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ROENTGENOLOGY

# Cervical Disc Arthroplasty: Review and Update for Radiologists

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## Introduction

Since its introducton in the 1950s, anterior cervical discectomy and fusion (ACDF) has evolved as the gold standard for the surgical treatment of degenerative cervical spine disease. Rates of fusion of ≥90% and excellent clinical outcomes have been reported with this technique.[1] Nevertheless, successful osseous fusion of a vertebral segment results in altered biomechanics in the adjacent vertebral levels with potentially increased likelihood of degenerative changes in the adjacent segments. A systematic review of the literature suggests that the cumulative risk of developing clinically significant adjacent segment disease ranges from 1.6% to 4.2% per year following cervical fusion.[2]

Cervical disc arthroplasty (CDA) was conceived as an alternative surgical option to ACDF for preserving physiologic cervical motion and reducing the incidence of adjacent segment disease. Furthermore, CDA avoids some of the complications that may occur with ACDF such as pseudarthrosis, prolonged cervical immobilization, graft donor site morbidity and issues with autografts or allografts and anterior cervical plating.[3]

CDA can be performed in select patients suffering from cervical degenerative disc disease. Per current standards of care, it has been estimated that 43% of patients who require surgery for cervical degenerative disc disease would meet the strict inclusion criteria for CDA candidacy.[4] There has been an increase in CDA utilization in the United States in recent years, with likely progressively increased rates of cervical disc replacement in the upcoming years.[5] Although not encountered by many radiologists on a routine basis thus far, it is likely that radiologists will encounter an increasing number of patients with CDA in the near future.

The goals of this article are to review the indications, specific surgical considerations, design principles and complications of CDAs, with an emphasis on the imaging appearance of normal and complicated hardware.

## History

Ulf Fernstrom is credited with implanting the first artificial cervical disc in 1966, but with unfavorable results.[6] In the 1980s and 1990s, with the popularity and widespread use of lumbar disc replacements (principally in Europe), and publication of the Cummins-Bristol artificial cervical disc implantation in 20 patients, the feasibility of motion preservation in the cervical spine gained renewed interest.[7] Since then, cervical artificial discs have gone through several design changes. The first clinical experience with artificial cervical discs in the United States was a prospective multicenter trial of the Bryan cervical disc prosthesis that was published in 2002.[8] The first CDA was approved by the United States Food and Drug administration (FDA) in July of 2007. Currently a variety of cervical artificial discs are being implanted in the United States. Some of these implants have gained FDA approval, while others are part of investigational device exemption trials for cervical degenerative disc disease.

## Trends in CDA

There has been an increase in CDA in recent years. A study analyzing the University Healthcare Consortium database for all elective surgeries for cervical radiculopathy due to disc herniation from October 2012 through September 2015 showed a nearly 150% increase in the utilization of disc arthroplasties, rising from 2% in 2012-2013 to nearly 5% in 2015.[5] Coverage is provided for FDA-approved cervical disc prostheses by various large, national commercial payors such as Aetna, Cigna, and United Healthcare, as well as many BlueCross and BlueShield plans. Conversely, medicare does not have a national coverage decision for FDA-approved CDAs. As expected, based on this medicare coverage deficiency, a recent study demonstrated that in comparison to

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https://doi.org/10.1053/j.ro.2018.06.001

ACDF, CDA was more common in self-paying patients, patients with private insurance and patients with military based insurance.[5]

## Indications and Contraindications

The current FDA-approved cervical artificial discs are indicated in skeletally mature patients for reconstruction of a single level disc from C3-C7 following single-level anterior discectomy for intractable radiculopathy (arm pain or a neurological deficit or both) or some cases of myelopathy, and at least one of the following conditions confirmed by imaging: disc herniation, osteophytes, and visible disc height loss.[9–14] In contrast to lumbar total disc replacement, which is indicated in select cases of intractable back pain, CDA is not recommended for isolated axial neck pain. The Mobi-C® cervical disc has also been approved by the FDA for use at 2 adjacent levels.[15]

CDA may be an acceptable treatment for myelopathy if the cord compression is anterior, occurs at the disc space and is not associated with dynamic instability.[1] CDA is contraindicated with anterior compressive pathology that occurs at the vertebral body level (such as ossification of the posterior longitudinal ligament), coexistent posterior compressive pathology (such as from facet arthrosis) or segmental instability ($>3.5$ mm sagittal plane translation on dynamic cervical spine radiographs).

Disc height $\geq 3$ mm or $\geq 50\%$ of original disc height has been recommended by some authors for successful CDA.[1,3] Narrower discs may prevent appropriate implant sizing with a potential for over-distraction of the disc space and facet joints.[1] In addition, with excessive disc space collapse there is progressive osteophyte formation and segmental motion decline. It must be stressed that CDA is a motion preserving, and not a motion restoring, procedure, therefore, CDA is contraindicated when segmental motion is absent ($<2^\circ$).

Other contraindications for this procedure are conditions that affect bone quality (e.g., trauma, active infection, active malignancy, and osteoporosis), significant sagittal imbalance with kyphotic deformity ($\geq 15^\circ$ sagittal angulation on cervical spine radiographs), $>11^\circ$ rotational difference between adjacent levels, diffuse idiopathic skeletal hyperostosis, allergy or sensitivity to the implant materials, systemic disease (e.g., autoimmune disease, insulin-dependent diabetes mellitus, HIV, and hepatitis B or C), morbid obesity and pregnancy.[3,12,16]

Although advancing age per se is not a contraindication to CDA, many of the contraindications to CDA (such as disc narrowing, facet arthrosis, segmental instability, kyphotic deformity and osteoporosis) become more prominent with aging. Therefore, CDA patients are on average 4.7 years younger than ACDF patients.[17]

## Preoperative Imaging Work-up

Anteroposterior (AP), lateral, and dynamic cervical spine radiographs along with cervical spine magnetic resonance imaging (MRI) (or cervical spine computed tomography [CT] myelogram, especially if MR imaging is contraindicated) are fundamental components of the presurgical evaluation of potential CDA candidates.

