M6c
artificial cervical disc

SpinalKinetics™
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December 2009 – Volume 1

Careful Attention to Technique will Maximize Success

Align neck in neutral position.

Identify the midline.

Thorough decompression and precise endplate preparation.

Can we say this any more clearly or emphasize this statement any stronger? This is just the fact of arthroplasty: **by utilizing the best technique, surgeons will maximize their opportunity for a successful outcome**. The attached paper recently published in the Journal of Bone & Joint Surgery (JBJS), "Cervical Disc Arthroplasty Compared with Arthrodesis for the Treatment of Myelopathy", highlights this very fact. The paper focuses on arthroplasty compared to fusion in patients with myelopathy. A good outcome for the arthroplasty group, (which is information you will want to share with your customers about their myelopathic patients) and to the point of this communication, the authors state areas of surgical technique that they believe very important to a successful outcome:

1. Careful attention to orientation of the neck in a neutral position
2. Identification of the midline
3. Precise endplate preparation
4. Complete and thorough decompression

As you review this paper you will note that all of these steps discussed by the authors have been previously highlighted in our Surgical Technique Manual. This is good validation to your surgeons that the recommended technique for M6-C is widely accepted as a standard of practice.

Cervical Disc Arthroplasty Compared with Arthrodesis for the Treatment of Myelopathy. Surgical Technique

Jacob M. Buchowski, Paul A. Anderson, Lali Sekhon and K. Daniel Riew

Cervical Disc Arthroplasty Compared with Arthrodesis for the Treatment of Myelopathy
Surgical Technique

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Investigation performed at Washington University in St. Louis, St. Louis, Missouri; Indiana Spine Group, Indianapolis, Indiana; and University of Wisconsin, Madison, Wisconsin

The original scientific article in which the surgical technique was presented was published in JBJS Vol. 90-A, pp. 2354-64, November 2008

ABSTRACT FROM THE ORIGINAL ARTICLE

BACKGROUND: Although there have been case reports describing the use of cervical disc arthroplasty for the treatment of myelopathy, there is a concern that motion preservation may maintain microtrauma to the spinal cord, negatively affecting the clinical results. As we are not aware of any studies on the use of arthroplasty in this scenario, we performed a cross-sectional analysis of two large, prospective, randomized multicenter trials to evaluate the efficacy of cervical disc arthroplasty for the treatment of myelopathy.

METHODS: The patients in the current study were a cohort of patients who were enrolled in the United States Food and Drug Administration Investigational Device Exemption studies of the Prestige ST and Bryan disc replacements (Medtronic, Memphis, Tennessee). The inclusion criteria were myelopathy and spondylosis or disc herniation at a single level from C3 to C7. Clinical outcome measures were collected preoperatively and at six weeks, three months, six months, twelve months, and twenty-four months postoperatively.

RESULTS: A total of 199 patients were included in the present study; 106 patients (53%) underwent arthroplasty, whereas ninety-three (47%) underwent arthrodesis. The Neck Disability Index, Short Form-36 scores, and specific arm and neck pain scores improved significantly from baseline at all time points. Patients in all four groups had improvement in the postoperative neurological status and gait function; at twenty-four months after surgery, 90% (95% confidence interval, 77.8% to 96.6%) of the patients in the arthroplasty group and 81% (95% confidence interval, 64.9% to 92.0%) of those in the arthrodesis group had improvement in or maintenance of the neurological status in the Prestige ST trial and 90% (95% confidence interval, 75.8% to 97.1%) of the patients in the arthroplasty group and 77% (95% confidence interval, 57.7% to 90.1%) of those in the arthrodesis group had improvement in or maintenance of the neurological status in the Bryan trial.

CONCLUSIONS: We found that patients in both the arthroplasty and arthrodesis groups had improvement following surgery; furthermore, improvement was similar between the groups, with no worsening of myelopathy in the arthroplasty group. While the findings at two years postoperatively suggest that arthroplasty is equivalent to arthrodesis for the treatment of cervical myelopathy for a single-level abnormality localized to the disc space, the present study did not evaluate the treatment of retrovertebral compression as occurs in association with ossification of the posterior longitudinal ligament, and we cannot comment on the treatment of this condition.

LEVEL OF EVIDENCE: Therapeutic Level II. See Instructions to Authors for a complete description of levels of evidence.

ORIGINAL ABSTRACT CITATION: "Cervical Disc Arthroplasty Compared with Arthrodesis for the Treatment of Myelopathy" (2008;90:2354-64).

