A Meta-Analysis Comparing the Results of Cervical Disc Arthroplasty with Anterior Cervical Discectomy and Fusion (ACDF) for the Treatment of Symptomatic Cervical Disc Disease

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Background: Anterior cervical discectomy and fusion is a standard treatment for symptomatic cervical disc disease, but pseudarthrosis and accelerated adjacent-level disc degeneration may develop. Cervical disc arthroplasty was developed to preserve the kinematics of the functional spinal unit. Trials comparing arthroplasty with anterior cervical discectomy and fusion have shown unclear benefits in terms of clinical results, neck motion at the operated level, adverse events, and the need for secondary surgical procedures.

Methods: Only randomized clinical trials were included in this meta-analysis, and the search strategy followed the requirements of the Cochrane Library Handbook. Two reviewers independently assessed the methodological quality of each included study and extracted the relevant data.

Results: Twenty-seven randomized clinical trials were included; twelve studies were Level I and fifteen were Level II. The results of the meta-analysis indicated longer operative times, more blood loss, lower neck and arm pain scores reported on a visual analog scale, better neurological success, greater motion at the operated level, fewer secondary surgical procedures, and fewer such procedures that involved supplemental fixation or revision in the arthroplasty group compared with the anterior cervical discectomy and fusion group. These differences were significant ($p < 0.05$). The two groups had similar lengths of hospital stay, Neck Disability Index scores, and rates of adverse events, removals, and reoperations ($p > 0.05$).

Conclusions: The meta-analysis revealed that anterior cervical discectomy and fusion was associated with shorter operative times and less blood loss compared with arthroplasty. Other outcomes after arthroplasty (length of hospital stay, clinical indices, range of motion at the operated level, adverse events, and secondary surgical procedures) were superior or equivalent to the outcomes after anterior cervical discectomy and fusion.

Level of Evidence: Therapeutic Level II. See Instructions for Authors for a complete description of levels of evidence.

For over fifty years, anterior cervical discectomy and fusion has been the standard treatment for symptomatic cervical disc disease resulting in pain, instability, and radiculopathy or myelopathy¹. However, this procedure usually results in the loss of motion at the operated level² and accelerated adjacent-level disc degeneration³. Pseudarthrosis can also occur. Cervical

disc arthroplasty was developed to preserve the kinematics of the functional spinal unit.

Arthroplasty and anterior cervical discectomy and fusion share similar indications and surgical approaches. Cervical disc arthroplasty in the well-selected patient may reduce the risk of adjacent-segment degeneration, by relieving neural

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compression and restoring intervertebral height and spinal alignment, as well as preserve motion⁴. Previous generations of cervical disc arthroplasty implants were associated with a high rate of complications. Recent designs, including Bryan (Medtronic Sofamor Danek, Memphis, Tennessee), ProDisc-C (Synthes Spine, Paoli, Pennsylvania), Prestige ST (Medtronic Sofamor Danek), and PCM (Cervitech, Rockaway, New Jersey) implants, are in the early stages of clinical use but appear to have fewer complications compared with previous prostheses.

Trials comparing arthroplasty with anterior cervical discectomy and fusion have been inconclusive in terms of clinical benefit⁵. The purpose of this study was to perform a meta-analysis of the available evidence comparing arthroplasty with anterior cervical discectomy and fusion for the treatment of symptomatic cervical disc disease.

Materials and Methods

Electronic Literature Database

We searched for relevant studies in accordance with the requirements of the Cochrane Library Handbook. Databases including the Cochrane Central Register of Controlled Trials, PubMed, and Embase were searched from the earliest available records in 1966 to March 2011 (see Appendix). There was no language restriction.

Randomized controlled trials comparing arthroplasty with anterior cervical discectomy and fusion in the target population of adult patients with symptomatic cervical disc disease (including radiculopathy, myelopathy, or disc herniation) without response to at least six weeks of nonoperative management were included. Multiple publications of the same study were not included. The types of cervical disc prostheses used for the arthroplasty included Bryan, ProDisc-C, Prestige ST, PCM, and other designs.

Data Extraction

Two reviewers (Y.G. and M.L.) independently performed the initial screening and data extraction, and two other investigators (T.L. and F.H.) then independently assessed all studies for eligibility for inclusion. Any disagreements were resolved by discussion among the investigators. Information retrieved from each study included the study design, number of participants, study setting, patient characteristics, sample size, follow-up duration, and outcome.

