional cost and possibility of complications with the use of plate [42,43]. Currently the wide array of anterior cervical fixation devices were developed and available. Cervical Spine Study Group [44] has classified them based to the biomechanical characteristics (Fig. 3). The earlier cervical plates had catastrophic issues such as screw backout and esophagus damage, but with the technical advance in implant design including locking mechanism, the complications have been decreased. Also use of locking screw eliminate the necessity of bicortical fixation and have decreased the possibility of spinal cord damage. Since then the concept of dynamization was introduced and many dynamic plate designs were developed. Compared to the existing static (constrained) plate, dynamic plate has an advantage of early bone fusion because it prevents the stress shielding and transfer axial loading onto bone graft sufficiently through settling [45]. Also metal failure such as screw loosening or breakage due to nonunion and subsidence of bone graft can be reduced. According to the dynamization method, dynamic plate types are classifies as; rotational plate, translational plate with slotted screw holes, translational plate with plate telescope (Fig. 4).

The complications related to the use of plates are rarely reported. Those are loosening of screw or plate, breakage and malpositioning, etc. [46]. There is a controversy that use of plate increases the prevalence of dysphagia which is a relatively common complication of anterior cervical fusion [47], but often cases of esophagus injury have been reported [48]. Adjacent-level ossification (ALO) is an interesting phenomenon occurs in instrumented ACDF but the clinical significance is not clear. It was reported that the placement of plate at least 5 mm away from the adjacent disc helps to reduce the prevalence of ALO [49].

Zero-P system (Synthes GmbH Switzerland, Oberdorf, Switzerland) has the design that fixes the existing stand alone cage onto vertebral body with screws, it shows...
comparable clinical outcomes and fusion rates relative to using anterior cervical plating, and is reported that it also reduced the prevalence of dysphagia or degenerative change of adjacent segment (Fig. 5) [50].

Resorbable plate was developed with the benefit of easy observation of fusion progression on imaging assessment after the surgery due to absence of opacity that metallic plate has. And it was anticipated that it may reduce hardware failure or stress shielding. Although some reports showed favorable results relative to the metal plate [51,52], it should be used with caution as the complications such as early failure, back-out, nonunion and kyphotic deformity.

2. Cervical disc arthroplasty

Since it have been suggested the fused segmentation from anterior fusion increases the load at adjacent segment and it may cause the adjacent segment degeneration, total disc replacement (TDR) that can preserve index level motion was proposed as a new alternative in cervical radiculopathy treatment [53,54] (Fig. 6). The efficacy of total disc arthroplasty has been recognized in stability, clinical outcome and maintenance of index level motion [55-58], but in the recovery or maintenance of sagittal balance, it showed the similar results to ACDF [59,60]. And complication like heterotopic ossification, prosthetic migration, segmental kyphosis, device failure, wear problem are remained to be resolved in TDR [61,62]. Many studies were conducted on the occurrence of adjacent segment disease (ASD) after TDR, and there were reports that it showed better results compared to ACDF, optimistic outcomes are not guaranteed [63].

ASD is a complication with a lot of controversy. It has not been determined if such ASD is the result of the nat-
ural progression of degenerative disc disease or biomechanical change after fusion surgery [64]. Also there have been no clear evidence that the increased stress or strain of adjacent segment from the fusion which is indicated as the cause of ASD increases the incidence of reoperation. Even in short-term studies comparing ACDF and TDR have failed to show any significant difference in the prevalence of adjacent segment pathology following surgery [65-67]. Existing studies comparing ACDF and TDR have been limited by small sample sizes and by the lack of long term follow-up.

Also the hybrid technique involving arthrodesis and TDR has a biomechanical advantage over two-level fusion in terms of reducing adjacent level hypermobility, but longer follow-up studies are needed to assess the clinical effect [68].