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INTRODUCTION

Anterior cervical discectomy and fusion is one of the most clinically and radiographically successful procedures for the treatment of cervical spondylotic myelopathy and/or radiculopathy[1-6]. Notwithstanding this success, its principal disadvantage is the loss of motion segments, which may accelerate adjacent disc degeneration. This process has been estimated to occur with an incidence of 2.9% per year, with an overall prevalence of 25.6% for symptomatic adjacent-segment degeneration at ten years following surgery[7]. Moreover, the treatment of degenerated segments adjacent to a previous fusion is more challenging and is fraught with more complications than isolated primary arthrodesis is[1,6,8-10]. Conversely, cervical disc arthroplasty in the correctly-selected patient can potentially reduce the risk of adjacent-segment degeneration by relieving neural compression, restoring intervertebral height and spinal alignment, and preserving motion[1,9-22].

Different arthroplasty systems involve the use of different methods for preparing the disc space: some involve preparation of the end plate either before or after decompression of the neural elements, and others require the use of a proprietary distraction system[1,9-22]. In the present report, we will only address a generic method of decompressing the disc space that is applicable to nearly all arthroplasty systems.

SURGICAL TECHNIQUE

Patient Positioning

At the time of cervical disc arthroplasty, the patient is positioned supine on a radiolucent table to allow imaging in both the anteroposterior and lateral planes in order to localize the affected levels and to provide guidance throughout the procedure (Fig. 1).

In order to optimize end plate preparation and the placement of the arthroplasty device, neutral positioning of the neck is critical when cervical disc arthroplasty is performed. If the neck is hyperextended, an excessive amount of the posterior end plate needs to be removed to produce parallel surfaces during end plate preparation. This

can result in a malpositioned, kyphotic prosthesis, especially in patients who are managed with an unconstrained device (Figs. 2 and 3). Conversely, if the neck is placed in a kyphotic position, too much of the anterior end plate is removed to produce parallel surfaces during end plate preparation and the prosthesis assumes an excessively lordotic position[1,13-16]. In order to prevent placing the disc in a scoliotic alignment, the neck should also be oriented squarely so that the spinous processes lie equidistant between the pedicles on anteroposterior images.

Exposure

The anterior part of the cervical spine is exposed with

FIG. 1

Photograph demonstrating the proper positioning for a patient undergoing cervical disc arthroplasty. Note the neutral positioning of the neck.
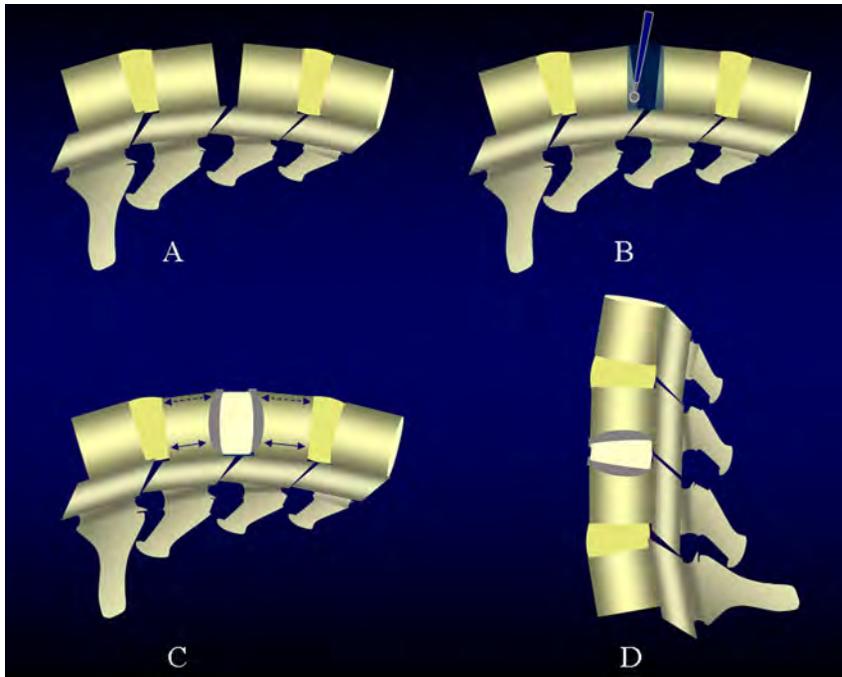
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FIG. 2

A: If the neck of the patient has been placed in a hyperextended position, the posterior aspect of the disc space is narrowed in comparison with the anterior aspect. *B:* If the end plate preparation is performed in this position, more of the posterior end plate must be removed. *C:* With the disc arthroplasty device in place, the anterior aspect of the vertebral body (dashed arrows) is longer than the posterior aspect of the body (solid arrows). This may not be noticed until the neck of the patient is placed in an upright position. *D:* Once the patient is upright, it becomes obvious that the prosthesis has been placed in a kyphotic position. This may be true even in the presence of neutral or even lordotic overall cervical alignment.