Surgical parameters (operative time, blood loss, and length of hospital stay), clinical indices (Neck Disability Index [NDI]⁶, visual analog scale [VAS] neck and arm pain scores, and neurological success), range of motion at the operated level, adverse events, and secondary surgical procedures (including removals, supplemental fixations, reoperations, and revisions)

were the primary criteria by which the studies included in the meta-analysis were evaluated. Neurological success was defined as maintenance or improvement in each of the neurological evaluation categories including sensory, motor, and reflex functions. Adverse events included adjacent-level disc disease, osteophyte formation, spontaneous fusion, heterotopic ossification, migration or subsidence of the artificial disc, and approach-related complications. Secondary surgical procedures were defined as any removal, supplemental fixation, reoperation, revision, or other relevant surgical procedure. Removal was defined as a procedure in which one or more components of the original implant configuration were removed without replacement. Supplemental fixation was defined as a procedure in which additional instrumentation not under study in the protocol was implanted (e.g., supplemental placement of a rod-and-screw system or a plate-and-screw system). Reoperation was defined as any surgical procedure at the involved level that did not remove, modify, or add any components. Revision surgery was defined as surgery to modify the original implant without removal of the entire construct.

Selection

In order to be included, a study had to have a therapeutic design and involve a randomized controlled trial with a Level of Evidence of I or II⁷. Trials without a randomized controlled design and case series (studies with a Level of Evidence of III or IV) were excluded.

Statistical Analysis

The odds ratio (OR) for the arthroplasty group and the accompanying 95% confidence interval (CI) were calculated for dichotomous outcomes, and the weighted mean difference (WMD) and the 95% CI were calculated for continuous outcomes. Heterogeneity was tested for with use of both the chi-square test and the I^2 test. A p value of <0.10 for the chi-square test was interpreted as evidence of heterogeneity, and I^2 was used to estimate total variation across the studies. A fixed-effect model was adopted if there was no statistical evidence of heterogeneity, and a random-effect model was adopted if significant heterogeneity was evident. The possibility of publishing bias was not evaluated because of the small number of studies assessed.

Source of Funding

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Results

After sixty-four duplicates were removed, 104 articles published from 1966 to March 2011 were retrieved (see Appendix). Twenty-seven of these studies were included after abstract screening and full-text screening (see Appendix). Assessment of the methodological quality of these studies revealed that twelve studies had a Level of Evidence of I; the

Fig. 1

Comparison of operative time between the arthroplasty group and the anterior cervical discectomy and fusion (ACDF, "control") group. SD = standard deviation, IV = inverse variance, CI = confidence interval, and df = degrees of freedom.

Fig. 2
Comparison of blood loss between the arthroplasty ("experimental") group and the anterior cervical discectomy and fusion (ACDF, "control") group. SD = standard deviation, IV = inverse variance, CI = confidence interval, and df = degrees of freedom.

remaining fifteen studies were classified as Level II because of unclear allocation concealment, blinding, or loss of follow-up (see Appendix). Demographic data at baseline were similar in the two treatment groups (see Appendix).

Surgical Parameters

Operative Time

Information on the operative time was provided in nine studies, and three of these studies with a total of 575 patients (310 in the arthroplasty group and 265 in the anterior cervical discectomy and fusion group) were eligible for meta-analysis. The operative time was significantly longer in the arthroplasty group (WMD, 22.03 minutes; 95% CI, 16.58 to 27.48 minutes; $p < 0.00001$) (Fig. 1).

Blood Loss

Information on total blood loss was provided in nine studies, and three of these studies with a total of 575 patients (310 in the

arthroplasty group and 265 in the anterior cervical discectomy and fusion group) were analyzed. Blood loss was significantly greater in the arthroplasty group (WMD, 16.31 mL; 95% CI, 7.59 to 25.03 mL; $p = 0.0002$) (Fig. 2).

Length of Hospital Stay

Information on the length of the hospital stay was provided in six studies, and three of these studies with a total of 575 patients (310 in the arthroplasty group and 265 in the anterior cervical discectomy and fusion group) were analyzed. The length of the hospital stay did not differ significantly between the two groups (WMD, -0.03 days for the arthroplasty group; 95% CI, -0.15 to 0.09 days; $p = 0.64$).

