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MOTION PRESERVING SPINE SURGERY (C KEPLER, SECTION EDITOR)

Cervical disc replacement surgery: biomechanical properties, postoperative motion, and postoperative activity levels

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Abstract
Purpose of review Cervical disc arthroplasty (CDA) is an evolving technique used in the treatment of cervical disc disease. To remain up to date on studies regarding its efficacy, we sought to answer three questions: What do biomechanical studies demonstrate in regard to the kinematics of CDA? How does CDA affect cervical motion? What are the postoperative activity levels of patients after cervical disc arthroplasty?
Recent findings

1) In regard to biomechanics, recent data suggests that CDA maintains motion while possibly altering facet biomechanics.
2) Radiographic data indicates a reliable maintenance of motion in the short and medium term.
3) Postoperative activity levels are assessed with clinical outcome data which demonstrate reliable improvement in pain and function.

Summary The data reviewed here establishes CDA as an efficacious treatment in the relief of symptoms from CDD. It is important to note however that an evaluation of CDA would benefit from more robust data, specifically in regards to long-term clinical outcomes.

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Introduction

Cervical disc arthroplasty (CDA) is a relatively new technology developed to treat cervical disc disease (CDD). The current gold standard treatment for CDD is anterior cervical discectomy and fusion (ACDF), which has high success rates and a tolerable side effect profile. However, one theorized sequelae of ACDF is adjacent segment disease (ASD), which can be a consequence of ACDF or simply the natural history of CDD. Regardless, CDA was developed in an effort to mitigate the theoretical risk associated with fusion. As this technology develops, it is important to assess its efficacy and determine its role in the treatment of CDD. This article reviews current literature regarding biomechanical properties, postoperative motion, and postoperative activity levels associated with CDA.

Biomechanical properties

Biomechanical data obtained through ex vivo models provide insight into how cervical disc prostheses behave in vivo. We sought to briefly review four of the most commonly referenced biomechanical studies evaluating disc arthroplasty in a succinct manner useful to the spine surgeon. Each of the following studies used cadaveric models to examine the biomechanics of various cervical disc prostheses.

One study assessed the motion parameters of the Cervicore TDR prosthesis versus anterior plating. The Cervicore prosthesis is a metal-on-metal implant with a saddle-shaped articulation. The theoretical benefit of a saddle-shaped joint is

separate axes of rotation for flexion/extension and lateral bending, which the Cervicore designer claims more closely mimics the native joint. The study demonstrated a decrease in the range of motion in both groups, but the Cervicore group was not as significantly affected as the anterior plate group. The study also demonstrated a highly variable trend towards increased facet loads during extension, which was believed to result from improper depth of prosthesis insertion [1].

A similar study evaluated the impact of the ProDisc C prosthesis on facet biomechanics. The prosthesis demonstrated a trend towards increased mean facet pressure in lateral bending and axial torsion. However, there was not a statistically significant difference between the ProDisc C and the intact spine because of high variability in results [2].

Another study evaluating the ProDisc C prosthesis focused on biomechanical changes observed in two-level surgery. The study compared two-level CDA with ProDisc C, two-level ACDF, and hybrid constructs by measuring intradiscal pressure and facet contact force. The ACDF group had a significant increase in caudal and cranial adjacent level intradiscal pressures compared to the CDA and hybrid groups. The ACDF and hybrid groups also trended towards increased facet contact force in the adjacent caudal level compared to the CDA group [3].

Finally, a kinematic analysis of the porous coated motion (PCM) device compared single-level ACDF, single-level CDA, and an intact spine. The ACDF group had a 33% increase in range of motion at the adjacent level. The CDA group and intact spine had equivalent range of motion in flexion, extension, and axial rotation. The groups also had a significant difference in centers of rotation. The fusion group demonstrated a more variable center of rotation with center of rotation moving posteriorly and inferiorly. In contrast, the CDA group's center of rotation closely mimicked the intact spine group [4].

These studies indicate that CDA may have a more physiologic motion profile, but may alter facet loading. Note that while the aforementioned studies are relevant to understanding CDA biomechanics, they are likely influenced by factors not accounted for in the cadaveric model.

Postoperative motion

One of the primary goals of CDA is to preserve segmental motion. While biomechanical data provides insight into the behavior of disc prostheses, radiographic data more accurately measures motion postoperatively. The following are examples of studies that examine postoperative motion radiographically.

Several studies have examined the Bryan prosthesis specifically. One study compared preoperative and 10-year follow-up X-rays. The range of motion decreased over the 10-year period from 7.8° to 4.7°. This decrease is theorized to be confounded by heterotopic ossification (HO), which had a prevalence of 70% in this study. In order to test this theory, a subgroup analysis was performed to compare patients that formed HO and those that did not. The range of motion of the HO group was 2°, while the range of motion of the non-HO group was 9° [5].