use of a standard Smith-Robinson approach. A retractor system is selected according to surgeon preference and, after the spine is exposed and the level of the abnormality is identified, the longus colli is elevated bilaterally. The midline is marked with unipolar electrocautery, which is then used to separate the muscle from its attachment to bone and the disc. A Penfield number-2 dissector is then used to elevate the longus colli further laterally in order to prevent inadvertent injury to an aberrant vertebral artery, which can occur if unipolar electrocautery is used in this area. The longus colli is elevated past the uncinate process and over the foramen transversarium. This allows for thorough decompression of the uncinate region as well as accurate confirmation of the midline and

the lateral extent of the vertebral body and the uncinate processes[1,13-16].

Osteophyte Removal

Once the level of interest has been thoroughly exposed, all an-

FIG. 3

If the prosthesis is in kyphosis, then it may limit how much flexion can occur across the motion segment. (Reproduced, with modification, from: Buchowski JM, Riew KD. Primary indications and disc space preparation for cervical disc arthroplasty. In: Yue JJ, Bertagnoli R, McAfee PC, An HS, editors. Motion preservation surgery of the spine: advanced techniques and controversies. Philadelphia: WB Saunders; 2008. p 185-92. Reprinted with permission.)
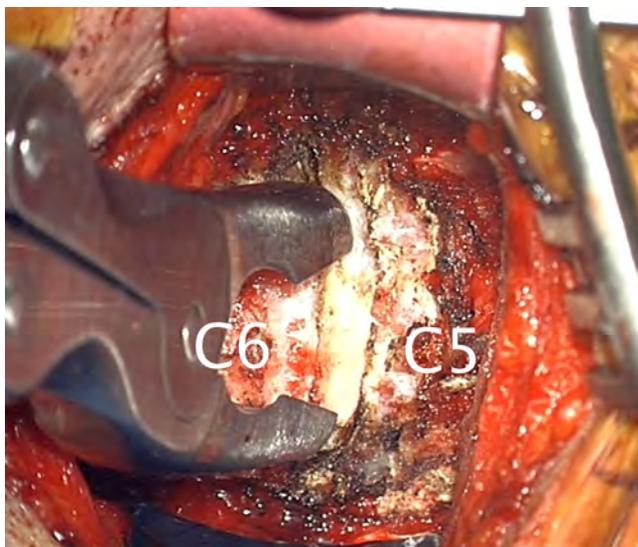
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FIG. 4 **FIG. 5**

Fig. 4 Intraoperative photograph demonstrating the use of a Leksell rongeur to resect all anterior osteophytes so that the anterior margin of the disc space is flush with the rest of the vertebral body. **Fig. 5** Photograph demonstrating the lateral extent of the exposure needed to obtain a thorough decompression. Note the Penfield number-2 dissectors (*) placed lateral to the uncinate bilaterally. (Reproduced, with modification, from: Buchowski JM, Riew KD. Primary indications and disc space preparation for cervical disc arthroplasty. In: Yue JJ, Bertagnoli R, McAfee PC, An HS, editors. Motion preservation surgery of the spine: advanced techniques and controversies. Philadelphia: WB Saunders; 2008. p 185-92. Reprinted with permission.)
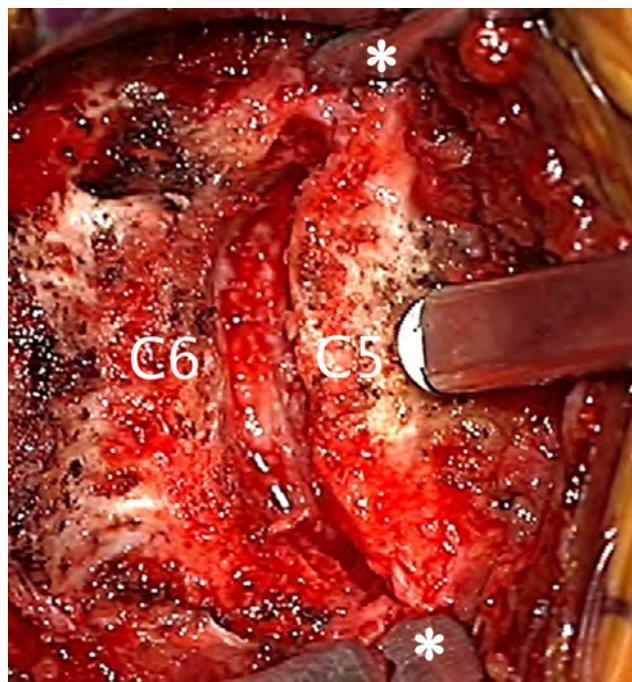
terior osteophytes are removed with a burr or a Leksell rongeur such that the anterior margin of the disc space is flush with the rest of the vertebral body (Fig. 4). Careful removal of these osteophytes is necessary as any remaining osteophytic lipping at the disc space may lead to errors in placement of the arthroplasty device. Palpation of the disc space is often the best way to determine if osteophyte removal is adequate[1].