## Design Principles of Cervical Disc Prostheses

Cervical artificial disc models are classified by anchorage, surface coating, friction couple, constrained vs non-constrained design, location of center of movement, type of articulation (nonarticulating, uniarticulating, or biarticulating), and compatibility with MR imaging.[18] The devices are either modular or non-modular, depending on whether they have or lack replaceable components, respectively.[19]

Contact between the implant and the vertebral plates (anchorage) may be by stem, screw or macrotexture. Surface coating facilitates long-term fixation via osseous integration and may be with hydroxyapatite, tricalcium phosphate, porous titanium, or chromium-cobalt. There are 4 types of friction couple: metal-polymer, metal-metal, ceramic-polymer, and ceramic-ceramic. The polymers used have been ultra-high molecular weight polyethylene (UHMWPE) or polyurethane. Metal components have been produced from titanium, stainless steel or chromium, often as an alloy to decrease corrosion. The current FDA-approved CDA models are either metal on metal or metal on polymer.

Degrees of freedom (df) is a useful concept for defining the number of independent motions one vertebra can have with respect to another. A normal disc has 6 df: 3 translations (medial-lateral, superior-inferior, and anterior-posterior) and 3 rotations (flexion-extension, twist, and lateral bend).[20] CDA designs can be non-constrained (6-df), semi-constrained (5-df with free nucleus), or constrained (3-df with fixed nucleus).[18]

Normally the center of rotation between 2 vertebral bodies is in the posterior half of the upper portion of the inferior vertebral body. The center of rotation of the CDA may be above or below the disk. The compatibility of cervical disc implants with MRI will be discussed further in the "Postoperative imaging evaluation of uncomplicated cervical disc implants" section.

## FDA Approved CDAs

The Prestige cervical disc prosthesis (Medtronic Sofamor Danek, Memphis, TN, USA) is the product of the evolution of the Cummins-Bristol artificial cervical disc. There have been several evolutions in the design of this metal-on-metal prosthesis. The Prestige® ST cervical disc (Fig. 1) was approved by the FDA in July of 2007. It has a uniarticular, ball-and-trough design consisting of metal-on-metal (stainless steel) blade-shaped endplates that are initially anchored to the vertebral bodies by screws. The design of the device permits relatively unconstrained motion. The surfaces of the device contacting the bony

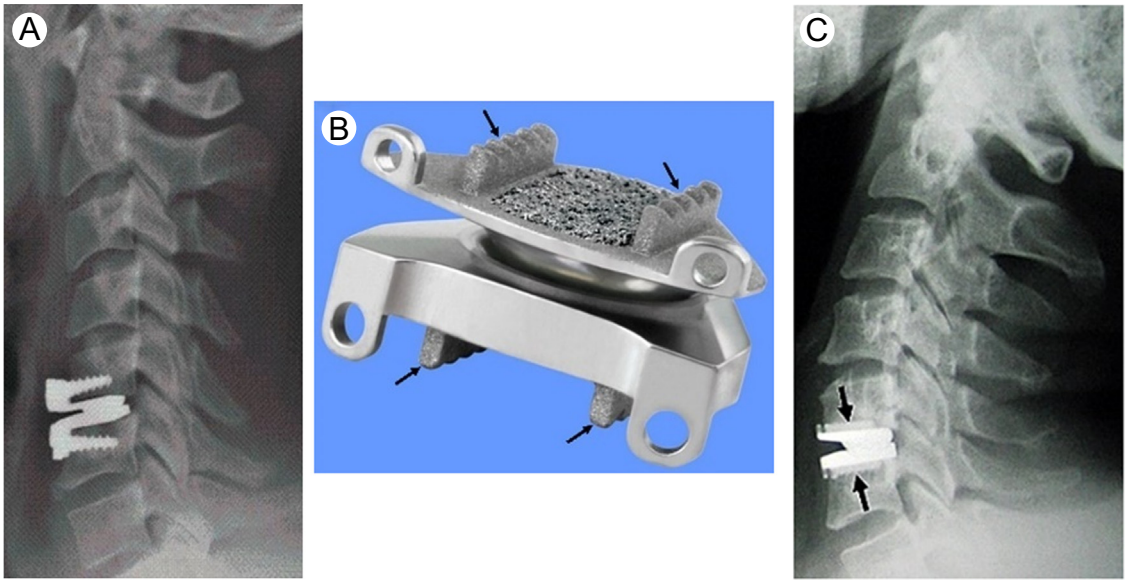


**Figure 1** Prestige cervical disc prosthesis (different patients). (A) Lateral radiograph of the cervical spine demonstrates implantation of Prestige® ST artificial disc at C5-C6 level. The Prestige ST device is composed of metal-on-metal blade-shaped endplates that are anchored to the vertebral bodies by screws. (B and C) Prestige® LP cervical disc system. (B) Photograph shows the metal on metal, ball-and-trough design of the implant. Initial fixation is achieved with rails (arrows) that are attached to the metallic endplates. (C) Lateral extension radiograph of the cervical spine shows a Prestige® LP disc implantation at C5/C6. Compare the lower anterior profile design of this device with the older generation Prestige® ST disc (arrows point to anchoring rails). (B and C) Courtesy of Yilmaz H, MD, University Hospital of Geneva, Switzerland.

endplates are grit-blasted to promote osteointegration. The Prestige® LP (Medtronic Sofamor Danek, Memphis, TN, USA) (Fig. 1) is the most recent version of the Prestige family and was approved by the FDA in July of 2014.[9,21] It is composed of titanium carbide with a plasmapore coating that facilitates osteointegration. Initial fixation is achieved through 2 rails on either side of the midline that are placed into predrilled endplate channels.