A second study of the Bryan prosthesis demonstrated that range of motion remained stable over a 5-year period. From preoperative to early postoperative periods, there was a slight 2° increase in range of motion at the superior adjacent level. This increase then held constant at 5 years postoperatively [6].

Finally, another study of the Bryan prostheses as part of an Investigation for Device Exemption (IDE) demonstrated an average range of motion of 8.08° and 8.48° at 24 and 48 months, respectively [7]. This data was corroborated by a multicenter randomized control trial, which demonstrated an average range of motion of 8.79° at 24 months. This was a clinically insignificant loss of only 0.79° [8].

Several studies have focused on the ProDisc C prosthesis. One prospective randomized trial compared ProDisc C with ACDF to evaluate range of motion at the operative and adjacent levels as well as total cervical range of motion. In the CDA group, total cervical range of motion increased while contribution of motion was equivalent and physiologic from all adjacent segments. In contrast, the ACDF group demonstrated a clinically insignificant loss of cervical motion while contribution of motion increased in all adjacent segments [9].

An FDA IDE study compared the ProDisc C to ACDF in order to examine operative level range of motion over time. In the ACDF group, there was a small increase in cranial and caudal range of motion at 24 months, 1.4 and 2.6°, respectively. The CDA group demonstrated a similar trend that did not reach statistical significance with increases in cranial and caudal range of motion of 0.8° and 1.3°, respectively. However, the treatment groups did not demonstrate a difference in range of motion [10].

Finally, a meta-analysis examined 12 studies of various prostheses to compare CDA and ACDF. Both groups exhibited up to 4° increases in range of motion at cranial and caudal levels at 24 months. A comparison between the groups did not elucidate a statistically significant difference. Additionally, the ACDF group demonstrated significantly more lordotic sagittal alignment. While the CDA group also demonstrated a trend towards increased global lordosis, this did not reach statistical significance. Two studies within the meta-analysis also evaluated changes in center of rotation. These studies found no significant difference between the CDA and ACDF groups [11•].

These radiographic data demonstrate a general trend towards maintenance of physiologic motion in the short and medium term. One large study also demonstrated an alteration in sagittal alignment. These changes are of unclear clinical

significance however. Clinical outcomes are therefore evaluated in the following section.

Postoperative activity levels

In addition to biomechanical data and postoperative motion, postoperative activity levels are an important factor in determining the viability of CDA. The following studies measure CDA pain and functional outcome scores. These scores provide insight into postoperative activity levels for patients undergoing CDA.

One study of 18 randomized controlled trials (RCT) provided a level 1 meta-analysis comparing CDA and ACDF clinical outcomes for single-level CDD. The CDA group demonstrated better neck and arm visual analogue scale (VAS) scores, fewer secondary procedures, and higher rates of neurologic improvement. At 24 months, the CDA group's neck pain VAS score was 1.99 points better than that of the ACDF group ($P = 0.0005$, 95% CI = −3.10 to −0.87). Arm pain VAS scores in the CDA group were 1.46 points better than those of the ACDF group ($P = 0.005$, 95% CI = −2.28 to −0.44). The CDA group had significantly better neurological success than the ACDF group (OR = 2.04, $P < 0.00001$, 95% CI = 1.56–2.67), although a sensitivity analysis demonstrated that two studies may have skewed the results. Finally, the CDA group had a lower rate of secondary procedures within 24 months (OR = 0.49, $P = 0.02$, 95% CI = 0.27–0.89), although the groups had no difference in adverse outcomes [12].

A Cochrane review also assessed the clinical differences between CDA and ACDF in the treatment of single-level CDD. Primary outcomes were favored in the CDA group, but the clinical relevance is questionable. VAS arm pain scores were statistically lower in the CDA group at 1–2 years, but these scores were based on low-quality evidence and the effect size was small (MD = −1.54; 95% CI = 2.86 to −0.22). The CDA group also had better VAS neck pain scores at 1–2 years, but the clinical relevance is again questionable due to moderate quality evidence and small effect size (MD = −3.12; 95% CI = −4.69 to −1.28). Lastly, the CDA group exhibited statistically superior neck-related function, but this again lacks clinical relevance due to small effect size (MD = −2.79; 95% CI = −4.73 to −0.85 at 1–2 years) [13•].

