The Spine Journal 14 (2014) 2195–2207

Basic Science

Effects of cervical arthrodesis and arthroplasty on neck response during a simulated frontal automobile collision

Nicholas A. White, PhD[a], Daniel P. Moreno, MS[a], Philip J. Brown, MS[a], F. Scott Gayzik, PhD[a], Wesley Hsu, MD[b], Alexander K. Powers, MD[b], Joel D. Stitzel, PhD[a,*]

[a]Center for Injury Biomechanics, Virginia Tech-Wake Forest University, 575 N. Patterson Ave., Suite 120, Winston-Salem, NC 27157, USA

[b]Department of Neurosurgery, Wake Forest University School of Medicine, Medical Center Blvd., Winston-Salem, NC 27157, USA

Received 12 September 2013; revised 5 February 2014; accepted 1 March 2014

Abstract

BACKGROUND CONTEXT: Whereas arthrodesis is the most common surgical intervention for the treatment of symptomatic cervical degenerative disc disease, arthroplasty has become increasingly more popular over the past decade. Although literature exists comparing the effects of anterior cervical discectomy and fusion and cervical total disc replacement (CTDR) on neck kinematics and loading, the vast majority of these studies apply only quasi-static, noninjurious loading conditions to a segment of the cervical spine.

PURPOSE: The objective of this study was to investigate the effects of arthrodesis and arthroplasty on biomechanical neck response during a simulated frontal automobile collision with air bag deployment.

FDA device/drug status: Approved (Prestige ST-Medtronic), (ProDisc-C; Synthes Spine).

Author disclosures: ***NAW:*** Grant: US Army Medical Research and Materiel Command (H, Paid directly to institution); Provision of writing assistance, medicines, equipment, or administrative support: Synthes Spine, ProDisc-C implant (B in product, Paid directly to institution), Medtronic, Prestige ST implant (donation of product, Paid directly to institution); Trips/Travel: US Army Medical Research and Materiel Command (H, Paid directly to institution); Research Support Investigator Salary: US Army Medical Research and Materiel Command (H, Paid directly to institution); Research Support Staff/Materials: US Army Medical Research and Materiel Command (H, Paid directly to institution). ***DPM:*** Grant: US Army Medical Research and Materiel Command (H, Paid directly to institution); Provision of writing assistance, medicines, equipment, or administrative support: Synthes Spine, ProDisc-C implant B in product, Paid directly to institution), Medtronic, Prestige ST implant (donation of product, Paid directly to institution); Trips/Travel: US Army Medical Research and Materiel Command (H, Paid directly to institution); Research Support Investigator Salary: US Army Medical Research and Materiel Command (H, Paid directly to institution); Research Support Staff/Materials: US Army Medical Research and Materiel Command (H, Paid directly to institution). ***PJB:*** Grant: US Army Medical Research and Materiel Command (H, Paid directly to institution); Provision of writing assistance, medicines, equipment, or administrative support: Synthes Spine, ProDisc-C implant (B in product, Paid directly to institution), Medtronic, Prestige ST implant (donation of product, Paid directly to institution); Trips/Travel: US Army Medical Research and Materiel Command (H, Paid directly to institution); Research Support Investigator Salary: US Army Medical Research and Materiel Command (H, Paid directly to institution); Research Support Staff/Materials: US Army Medical Research and Materiel Command (H, Paid directly to institution). ***FSG:*** Grant: US Army Medical Research and Materiel Command (H, Paid directly to institution); Provision of writing assistance, medicines, equipment, or administrative support: Synthes Spine, ProDisc-C implant (B in product, Paid directly to institution), Medtronic, Prestige ST implant (donation of product, Paid directly to institution); Trips/Travel: US Army Medical Research and Materiel Command (H, Paid directly to institution); Research Support Investigator Salary: US Army Medical Research and Materiel Command (H, Paid directly to institution); Research Support Staff/Materials: US Army Medical Research and Materiel Command (H, Paid directly to institution). ***WH:*** Grant: US Army Medical Research and Materiel Command (H, Paid directly to institution); Provision of writing assistance, medicines, equipment, or administrative support: Synthes Spine, ProDisc-C implant (B in product, Paid directly to institution), Medtronic, Prestige ST implant (donation of product, Paid directly to institution). ***AKP:*** Grant: US Army Medical Research and Materiel Command (H, Paid directly to institution); Provision of writing assistance, medicines, equipment, or administrative support: Synthes Spine, ProDisc-C implant (B in product, Paid directly to institution), Medtronic, Prestige ST implant (donation of product, Paid directly to institution). ***JDS:*** Grant: US Army Medical Research and Materiel Command (H, Paid directly to institution); Provision of writing assistance, medicines, equipment, or administrative support: Synthes Spine, ProDisc-C implant (B in product, Paid directly to institution), Medtronic, Prestige ST implant (donation of product, Paid directly to institution); Trips/Travel: US Army Medical Research and Materiel Command (H, Paid directly to institution); Research Support Investigator Salary: US Army Medical Research and Materiel Command (H, Paid directly to institution); Research Support Staff/Materials: US Army Medical Research and Materiel Command (H, Paid directly to institution).

