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Biomechanics of two-level Charité artificial disc placement in comparison to fusion plus single-level disc placement combination

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Abstract

BACKGROUND CONTEXT: Biomechanical studies of artificial discs that quantify parameters such as load sharing and stresses have been reported in literature for single-level disc placements. However, literature on the effects of using the Charité artificial disc (ChD) at two levels (2LChD) as compared with one-level fusion (using a cage [CG] and a pedicle screw system) plus one-level artificial disc combination (CGChD) is sparse.

PURPOSE: To determine the effects of the 2LChD and CGChD across the implanted and adjacent segments.

STUDY DESIGN: A finite element model of a L3–S1 segment was used to compare the biomechanical effects of the ChD placed at two lower levels (2LChD model) with L5–S1 fusion (using a CG and a pedicle screw system) plus L4–L5 level ChD placement combination (CGChD model).

METHODS: We used our recently published and experimentally validated L3–S1 finite element model for the present study. The intact model was subjected to 400 N axial compression and 10.6 Nm of flexion/extension moments. The experimental constructs described above were then subjected to 400 N axial compression and a moment that produced overall motion equal to the intact model predictions (hybrid testing protocol). Resultant motion, loads across facets, and other parameters were analyzed at the experimental and adjacent levels.

RESULTS: In flexion, the bending moments for the CGChD and 2LChD models were 15.4 Nm (fusion effect) and 7.3 Nm (increase in flexibility effect), respectively in comparison to 10.6 Nm for the intact model. The corresponding values in the extension mode were 11.2 Nm and 7.2 Nm. The predicted flexion rotations across the L5–S1 segment for the CGChD decreased by 76% (fusion effect), and increased at the L4–L5 and the L3–L4 levels by 68.5% and 28%, respectively. In the extension mode, motion across the L5–S1 segment decreased by 96.4% whereas it increased 74.6% and 18.2% across the L4–L5 and L3–L4 levels, respectively. For the 2LChD model, the flexion rotation across the L5–S1 segment increased by 28.2%. The motions across the L4–L5 and L3–L4 segments decreased by 12% and 24%, respectively. In extension, the corresponding changes were 10% increase, 10% increase, and 21% decrease at the L5–S1, L4–L5, and L3–L4 levels, respectively. The facet loads were in line with the changes in motion, except for the 2LChD case.

CONCLUSIONS: The changes at L3–L4 level for both of the cases were of similar magnitude (approximately 25%), although in the CGChD model it increased and in the 2LChD model it decreased. The changes in motion at the L4–L5 level were large for the CGChD model as compared

FDA device/drug status: approved for one-level, but not cleared for two-level (Charité artificial disc).

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with the 2LChD model predictions (approximately 70% increase vs. 10% increase). It is difficult to speculate if an increase in motion across a segment, as compared with the intact case, is more harmful than a decrease in motion. © 2006 Elsevier Inc. All rights reserved.

Keywords: Biomechanics; Finite element model (FEM); Artificial disc; Kinematics; Two-level placement; Fusion

Introduction

In certain cases where conservative treatment has failed, surgical intervention may be considered for degenerative lumbar pathologies. However, the results of fusion for axial low back pain are not always successful [1–7]. Further, there is the concern of accelerating degeneration adjacent to a fusion construct secondary to force concentrations. To avoid these limitations of fusion for low back pain, serious consideration is now being given to total disc replacement (TDR) as a potential alternative to fusion surgery.

A limited number of finite element and cadaver studies delineating the biomechanical characteristics of TDR devices have been pursued from laboratories, including our own [2,8–10]. For example, the effect of a ball-and-socket type disc design on the implanted level was investigated with a Functional Spinal Unit finite element model [9]. Cunningham et al. studied the effects of the Charité artificial disc (ChD, mobile core type design) on the implanted and adjacent levels using fresh ligamentous lumbar specimens [2]. The investigation of Leary et al., although similar in design to that of Cunningham et al., has documented motion patterns of the Charité disc components during cadaver testing, using the Optrak 3-D motion measurement system and digital fluoroscopy [11]. The authors of both of these studies applied the same amount of pure moments for both the intact and instrumented cases (flexibility or load-controlled testing protocol), which in our opinion is not clinically relevant, as explained in our previous publication and in the present study as well.

Our group recently reported on the changes in load sharing and stresses at the experimental and adjacent levels after single-level ChD placement (L5–S1), as compared with the intact segment, using a hybrid testing protocol [8]. This protocol involves loading an intact spine with a defined moment. Subsequently, tested constructs were displaced to the same degree as the intact specimen with the defined moment, regardless of the moment required to achieve this displacement. The ChD led to motion increases in flexion (19%) and extension (44%) at the implanted L5–S1 level. Facet loads decreased 13% at this instrumented level, 25% at L4–L5, and 26% at L3–L4. Intradiscal pressure changes in the L4–L5 and L3–L4 segments were minimal. Shear stresses at the ChD–L5 end plate interface were higher than those at the S1 interface.

Currently, surgeons have started using TDR adjacent to fused levels in clinical practice. The goal of this practice is to limit the force concentrations at levels adjacent to long fusion constructs. The biomechanical advantages of such constructs have not been well documented.

The present study uses our previously reported hybrid loading protocol to investigate the effects of the ChD disc implantation at two levels (2LChD) vs. the combination of fusion simulated using a cage and the pedicle screw system plus one-level disc placement (CGChD) on the kinematics, load sharing, and stresses in various structures at the implanted and adjacent segments.

Methods

Finite element models of the ligamentous L3–S1 segment

The lumbar spine finite element model consisted of a three-dimensional element mesh of L3 through S1 [8,9,12–14]. The procedure used to develop the model and some pertinent details of the present model are briefly described below.

Intact L3–S1 finite element model. The present intact L3–S1 finite element model included 27,540 elements and 32,946 nodes (Fig. 1A). The mesh was generated from digitized computer tomography scans (transverse sections of 1.5 mm thickness) of a ligamentous human lumbar spine specimen. The specimen was free of deformities or abnormalities, including severe degeneration. The mesh was symmetric across the midsagittal plane.

Material properties of the various tissues (Table 1) were selected from the literature, including our own experimental data. A lordotic curve of approximately 27° was simulated across the L3–S1 level, with mid L3–L4 disc plane kept horizontal. The vertebral bodies were defined as cancellous bone cores surrounded by 0.5-mm-thick cortical shells. The posterior bone regions were assigned a single set of material properties.

The apophyseal (facet) joints were simulated with three-dimensional gap contact elements (GAPUNI). These elements transferred force between nodes along a single direction as a specified gap between these nodes closed. The cartilaginous layer between the facet surfaces was simulated using ABAQUS's (HKS, Pawtucket, RI) ''softened contact'' parameter, which exponentially adjusted force transfer across the joint depending on the size of the gap. An initial gap of 0.5 mm was specified as reported for cadaveric specimens. At full closure, the joint assumed the same stiffness as the surrounding bone.

The intervertebral disc annulus was modeled as a composite of a solid matrix with embedded fibers (via the REBAR parameter) in concentric rings around a pseudo-fluid

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