Summary

The aim of ACDF is to obtain sufficient decompression and successful fusion. There was a lot of effort to increase fusion rate and decrease donor site morbidity, and although there was controversy about the use of a various synthetic graft materials and anterior cervical plate, but currently those have been established as a accepted treatment regime for ACDF. The use of cervical plate in ACDF increases fusion rate and has a theoretical advantage of reducing ASD by maintaining cervical lordosis, on the other hand there is a report that it increases stress of adjacent segment and it rather accelerates the adjacent segment degenerative change. TDR is also introduced for reducing ASD, but from the med-long term follow-up of ACDF and TDR, it have failed to identify any significant difference in the prevalence of ASD between them. Eventually the focus on TDR to overcome the limitation of fusion surgery could not show superiority in comparison to ACDF, hence it can be an alternative to fusion surgery, but it will be hard to substitute ACDF.

Conclusions

ACDF showed excellent results for decades in terms of efficacy and safety, and it is an procedure with expectation of better results together with the development of surgical techniques and instruments. However, longer-term follow-up of prospective, randomized multi-center studies are needed to answer the questions about complication or on-going issues like ASD .There is a tendency of expanding indication of ACDF due to its excellent treatment outcomes, but should not neglect the value of conservative treatment in degenerative cervical spinal diseases.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

References

1. Angevine PD, Arons RR, McCormick PC. National and regional rates and variation of cervical discectomy with and without anterior fusion, 1990-1999. Spine (Phila Pa 1976) 2003;28:931-9.
2. Lahey FH, Warren KW. Esophageal diverticula. Surg Gynecol Obstet 1954;98:1-28.
3. Smith GW, Robinson RA. The treatment of certain cervical-spine disorders by anterior removal of the intervertebral disc and interbody fusion. J Bone Joint Surg Am 1958;40:607-24.
4. Cloward RB. The anterior approach for removal of ruptured cervical disks. J Neurosurg 1958;15:602-17.
5. Bailey RW, Badgley CE. Stabilization of the cervi-

Fig. 6. Cervical artificial disc. (A) Bryan (adapted from http://www.BryanDisc.com/, with permission of Medtronic). (B) Prestige ST (adapted from http://www.PrestigeDisc.com/, with permission of Medtronic). (C) Mobi-C (adapted from http://www.LDR.com/, with permission of LDR spine). (D) Prodisc-C (adapted from http://www.synthes.com/, with permission of Depuy Synthes).
1. Cervical discectomy by anterior fusion. J Bone Joint Surg Am 1960;42:565-94.

6. Simmons EH, Bhalla SK. Anterior cervical disectomy and fusion: a clinical and biomechanical study with eight-year follow-up. J Bone Joint Surg Br 1969;51:225-37.

7. Bloom MH, Raney FL Jr. Anterior intervertebral fusion of the cervical spine: a technical note. J Bone Joint Surg Am 1981;63:842.

8. White AA 3rd, Hirsch C. An experimental study of the immediate load bearing capacity of some commonly used iliac bone grafts. Acta Orthop Scand 1971;42:482-90.

9. Bohlman H. Degenerative arthrosis of the lower cervical spine. In: Evarts CM, editor. Surgery of the musculoskeletal system. Vol. 2. New York: Churchill Livingstone; 1983. p. 25-55.

10. Kurz LT, Herkowitz HN. Surgical management of myelopathy. Orthop Clin North Am 1992;23:495-504.

11. Silber JS, Anderson DG, Daffner SD, et al. Donor site morbidity after anterior iliac crest bone harvest for single-level anterior cervical disectomy and fusion. Spine (Phila Pa 1976). 2003;28:134-9.

12. Bishop RC, Moore KA, Hadley MN. Anterior cervical interbody fusion using autogeneic and allogeneic bone graft substrate: a prospective comparative analysis. J Neurosurg 1996;85:206-10.

13. Young WF, Rosenwasser RH. An early comparative analysis of the use of fibular allograft versus autologous iliac crest graft for interbody fusion after anterior cervical discectomy. Spine (Phila Pa 1976) 1993;18:1123-4.