Clinical Indices

Neck Disability Index (NDI)

NDI scores were provided in ten studies, and three of these studies with a total of 677 patients (354 in the arthroplasty

Fig. 3
Comparison of visual analog scale (VAS) neck (top) and arm (bottom) pain scores between the arthroplasty ("experimental") group and the anterior cervical discectomy and fusion (ACDF, "control") group. SD = standard deviation, IV = inverse variance, CI = confidence interval, and df = degrees of freedom.

Fig. 4

Comparison of neurological success between the arthroplasty ("experimental") group and the anterior cervical discectomy and fusion (ACDF, "control") group. MH = Mantel-Haenszel, CI = confidence interval, and df = degrees of freedom.

group and 323 in the anterior cervical discectomy and fusion group) were analyzed. The NDI scores did not differ significantly between the two groups (WMD, 1.63; 95% CI, -0.46 to 3.72; $p = 0.13$).

VAS Pain

VAS pain scores were provided in eight studies, and four of these studies with a total of 249 patients (124 in the arthroplasty group and 125 in the anterior cervical discectomy and fusion group) were analyzed. The arthroplasty group had significantly lower neck pain scores (WMD, -0.20; 95% CI, -0.36 to -0.04; $p = 0.01$) and significantly lower arm pain scores (WMD, -0.15; 95% CI, -0.27 to -0.02; $p = 0.02$) (Fig. 3).

Neurological Success

Four studies provided data on neurological success, and all four studies with a total of 1056 patients (590 in the arthroplasty group and 466 in the anterior cervical discectomy and fusion group) were analyzed. The arthroplasty group had significantly better neurological success compared with the anterior cervical discectomy and fusion group (OR, 2.21; 95% CI, 1.45 to 3.38; $p = 0.0002$) (Fig. 4).

Range of Motion at the Operated Level

Data on the range of motion at the operated level were provided in twelve studies, and three of these studies with a total of 1097 patients (603 in the arthroplasty group and 494 in the anterior

cervical discectomy and fusion group) were analyzed. The arthroplasty group had significantly better range of motion at the operated level compared with the anterior cervical discectomy and fusion group (WMD, 5.70°; 95% CI, 5.33° to 6.07°; $p < 0.00001$) (Fig. 5).

Adverse Events

Information on adverse events was provided in ten studies, and eight of these studies with a total of 1759 patients (773 in the arthroplasty group and 986 in the anterior cervical discectomy and fusion group) were analyzed. The rate of adverse events in the arthroplasty group was not significantly different from that in the anterior cervical discectomy and fusion group (OR, 1.09; 95% CI, 0.80 to 1.50; $p = 0.58$).

Secondary Surgical Procedures

Details regarding second surgical procedures were provided in eleven studies, and five of these studies with a total of 1237 patients (656 in the arthroplasty group and 581 in the anterior cervical discectomy and fusion group) were analyzed. There were significantly fewer secondary surgical procedures in the arthroplasty group (OR, 0.52; 95% CI, 0.32 to 0.86; $p = 0.01$) (Fig. 6).

Removals, supplemental fixations, reoperations, and revisions were also analyzed separately. Significantly fewer supplemental fixations ($p = 0.0009$) and revisions ($p = 0.003$) were performed in the arthroplasty group. There were no significant differences in the number of removals

Fig. 5

Comparison of motion at the operated level between the arthroplasty ("experimental") group and the anterior cervical discectomy and fusion (ACDF, "control") group. SD = standard deviation, IV = inverse variance, CI = confidence interval, and df = degrees of freedom.

Fig. 6

Comparison of secondary surgical procedures between the arthroplasty ("experimental") group and the anterior cervical discectomy and fusion (ACDF, "control") group. MH = Mantel-Haenszel, CI = confidence interval, and df = degrees of freedom.

($p = 0.07$) and reoperations ($p = 0.12$) between the two groups.

Discussion

Anterior cervical discectomy and fusion is one of the most commonly performed spinal procedures^{8,9}. The clinical outcome of this procedure is satisfactory in the majority of cases. The most common finding after anterior cervical discectomy and fusion is loss of range of motion in the cervical spine, as would be expected following the local fusion.