Initial Disc Space Preparation
The anterior anulus is incised with use of a number-15 scalpel; pituitary rongeurs and small curettes (typically 3 or 4-mm up-angled curettes) are used to remove the initial disc material and fragments. While the disc material is being removed, the surgeon should be continuously mindful of the lateral border of the vertebral body in order to avoid inadvertently damaging the vertebral artery. Once the initial discectomy has been performed, the lateral borders of the uncinate processes are carefully identified. A small, 2-mm up-angled curette is used to initially identify the uncinate processes and their lateral extent and to denude the uncovertebral joints of any disc and cartilaginous material. When this maneuver is performed, care should be taken to prevent accidental injury to the vertebral artery, which can occur if the curette is used to scrape in a lateral direction[1,13-16]. The extent of the initial disc space preparation is shown in Figure 5.

Identification of the Midline
Confirmation of the midline location can be accomplished at this juncture by looking at the two denuded uncinate processes (Fig. 5).

End Plate Preparation
At this point, either end plate

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FIG. 6-A   **FIG. 6-B**

Fig. 6-A Sagittal computed tomography reconstruction illustrating the amount of end plate and posterior vertebral osteophyte resection needed at C5-C6 to achieve a thorough central decompression. **Fig. 6-B** Axial computed tomography image demonstrating the absence of facet joint arthropathy or hypertrophy at C5-C6.

preparation or decompression is performed. For devices that allow the decompression to take place before end plate preparation is performed, pins are placed into the vertebral bodies in the midline to facilitate distraction across the disc space. Once the pins have been inserted and distraction has been applied, the burr is then used to flatten the end plates. This is done by first removing any remaining cartilage and by lightly decorticating the inferior end plate of the cephalad vertebra. The end plate initially is decorticated anteriorly and

then is decorticated progressively more posteriorly down to the posterior longitudinal ligament, with removal of any remaining disc material, including the posterior anulus, during the process. A similar technique is then used to remove any remaining cartilage and to minimally decorticate the superior end plate of the caudad vertebra[1,13-16].

Decompression

For disc arthroplasty to be successful, a thorough decompression must be performed and all posterior vertebral and uncinate

osteophytes must be removed (Figs. 6-A through 7-D). We prefer to resect the osteophytes with a burr in order to avoid additional trauma to the spinal cord, which is especially important in the setting of myelopathy. A side-cutting matchstick burr is preferred so that the tip can rest lightly on the posterior longitudinal ligament (and even briefly on the dura) without damaging the soft tissues (Fig. 7-A). Once the posterior osteophytes have been removed, bone wax is applied to the bleeding cancellous bone to achieve hemostasis as
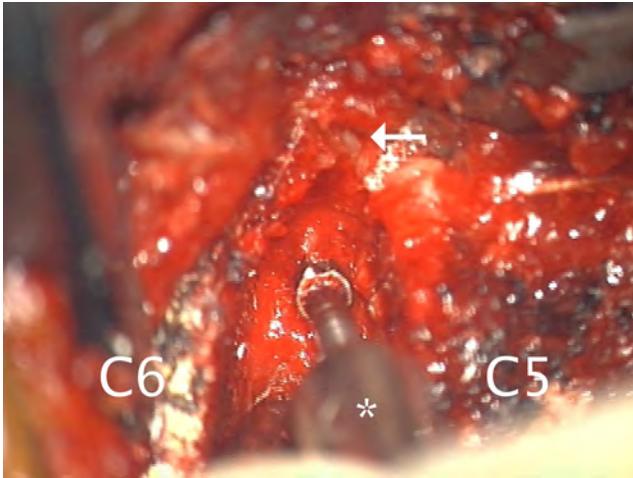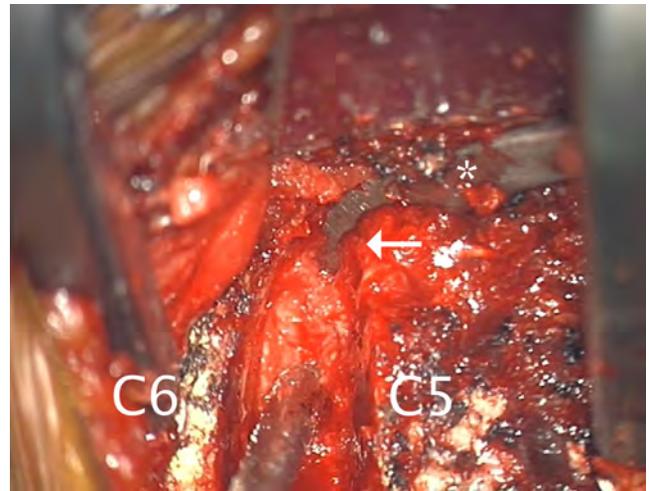
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FIG. 7-A **FIG. 7-B**