14. Delloye C, Cornu O, Druetz V, Barbier O. Bone allografts: What they can offer and what they cannot. J Bone Joint Surg Br 2007;89:574-9.

15. Shapiro S. Banked fibula and the locking anterior cervical plate in anterior cervical fusions following cervical disectomy. J Neurosurg 1996;84:161-5.

16. Kaiser MG, Haid RW Jr, Subach BR, Barnes B, Rodts GE Jr. Anterior cervical plating enhances arthrodesis after disectomy and fusion with cortical allograft. Neurosurgery 2002;50:229-36.

17. An HS, Simpson JM, Glover JM, Stephany J. Comparison between allograft plus demineralized bone matrix versus autograft in anterior cervical fusion: a prospective multicenter study. Spine (Phila Pa 1976) 1995;20:2211-6.

18. Ramani PS, Kalbag RM, Sengupta RP. Cervical spinal interbody fusion with Kiel bone. Br J Surg 1975;62:147-50.

19. Siqueira EB, Kranzler LI. Cervical Interbody fusion using calf bone. Surg Neurol 1982;18:37-9.

20. Sutter B, Friehs G, Pendl G, Tolly E. Bovine dowels for anterior cervical fusion: experience in 66 patients with a note on postoperative CT and MRI appearance. Acta Neurochir (Wien) 1995;137:192-8.

21. Xie Y, Chopin D, Hardouin P, Lu J. Clinical, radiological and histological study of the failure of cervical interbody fusions with bone substitutes. Eur Spine J 2006;15:1196-203.

22. Park HW, Lee JK, Moon SJ, Seo SK, Lee JH, Kim SH. The efficacy of the synthetic interbody cage and Grafton for anterior cervical fusion. Spine (Phila Pa 1976) 2009;34:E591-5.

23. Wang JC, McDonough PW, Endow KK, Delamarber RB. Increased fusion rates with cervical plating for two-level anterior cervical disectomy and fusion. Spine (Phila Pa 1976) 2000;25:411-5.

24. Gercek E, Arlet V, Delisie J, Marchesi D. Subsidence of stand-alone cervical cages in anterior interbody fusion: warning. Eur Spine J 2003;12:513-6.

25. Cho DY, Liau WR, Lee WY, Liu JT, Chiu CL, Sheu PC. Preliminary experience using a polyetheretherketone (PEEK) cage in the treatment of cervical disc disease. Neurosurgery 2002;51:1343-49.

26. Celik SE, Kara A, Celik S. A comparison of changes over time in cervical foraminal height after tricortical iliac graft or polyetheretherketone cage placement following anterior disectomy. J Neurosurg Spine 2007;6:10-6.

27. Whitecloud TS 3rd. Modern alternatives and techniques for one-level disectomy and fusion. Clin Orthop Relat Res 1999;(359):67-76.

28. Kitchel SH. Cervical interbody fusion cages: indications, techniques and results. Philadelphia: Hanley & Belfus; 1997. p. 423-32.

29. Brooke NS, Rorke AW, King AT, Gullan RW. Preliminary experience of carbon fibre cage prostheses for treatment of cervical spine disorders. Br J Neurosurg 1997;11:221-7.

30. Cook SD, Dalton JE, Tan EH, Tejeiro WV, Young MJ, Whitecloud TS 3rd. In vivo evaluation of anterior cervical fusions with hydroxylapatite graft material.
31. Suetsuna F, Seido H, Tooru Y. Anterior cervical interbody fusion with using porous hydroxyapatite ceramics-radiographic findings of bone union between HA and vertebra. Orthop Trans 1997;21:482-3.

32. Zdeblick TA, Cooke ME, Kunz DN, Wilson D, McCabe RP. Anterior cervical disectomy and fusion using a porous hydroxyapatite bone graft substitute. Spine (Phila Pa 1976) 1994;19:2348-57.