The loss of range of motion at the operated level is commonly compensated for at the adjacent levels. A cadaveric biomechanical study of the cervical spine characterized this motion compensation after anterior cervical discectomy and fusion at different levels¹⁰. In vitro studies supported the conclusion that anterior cervical discectomy and fusion at the operated level increases intersegmental motion as well as load and intradiscal pressure at the adjacent levels and may induce progressive disc degeneration at these levels⁹. Some studies have also shown a relationship between the loss of range of motion at the operated level after this procedure and persistent neck pain, poor functional recovery, cervical instability, or even development of accelerated adjacent-level disc degeneration, which is one of the main reasons for the failure of this treatment^{2,11-14}. Hilibrand et al.¹⁵ reported the annual incidence of symptomatic adjacent-level disc degeneration after fusion to be 2.9%. Studies^{1,14,15} with longer follow-up periods revealed that up to 25% of patients may develop recurrent radicular symptoms from adjacent-level disc degeneration. On the basis of these results, Eck et al.¹¹ suggested in a biomechanical and kinematic study that preservation of motion at the site of the surgery might help to lessen the incidence of adjacent-level disc degeneration. Arthroplasty was designed to restore physiologic biomechanics and to reduce the adjacent-level forces, thereby reducing the potential for accelerated adjacent-level disc degeneration.

In our meta-analysis, the arthroplasty group had better range of motion at the operated level compared with the anterior cervical discectomy and fusion group, as expected after a

local fusion. Furthermore, the arthroplasty group had a better rate of neurological success and lower neck and arm pain scores while maintaining a similar Neck Disability Index (NDI) score. Pseudarthrosis after an anterior cervical fusion may lead to continued pain and disability¹⁶. Previously, Steinmetz et al.¹⁶ found that patients undergoing arthroplasty appear to have a better quality of life in the short term and earlier return to work.

Arthroplasty and anterior cervical discectomy and fusion share similar indications, including radiculopathy, myelopathy, cervical disc herniation, or spondylosis not responding to nonoperative treatment¹⁷. Because of the similarity in the surgical procedures, we inferred that arthroplasty and anterior cervical discectomy and fusion had a similar rate of approach-related complications. In this meta-analysis, the arthroplasty group had longer operative times and more blood loss than the anterior cervical discectomy and fusion group, whereas both groups had similar lengths of hospital stay. Murray et al.¹⁸ considered the increased operative time for arthroplasty to be attributable to the time required to learn the new technique and time due to additional use of fluoroscopy. The increased blood loss was attributed to bleeding from the keel cuts into cancellous bone required by the arthroplasty technique. Although both of these differences were statistically significant, neither was considered clinically important.

Previous generations of cervical arthroplasty implants were associated with a high frequency of adverse events. The Bristol/Cummins joint (Medtronic Sofamor Danek) involved a stainless-steel ball-and-socket design and was secured in place with plates and screws. Screw failure, joint subluxation, and high rates of dysphagia occurred in patients who underwent procedures with this implant¹⁹. More recent models such as the Bryan, ProDisc-C, Prestige ST, and PCM appear to provide better results and have fewer prosthesis-related complications^{12,13,20}, which may be the reason why fewer supplemental fixations and revisions were required in the arthroplasty group. Although the two groups had similar removal and reoperation rates, the difference in the overall rate of secondary surgical procedures required was significant. Moreover, nonunion, graft

collapse, and expulsion, which have been reported as the complications of fusion and require secondary surgical procedures, cannot occur after arthroplasty¹⁷.

Data on adverse events were not consistent. Some studies indicated fewer adverse events in the arthroplasty group²¹, whereas others indicated the opposite^{14,22}. Because of the similarity in the surgical procedures, arthroplasty and anterior cervical discectomy and fusion had a similar rate of approach-related complications. The authors of a recent literature review regarding complications of anterior cervical discectomy and fusion reported overall prevalences of dysphagia, hoarseness, and unilateral vocal cord paralysis to be 12.3%, 4.9%, and 1.4%, respectively²³. Such complications, as well as recurrent laryngeal nerve injury, are recognized as risks of the anterior approach to the cervical spine and are not risks specific to arthroplasty. We believe that the similarities in the surgical procedures and associated perioperative and postoperative management may be the reason why the rates of these adverse events were similar. Other adverse events will still depend on the surgical technique; more adverse events caused by the reduced range of motion at the operated level occurred in the anterior cervical discectomy and fusion group, but subsidence and migration of the prosthesis could only occur in the arthroplasty group¹⁹.

