Analysis of in vivo kinematics of 3 different cervical devices: Bryan disc, ProDisc-C, and Prestige LP disc

Clinical article

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Object. Cervical arthroplasty has emerged as a means of preventing adjacent segment disease by preserving motion, restoring sagittal balance, and mimicking natural spinal kinematics. The purpose of this retrospective in vivo study was to characterize the impact of arthroplasty on sagittal balance and segmental kinematics of the cervical spine.

Methods. Sixty patients receiving the Bryan disc, ProDisc-C, or Prestige LP disc were retrospectively analyzed. Only single-level arthroplasty cases were included in this study. Lateral dynamic radiographs of the cervical spine were obtained using quantitative measurement analysis software to determine the kinematics at the index level both preoperatively and 1 year postoperatively. Collected parameters included range of motion (ROM), disc angles, shell angles, anterior and posterior disc heights (ADHs/PDHs), translation, and center of rotation (COR). Preoperative and postoperative data were compared using the Student t-test, with p < 0.05 indicating significance.

Results. The Bryan and Prestige LP discs preserved motion, whereas the ProDisc-C increased segmental ROM from extension to flexion. Following surgery, the Bryan disc exhibited significant shell angle kyphosis, while ProDisc-C and Prestige LP retained lordosis. Both ADHs and PDHs decreased following insertion of the Bryan disc. In contrast, the ProDisc-C increased the ADHs and PDHs by 80% and 52%, respectively, and the Prestige LP disc increased the ADHs and PDHs by 20%. Only the ProDisc-C demonstrated significant translation of 0.7 mm. The ProDisc-C shifted the COR x by 0.9 mm anteriorly, while the Prestige LP disc demonstrated a significant superior shift of 2.2 mm in COR y.

Conclusions. All discs adequately maintained ROM at the surgical level. The greatest difference among the 3 devices was in the disc height and index angle measurements. (DOI: 10.3171/2011.8.SPINE11273)

Key Words • cervical arthroplasty • cervical disc prosthesis • kinematics • lordosis • total disc replacement

Degenerative disc disease is characterized by the deterioration and collapse of the intervertebral disc1,6,42 accompanied by alterations in the spinal curvature.12,24 Changes in disc height can contribute to the loss of the normal cervical lordosis seen in patients with DDD.5,9,31 Anterior cervical disectomy and fusion has been the standard treatment for decompression of the neural elements and restoration of the natural sagittal balance in the cervical spine.34 However, this procedure has been associated with increased stress on adjacent levels and has been implicated as a cause of adjacent segment disease.2,7,10,11,14,15,17,23,43,45 Cervical arthroplasty has emerged as an option in treating cervical DDD, providing the advantages of preserving motion and potentially preventing adjacent segment disease. To provide these advantages, an intervertebral disc prosthesis must mimic the natural spinal kinematics, provide motion, and allow the restoration of sagittal balance. By comparing and contrasting the clinical and kinematic behavior of spinal devices, surgeons will be able to customize device selection for specific patient populations.

Various device designs have been given FDA approval. The Bryan cervical disc prosthesis (Medtronic Sofamor Danek) consists of a low-friction polyurethane core situated between 2 titanium alloy shells and surrounded by a polyurethane sheath. Pickett et al.26 first demonstrated a mobile COR in an in vivo kinematic analysis of radiographs obtained in patients undergoing Bryan disc insertion. In contrast, the ProDisc-C (Synthes Spine)
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is a cobalt chromium-on-polyethylene ball and socket device that has a fixed COR. Bertagnoli et al. reported a 240% increase in ROM in 27 patients with ProDisc-C at the 1-year follow-up. The Prestige LP (Medtronic Sofamor Danek), a 5th generation disc in the Prestige family, incorporates a ball and trough design (ball on top and trough on the bottom) that provides translation and a mobile COR. The purpose of this retrospective in vivo study was to characterize the preoperative changes that occur with DDD and examine how the Bryan cervical disc, ProDisc-C, and Prestige LP disc impact the sagittal balance and segmental kinematics of the cervical spine.

Methods

The Health Sciences Research Ethics Board at the University of Western Ontario approved this study.

Patient Population

Sixty consecutive patients with objective clinical and radiographic evidence of single-level DDD were included in this study. All patients presented with single-level radiculopathy and/or myelopathy with no degenerative changes at the adjacent levels. Patients underwent anterior cervical discectomy followed by implantation of a cervical disc prosthesis: Bryan disc, ProDisc-C, or Prestige LP disc. Each disc type was inserted in 20 patients.