33. Madawi AA, Powell M, Crockard HA. Biocompatible osteoconductive polymer versus iliac graft: a prospective comparative study for the evaluation of fusion pattern after anterior cervical disectomy. Spine (Phila Pa 1976) 1996;21:2123-9.

34. van den Bent MJ, Oosting J, Wouda EJ, van Acker RE, Ansink BJ, Braakman R. Anterior cervical disectomy with or without fusion with acrylate. A randomized trial. Spine (Phila Pa 1976) 1996;21:834-9.

35. Urist MR. Bone: formation by autoinduction. Science 1965;150:893-9.

36. Boden SD, Zdeblick TA, Sandhu HS, Heim SE. The use of rhBMP-2 in interbody fusion cages: definitive evidence of osteoinduction in humans: a preliminary report. Spine (Phila Pa 1976) 2000;25:376-81.

37. Burkus JK, Heim SE, Gornet MF, Zdeblick TA. Is INFUSE bone graft superior to autograft bone? An integrated analysis of clinical trials using the LT-CAGE lumbar tapered fusion device. J Spinal Disord Tech 2003;16:113-22.

38. Shields LB, Raque GH, Glassman SD, et al. Adverse effects associated with high-dose recombinant human bone morphogenetic protein-2 use in anterior cervical spine fusion. Spine (Phila Pa 1976) 2006;31:542-7.

39. Smucker JD, Rhee JM, Singh K, Yoon ST, Heller JG. Increased swelling complications associated with off-label usage of rhBMP-2 in the anterior cervical spine. Spine (Phila Pa 1976) 2006;31:2813-9.

40. US Food and Drug Administration. FDA public health notification: life-threatening complications associated with recombinant human bone morphogenetic protein in cervical spine fusion. Silver Spring: US Food and Drug Administration; 2008.

41. Song KJ, Kim GH, Choi BY. Efficacy of PEEK cages and plate augmentation in three-level anterior cervical fusion of elderly patients. Clin Orthop Surg 2011;3:9-15.

42. Wang JC, McDonough PW, Endow K, Kanim LE, Delamarter RB. The effect of cervical plating on single-level anterior cervical disectomy and fusion. J Spinal Disord 1999;12:467-71.

43. Grob D, Peyer JV, Dvorak J. The use of plate fixation in anterior surgery of the degenerative cervical spine: a comparative prospective clinical study. Eur Spine J 2001;10:408-13.

44. Haid RW, Foley KT, Rodts GE, Barnes B. The Cervical Spine Study Group anterior cervical plate nomenclature. Neurosurg Focus 2002;12:E15.

45. Brodke DS, Gollogly S, Alexander Mohr R, Nguyen BK, Dailey AT, Bachus a K. Dynamic cervical plates: biomechanical evaluation of load sharing and stiffness. Spine (Phila Pa 1976) 2001;26:1324-9.

46. Ning X, Wen Y, Xiao-Jian Y, et al. Anterior cervical locking plate-related complications; prevention and treatment recommendations. Int Orthop 2008;32:649-55.

47. Foutan KN, Kapsalki EZ, Nikolakakos LG, et al. Anterior cervical disectomy and fusion associated complications. Spine (Phila Pa 1976) 2007;32:2310-7.

48. Foutan KN, Kapsalki EZ, Machinis T, Robinson JS. Extrusion of a screw into the gastrointestinal tract after anterior cervical spine plating. J Spinal Disord Tech 2006;19:199-203.

49. Park JB, Cho YS, Riew KD. Development of adjacent-level ossification in patients with an anterior cervical plate. J Bone Joint Surg Am 2005;87:558-63.

50. Li Y, Hao D, He B, Wang X, Yan L. The efficiency of zero-profile implant in anterior cervical disectomy fusion: a prospective controlled long-term follow-up study. J Spinal Disord Tech 2013 Oct 16 [Epub]. http://dx.doi.org/10.1097/BSD.0000000000000032.