Fig. 7-A Clinical intraoperative photograph demonstrating the use of a matchstick burr (*) to decorticate the end plates and posterior vertebral body osteophytes. Note the location of the uncovertebral joint (arrow). **Fig. 7-B** Intraoperative photograph demonstrating the uncinate process (arrow), which must be thinned out in order to thoroughly decompress the foramen. Note the Penfield number-2 dissector (*) placed lateral to the uncinate process.
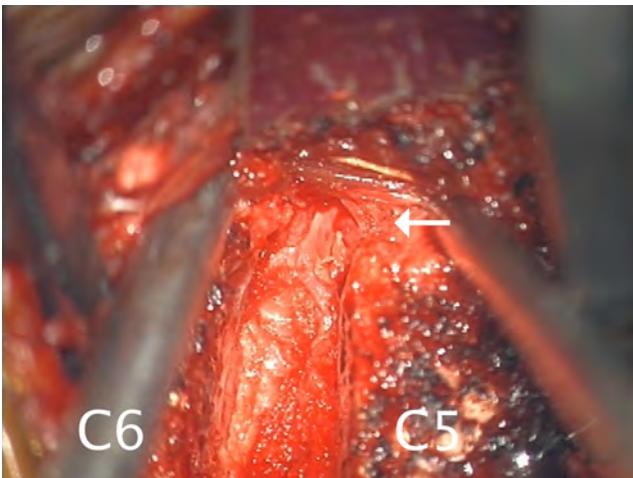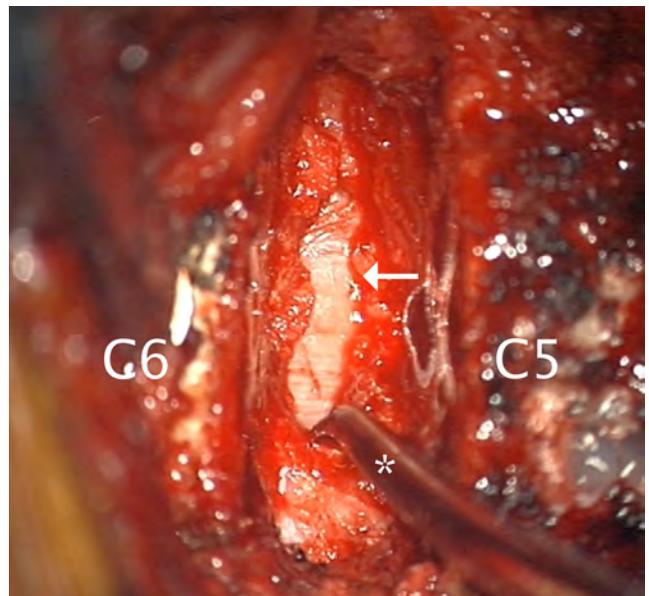

FIG. 7-C **FIG. 7-D**

Fig. 7-C Photograph demonstrating a partial uncinate process resection and foraminal decompression (arrow). **Fig. 7-D** Photograph demonstrating partial resection of the posterior longitudinal ligament (arrow), which may be necessary in order to remove sequestered invaginated disc fragments from behind the ligament (arrow). A small curette (a 2-mm up-angled curette) (*) can be used to resect the ligament and remove the disc fragments.

well as to prevent ossification that may compromise postoperative segment motion[1]. If a large disc herniation is present on preoperative imaging studies, the sequestered invaginated disc fragments behind the posterior longitudinal ligament should be identified and removed (Fig. 7-D). While some surgeons prefer to resect the posterior longitudinal ligament in all cases, we usually thin it down and leave it in place unless there is a large disc fragment lying behind the ligament. In addition, the posterior longitudinal ligament may need to be preserved for stability when some disc replacement designs are used, and the surgeon should be aware of these specific requirements. If the preoperative imaging studies reveal foraminal stenosis, the stenotic foramina are decompressed once the central decompression has been completed (Fig. 7-C). First, any remaining cartilage within the uncovertebral joint is removed with use of a microcurette to determine the lateral margin of the uncinate process. A matchstick burr is then used to decompress the stenotic foramen. Although we prefer a burr for this task, a small (1-mm) Kerrison rongeur can be used instead[1]. The disadvantage of using a Kerrison rongeur is that the tip of the device must be placed blindly into the foramen and can inadvertently injure the vertebral artery or nerve root, especially if the foramen is already severely narrowed. Great care must be taken to avoid injury to these structures during the foraminal decompression. Occasionally, a partial or subtotal uncinate process resection is necessary to achieve a thorough foraminal decompression; however, bilateral complete resection of the uncinate processes should be avoided because of their contribution to overall spinal stability and kinematics. Biomechanical studies have shown that cervical range of motion increases substantially in all planes with progressive resection of the uncovertebral joints but, whereas resection of one uncinate process allows preservation of rotational stability with an unconstrained prosthesis, resection of both may lead to spinal instability[1,23,24]. Importantly, we use copious irrigation to remove any bone dust that results from burring and we apply wax to all bleeding surfaces of the uncinate process in order to prevent unintended fusion.