The disclosure key can be found on the Table of Contents and at www.TheSpineJournalOnline.com.

This study was funded by the US Army Medical Research and Materiel Command. It was supported through a $1,514,365 grant and a $5,899 donation in product. The authors have no potential conflicts of interest to report.

* Corresponding author. Center for Injury Biomechanics, Virginia Tech-Wake Forest University, 575 N. Patterson Ave., Suite 120, Winston-Salem, NC 27157, USA. Tel.: (336) 716-5597; fax: (336) 716-5491.

E-mail address: jdstitzel@gmail.com (J.D. Stitzel)

1529-9430/$ - see front matter
http://dx.doi.org/10.1016/j.spinee.2014.03.001

STUDY DESIGN: This study used a full-body, 50th percentile seated male finite element (FE) model to evaluate neck response during a dynamic impact event. The cervical spine was modified to simulate either an arthrodesis or arthroplasty procedure at C5–C6.

METHODS: Five simulations of a belted driver, subjected to a 13.3 m/s ΔV frontal impact with air bag deployment, were run in LS-DYNA with the Global Human Body Models Consortium full-body FE model. The first simulation used the original model, with no modifications to the neck, whereas the remaining four were modified to represent either interbody arthrodesis or arthroplasty of C5–C6. Cross-sectional forces and moments at the C5 and C6 cervical levels of the neck, along with interbody and facet forces between C5 and C6, were reported.

RESULTS: Adjacent-level, cross-sectional neck loading was maintained in all simulations without exceeding any established injury thresholds. Interbody compression was greatest for the CTDRs, and interbody tension occurred only in the fused and nonmodified spines. Some interbody separation occurred between the superior and inferior components of the CTDRs during flexion-induced tension of the cervical spine, increasing the facet loads.

CONCLUSIONS: This study evaluated the effects of C5–C6 cervical arthrodesis and arthroplasty on neck response during a simulated frontal automobile impact. Although cervical arthrodesis and arthroplasty at C5–C6 did not appear to significantly alter the adjacent-level, cross-sectional neck responses during a simulated frontal automobile impact, key differences were noted in the interbody and facet loading.

Keywords: Arthrodesis; Arthroplasty; ProDisc-c; Prestige ST; Finite element analysis; GHBMC

Introduction

The use of finite element (FE) methods for orthopedic applications, particularly those involving the cervical spine, began over 20 years ago with a simple two-dimensional model used to study postlaminectomy deformities [1]. The first FE study of an anterior cervical spine fusion was conducted by Kumaresan et al. [2] to evaluate the effects of fusion materials and surgical procedure on the biomechanical response of a C4–C6 spine model. Since this publication, close to two-dozen additional FE studies have been conducted, evaluating the effects of both anterior cervical discectomy and fusion (ACDF) and cervical total disc replacement (CTDR) on the biomechanics of the cervical spine [3–25]. Typically, the implant was modeled between either C4–C5 or C5–C6, and the simulations were run as quasi-static events using an implicit FE solver (Table 1). The present study uses a state-of-the-art full-body FE model to evaluate dynamic neck kinematics and loading, with simulated arthrodesis and arthroplasty at the C5–C6 level, during a frontal automobile collision.

Materials and methods

General model overview

The Global Human Body Models Consortium (GHBMC) 50th percentile seated male FE model (version 3.5) was used to study the cervical spine response because of a simulated arthrodesis and arthroplasty [26,27]. The biofidelity of the neck (Fig. 1) has been rigorously validated both at individual cervical segment levels and for the full cervical spine [28–31]. Additionally, whole body validation has been conducted for a number a different impact scenarios [32–35]. Neck muscle activation, based on the experimental volunteer studies, was included in the current simulations [36]. The flexor and extensor muscles were activated 74 ms after impact and remained active for 100 ms.

Cervical spine modifications for ACDF and CTDR

To mimic actual surgical technique for both these procedures, the intervertebral disc (IVD), end plates, and anterior longitudinal ligaments (ALL) associated with this level of the cervical spine were removed from the model. Vertebral body (VB) geometric modifications consistent with these surgeries were accomplished through a combination of select element deletion and advanced morphing techniques using HyperMesh version 11.0 (Altair Engineering, Troy, MI, USA). The geometries of both CTDRs used in this study were reverse engineered from the corresponding physical implants. The ACDF and CTDRs were secured to the VBs using tied nodes to surface offset contacts. Material properties for the IVDs, ACDF, and CTDRs are reported in Table 2 [24,37–42].

Arthrodesis at the C5–C6 cervical level was modeled using two different methods, one involving constrained nodal rigid bodies (CNRBs) and the other a cage, core, and anterior plate (ACDF). The CNRB fusion rigidly constrained more than 100 individual node sets from the inferior VB surface of C5 to the superior VB surface of C6. The geometries of VB surfaces were not modified, and no additional contacts were required because a physical implant was not modeled. The ACDF was modeled as a 14×15×6 mm solid organic polymer polyether ether ketone cage, 1 mm thick, and a solid trabecular bone core (Fig. 2, Top Left). The C5 and C6 VBs were modified to create surfaces parallel to