The future in the care of the cervical spine: interbody fusion and arthroplasty

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In the past 50 years tremendous advances have been made in the treatment of cervical disc disease with cervical fusion. Fusion rates have surpassed 95% after application of anterior cervical implants. Adjacent-segment degeneration, however, has plagued the long-term clinical success of cervical fusion.

Cervical arthroplasty has been introduced to maintain cervical motion and potentially avoid or minimize adjacent-segment degeneration. If cervical arthroplasty is successful, the long-term results of surgery for cervical disc disease may improve; however, there are associated drawbacks that must be overcome. Implant wear, fatigue, and failure have been reported in cases of large-joint arthroplasty, and research is underway to limit these problems in cervical arthroplasty.

In this article the authors trace the evolution of cervical fusion and the new technique of cervical arthroplasty. The nomenclature of cervical arthroplasty will also be introduced.

KEY WORDS • cervical disc • fusion • bone morphogenetic protein • arthroplasty

Evolution of ACDF

Anterior cervical discectomy and fusion was first described by Smith and Robinson in the 1950s. Initial attempts were performed without anterior plate fixation. Initially, iliac crest autograft was placed as the interbody spacer. Although ACDF transmits loads, it limits the normal controlled range of motion of the cervical spine.

Evolution of Cervical Arthroplasty

Anterior cervical discectomy and fusion is currently the gold-standard treatment for herniated cervical discs.
Arthrodesis, which was previously associated with fusion rates greater than 90% when allograft was combined with anterior cervical plate fixation, now approaches rates of 100% when the new synthetic materials such as PEEK and rhBMP-2 are used. The question arises: is cervical arthroplasty better than ACDF?

During the past decade, ACDF has been found to be associated with symptomatic adjacent-segment disease. Hilibrand, et al.,\textsuperscript{10,11} reported that surgical intervention was necessary for 2.9% of patients annually because of symptomatic adjacent-segment disease following ACDF. Furthermore, they found that 10 years after ACDF 25% of patients reported symptoms due to adjacent-segment disease. In addition, Goffin, et al.,\textsuperscript{9} reported that in 92% of fusion-treated patients radiographic evidence of adjacent-segment degenerative disc disease was demonstrated 5 years postoperatively. The cause of this adjacent-segment disease appears to be the abnormal kinematics (higher shear strains) that occur at levels adjacent to anterior cervical fusions.\textsuperscript{13} Cervical disc arthroplasty, therefore, could be beneficial because adjacent-segment disease might be avoided by maintaining normal neck mobility.

Attempts at replacing a disc with an artificial cervical disc were made more than 10 years ago.\textsuperscript{5} Early designs of these implants were modeled on artificial joints (arthroplasties) implanted by orthopedists in the knees, hips, and shoulders.

In large-joint replacement procedures involving knees and hips, the implants are subject to repetitive stresses and generate wear-related debris. Tribology (the study of friction, lubrication, and wear of interacting surfaces in relative motion) has been a primary focus for the developers of large-joint prostheses in recent years. Like other total joints, artificial disc prostheses have articulating surfaces that will wear down during the life of the implant. With the potential increase in use of articulating devices in the cervical spine in coming years, it is necessary to evaluate the amount of wear debris generated in in vivo loading conditions. Tribology is central to the success of cervical arthroplasty because artificial disc designs that are prone to excessive wear debris may contribute to metal toxicity and foreign-body reactions, which would make them suboptimal for application in humans. In general, artificial joints that induce excessive wear debris may stimulate a host response to generate macrophages and multinucleated giant cells (inflammatory reaction) to surround the wear debris. These cells can release cytokines that initiate a cascade that ultimately could result in osteolysis and loosening of the implant. In addition to wear debris, several other potential drawbacks may limit the widespread use of cervical arthroplasty. These drawbacks include material fatigue and catastrophic failure of the artificial joint in traumatic situations.

To quantify the amount of wear debris generated by these devices, wear testing has been recently performed on two different cervical prostheses, a metal-on-metal disc (PRESTIGE Artificial Disc; Medtronic Sofamor Danek, Memphis, TN) and a polyurethane-on-metal disc (BRYAN Artificial Disc; Medtronic Sofamor Danek) under normal physiological loads and motions. Testing was conducted to a total of 20 million cycles in a cervical spine simulator that applied the loads and motions associated with activities of daily living. It was found that the mean wear rate for the metal-on-metal device was 0.46 ± 0.29 mm$^3$/million cycles, whereas that for the polyurethane-on-metal device was 0.97 ± 0.87 mm$^3$/million cycles. These rates are orders of magnitude less than rates of currently available large-joint prostheses. Furthermore, evaluation of a cervical arthroplasty device explanted after 3.25 years has shown the wear equivalent to be approximately 311,000 cycles of in vitro wear testing.\textsuperscript{1,6,17}

**Nomenclature of Cervical Arthroplasty**

During the 1990s, numerous new-generation artificial discs were created. To track the evolving generations of artificial cervical discs, the Cervical Spine Study Group developed a new nomenclature system for cervical arthroplasty. Currently, artificial discs are classified into three types: non-, uni-, and biarticulating. The implant may consist of a metal-on-metal design (Fig. 2), a metal-on-polymer (that is, ultra–high molecular-weight polyethylene) (Fig. 3), a ceramic-on-polymer, or a ceramic-on-ceramic design. The disc is either modular (having replaceable components) or nonmodular (lacking replaceable compo-
Cervical interbody fusion and arthroplasty

Investigators in European and Australian clinical trials have demonstrated superior results when using the metal-on-metal and metal-on-polymer discs compared with ACDF; these results were based on neck disability index and arm pain intensity visual analog scale scores as well as neurological status. Excessive metal debris, material fatigue with fracture, and catastrophic failure have not been shown to be problematic in the European trials, the results of which indicate that the advantages (motion maintenance and potential improved clinical outcome) of arthroplasty outweigh its disadvantages (wear debris, material fatigue, and joint failure).

In the US, three artificial discs are undergoing prospective, randomized clinical trials in which outcomes are being compared with those demonstrated after cervical fusion. They include the Prestige Artificial Disc (Fig. 2), Bryan Artificial Disc (Fig. 3), and the ProDisc-C (Synthes, Paoli, PA) (Fig. 5). Based on the accrual of these Class I data derived from comparing cervical arthroplasty with cervical interbody fusion, clinicians will be able to determine whether arthroplasty is equivalent or superior.
Conclusions

In the last half century, the philosophy of spine surgeons was to undertake cervical fusion to manage symptomatic cervical disc herniations. The focus of research was to improve fusion rates to 100%. Spinal implants improved the fusion rates significantly while minimizing morbidity (for example, iliac crest donor site pain).

In the next 50 years spine surgeons will likely witness the emergence of a new philosophy, centered around the maintenance of motion when treating spinal segmental disease, which will revolutionize the treatment paradigms in clinical use. Certain obstacles, however, must be over-

come to realize the goals of arthroplasty. Material wear, fatigue, and failure must be minimized. Current research is focused on the tribology of cervical arthroplasty, and strides are being made to overcome the obstacles to maintaining cervical motion.

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Cervical interbody fusion and arthroplasty


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