Implant Insertion

Once the neural elements have been thoroughly decompressed and the end plates have been prepared, sizing trials are used (with most systems) to determine the appropriate size of the arthroplasty device[1,9-22]. The trial prosthesis should fit snugly within the disc space; however, if it is too tight, the ligamentous structures around the motion segment may be too taut, possibly causing posterior neck pain and limiting motion. Conversely, if the device is too loose, the intervertebral height may not be adequate, resulting in foraminal stenosis and poor function of
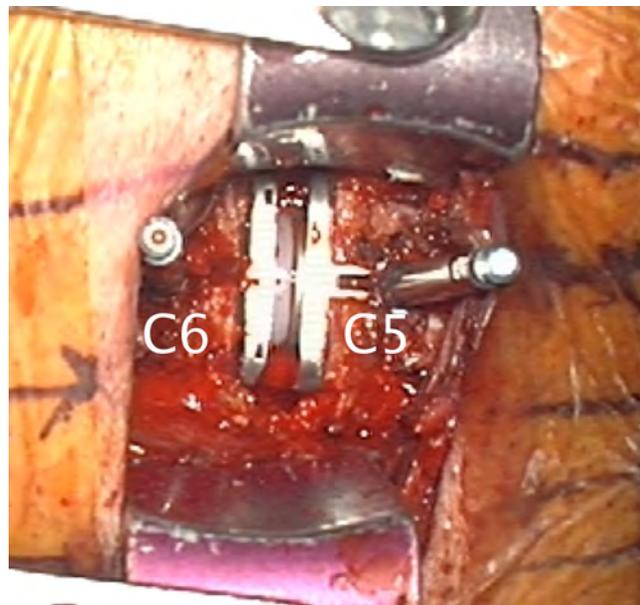

FIG. 8

Intraoperative photograph demonstrating the insertion of a cervical disc arthroplasty device.

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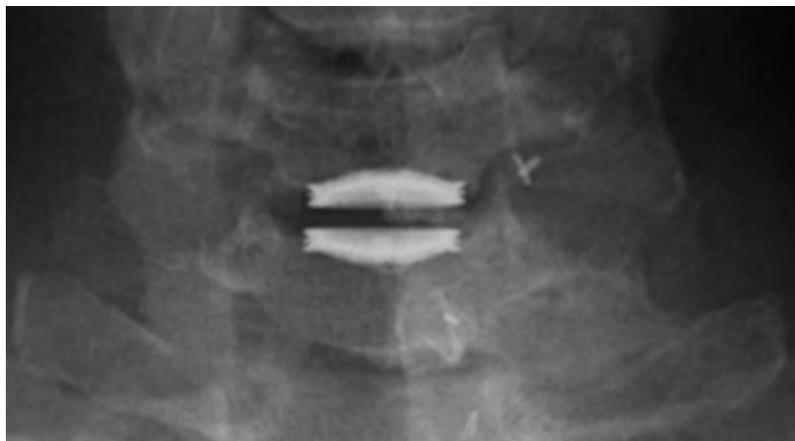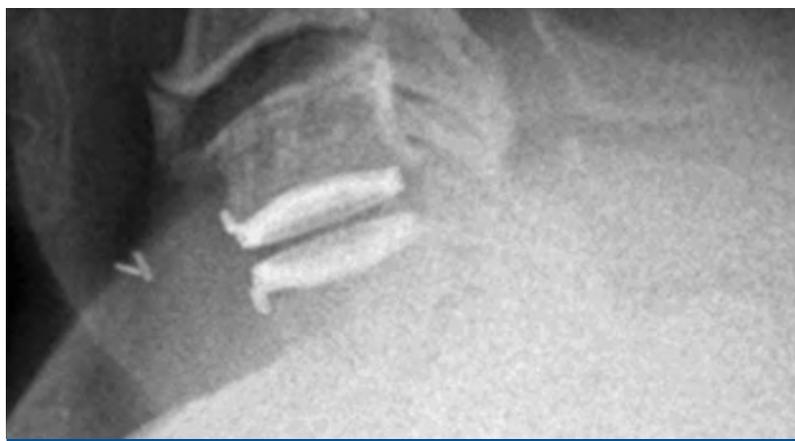
FIG. 9-A