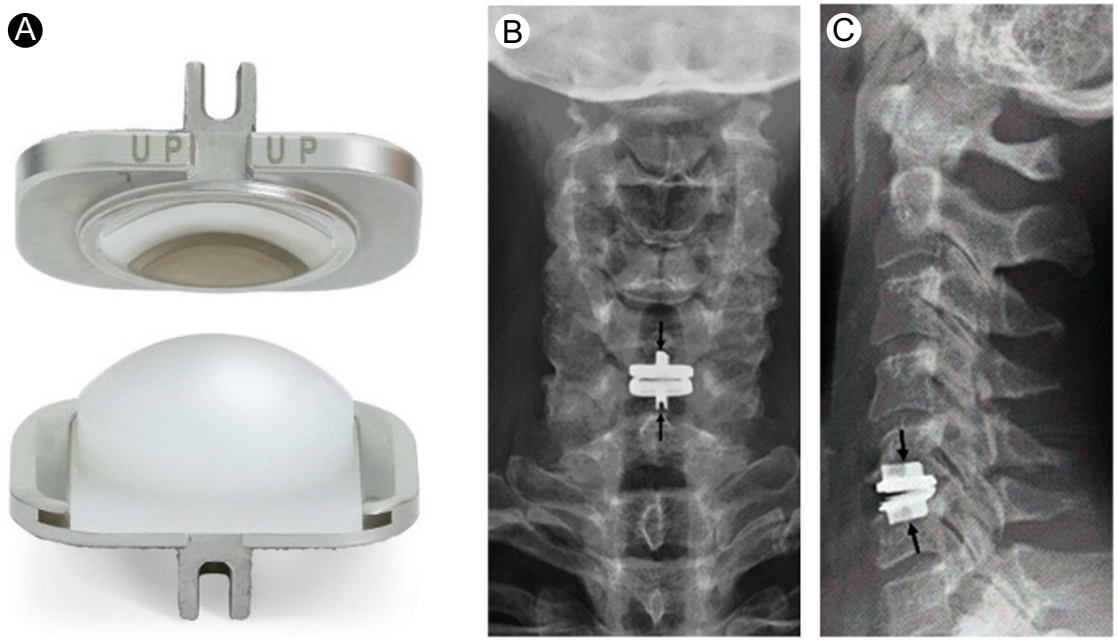


**Figure 2** Prodisc® C. (A) Photograph shows the ball and socket semi-constrained design of the implant. The articulating surface consists of a polyethylene hemispheric surface (locked to the inferior metallic endplate) with a reciprocating socket in the superior metallic endplate. The metallic endplates are embedded initially into the vertebral bodies via central keels. Courtesy of Centinel Spine. (B and C) Prodisc-C total disc replacement. Anteroposterior (A) and lateral (B) cervical spine radiographs show Prodisc-C total disc replacement at C5-C6. Observe the central keels (arrows) of the metallic endplates.

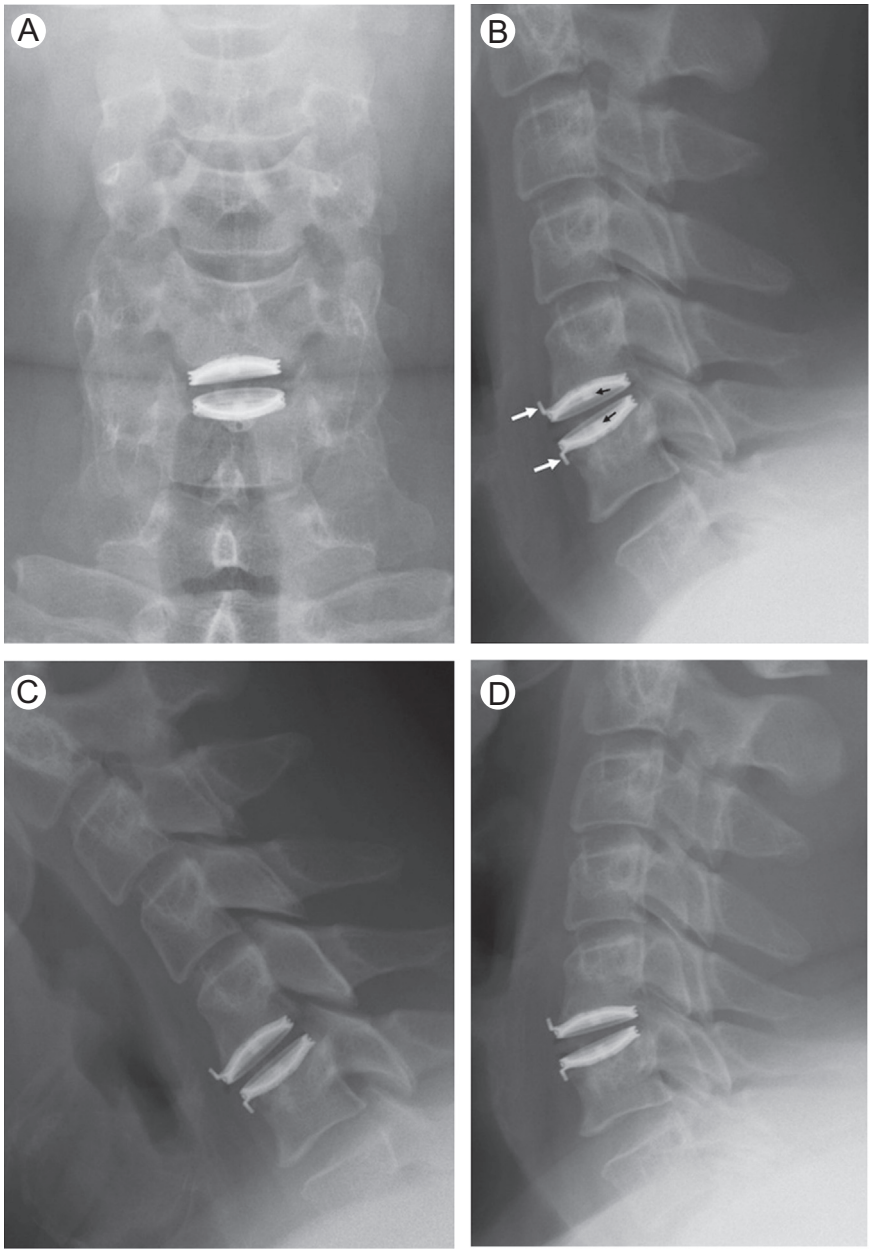


**Figure 3** Bryan cervical disc prosthesis. (A-D) Anteroposterior (A), lateral (B), lateral flexion (C), and lateral extension (D) cervical spine radiographs show a Bryan disc prosthesis at C5-C6 level. On the lateral radiograph, observe the outwardly convex metallic endplates with anterior stops (white arrows) and central posts (black arrows) that fit into opposing dents in the lucent polyurethane nucleus. Flexion and extension radiographs show physiological range of motion at the arthroplasty level. Courtesy of Petscavage-Thomas J, MD, Penn State Hershey Medical Center, Hershey, Pennsylvania.

