BIOMECHANICAL EVALUATION OF DIFFERENT DESIGN TYPES OF ARTIFICIAL CERVICAL DISCS

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INTRODUCTION

For a number of years, cervical spinal diseases have been treated primarily with anterior discectomy and fusion (ACDF), which provides a good rate of success and early recovery of the patient [1]. However, clinical studies showed that fusion is associated with a decreased range of motion and leads to accelerated adjacent segment degeneration [2]. Cervical disc arthroplasty, which provides motion preservation of the implanted functional spine unit, could reasonably slow down or eliminate adjacent segment degeneration [2-5]. Many designs have been advocated as cervical total disc replacements (C-TDRs) that consist of either articulating or non-articulating components constructed from various materials. Nevertheless, it has been reported that the main complications for C-TDRs are: degeneration of the facet joints at the same level, degeneration of the disc and the facet joints at adjacent levels, and subsidence or migration of the artificial disc.

In order to identify the biomechanical changes associated with C-TDRs. The objective of this study is to compare the biomechanical alterations of the cervical spine subject to implantation of 3 different typical prosthetic disc devices under various loading conditions.

METHODS

A three-dimensional model of a four-level ligamentous cervical segment (5 vertebrae and 4 discs) was built and implemented with the finite-element method (FEM) software MSC Mentat (MSC Software Corp., Los Angeles, U.S.A.). Two different configurations of the model were considered: (a) an intact model; (b) three mobile models with the C5-C6 level implanted with three different simplified C-TDRs, respectively. The intact model consisted of approximately 76,400 10-node tetrahedral elements as shown in Fig. 1a.

Intact model

A 3D FE model of the intact C3-C7 spine was built. The geometry of the cervical spine was reconstructed from computer tomography (CT) scans taken from the Visible Human Dataset, a collection of radiographic images and photos of sections of the whole human body made available by the American National Institute of Health. A commercial software (Amira, TGS, San Diego, CA, USA) was used to transform the planar CT scans into solid models of the vertebrae considered.

The structure of intervertebral disc was subdivided into an inner volume representing the nucleus pulposus and an external layer representing the annulus fibrosus. The ligaments modeled were the anterior longitudinal ligament (ALL), the posterior longitudinal ligament (PLL), the flaval ligament (FL) and the interspinous ligament (ISL). All ligaments were modeled as continua.

Mobile models

The mobile models incorporated three movable disc prostheses in the C5-C6 intervertebral space, respectively. Several simplifications of geometries for those devices in order to reduce simulation solution time, the simple models for the three types of C-TDRs were shown in Fig. 2 and classified as below:

- Type I and Type II: Both upper and lower sides were two metal sheets made of CoCrMo alloy. The internal part was movable joint made of UHMWPE in a semi-globe shape. Type I was a ball-and-socket joint with large radius of curvature. Type II was a type of structure with a small radius of curvature. (Fig. 2a and 2b).

- Type III: Both upper and lower sides were two metal sheets made of titanium alloy. The center part between sides was a flexible nucleus. The outer parts were clad with a PU membrane 0.5 mm in thickness. The membrane model was shown in Fig. 2c.

The FE models of the C3-C7 motion segments implanted with three different C-TDRs are shown in Figs. 1b-d. Material properties were taken from published literature [6], and shown in Table 1. The loading conditions were applied on the superior surface of the C3 with a 73.6 N compressive preload, together with four different kinds of 1.0N-m moments to simulate the following motions: (1) flexion, (2) extension, (3) lateral bending, (4) torsion, respectively [7]. All analysis results for the models with artificial disc prostheses were compared with those of the corresponding intact ones.

Figure 1: Finite element models of the C3-C7 spinal unit with and without the implanted prosthesis. (a) Intact (b) Type I TDR (c) Type II TDR (d) Type III TDR

Figure 2: The FE models of the TDRs (a) Type I (b) Type II (c) Type III
RESULTS

FE model Validation

Fig. 3 presents a comparison between the load displacement curves from the FE calculation and in vitro studies [6, 7], under flexion-extension condition. Those results were closely correlated to the data of past studies, which supports further utilization of the model in extended analysis.

![Figure 3: Validation of present intact FE model, as compared with Galbusera, Goel et al. studies. [6, 7]](image)

DISCUSSION

Compared with past experimental studies, our analysis results were somehow different. It was possibly caused by the simplified condition associated with the height of simple models in artificial cervical discs. The oversize on models could possibly result in numerical variance. The Type III movable joint was designed with a flexible structure and this design concept is more similar to the real structure of cervical disc. In addition, Type I and Type II movable joints were designed with a ball-and-socket joint, as well as the design of sliding joint. Thus, after the implantation, there would be height variances on the distribution of COR.

CONCLUSIONS

The current study compared the influence on cervical spine motion of the intact group with and without the implantations of artificial cervical discs with various movable joint designs. The distribution of COR in Type III were closer to that of the intact group. The design for movable joints with implanted objects could affect the locus heights or the forward and backward shifts for the COR when receiving loading moments.

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REFERENCES