Patient Selection Criteria

Surgery was offered to patients with a clinical history, physical findings, and MR images that were consistent with cervical radiculopathy and/or myelopathy. Preoperative radiographs exhibiting only single-level DDD were included in this study. Patients with multilevel arthroplasty, previous cervical spine surgery, and a follow-up < 12 months were excluded. A standard, right-sided cervical approach for anterior cervical discectomy was used in all patients. The same surgeon (N.D.) performed all surgeries. Selection of the arthroplasty device depended on availability; disc level, body habitus, and type of pathology were not considered important factors in device selection. Each device was implanted utilizing the exact technique recommended by the manufacturer.

Radiographic Analysis

Static and dynamic standing upright neutral, flexion, and extension cervical radiographs were obtained preoperatively and at the latest postoperative follow-up to assess device kinematics and alignment. The radiographic technique has been described previously. Validated radiographic quantitative motion analysis software (Medical Metrics, Inc.) was used to evaluate the kinematics at the index levels. This software uses an advanced pattern-recognition algorithm to generate accurate measurements of ROM, DA, SA, ADH, PDH, sagittal plane translation, and COR in the x and y directions. The COR was obtained for the index spinal level and reported as (x, y) offset from the midline of the superior endplate of the caudal vertebral body.

Statistical Analysis

Mean values and standard deviations were determined for ROM, DA, SA, ADH, PDH, translation, and COR x and y. The ANOVA was used to assess statistical significance among the 3 devices. Further analysis was completed using the Student t-test. All statistical tests were 2-sided, with significance set at the 0.05 level.

Results

Patient Population

Sixty patients (30 men and 30 women) with a mean age of 44.4 years (range 32–66 years) were consecutively enrolled in this study (Table 1). Each patient underwent a single-level disc arthroplasty, receiving one of the following devices: Bryan disc, ProDisc-C, or Prestige LP disc. Surgical levels included C3–4 in 2 patients, C4–5 in 5, C5–6 in 33, and C6–7 in 20. There was immediate relief of radiculopathy and/or myelopathy in all cases, with no operative or device-related complications. No early approach-, instrumentation-, or device-related complications were encountered. Heterotopic ossification occurred in 2 cases, with 1 fusion in the Bryan group (ROM = 10.7° vs 0.8°) and 1 in the Prestige group (ROM = 8.2° vs 0.8°). Transient dysphagia was seen in the early postoperative course but was not considered a complication of surgery. No explantations or reoperations have been performed. No patient was lost to follow-up, which was 12 months.

Range of Motion

The preoperative ROM for the 60 patients was 8.2° ± 4.2°. Following disc replacement, motion was preserved with the Bryan disc (9.5° ± 4.9° preoperatively vs 8.1° ± 4.3° postoperatively, p > 0.05) and the Prestige LP disc (7.2° ± 3.5° preoperatively vs 9.7° ± 5.2° postoperatively, p > 0.05). A significant increase in the segmental ROM from extension to flexion was provided by the ProDisc-C (8.0° ± 4.0° preoperatively vs 10.7° ± 5.5° postoperatively, p = 0.048). There was no difference in ROM among the 3 devices. In each device group, the change in ROM was not significantly different for the C3–4 surgical level compared with the C4–5, the C5–6, or the C6–7 surgical levels (Table 2).

Disc Angle and SA

The DA represents the angle of the diseased disc space prior to surgery. The mean DA for the entire cohort of 60 patients was 2.5° ± 3.2°. The SA was defined as the angle between the superior and inferior endplates of the cervical TDR (Fig. 1). Preoperatively, for patients in the Bryan disc cohort, the DA was 3.0° ± 3.1° (lordosis). Following surgery, there was significant SA kyphosis (−3.4° ± 4.7°, p < 0.0001; Fig. 2). An increase in kyphosis (> 4° change) at the index level in the neutral position was found in 60% of patients.

The ProDisc-C DA at the surgical level was almost parallel at 1.2° ± 3.3°. Following surgery, the device SA was 1.1° ± 3.6° (p = 0.64; Fig. 2). The postoperative SA was variable, with 3 patients (15%) demonstrating > 2° worsening of kyphosis at the late follow-up. In contrast, 3
patients (15%) demonstrated postoperative hyperlordosis (SA > 5°).

In the Prestige group, the preoperative DA was 3.3° ± 2.9°. Following surgery, the SA was 1.1° ± 4.2° (p = 0.04; Fig. 2). In 5 patients (25%), > 2° of index kyphosis was found postoperatively. Only 2 patients (10%) demonstrated a significant increase in postoperative lordosis (> 2° change).

Both the ProDisc-C and Prestige LP showed a lordotic SA configuration compared with the Bryan disc (p = 0.002 and 0.006, respectively).