The Prodisc® C (Centinel Spine, West Chester, Philadelphia, USA) (Fig. 2) was approved by the FDA in December of 2007.[12] It has a uniarticular, ball and socket, semi-constrained design consisting of cobalt-chromium alloy endplates that are initially embedded into the vertebral bodies with central keels. The endplates are coated with titanium plasmapore that encourages long term bony ingrowth. The articulating surface consists of a polyethylene hemispheric surface (locked to the inferior metallic endplate) with a reciprocating cobalt-chrome alloy socket, superiorly.[18,22]

The Bryan® (Medtronic Sofamor Danek, Memphis, TN, USA) cervical disc prosthesis (Fig. 3) was approved by the FDA in May of 2009.[11] It is a biarticulating, relatively nonconstrained device consisting of a polyurethane nucleus that fits between 2 outwardly convex titanium alloy shells.[19] Each shell has an anterior flange that facilitates insertion and prevents posterior migration. The shock absorbing polyurethane nucleus is wrapped by a sheath that contains sterile saline lubricant. Initial stability is achieved by precision milling of the vertebral endplates, while long-term stability is with osteointegration of the porous coated titanium alloy endplates.[23]

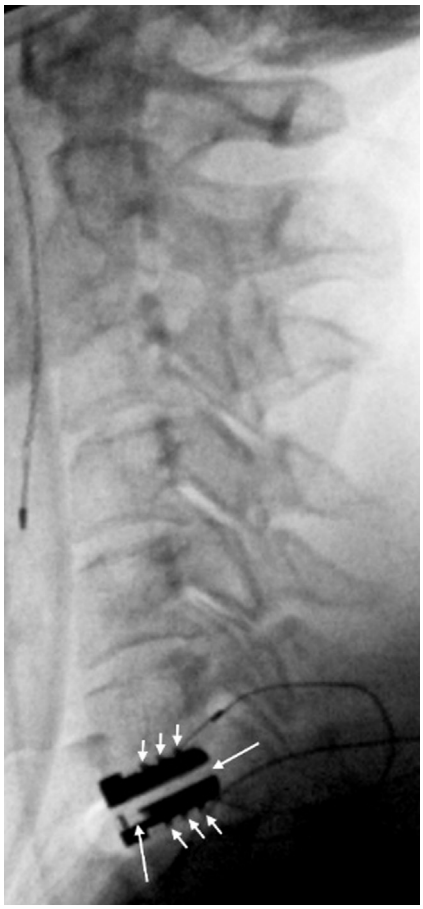

**Figure 4** PCM V-Teeth cervical disc prosthesis. Lateral intraoperative fluoroscopic image of the cervical spine shows PCM V-Teeth cervical disc prosthesis at C6-C7. Observe the V-shaped teeth (small arrows) on the metallic endplates, and the lucent polyethylene bearing attached (large arrows) to the inferior plate. Courtesy of Mirzadeh Z, MD, Barrow Neurological Institute, Phoenix, AZ.

The PCM® (porous-coated motion) cervical disc system (NuVasive Inc, San Diego, CA, USA) (Fig. 4) was approved by the FDA in October of 2012.[10] It is an unconstrained device composed of 2 cobalt chromium molybdenum alloy endplates with an ultrahigh-molecular-weight polyethylene bearing attached to the inferior plate. The outer surfaces of the endplates are serrated and coated with titanium or calcium phosphate, thus allowing for osteointegration.[24] The prosthesis has been modified from its original design, with 2 V-shaped rows of teeth added on the porous coated surfaces to prevent displacement. The broad radius of curvature of the endplates is designed to match the curvature of the vertebral surfaces. In addition to the PCM V-Teeth which is the standard press-fit model, the PCM model includes a variety of designs that have been tailored for specific indications.[25]

The Mobi-C® cervical disc (Zimmer Biomet, Warsaw, IN, USA) (Fig. 5) was approved by the FDA in August of 2013.[14] It is the only artificial cervical disc approved for both 1- and contiguous 2-level disc reconstructions.[15] The prosthesis is a semi-constrained design composed of 2 cobalt-chrome alloy endplates (with plasma sprayed titanium and hydroxyapatite coatings), and a polyethylene insert. Small spikes initially stabilize the endplates to bone.[26,27] Two lateral stops on the inferior endplate stabilize the polyethylene insert. In comparison to other disc prostheses, the Mobi-C is associated with higher rates of heterotopic ossification (HO).[27]

The Secure-C® artificial disc (Globus Medical, Audubon, PA, USA) (Fig. 6) was approved by the FDA in September of 2012.[13] It is a selectively constrained device, that consists of 2 cobalt-chrome alloy endplates with serrated keels and a polyethylene nucleus.[28]

## Postoperative Imaging Evaluation of Uncomplicated Cervical Disc Implants

AP, lateral and dynamic cervical spine radiographs are routinely used to assess cervical disc prostheses (Fig. 3). Lateral flexion and extension along with AP lateral bending cervical spine radiographs permit multiplanar assessment of cervical spine motion. An appropriately placed cervical disc implant is used to restore disc height, neural foraminal height and overall cervical sagittal and coronal alignment, while maintaining physiologic cervical segmental motion.[3]

On lateral and AP cervical spine radiographs, the size and position of the implant should be assessed. There is scant literature dedicated to the radiologic assessment and clinic-radiologic correlation of CDAs.[29] According to the surgical literature, an ideal-sized implant should have a height similar to adjacent normal discs and provide as much surface coverage of the opposing endplates as possible (Figs. 7 and 8).[1,3,19] An optimally positioned prosthesis is centrally placed and aligned according to the global alignment of the cervical spine (Fig. 7).

When complications are suspected, further imaging with MRI, CT or CT myelography may be performed. Several strategies may be implemented to reduce metal-induced artifacts on CT and MRI (Tables 1 and 2).[30–32] On MRI, the severity of metal-induced artifacts is influenced by the metal type. Progressively severe metal-induced artifacts are detected on both CT and MRI with the following materials: titanium, cobalt-chromium, and stainless-steel.[32–34] In a cadaveric study using T2-weighted turbo spin-echo images obtained on a 1.5 T MRI scanner, index, and adjacent levels were accurately evaluated with titanium cervical disc prostheses.[35] The same study demonstrated that with cobalt-chromium cervical disc implants the surgical level could not be fully evaluated (due to distortion by artifact), while the adjacent levels were easily visualized, and that neither the index nor the adjacent levels could be fully evaluated with a stainless steel (Prestige ST) cervical disc prosthesis.[35]

## Complications

While the results of several studies have confirmed the clinical safety and efficacy of cervical disc replacements, complications can occur (Table 3). Technical errors and poor patient selection are the most common causes of poor outcomes after CDA. The published rates of reoperation following CDA are low and either comparable to, or lower than the published rates following ACDF.[1,36–38]

