Implementation of physiological facet cartilage thickness mapping in a high resolution finite element model of the cervical spine and implant-related facet force transmission predictions

W J Womack, C M Puttlitz
Orthopaedic Bioengineering Research Laboratory
Colorado State University
Fort Collins, CO USA

Introduction

Although many finite element models (FEMs) have provided important insight into the kinematics and load transmission profile of the spine, the accuracy of the predictions has not been rigorously demonstrated, especially with regard to internal mechanical parameters (such as stress and strain). Specifically, almost all of these models validate using only range of motion data. Thus, there is an underlying assumption with regard to the correspondence between kinematics and force/stress profile. In addition, many of the soft tissue structures, especially the facet cartilage, are geometrically simplified (usually via a homogeneous extrusion from the osteochondral interface). In spite of this, predictions of facet force transmission due to instrumentation of the disc space have been published. To overcome theses aforementioned shortcomings, we have developed a high resolution finite element model of the lower cervical spine and validated it experimentally using both kinematic and strain/pressure measurements. The physiologic spatial variation in facet cartilage thickness has been experimentally measured and implemented in the FEM model, which has been used to investigate the effect of a cervical disc replacement implant on spine kinematics and facet joint contact forces.

Materials and Methods

A cadaveric qCT-based FEM was generated, and mesh convergence and model validation were demonstrated based on kinematics, facet contact forces, nuclear pressures, and annular and cortical strains. Facet cartilage thickness was based on our experimentally-derived spatial distributions [Womack *et al* 2007]:

$$t_{fit}(r,\theta) = t_{max}\left[\cos\left(\frac{\pi r}{2r_{perim}(\theta)}\right)\right]^k$$

Where t_{max} is the maximum thickness of the facet cartilage, r, r_{perim} and θ describe facet geometry in cylindrical coordinates, and the shape parameter *k* was found to be 0.5. A second implementation of this model was developed by replacing the entire C4-5 disc space with a ProDisc-C implant. Additional models utilizing common non-physiologic cartilage thickness distributions were also developed and analyzed.

Results

Changes in range of motion and coupled rotations after disc replacement were negligible [Figure 1]. Changes in facet contact forces under lateral bending were negligible, but increased contact force was observed at the implanted level under axial torsion [Figure 2].

Figure 1: Lateral Bending ROM after disc

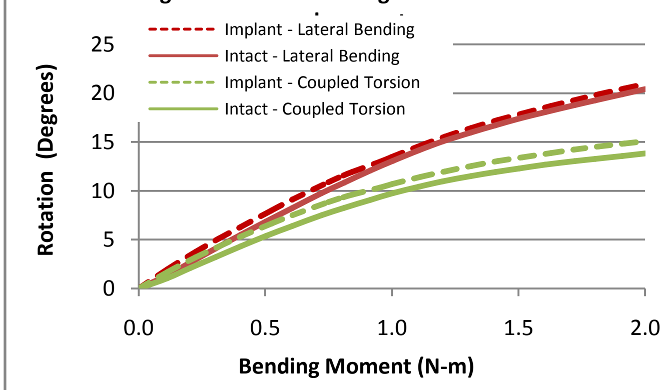
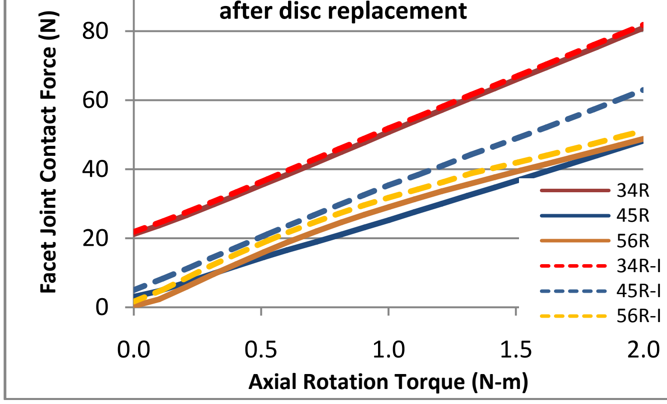


Figure 2: Facet Contact Forces in axial torsion after disc replacement



Discussion

Comparison of the contact pressure distributions using physiologic and simplified cartilage distributions reveals the importance of high-fidelity geometric representation of the cartilage. The lack of changes in ROM while significant changes in contact forces are observed indicates that ROM alone is an insufficient indicator of model performance. The effect of implant size on kinematics and contact forces is currently under investigation and these data will be presented.