Only randomized trials were included in the meta-analysis. We did not undertake a subgroup analysis according to prosthesis model because the data were insufficient. Bias could have resulted from the insufficient data provided in many

studies, such as the lack of standard deviations, and from industry funding of some trials (see Appendix).

In summary, this meta-analysis indicated that the surgical parameters for anterior cervical discectomy and fusion were superior or equivalent to those for arthroplasty. However, other outcomes after arthroplasty were superior or equivalent to the same outcomes after anterior cervical discectomy and fusion.

Appendix

Tables summarizing the literature search and excluded studies as well as the methodological quality, characteristics, and funding of the included studies are available with the online version of this article as a data supplement at jbjs.org. ■

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References

- Goffin J, Geusens E, Vantomme N, Quintens E, Waerzeggers Y, Depreitere B, Van Calenberg F, van Loon J. Long-term follow-up after interbody fusion of the cervical spine. *J Spinal Disord Tech*. 2004 Apr;17(2):79-85.
- Yang YC, Nie L, Cheng L, Hou Y. Clinical and radiographic reports following cervical arthroplasty: a 24-month follow-up. *Int Orthop*. 2009 Aug;33(4):1037-42. Epub 2008 May 22.
- Peng-Fei S, Yu-Hua J. Cervical disc prosthesis replacement and interbody fusion: a comparative study. *Int Orthop*. 2008 Feb;32(1):103-6. Epub 2006 Dec 16.
- Buchowski JM, Anderson PA, Sekhon L, Riew KD. Cervical disc arthroplasty compared with arthrodesis for the treatment of myelopathy. *Surgical technique*. *J Bone Joint Surg Am*. 2009 Oct 1;91 Suppl. 2:223-32.
- Bartels RH, Donk R, Verbeek AL. No justification for cervical disk prostheses in clinical practice: a meta-analysis of randomized controlled trials. *Neurosurgery*. 2010 Jun;66(6):1153-60; discussion 1160.
- Vernon H, Mior S. The Neck Disability Index: a study of reliability and validity. *J Manipulative Physiol Ther*. 1991 Sep;14(7):409-15.
- Wright JG, Swiontkowski MF, Heckman JD. Introducing levels of evidence to the journal. *J Bone Joint Surg Am*. 2003 Jan;85-A(1):1-3.
- Cao J, Shen Y, Yang D, Ding W, Meng X, Zhang W, Li Z. [Contrastive analysis of neck axial symptoms after Bryan cervical disc arthroplasty or traditional anterior cervical discectomy and fusion]. *Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi*. 2008 Oct;22(10):1200-4. Chinese.
- Riew KD, Buchowski JM, Sasso R, Zdeblick T, Metcalf NH, Anderson PA. Cervical disc arthroplasty compared with arthrodesis for the treatment of myelopathy. *J Bone Joint Surg Am*. 2008 Nov;90(11):2354-64.
