ANALYSIS OF MULTIPLE LEVEL SPINE BIOMECHANICS AFTER CHARITE ARTIFICIAL DISC ARTHROPLASTY BY IN VIVO IMAGE-BASED FINITE ELEMENT MODELING

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Introduction
Degenerative Disc Disease (DDD) is a disorder affecting intervertebral disks that significantly reduces intervertebral disk space. DDD leads to abnormal loading of the disc’s annulus fibrosis and the facet joints of the posterior spine. The altered biomechanics may lead to chronic axial back pain [1]. Artificial Disc Replacement (ADR) is an emerging surgical alternative to the gold standard of spinal fusion in the treatment of DDD as evidences have shown the increased mobility at adjacent spine segments to compensate the limited motion of the fused segments can cause the non-aging degeneration of the discs at these segments [2]. Devices such as the Charite Artificial Disc (DePuy Spine, Raynham, MA) function to reduce discogenic back pain and restore physiologic motion to a diseased spine segment. Clinical and biomechanical research continues into the complications of Charite ADR, which may include posterior facet joint arthrosis and device subsidence [3]. However, alterations in adjacent segment mechanics have not been well characterized. This study uses image-based Finite Element Analysis (FEA) of multiple level spine models of L3-S1 directly from patients to track the alteration pre- and post-operatively with Charite ADR and to investigate stresses in the spine segment that may relate to facet arthrosis and device subsidence.

Materials and Methods
Two patients with mechanical back pain were included in this study. MRI of lumbar spine and discogram from patients show degeneration of the L5-S1 disc or desiccation of the L5-S1 disc space with concordant pain at this level with a negative control at L4-5. Two cases satisfied the criteria for the indication of using Charite ADR as instructed by FDA. All data processed from the image modality on patients were supervised by the internal review board at the University of Michigan.

Finite Element Modeling: L3-S1 voxel finite element models were created pre- and postoperatively directly from patients’ computed tomography scans. CT images were converted to grayscale and segmented using the image processing software Analyze (AnalyzeDirect, Lenexa, KS). The spine model was reconstructed by assembling segmented images into three dimensional models in the commercial voxel-based finite element package Voxelcon (Quint, Inc., Tokyo, Japan) with 500,000 voxels for the analysis (Figure 1A).

Material Properties: The constraints of the Voxelcon program limited the analysis to four material properties. The homogenized value as a single material property was given to the intervertebral disc in the normal and degenerate models. The components of the spine segment were assumed to be isotropic and homogeneous. The Young’s modulus and Poisson’s ratio of each component was assigned to the corresponding voxels to replicate the material properties of the spine (CoCrMo: E=21 GPa, ν=0.3, cortical bone: E=12 GPa, ν=0.3, cancellous bone: E=100 MPa, ν=0.2, homogenized disc: E=8 MPa, ν=0.4, UHMWPE assumed equal to cancellous bone) (Figure 1B).

Boundary Conditions: A zero displacement boundary condition was applied at the bottom of the sacrum. The first loading condition applied a force of 1200 N to the top surface of the L5 vertebral body/endplate to simulate axial compression. The second loading condition, axial compression with flexion, added a 10 N-m moment to the anterior 1/3 of the area under the 1200 N compression.

Results
In patient one, the preoperative model showed that high stress occurred at the endplates and some at the posterior elements through the pedicles. The L5-S1 facet reached maximal principle stress of 20 MPa even though no facet arthropathy was noted before the surgery. High stress concentrated at the inferior endplate on the level above and some at sacrum, while vertebral columns also shared lower high stress of 8 MPa (Figure 2A). After the disc arthroplasty, stress transfer was noted on FEA. The stress on endplates was reduced and instead, the metal endplates of the artificial disc was found with high stress of 10 MPa. Previous high principle stress on the facet joint was alleviated but still remained with lower magnitude (Figure 2B). The results were similar in patient 2, except the stress on the CoCrMo alloy endplates was higher and occurred on both inferior and superior sides.

Discussion
Image-based finite element modeling makes clinical patient specific modeling possible. This type of modeling allows more accurate and more rapid representation of anatomic structures than conventional geometric modeling, making multiple spine segment modeling feasible. The result of this study indicates that Charite ADR can reduce the elevated stress at adjacent levels induced by the degenerative spine abnormality and thus potentially relieve the axial discogenic pain. However, high stress on CoCrMo enplates may indicate potential device subsidence, while the enduring stress on facets may induce posterior facet joint arthrosis.