FIG. 9-B

Postoperative anteroposterior (Fig. 9-A) and lateral (Fig. 9-B) plain radiographs of a forty-three-year-old man with C6-C7 spondylosis who underwent total disc arthroplasty. (Reproduced, with modification, from: Buchowski JM, Riew KD. Primary indications and disc space preparation for cervical disc arthroplasty. In: Yue JJ, Bertagnoli R, McAfee PC, An HS, editors. Motion preservation surgery of the spine: advanced techniques and controversies. Philadelphia: WB Saunders; 2008. p 185-92. Reprinted with permission.)

the device. Therefore, care must be taken to ensure the selection of an appropriately sized implant. In most cases, a 5 or 6-mm height is appropriate. Once the proper size has been determined, slots or mortises may need to be fashioned in the vertebral body to allow for the placement and fixation of the arthroplasty device. The definitive device is then inserted into the interspace, usually under fluoroscopic guidance (Fig. 8). Final placement of the device is then confirmed radiographically in both the anteroposterior and lateral planes (Figs. 9-A and 9-B). If required, screws are placed with use of standard techniques. The wound is then irrigated and closed in the customary fashion. Postoperative immobilization typically is not necessary.

CRITICAL CONCEPTS

INDICATIONS[1,6,9-22]:
- Radiculopathy attributable to cervical disc degeneration at one, two, or three levels or myelopathy due to cervical disc degeneration and minimal spondylotic changes at one, two, or three levels with retrodiscal spinal cord compression
- Radiographic evidence of cervical disc herniation or spondylosis at one, two, or three levels
- Symptoms corresponding to anatomical findings between C3 and C7
- Failure of nonoperative treatment (after a minimum of six weeks, but most commonly after three months)

CRITICAL CONCEPTS

CONTRAINDICATIONS[1,6,9-22]:

· Structural instability of the cervical spine, acute fracture, rheumatoid arthritis with instability, or previous cervical laminectomy, which could lead to instability after the procedure

· Severe spondylosis with complete loss of disc height or motion of <2°, ankylosing spondylitis, or diffuse idiopathic skeletal hyperostosis, which could limit the amount of motion following the procedure

· Congenital stenosis, ossification of the posterior longitudinal ligament, or myelopathy due to any other etiology that causes retrovertebral compression

· Axial neck pain as the solitary symptom (because axial neck pain, which is often due to facet arthropathy and/or disc degeneration, does not predictably resolve following cervical disc arthroplasty)

· A history of recent cervical spine infection

· Osteoporosis and related metabolic bone diseases, which may preclude osseous growth into the arthroplasty device, leading to its loosening

· Morbid obesity that precludes an anterior cervical approach

· Inability to visualize the treated segment radiographically during surgery

PITFALLS:

Neutral positioning of the neck during the procedure is critical. If the neck is hyperextended, an excessive amount of the posterior end plate may be removed to produce parallel surfaces during end plate preparation, resulting in a prosthesis that rests in a kyphotic position. If the neck is placed in a kyphotic position, too much of the anterior end plate is removed and the prosthesis may rest in a lordotic position.

Successful disc space preparation requires only light decortication of both end plates, removal of all posterior vertebral osteophytes, and thorough foraminal decompression.

Accurate identification of the midline is required. Furthermore, midline placement of distraction pins that are used during the decompression is critical in order to avoid asymmetric distraction across the disc space, with resultant asymmetric decompression and end plate preparation, the potential development of uneven loads across the segment, and, in severe cases, a scoliotic deformity.

End plate preparation must be performed carefully and judiciously in order to minimize excessive end plate resection because the majority of the end plate should be preserved to support the stresses associated with motion across the disc space and to prevent end plate subsidence. Furthermore, the various arthroplasty systems have different requirements for end plate removal, with which the surgeon should be familiar.

A wider and more thorough uncinate process and osteophyte resection is necessary when a cervical disc replacement is performed in patients with myelopathy (and even in patients with spondylotic radiculopathy) than is the case when a fusion is performed in such patients. If the decompression is inadequate, continued motion across the segment may lead to recurrence of symptomatic spondylosis; in contrast, after cervical fusion procedures, osteophytes often regress once a solid fusion has been obtained.

Sizing should be critically assessed to allow as large an end plate footprint as possible. Overdistraction should be avoided.