51. Vaccaro AR, Carrino JA, Venger BH, et al. Use of a bioabsorbable anterior cervical plate in the treatment of cervical degenerative and traumatic disc disruption. J Neurosurg 2002;97:473-80.

52. Aryan HE, Lu DC, Acosta FL Jr, Hartl R, McCormick PW, Ames CP. Bioabsorbable anterior cervical plate: initial multicenter clinical and radiographic experience. Spine (Phila Pa 1976) 2007;32:1084-8.

53. Schwab JS, Diangelo DJ, Foley KT. Motion compensation associated with single-level cervical fusion: where does the lost motion go? Spine (Phila Pa 1976) 2006;31:2439-48.

54. Eck JC, Humphreys SC, Lim TH, et al. Biomechanical study on the effect of cervical spine fusion on
adjacent-level intradiscal pressure and segmental motion. Spine (Phila Pa 1976) 2002;27:2431-4.

55. Garrido BJ, Taha TA, Sasso RC. Clinical outcomes of Bryan cervical disc arthroplasty a prospective, randomized, controlled, single site trial with 48-month follow-up. J Spinal Disord Tech 2010;23:367-71.

56. 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.

57. Murrey D, Janssen M, Delamarter R, et al. Results of the prospective, randomized, controlled multicenter Food and Drug Administration investigational device exemption study of the ProDisc-C total disc replacement versus anterior discectomy and fusion for the treatment of 1-level symptomatic cervical disc disease. Spine J 2009;9:275-86.

58. Auerbach JD, Anakwenze OA, Milby AH, Lonner BS, Balderston RA. Segmental contribution toward total cervical range of motion: a comparison of cervical disc arthroplasty and fusion. Spine (Phila Pa 1976) 2011;36:E1593-9.

59. Sears WR, Sekhon LH, Duggal N, Williamson OD. Segmental malalignment with the Bryan Cervical Disc prosthesis: does it occur? J Spinal Disord Tech 2007;20:1-6.

60. Sasso RC, Metcalf NH, Hipp JA, Wharton ND, Anderson PA. Sagittal alignment after Bryan cervical arthroplasty. Spine (Phila Pa 1976) 2011;36:991-6.

61. Pickett GE, Sekhon LH, Sears WR, Duggal N. Complications with cervical arthroplasty. J Neurosurg Spine 2006;4:98-105.

62. Leung C, Casey AT, Goffin J, et al. Clinical significance of heterotopic ossification in cervical disc replacement: a prospective multicenter clinical trial. Neurosurgery 2005;57:759-63.

63. Robertson JT, Papadopoulos SM, Traynelis VC. Assessment of adjacent-segment disease in patients treated with cervical fusion or arthroplasty: a prospective 2-year study. J Neurosurg Spine 2005;3:417-23.

64. Song KJ, Choi BW, Jeon TS, Lee KB, Chang H. Adjacent segment degenerative disease: is it due to disease progression or a fusion-associated phenomenon? Comparison between segments adjacent to the fused and non-fused segments. Eur Spine J 2011;20:1940-5.

65. Maldonado CV, Paz RD, Martin CB. Adjacent-level degeneration after cervical disc arthroplasty versus fusion. Eur Spine J 2011;20 Suppl 3:403-7.

66. Burkus JK, Haid RW, Traynelis VC, Mummaneni PV. Long-term clinical and radiographic outcomes of cervical disc replacement with the Prestige disc: results from a prospective randomized controlled clinical trial. J Neurosurg Spine 2010;13:308-18.

67. Botelho RV, Moraes OJ, Fernandes GA, Buscariolli Ydos S, Bernardo WM. A systematic review of randomized trials on the effect of cervical disc arthroplasty on reducing adjacent-level degeneration. Neurosurg Focus 2010;28:E5.

68. Cardoso MJ, Mendelsohn A, Rosner MK. Cervical hybrid arthroplasty with 2 unique fusion techniques. J Neurosurg Spine 2011;15:48-54.