Motion Preservation Technologies in Cervical Spine Surgery

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ABSTRACT

When considering anterior cervical spine surgery there continues to exist controversy between fusion and motion sparing disc arthroplasty. Anterior cervical discectomy and fusion is a well-known commodity with over 50 years of experience to support it, while total disc arthroplasty remains a relatively new option in need of more research. In this paper we review the biomechanics of age associated changes in cervical degenerative disease. We then examine the principles and data of the motion sparing arthroplasty. Initially, cervical disc arthroplasty fell into disfavor due to early complications however renewed interest resulted in promising research outcomes for arthroplasty. Motion preserving surgery appears to be more biomechanically favorable than fusion, although the definitive clinical conclusions are limited based on current research. We conclude that total disc arthroplasty, as a motion-preservation strategy, may be a safe and effective alternative to anterior fusion for appropriately selected patients in the short term.

KEY WORDS: Biomechanics, cervical degenerative disease, motion preservation, total disc arthroplasty

"There are lies, damned lies, and statistics" – Mark Twain

INTRODUCTION

The Controversy

Anterior cervical discectomy and fusion (ACDF) has been a surgical option for the management of cervical disc disorders since 1958 (16). Over time, long-term outcome studies increasingly focused on adverse effects, specifically on the vertebrae and the intervertebral discs adjacent to the level fused (2,8,10). The concern that spinal fusion may potentially contribute to the acceleration of adjacent segment degeneration led to increased interest in “motion preservation” technology and popularity of cervical disc replacement in the reconstruction after anterior cervical decompressive operations.

The clinical success of ACDF is evident in the literature. Bohlman et al. reported 67% of patients with no neck or arm pain 20-33 years after initial surgery at single and multiple levels (4). 88.5% of patients had no functional deficit postoperatively, in comparison with 45% with motor deficit and 63% with sensory deficit preoperatively. Unlike the long follow-up period in outcome studies for ACDF, the longest published follow-up period for total disc arthroplasty (TDA) is approximately 8 years (7). Furthermore, the data for TDA are usually gathered from patients who participated in randomized controlled trials for particular implants, which are usually industry funded and amenable to significant selection bias. As a result, an accurate comparison of the outcomes after the two procedures remains challenging.

Biomechanics of the Aging Spine

The spine provides structural support for the entire body. The cervical spine specifically enables mobility of the head. Wolff proposed the notion that the shape or form of bone is determined by its function (17). As load is applied to the bone, primarily during compression, the trabeculae develop along the stress vector lines, thus providing maximal strength with minimal change in overall mass. For example, trabecular bone in the vertebral body is aligned in the vertical direction.

The healthy intervertebral disc provides mobility to the spine and transfers load via hydrostatic pressurization of the hydrated nucleus pulposus. Aging-associated changes
Hooke’s law states that elastic materials deform to an extent proportional to the external force and the material’s elasticity. The stress-strain curve illustrates this physical law of how solids respond to a full range of deforming forces, from net zero force to forces that alter the mechanical properties of the solid. The curve is comprised of the neutral zone, elastic zone, plastic zone, and point of failure (Figure 2). The neutral zone (AB), preceding the linear area of the curve, represents an area of non-engagement with minimal deformation. Hooke’s law only applies when the deformation occurs within the linear elastic zone (BC), in which it completely recovers after removal of the load. The slope of this linear relationship represents stiffness of the material. Deformation remains proportional to the deforming force until the elastic limit, after which the linear relationship between force and deformation ceases to exist.

In the plastic zone (CD), beyond the elastic limit, the solid acquires permanent deformation and no longer completely recovers after removal of the external stress. Eventually the point of failure (DE) is reached as the force continues to be applied. The area under the curve represents the total energy absorbed and material strength. A mechanically unstable motion segment is associated with widening of the neutral zone and shifting of the curve to the right (hashed curve).

Figure 2: The stress-strain curve illustrates Hooke’s law of how solids respond to a full range of deforming forces, from net zero force to forces that alter the mechanical properties of the solid. The neutral zone (AB), preceding the linear area of the curve, represents an area of non-engagement with minimal deformation. Hooke’s law only applies when the deformation occurs within the linear elastic zone (BC), in which it completely recovers after removal of the load. The slope of this linear relationship represents stiffness of the material. Deformation remains proportional to the deforming force until the elastic limit, after which the linear relationship between force and deformation ceases to exist. In the plastic zone (CD), beyond the elastic limit, the solid acquires permanent deformation and no longer completely recovers after removal of the external stress. Eventually the point of failure (DE) is reached as the force continues to be applied. The area under the curve represents the total energy absorbed and material strength. A mechanically unstable motion segment is associated with widening of the neutral zone and shifting of the curve to the right (hashed curve).