AUTHOR UPDATE:

Cervical disc arthroplasty continues to be a successful procedure for the treatment of myelopathy when spinal cord compression is localized to the disc space (i.e., when compression is retrodiscal in nature) and mild spondylotic changes (or no such changes) are present. For these reasons, in general, the procedure is most successful for patients younger than those with cervical spondylotic myelopathy (who frequently present with substantial degenerative changes such as facet arthropathy, which is a contraindication to cervical disc arthroplasty).

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REFERENCES

1. Buchowski JM, Riew KD. Primary indications and disc space preparation for cervical disc arthroplasty. In: Yue JJ, Bertagnoli R, McAfee PC, An HS, editors. Motion preservation surgery of the spine: advanced techniques and controversies. Philadelphia: WB Saunders; 2008. p 185-92.

2. Emery SE, Bolesta MJ, Banks MA, Jones PK. Robinson anterior cervical fusion comparison of the standard and modified techniques. Spine. 1994;19:660-3.

3. Bohlman HH, Emery SE, Goodfellow DB, Jones PK. Robinson anterior cervical discectomy and arthrodesis for cervical radiculopathy. Long-term follow-up of one hundred and twenty-two patients. J Bone Joint Surg Am. 1993;75:1298-307.

4. Brodke DS, Zdeblick TA. Modified Smith-Robinson procedure for anterior cervical discectomy and fusion. Spine. 1992;17(10 Suppl):S427-30.

5. Williams JL, Allen MB Jr, Harkess JW. Late results of cervical discectomy and interbody fusion: some factors influencing the results. J Bone Joint Surg Am. 1968;50:277-86.

6. Acosta FL Jr, Ames CP. Cervical disc arthroplasty: general introduction. Neurosurg Clin N Am. 2005;16:603-7.

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;81:519-28.

8. Hilibrand AS, Yoo JU, Carlson GD, Bohlman HH. The success of anterior cervical arthrodesis adjacent to a previous fusion. Spine. 1997;22:1574-9.

9. McAfee PC. The indications for lumbar and cervical disc replacement. Spine J. 2004;4(6 Suppl):177S-181S.

10. Albert TJ, Eichenbaum MD. Goals of cervical disc replacement. Spine J. 2004;4(6 Suppl):292S-293S.

11. Durbhakula MM, Ghiselli G. Cervical total disc replacement, part I: rationale, biomechanics, and implant types. Orthop Clin N Am. 2005;36:349-54.

12. Bertagnoli R, Duggal N, Pickett GE, Wigfield CC, Gill SS, Karg A, Voigt S. Cervical total disc replacement, part two: clinical results. Orthop Clin N Am. 2005;36:355-62.

13. Phillips FM, Garfin SR. Cervical disc replacement. Spine. 2005;30(17 Suppl):S27-33.

14. Traynelis VC. The Prestige cervical disc. Neurosurg Clin N Am. 2005;16:621-8.

15. Papadopoulos S. The Bryan cervical disc system. Neurosurg Clin N Am. 2005;16:629-36.

16. Chi JH, Ames CP, Tay B. General considerations for cervical arthroplasty with technique for ProDisc-C. Neurosurg Clin N Am. 2005;16:609-19.

17. Pimenta L, McAfee PC, Cappuccino A, Bellera FP, Link HD. Clinical experience with the new artificial cervical PCM (Cervitech) disc. Spine J. 2004;4(6 Suppl):315S-321S.

18. Goffin J, Van Calenbergh F, van Loon J, Casey A, Kehr P, Liebig K, Lind B, Logroscino C, Sgrambiglia R, Pointillart V. Intermediate follow-up after treatment of degenerative disc disease with the Bryan Cervical Disc Prosthesis: single-level and bi-level. Spine. 2003;28:2673-8.

19. Goffin J, Casey A, Kehr P, Liebig K, Lind B, Logroscino C, Pointillart V, Van Calenbergh F, van Loon J. Preliminary clinical experience with the Bryan Cervical Disc Prosthesis. Neurosurgery. 2002;51:840-7.

20. 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.

21. 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. 2009;34:101-7.

22. 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;9:275-86.

23. McAfee PC, Cunningham BW, Hayes V, Sidigi F, Dabbah M, Sefter JC, Hu N, Beatson H. Biomechanical analysis of rotational motions after disc arthroplasty: implications for patients with adult deformities. Spine. 2006;31(19 Suppl):S152-60.

24. Snyder J, Ghanayem A, Rinella A, Voronov L, Patwardhan A, Dooris A, Renner S, Havey R. Effect of partial versus total uncovertebral joint excision in cervical total disc replacement. Read at the 34th Annual Meeting of the Cervical Spine Research Society; 2006 Nov 30-Dec 2; Palm Beach, FL.