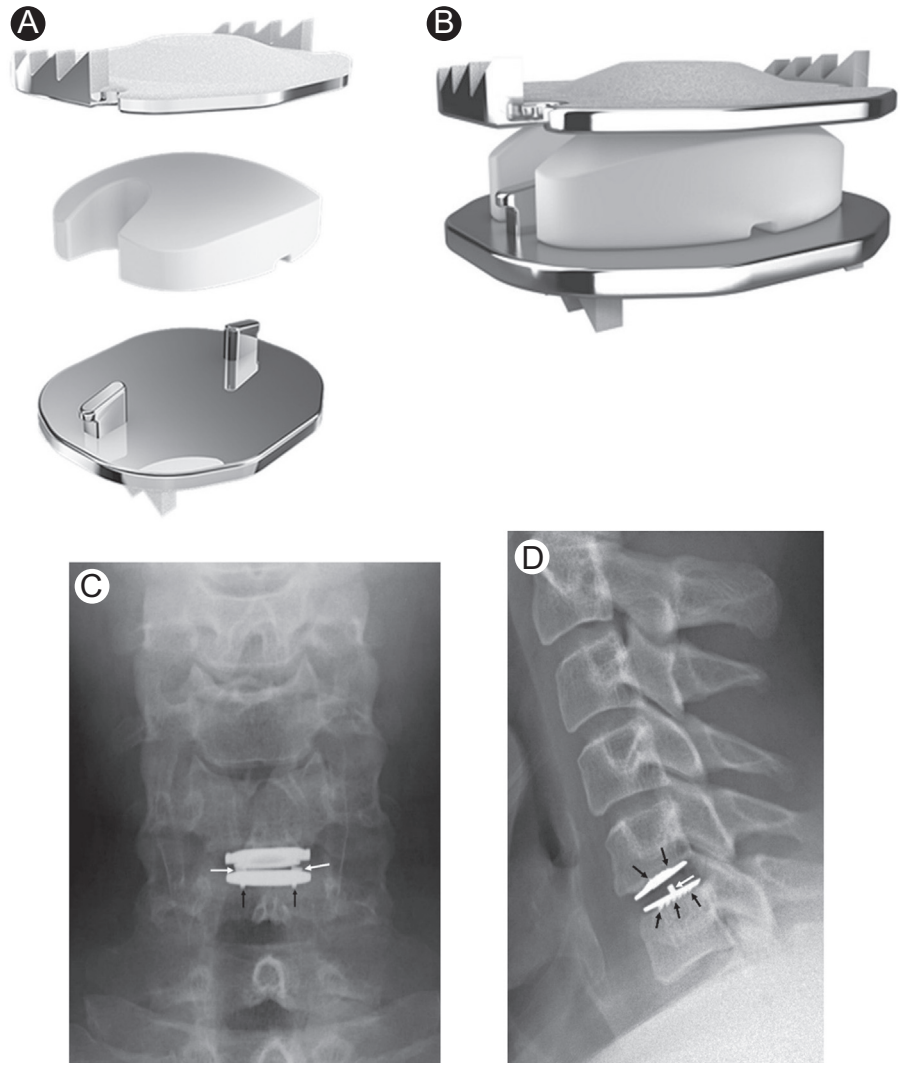


**Figure 5** Mobi-C® cervical disc. (A and B) Photographs show the 3-piece design (A) and assembled appearance (B) of the implant. The prosthesis is composed of 2 metallic endplates (initially stabilized to bone by small spikes) with an intervening polyethylene insert that is secured via 2 lateral stops on the inferior metallic endplate. (A and B) Courtesy of Zimmer Biomet. (C and D) Anteroposterior (C) and lateral (D) cervical spine radiographs demonstrate Mobi-C cervical disc at C5-C6. Observe the small spikes (black arrows) on the external surfaces of the metallic endplates and lateral stops (white arrows) on the inferior metallic endplate. Courtesy of Roth E, MD, Irving Radiological Associates, Irving, Texas.

## Complications Related to the Anterior Cervical Surgical Approach

Dysphagia, hematoma and recurrent laryngeal nerve palsy are the most common postoperative complications of the anterior cervical spine approach.[3,39] Dysphagia is usually secondary to the required esophageal retraction that accompanies the anterior cervical surgical approach. Imaging of the neck is often normal in postoperative dysphagia unless there is esophageal impingement by hardware malpositioning or failure. In comparison with ACDF, CDA is less likely to be associated with dysphagia.[40,41]

Less common complications of the anterior cervical approach include esophageal perforation, airway compromise (due to hematoma or edema), vertebral body fracture, vertebral artery injury, dural leak, and radiculopathy or myelopathy.[3,39]

## Hardware-related Complications

Subsidence (axial migration) of cervical disc implants (Fig. 9) may result in kyphosis and is often seen with undersized implants.[18,42] Anterior or posterior migration of the CDA may result in esophageal compression or neurologic compromise, respectively.[18] Migration is rare, and typically occurs anteriorly along the operative approach.[42] Currently, the most obvious type of hardware failure on follow-up imaging is subtle implant migration and loosening, most of which are asymptomatic.[3] Migration and loosening frequently result from poor intraoperative implant sizing.

A device with moving parts creates wear debris and can potentially result in immune-mediated particle disease. The limited range of motion in the cervical spine compared with other joint replacements reduces the volumetric wear of