Figure 1: The healthy intervertebral disc provides mobility to the spine and transfers load via hydrostatic pressurization of the hydrated nucleus pulposus (A). Aging-associated changes to the disc, including dehydration and reorganization of the nucleus pulposus and stiffening of the annulus fibrosus (B,C), markedly alter the mechanics of load transfer in the spine. (with permission from Thieme Publishing, New York, NY; in Biomechanics of the Spine (editor/author: Edward C. Benzel), in press 2014)
and adjacent-level hypermobility (1). However, motion-into early disfavor due to hardware-related complications spine.
disc placement location and orientation within the cervical postural changes, or surgery-related variables such as the biomechanical parameters, such as facet loading and degenerative changes.

Motion-preservation strategies aim to eliminate mechanical pain. The devices used in TDA replicate the normal anatomy, motion, and mechanics of the cervical spine while attempting to minimize complications, optimize longevity, and impede degenerative changes for symptomatic relief. Replication of motion takes into consideration various planes including axial, translational, and bending as well as multiple axes including axial, coronal, and sagittal. In addition, the mechanics of the device-and-spine construct account for stiffness and shock absorption properties. Bearing material, position, joint configuration (uniarticular ball and socket, uniarticular ball and trough, biarticular ball and socket, or biarticular saddle configuration), and geometry of the articulation create a unique kinematic profile for each device. These devices act as spacers that widen the neutral zone (AB) of the stress-strain curve in an attempt to reduce mechanical pain.

Biomechanical studies suggest that artificial disc prostheses mimic natural cervical motion at the operated level. Chang et al assessed the effects of two types of artificial discs on the range of motion in cadaveric cervical spines (6). Both disc types yielded a significant increase in the range of motion, particularly in extension. In vitro, cervical disc arthroplasty appears to be more biomechanically favorable than fusion, although the simplistic biomechanical approaches utilized do not fully characterize all pertinent biomechanical parameters, such as facet loading and postural changes, or surgery-related variables such as the disc placement location and orientation within the cervical spine.

Cervical adjacent segment disease (ASD)

Cervical disc arthroplasty, as an alternative to fusion, fell into early disfavor due to hardware-related complications and adjacent-level hypermobility (1). However, motion-preservation strategies were gradually reconsidered due to clinical and radiographic prevalence of progressive degenerative disease at levels immediately adjacent to surgically fused segments (adjacent segment disease, ASD). In 1980, Lunsford et al reported a 6.7% reoperation rate for newly symptomatic levels in 253 patients treated for disc herniation with at least one-year follow-up (13). Hilibrand et al reviewed three large-scale studies and reported that the annual incidence of ASD requiring additional surgery ranges between 1.5 and 4%. (11) Furthermore, Hilibrand et al reported that the risk of new disease at an adjacent level was significantly lower following multi-level arthrodesis in comparison to single level and concluded that the degenerative process is likely secondary to progression of disease rather than being the result of the fusion itself (10).

As the interest in TDA resurfaced, several studies enrolled and randomized patients with radicular symptoms related to degenerative disc disease to undergo ACDF versus investigational arthroplasty device implantation. Mummaneni et al reported lower rates of adjacent level surgeries with Prestige ST (Medtronic, Minneapolis, Minnesota) placement compared to ACDF at 24-month follow-up; (14) however, the more recently published five-year follow-up data failed to demonstrate a statistically significant benefit in terms of surgery performed for ASD (5). Similarly, Murrey et al reported statistically significant results favoring arthroplasty with the ProDisc-C (DePuy Synthes, East West Chester, Pennsylvania) device in terms of the need for secondary surgery at last follow-up. (15) Of note, only 84.4% of patients in the investigational arm met criteria for motion preservation at two-year follow-up. In a Bryan cervical disc trial by Heller et al, statistically significant differences favoring arthroplasty were reported for the neck disability index, time to return to work, and specific criteria for “overall success” (9). However, radiographic or symptomatic adjacent level disease was not reported.

The findings of these published studies are inconclusive due to the following limitations: non-inferiority study design, short-term follow-up, biases associated with lack of blinding, failure to specifically address ASD as a primary outcome measure, and the use of survey data. In fact, Bartels et al concluded in a meta-analysis of these randomized controlled trials that the clinical use of cervical disc prostheses was unjustified largely due to the faulty, non-blinded, study design as well as significant bias. (3) Furthermore, Jawahar et al examined the incidence of ASD
among 93 patients randomized to one or two level ACDF versus arthroplasty, incorporating three different device FDA Investigational Device Exemption clinical trials. They reported no statistically significant difference in the development of ASD at mean follow-up of 36.4 months.\(^{(12)}\)

**Summary**

Total disc arthroplasty, as a motion-preservation strategy, may be a safe and effective alternative to anterior fusion for appropriately selected patients in the short term.

There is no compelling long-term level-one clinical evidence to recommend TDA for routine use over fusion, using reduction in the development of symptomatic ASD as a primary outcome. Moreover, the short-term and long-term effects of motion preservation on the posterior elements, including the ligamentum flavum and facet joints, has not been comprehensively studied and reported in the literature. Although the marketed arthroplasty devices have a broad range of biomechanical and kinematic properties, their long-term clinical consequences are incompletely understood.

“Nearly all men die of their medicines, not of their disease” – Moliere

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**REFERENCES**


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