Disc Height

Preoperatively (60 cases), the mean ADH was 3.9 ± 1.1 mm, while the mean PDH was 3.2 ± 0.8 mm. Following insertion of the Bryan disc, the ADH decreased by 32% (4.4 ± 1.0 mm preoperatively vs 3.0 ± 1.1 mm postoperatively, p < 0.0001), and the PDH decreased by 14% (3.5 ± 0.9 mm preoperatively vs 3.0 ± 1.0 mm postoperatively, p = 0.0005). In contrast, the ADH increased by 80% (3.4 ± 1.0 mm preoperatively vs 6.1 ± 1.0 mm postoperatively, p < 0.0001) in the ProDisc-C group, while the PDH increased by 52% (3.1 ± 0.9 mm preoperatively vs 4.7 ± 0.7 mm postoperatively, p < 0.0001). In all cases with the ProDisc-C, a 5-mm polyethylene device was used. In the Prestige LP group, there was a 20% increase in both the ADH (4.0 ± 1.0 mm preoperatively vs 4.8 ± 1.1 mm postoperatively, p = 0.008) and the PDH (3.0 ± 0.7 mm preoperatively vs 3.7 ± 0.6 mm postoperatively, p = 0.001). The disc height for all Prestige LP devices was 5 mm.

There were significant differences in postoperative ADH and PDH values among all 3 devices (p < 0.05; Fig. 3). Both ProDisc-C and Prestige LP were associated with significant increases in ADH and PDH compared with the Bryan disc (p < 0.05).

Sagittal Plane Translation

Changes in segmental translation for the Bryan disc (1.0 ± 0.7 mm preoperatively vs 1.0 ± 0.7 mm postoperatively, p = 0.98) and the Prestige LP disc (0.8 ± 0.5 mm preoperatively vs 0.9 ± 0.4 mm postoperatively, p = 0.33) were negligible, resembling the translation found before implantation of the device. The ProDisc-C demonstrated translation of 0.7 mm (0.7 ± 0.5 mm preoperatively vs 1.5 ± 0.6 mm postoperatively, p < 0.0001).

There was no significant difference in translation between the Prestige LP and Bryan group (p = 0.78). Significant differences were found between the ProDisc-C with the Bryan and Prestige LP (p < 0.05).

Center of Rotation

The Bryan disc did not significantly change the COR x or COR y (p = 0.16 and 0.27, respectively). The COR x underwent a statistically significant anterior shift of 0.9 mm after the introduction of ProDisc-C (−0.8 ± 1.2 vs 0.2 ± 0.8 mm, p = 0.002); there were no significant changes in COR y (p = 0.99). Following insertion of the Prestige LP, the COR x remained unchanged (p = 0.32), while a significant superior shift occurred in COR y (3.2 ± 2.1 mm preoperatively vs 1.0 ± 2.2 mm postoperatively, p = 0.0003).

When comparing the 3 devices, significant differences were found for the COR x and y parameters between...
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**Discussion**

Sixty patients with single-level DDD presented with a ROM of 8.2° ± 4.2°, a DA of 2.5° ± 3.2°, ADH of 3.9° ± 1.1 mm, PDH of 3.2 ± 0.8 mm, translation of 0.8 ± 0.6 mm, COR x of −1.6 ± 1.4 mm, and a COR y of −1.9 ± 6.8 mm. One of the goals of arthroplasty is the preservation of motion and cervical kinematics. To accomplish these goals, the surgeon must consider biomechanics at the surgical level, device design, instruments for implantation, and surgical technique. The current study provided a unique opportunity to illustrate the differences in the kinematic performance of 3 popular arthroplasty devices.

**Range of Motion**

Postoperatively, ROM was preserved at the index level for all devices: Bryan disc (8.4° ± 4.3°), ProDisc-C (10.7° ± 5.5°), and Prestige LP (9.7° ± 5.2°). No significant differences were found between the devices with respect to ROM. The ProDisc-C not only maintained but also increased ROM at the index level. This result is consistent with the data collected by Bertagnoli et al.,4 who reported a significant increase in vivo in sagittal ROM (4° preoperatively vs 12° postoperatively) following insertion of the ProDisc-C. In contrast to the ProDisc-C, both the Bryan and Prestige LP discs did not significantly change ROM at the index levels, although a trend in increasing ROM was found for the latter. Similarly, Wigfield et al.43 reported that the Prestige LP disc remained stable in 15 of 16 patients and that motion was preserved in all but 1 patient. In contrast, Rousseau et al.45 found that ROM was decreased in patients with the Prestige ST (5.1°) and ProDisc-C (3.6°) compared with that in healthy volunteers (13.4°). The devices in our study preserved preoperative motion after TDR. The prosthesis adapted itself into the local biomechanical profile provided by adjacent vertebral bodies, ligaments, and facet joints.