- Kim SW, Limson MA, Kim SB, Arbatin JJ, Chang KY, Park MS, Shin JH, Ju YS. Comparison of radiographic changes after ACDF versus Bryan disc arthroplasty in single and bi-level cases. *Eur Spine J*. 2009 Feb;18(2):218-31. Epub 2009 Jan 6.
- Eck JC, Humphreys SC, Lim TH, Jeong ST, Kim JG, Hodges SD, An HS. Biomechanical study on the effect of cervical spine fusion on adjacent-level intradiscal pressure and segmental motion. *Spine (Phila Pa 1976)*. 2002 Nov 15;27(22):2431-4.
- Ruetten S, Komp M, Merk H, Godolias G. Full-endoscopic anterior decompression versus conventional anterior decompression and fusion in cervical disc herniations. *Int Orthop*. 2009 Dec;33(6):1677-82. Epub 2008 Nov 18.
- Liao JC, Niu CC, Chen WJ, Chen LH. Polyetheretherketone (PEEK) cage filled with cancellous allograft in anterior cervical discectomy and fusion. *Int Orthop*. 2008 Oct;32(5):643-8. Epub 2007 Jul 17.
- Heller JG, Sasso RC, Papadopoulos SM, Anderson PA, Fessler RG, Hacker RJ, Coric D, Cauthen JC, Riew DK. Comparison of BRYAN cervical disc arthroplasty with anterior cervical decompression and fusion: clinical and radiographic results of a randomized, controlled, clinical trial. *Spine (Phila Pa 1976)*. 2009 Jan 15;34(2):101-7.
- Hilibrand AS, Carlson GD, Palumbo MA, Jones PK, Bohlman HH. Radiculopathy and myelopathy at segments adjacent to the site of a previous anterior cervical arthrodesis. *J Bone Joint Surg Am*. 1999 Apr;81(4):519-28.
- Steinmetz MP, Patel R, Traynelis V, Resnick DK, Anderson PA. Cervical disc arthroplasty compared with fusion in a workers' compensation population. *Neurosurgery*. 2008 Oct;63(4):741-7; discussion 747.
- Ruetten S, Komp M, Merk H, Godolias G. Full-endoscopic cervical posterior foraminotomy for the operation of lateral disc herniations using 5.9-mm endoscopes: a prospective, randomized, controlled study. *Spine (Phila Pa 1976)*. 2008 Apr 20;33(9):940-8.
- Murrey D, Janssen M, Delamarter R, Goldstein J, Zigler J, Tay B, Darden B. 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 Apr;9(4):275-86. Epub 2008 Sep 6.
- Pickett GE, Sekhon LH, Sears WR, Duggal N. Complications with cervical arthroplasty. *J Neurosurg Spine*. 2006 Feb;4(2):98-105.
- Nabhan A, Ahlhelm F, Pitzen T, Steudel WI, Jung J, Shariat K, Steimer O, Bachelier F, Pape D. Disc replacement using Pro-Disc C versus fusion: a prospective randomised and controlled radiographic and clinical study. *Eur Spine J*. 2007 Mar;16(3):423-30. Epub 2006 Nov 14.
- Coric D, Cassis J, Carew JD, Boltes MO. Prospective study of cervical arthroplasty in 98 patients involved in 1 of 3 separate investigational device exemption studies from a single investigational site with a minimum 2-year follow-up. *Clinical article*. *J Neurosurg Spine*. 2010 Dec;13(6):715-21.