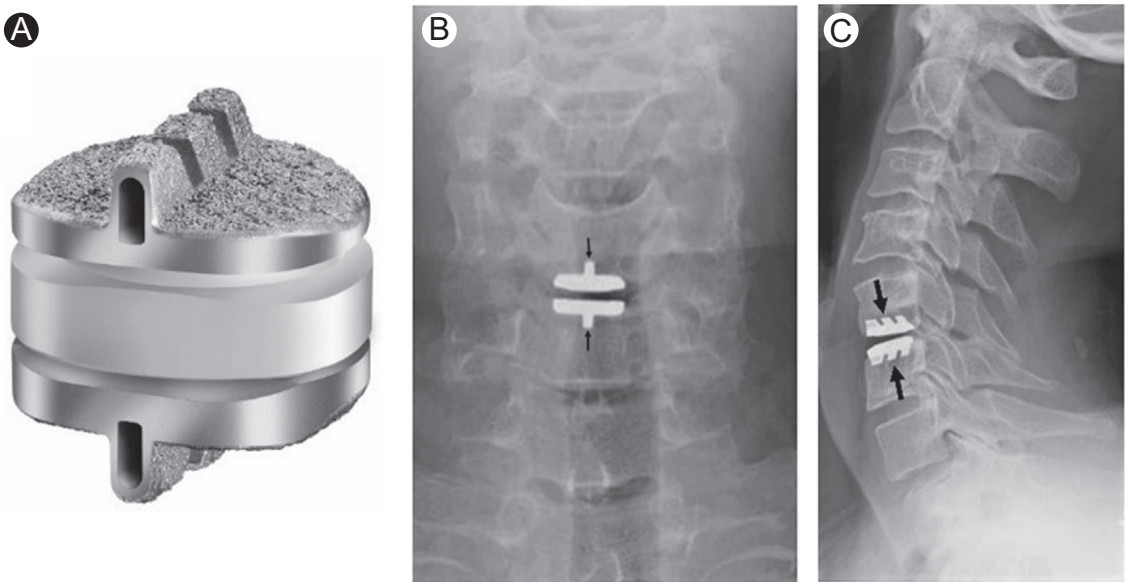


**Figure 6** Secure-C® artificial disc. (A) Photograph demonstrates the Secure-C® artificial disc composed of 2 metallic endplates with serrated keels and an intervening polyethylene nucleus. (B and C) Anteroposterior (B) and lateral extension (C) cervical spine radiographs show Secure-C artificial disc at C5-C6 level. Observe the serrated keels (black arrows) anchoring the metallic endplates to the vertebral bodies. Courtesy of Globus Medicus.

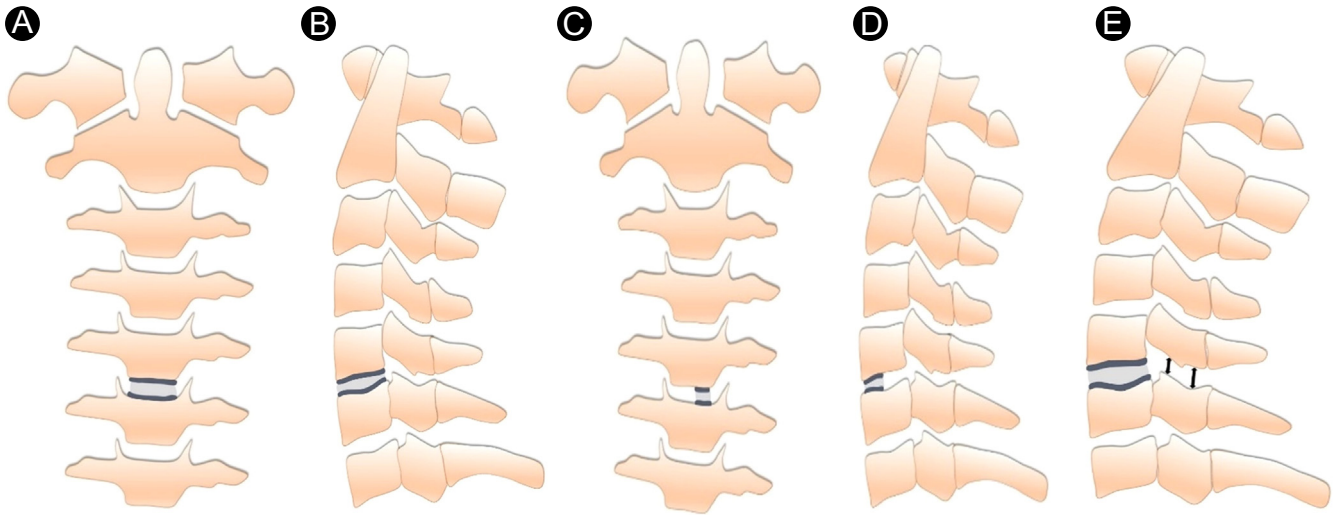


**Figure 7** Ideal size and positioning of cervical disc prostheses. (A and B) Ideal cervical disc prosthesis. An ideal cervical disc implant should have a height similar to adjacent normal discs, provide as much surface coverage of the opposing endplates as possible, and be centrally positioned in both the sagittal and coronal planes. (C and D) Undersized and eccentrically positioned disc prosthesis. Undersized implants increase stress concentrations per unit area and may increase the risk of subsidence. In addition, inadequate coverage of the endplates by an undersized prosthesis may predispose to heterotopic ossification and posterior osteophyte formation with ultimate restricted cervical segmental motion. Prostheses that are not centrally positioned on AP and lateral radiographs may predispose to adjacent segment degeneration.[29] In addition, malpositioning of the disc prosthesis in the coronal plane (C) may cause unilateral neural foraminal narrowing with resultant radiculopathy.[3] (E) Oversized implant. Overstuffing the disc space by an oversized implant results in distraction of the facet joints (arrows). This can cause axial neck pain, referred scapular pain and decreased cervical spine segmental motion.[1,3]

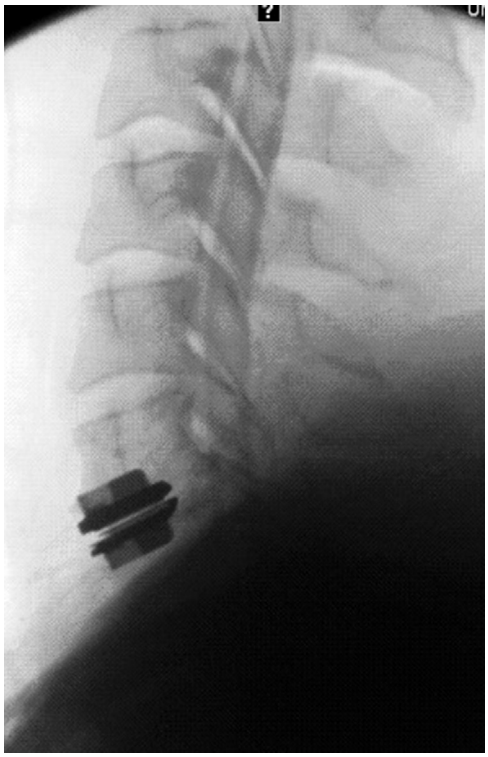

**Figure 8** Undersized cervical disc implant. Lateral intraoperative fluoroscopic image of the cervical spine shows an undersized Prodisc-C total disc replacement at C6-C7 level.

cervical artificial discs. Particle disease resulting in CDA failure has been documented in only a few case reports. Cavanaugh et al.[43] reported on a case of a pseudotumor (metal granuloma) encroaching on the cervical cord at the level of an implanted cervical artificial disc, 9 months after the index procedure. Tumialán et al.[44] reported on a case of progressive vertebral body osteolysis, 9 and 15 months after total CDA.