In addition, some differences in ROM may be attributed to device design or the surgical technique. A hyperlordotic configuration of ProDisc-C endplates at the surgical level was associated with restricted segmental ROM and translation from neutral to extension.28 Like the Bryan disc, the ProDisc-C was not designed to ac-

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**Fig. 2.** Bar graph demonstrating the postoperative SA following insertion of a cervical TDR. Bars represent the standard deviations. Asterisk represents a significance level of p < 0.05.

the Bryan disc and ProDisc-C (p < 0.0001), as well as between the Bryan and Prestige LP discs (p < 0.0001).

**Disc Angle and SA**

The preservation or restoration of normal sagittal balance in the cervical spine has become an important and recognized goal in cervical spine surgery.19,46,47 Kyphosis has been associated with an increased incidence of adjacent segment disease,18 increased loading on the vertebral bodies and discs, and a significantly higher incidence of degenerative changes.17,18,30,44 The Bryan disc demonstrated −3.4° ± 4.7° of SA kyphosis, with 60% of patients demonstrating postoperative device endplate kyphosis (Fig. 4). Pickett et al.37 reported the development of kyphosis with a mean loss of 6° of functional spinal units during the early follow-up time postsurgery with the Bryan disc. In fact, the Bryan disc design has a passive nature and is not designed to correct kyphosis, as it seems unable to restore lordosis to the spine.21 The ProDisc-C had a slightly lordotic SA of 1.1° ± 3.6°, with 15% of patients demonstrating worsening kyphosis and 15% demonstrating hyperlordosis. In contrast, the Prestige LP disc demonstrated 1° lordosis at the index level and corrected sagittal alignment by maintaining and increasing postoperative lordosis in 10% of patients. Unfortunately, the Prestige LP disc and ProDisc-C did not have a predictable and reliable device endplate alignment.

**Disc Height and Translation**

Our results lend further evidence to previous studies suggesting that the loss of disc space height (collapse of the intervertebral disc)6,42 and changes in the spinal curvature accompany the process of DDD.12,24 Specifically, our results reveal that the loss of ADH at the index level produces parallelism of the vertebral endplates so that the ADH approaches the PDH, resulting in a focal loss of lordosis. Parallelism of the vertebral endplates due to DDD has been shown in previous kinematic studies.19,20,27,38,41 Shim et al.40 reported a preoperative DA (at the index level) of −0.7° (47 patients). Fong et al.15 studied 10 patients undergoing Bryan disc arthroplasty and found that 40% had angles between 1° and 2° and that 30% had angles
that were straight (parallel with 0°). Johnson et al.19 studied 13 patients with a mean preoperative angle of 1° and noted that the symptomatic segment was kyphotic because of a loss of ADH. Our results confirm that DDD results in focal loss of lordosis. Harrison et al.16 studied 252 individuals and found that the average lordosis between cervical vertebrae was between 6° and 7°, with a disc height/vertebral body height ratio of 2:5. It is important to note that only individuals with lordotic curvatures were considered. These results would suggest that to restore sagittal alignment, which is lost in DDD, the TDR must introduce approximately 6° of lordosis. Incorporating the need for sagittal balance will be an important feature in selecting the most appropriate disc replacement option.

Center of Rotation

Normal motion between 2 vertebrae occurs around the COR, which is typically located in the posterior half of the upper portion of the inferior vertebral body. To protect the facet joints from abnormal forces and stress, cervical arthroplasty devices should attempt to maintain the COR of the normal spine. The ProDisc-C incorporates a ball-and-socket joint mechanism with a fixed axis of rotation. Hence, the location of the COR depends on placement of the device in the anterior-posterior plane. The COR x shifted anteriorly by 1.0 mm (p = 0.002), suggesting that the device could have been placed in a more posterior location. The Prestige LP disc also provided a change in the COR from the preoperative values; a significant superior shift in the COR y value is most likely related to the ball’s location on the superior endplate. The Bryan disc best preserved the physiological location of the preoperative COR.

Study Limitations

The radiographic analysis software that we used has been extensively validated.26,32,33,36,37,46 Potential sources of error and variability for kinematic analysis of spinal biomechanics have been addressed in the past and include the quality of flexion and extension imaging, the imaging technique, and out-of-plane motion, as well as patient discomfort, effort, and body habitus.26,29 These factors can introduce significant inaccuracies into the calculation of all biomechanical parameters, especially when examin-

Conclusions

A better understanding of the different device designs will ultimately lead to refined indications and device selection with a focus on improving the quality of motion. This in vivo study demonstrated that the Bryan disc, ProDisc-C, and Prestige LP disc adequately maintained ROM at the index level. There were design-specific differences in increasing the disc height, creating a lordotic SA, and maintaining natural COR x and y values. Longer follow-up is required to assess the durability of kinematic changes seen following cervical TDR.

Disclosure

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