22. Anderson PA, Sasso RC, Riew KD. Comparison of adverse events between the Bryan artificial cervical disc and anterior cervical arthrodesis. *Spine (Phila Pa 1976)*. 2008 May 20;33(12):1305-12.
23. Baron EM, Soliman AM, Gaughan JP, Simpson L, Young WF. Dysphagia, hoarseness, and unilateral true vocal fold motion impairment following anterior cervical discectomy and fusion. *Ann Otol Rhinol Laryngol*. 2003 Nov;112(11):921-6.
24. 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 Sep;13(3):308-18.
25. Cheng L, Nie L, Zhang L, Hou Y. Fusion versus Bryan Cervical Disc in two-level cervical disc disease: a prospective, randomised study. *Int Orthop*. 2009 Oct;33(5):1347-51. Epub 2008 Oct 28.
26. Coric D, Finger F, Boltes P. Prospective randomized controlled study of the Bryan Cervical Disc: early clinical results from a single investigational site. *J Neurosurg Spine*. 2006 Jan;4(1):31-5.
27. Delamarter RB, Murrey D, Janssen ME, Goldstein JA, Zigler J, Tay BK, Darden B. Results at 24 months from the prospective, randomized, multicenter Investigational Device Exemption trial of ProDisc-C versus anterior cervical discectomy and fusion with 4-year follow-up and continued access patients. *SAS J*. 2010 Dec;4(4):122-8.
28. 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 Aug;23(6):367-71.
29. Grob D, Porchet F, Kleinstück FS, Lattig F, Jeszenszky D, Luca A, Mutter U, Mannion AF. A comparison of outcomes of cervical disc arthroplasty and fusion in everyday clinical practice: surgical and methodological aspects. *Eur Spine J*. 2010 Feb;19(2):297-306. Epub 2009 Oct 31.
30. Jawahar A, Cavanaugh DA, Kerr EJ 3rd, Birdsong EM, Nunley PD. Total disc arthroplasty does not affect the incidence of adjacent segment degeneration in cervical spine: results of 93 patients in three prospective randomized clinical trials. *Spine J*. 2010 Dec;10(12):1043-8. Epub 2010 Sep 24.
31. Kelly MP, Mok JM, Frisch RF, Tay BK. Adjacent segment motion after anterior cervical discectomy and fusion versus Prodisc-c cervical total disk arthroplasty: analysis from a randomized, controlled trial. *Spine (Phila Pa 1976)*. 2011 Jul 1;36(15):1171-9.
32. McAfee PC, Cappuccino A, Cunningham BW, Devine JG, Phillips FM, Regan JJ, Albert TJ, Ahrens JE. Lower incidence of dysphagia with cervical arthroplasty compared with ACDF in a prospective randomized clinical trial. *J Spinal Disord Tech*. 2010 Feb;23(1):1-8.
33. 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 Mar;6(3):198-209.
34. Nabhan A, Ahlhelm F, Shariat K, Pitzen T, Steimer O, Steudel WI, Pape D. The ProDisc-C prosthesis: clinical and radiological experience 1 year after surgery. *Spine (Phila Pa 1976)*. 2007 Aug 15;32(18):1935-41.
35. Park DK, Lin EL, Phillips FM. Index and adjacent level kinematics after cervical disc replacement and anterior fusion: in vivo quantitative radiographic analysis. *Spine (Phila Pa 1976)*. 2011 Apr 20;36(9):721-30.
36. Porchet F, Metcalf NH. Clinical outcomes with the Prestige II cervical disc: preliminary results from a prospective randomized clinical trial. *Neurosurg Focus*. 2004 Sep 15;17(3):E6.
37. Powell JW, Sasso RC, Metcalf NH, Anderson PA, Hipp JA. Quality of spinal motion with cervical disk arthroplasty: computer-aided radiographic analysis. *J Spinal Disord Tech*. 2010 Apr;23(2):89-95.
38. Sasso RC, Smucker JD, Hacker RJ, Heller JG. Clinical outcomes of BRYAN cervical disc arthroplasty: a prospective, randomized, controlled, multicenter trial with 24-month follow-up. *J Spinal Disord Tech*. 2007 Oct;20(7):481-91.
39. Sasso RC, Best NM. Cervical kinematics after fusion and bryan disc arthroplasty. *J Spinal Disord Tech*. 2008 Feb;21(1):19-22.
40. Sasso RC, Smucker JD, Hacker RJ, Heller JG. Artificial disc versus fusion: a prospective, randomized study with 2-year follow-up on 99 patients. *Spine (Phila Pa 1976)*. 2007 Dec 15;32(26):2933-40; discussion 2941-2.
41. Sasso RC, Best NM, Metcalf NH, Anderson PA. Motion analysis of bryan cervical disc arthroplasty versus anterior discectomy and fusion: results from a prospective, randomized, multicenter, clinical trial. *J Spinal Disord Tech*. 2008 Aug;21(6):393-9.
42. Sasso RC, Metcalf NH, Hipp JA, Wharton ND, Anderson PA. Sagittal alignment after Bryan cervical arthroplasty. *Spine (Phila Pa 1976)*. 2011 Jun;36(13):991-6.
43. Segebarth B, Datta JC, Darden B, Janssen ME, Murrey DB, Rhyne A, Beckham R, Ponce C. Incidence of dysphagia comparing cervical arthroplasty and ACDF. *SAS J*. 2010;4(1):3-8.
44. Wang Y, Cai B, Zhang XS, Xiao SH, Wang Z, Lu N, Chai W, Zheng GQ. [Clinical outcomes of single level Bryan cervical disc arthroplasty: a prospective controlled study]. *Zhonghua Wai Ke Za Zhi*. 2008 Mar 1;46(5):328-32. Chinese.
45. Anakwenze OA, Auerbach JD, Milby AH, Lonner BS, Balderston RA. Sagittal cervical alignment after cervical disc arthroplasty and anterior cervical discectomy and fusion: results of a prospective, randomized, controlled trial. *Spine (Phila Pa 1976)*. 2009;34(19):2001-7.