## Iatrogenic Deformity

Off-axis or undersized implant positioning and multilevel CDA may predispose to postoperative segmental kyphotic deformity.[3] The Bryan disc prosthesis is relatively unconstrained, and may lead to shell tilting and potential kyphosis in some patients.[45]

**Table 1** Techniques for Decreasing Metal-Induced Artifacts on CT Imaging

| Techniques |
|---|
| Increasing tube potential* |
| Increasing tube current* |
| Reducing beam width* |
| Utilizing narrow collimation and thinner slices* |
| Optimizing image reconstruction parameters by using a smooth reconstruction algorithm, wide window settings and thicker slice reconstructions* |
| Dual-energy CT |
| Replacing corrupted raw data (sinogram inpainting method) |

Adapted with permission from Kani and Chew.[30]
*Can be performed on most CT scanners without need for specific hardware or software.

## Heterotopic Ossification

HO is frequently associated with cervical artificial discs. HO may result in spontaneous fusion at the CDA level thus defeating the purpose of implantation of a motion preserving device. The etiology of HO associated with CDA is unknown. A postoperative course of nonsteroidal anti-inflammatory drugs may decrease the incidence of HO in high-risk patients.[3]

Currently, the most widely used classification of HO for disc prosthesis is the radiographic classification proposed by McAfee et al.[46] (Figs. 10 and 11). The incidence of HO causing restricted range of motion of the prosthesis appears to increase with time. In a meta-analysis study, advanced HO (defined as McAfee grades 3 and 4) was seen in 11.1% and 16.7% of patients at 12 and 24 months after surgery, respectively.[47] Advanced HO impacts clinical outcomes in an inverse manner.[48]

**Table 2** Techniques for Decreasing Metal-Induced Artifacts on MR Imaging

| Optimization of Conventional MR Sequences | Advanced MR Sequences (MARS)* |
|---|---|
| 1.5T in lieu of 3T MR scanner | View-angle tilting (VAT) |
| Implant positioning with long axis parallel to magnetic field | Multispectral imaging (MSI): |
| Turbo spin echo in lieu of gradient echo sequences | – Multiacquisition variable-resonance image combination (MAVRIC) |
| Short tau inversion recovery (STIR) in lieu of spectral-based fat suppression† | – Slice-encoding for metal artifact correction (SEMAC) |
| Increasing readout bandwidth‡ | – Combination of MAVRIC and SEMAC |
| Decreasing echo times | – MAVRIC or SEMAC with off-resonance suppression |
| Switching frequency and phase-encoding directions | |
| Increasing matrix size | |
| Decreasing slice thickness | |

Adapted with permission from Kani and Chew.[30]
*MARS may be supplemented with advanced image acquisition techniques (e.g., parallel imaging) and advanced postprocessing techniques (e.g., iterative reconstruction) for optimizing image quality and decreasing scan time.
†Dixon sequences or subtracted pre- and postcontrast T1-weighted images may be used with contrast administration.
‡Most effective parameter for artifact reduction in many clinical situations.

**Table 3** Complications After Cervical Disc Arthroplasty

| Categories | Subcategories |
|---|---|
| Complications related to anterior cervical surgical approach | — |
| Hardware-related complications | Hardware loosening, fracture, subsidence and migration; Polyethylene wear; Particle disease |
| Iatrogenic deformity | Loss of preoperative lordosis; Kyphosis; Scoliosis |
| Heterotopic ossification | May cause restricted or loss of motion at the surgical level |
| Degenerative changes at and adjacent to the CDA level | Facet arthrosis at CDA level; Adjacent segment degeneration |
| Miscellaneous | Vertebral fracture; Infection; Supra-physiological motion; Facet joint distraction at level of oversized disc implant |

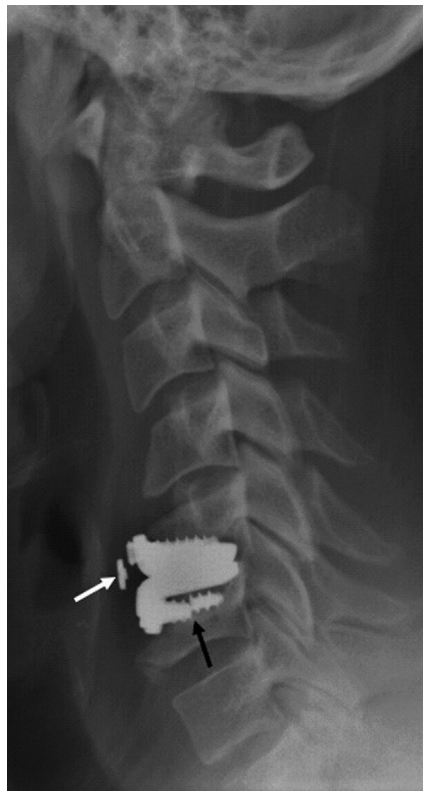

**Figure 9** Hardware fracture and subsidence. Lateral radiograph of the cervical spine (same patient as Fig. 1A; Image obtained 4 years after Fig. 1A) demonstrates fracture of the C5-C6 Prestige ST artificial disc. Observe the anteriorly displaced fragment arising from the superior metallic endplate (white arrow) and the inferior vertebral body screw fracture (black arrow). There is subsidence of the implant into the opposing vertebral bodies.

## Degenerative Changes at and Adjacent to the CDA Level

Unlike ACDF, CDA allows motion both at the disc and facet joint levels, therefore, painful facet arthropathy may progress or develop after CDA. By altering the biomechanics of the posterior column, oversized or undersized implants may potentiate facet arthropathy.[3]

The philosophy underlying "motion preservation" with total cervical disc replacement is decreasing the risk of adjacent segment degeneration. However, results of clinical trials have been inconsistent in this regard with some studies demonstrating decreased, while others showing similar rates of adjacent segment disease (Fig. 12) when CDA is performed instead of ACDF.[49,50]