Another meta-analysis of four prospective FDA IDE trials compared the clinical efficacy of CDA and ACDF with 24-month follow-up. The study evaluated the Bryan, Prestige, PCM, and ProDisc C prostheses. Outcomes measured included the neck disability index (NDI) and neurologic maintenance and improvement. NDI success was defined as a 15-point improvement from baseline. The pooled odds ratio was 0.786 favoring CDA ($P = 0.103$, CI = .589–1.05), but this did not reach statistical significance. Neurological success was defined as "maintenance or improvement of muscle strength, muscle atrophy, and reflex scores," and failure was defined as a loss of one or more points in any category. The CDA group had a higher rate of neurological success. The pooled odds ratio was 0.552 ($P = 0.005$, 95% CI = 0.364–0.835), with 93.6% of the CDA group and 88.9% of the ACDF group achieving neurologic success [14•].

Another study prospectively examined a cohort of CDA patients in the Swiss spine registry. The prostheses in this database included DePuy's Discover, Medtronic's Bryan and Prestige, ScientX's Discocerv, Spineart's Baguera C, and Synthes' Prodisc C. Clinically relevant neck and arm pain reduction was defined as a 20-point improvement on the VAS scale. At 2 years, 68.4% of patients achieved clinically relevant neck pain improvement, and 78.4% achieved clinically relevant arm pain reduction. However, limitations of this study include its observational nature and lack of comparison to ACDF [15].

In addition to these broad studies, there are also several studies that focus on specific prostheses. One such study prospectively compared ACDF to CDA with the Bryan prosthesis. The CDA group had better NDI scores, with an average score of 8 in the CDA group and 15 in the ACDF group ($P = 0.048$). At 7 years, the CDA group also had a VAS score reduction from 7.2 to 0.45 compared with a reduction from 7.5 to 1.88 in the ACDF group ($P = 0.032$). However, this difference was not observed at 10 years [16]. Another study compared the Bryan prosthesis to ACDF in a meta-analysis of six FDA IDE trials and two additional trials totaling 1800 patients. At 2–3 years, both CDA and ACDF groups showed equivalent NDI score improvement. At 4 years, however, the CDA group had improved NDI scores compared to those of the ACDF group (SMD = −0.37, $P = .001$) [17].

The Prodisc C prosthesis developers continue to evaluate the FDA IDE trials comparing CDA with the ProDisc C and ACDF. At 7 years, both groups demonstrated equivalent and sustained improvements in NDI scores, SF36 outcomes, and VAS scores. The CDA group exhibited an average 8° range of motion at the operative level [18].

Similarly, the PCM prosthesis is also continuing the FDA IDE trials comparing CDA and ACDF. At 5–7 years, both groups exhibited improved NDI scores, but the CDA group showed greater improvement ($P = 0.001$). Both groups exhibited improved VAS scores at all time points, and only showed a difference favoring CDA at the 5-year mark. At 5 years, 73% of the CDA group and 56% of the ACDF group reported clinically significant improvement in SF36 physical component scores [19].

Finally, the IDE trials on the Secure C prosthesis comparing CDA and ACDF are also ongoing. At 2 years, both groups demonstrated improved NDI scores. Specifically, 91% of patients who underwent CDA experienced a 25% improvement in NDI scores, while 80% experienced a reduction of at least 20 mm on the VAS scale [20].

Finally, two studies specifically address postoperative activity levels in CDA patients who received either the Prestige or ProDisc C. These studies are both retrospective reviews of 200 patients undergoing CDA at the same single-center tertiary care facility. In this cohort, 94.5% received the Prestige and 5.5% received the ProDisc C. In the first study, 92.2% of patients were able to return to full activity levels postoperatively [21]. The second study compared postoperative activity levels of CDA and ACDF patients. In this study, 93% of the CDA group and 86% of the ACDF group were able to return to full activity postoperatively. Also, 91% of the CDA group and 88% of the ACDF group experienced full relief of preoperative symptoms [22].

Conclusion

The aforementioned studies provide insight into biomechanical properties, postoperative motion, and postoperative activity levels associated with CDA. Biomechanical data, while limited in its ability to extrapolate to in vivo function, suggests that CDA maintains motion while possibly altering facet biomechanics. It is also important to note that each prosthesis has a unique design that affects center of rotation and motion differently, and there is currently no consensus on which, if any, prosthesis has a more physiologic motion profile. It is important to note that facet loading may be altered with CDA. Radiographic data demonstrates that CDA generally maintains postoperative motion at the level of surgery and adjacent levels are minimally affected. Whether that maintenance of motion translates to reduction in rates of ASD is beyond the scope of this paper. Finally, clinical outcomes provide insight into CDA postoperative activity levels. It is clear that arm and neck pain are reliably improved, as are functional scores. Two papers specifically addressed return to preoperative activity and found rates in excess of 90%. Long-term data are lacking at this point; but, in the short- to mid-term periods, it is clear that CDA is at least as reliable as ACDF in providing relief from CDD.

Compliance with ethical standards

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

Human and animal rights and informed consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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