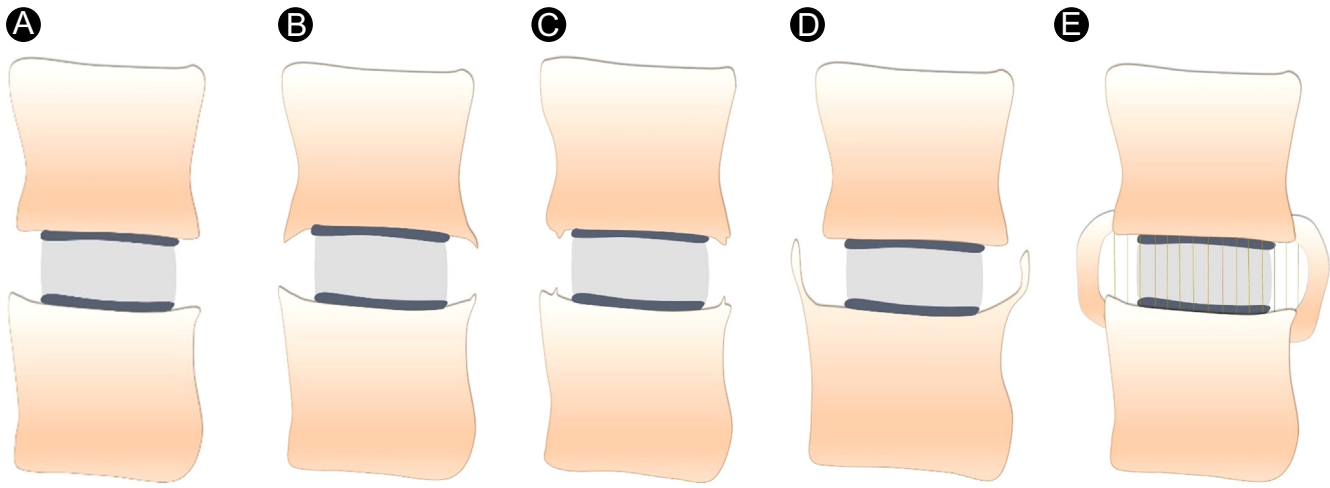


**Figure 10** McAfee classification of heterotopic ossification (HO). (A) Grade O: no HO present. (B) Grade I: HO outside the anatomic disc space; motion not affected. (C) Grade II: nonbridging HO in the anatomic disc space; motion may be affected. (D) Grade III: prominent HO or osteophytes or both restricting motion on flexion-extension or lateral bending radiographs. (E) Grade IV: bridging HO causing bony ankylosis with $<3^{\circ}$ motion on flexion-extension radiographs.

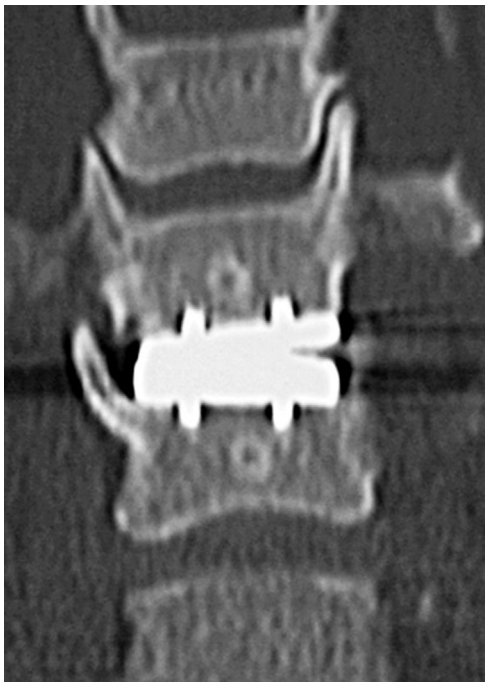

**Figure 11** Heterotopic ossification. Coronal reconstructed CT image viewed with bone windows, 1 year after placement of Prestige LP cervical disc shows near bridging heterotopic ossification laterally (McAfee grade III). Courtesy of Yilmaz H, MD, University Hospital of Geneva, Switzerland.

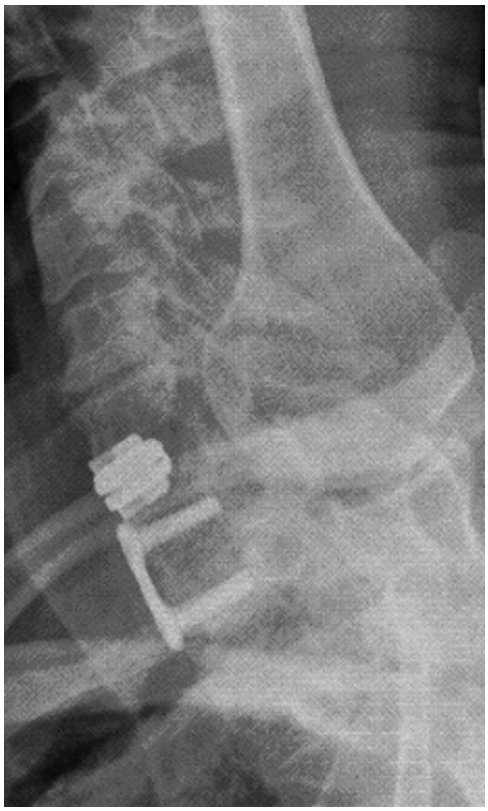

**Figure 12** Adjacent segment disease. Swimmer's view (same patient as Fig. 8; Image was obtained 4 years after Fig. 8) shows C6-C7 Prodisc-C total disc replacement and subsequent C7-T1 ACDF for adjacent segment disease.

## Miscellaneous Complications

Vertebral body fracture has been associated with implant design, surgical technique, and trauma. It is commonly reported in multi-level CDAs and in implants using keel fixation.[3]

Infection is an uncommon complication of CDA. Treatment of acute infections solely with antibiotics can lead to progressive bone destruction and morbidity, and revision to fusion is usually recommended in such cases.[1]

# CDA vs ACDF

CDA is a safe and effective alternative to fusion for appropriately selected patients with cervical radiculopathy and myelopathy. Several meta-analyses have shown CDA to be superior to ACDF for treatment of symptomatic cervical disc disease in terms of overall success, neurologic success, implant or surgery-related serious adverse events, reoperation rates, mid- to long-term functional recovery and patient satisfaction.[36,38,51] Some economic analyses suggest the cost-effectiveness of CDA compared to ACDF.[52,53]

# Conclusion

The results of several studies have confirmed the clinical safety and efficacy of cervical disc replacements. Although not encountered by many radiologists on a routine basis thus far, it is likely that radiologists will encounter an increasing number of patients with CDA in the near future. Successful imaging evaluation of potential preoperative CDA candidates and postoperative patients requires an understanding of patient selection criteria, hardware design and imaging appearance of normal hardware and the spectrum of postoperative complications.

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