Specimen-specific Model for Kinematic Assessment of Cervical Facet Joints

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Introduction: Cervical total disc replacement (TDR) has been used clinically for a number of years. While TDR's have been shown to preserve the range of motion, recent clinical studies have shown accelerated degeneration of the facet joints at the index level. These degenerative changes may be due to abnormal motion of the facets as a result of a mismatch between the kinematics of the native anatomy and the kinematic characteristics of the prosthesis, leading to abnormal loading of the facets and capsular ligaments. Our goal was to develop a tool to assess the effect of motion preservation devices on the facet joint motions without making any assumptions regarding the host anatomy, tissue properties, or the performance of the prosthesis implanted in a motion segment.

Methods: Cervical spine specimens (C3-T1) were instrumented with a minimum of 3 radiopaque markers per vertebral body. A 3-dimensional (3-D) specimen-specific anatomical model of the specimen was reconstructed using fine-slice axial CT scans. Therefore, the anatomy of each vertebra was defined in relation to the markers attached to that vertebra. The next step was to establish a digital link between the radiopaque markers in the CT reconstruction and the motion sensors attached to each vertebra by digitizing the location of the markers on each body relative to the motion sensors on that body. Next, the specimen's kinematic response was measured in response to flexion-extension, lateral bending, and axial rotation moments. Three-dimensional motion of each vertebral body was tracked using an optoelectronic motion measurement system. The 3-D motion data obtained during the flexibility test was then used to drive the 3-D CT anatomical model. As a result, 3-D motion of any anatomical landmark on the specimen could be assessed in response to the loads applied to the specimen during flexibility testing.

Results: The model was used to visualize and quantify the facet motions at all motion segments for all loading modes. An illustrative application is shown for calculation of facet overlap area at the C4-C5 segment undergoes motion in flexion-extension (Figures 1 & 2).
Figure 1: Facet Overlap Area at C4-C5

[Figure 1]
Conclusions: This model couples an individual specimen's 3D CT reconstruction with its own kinematic data collected in the laboratory. In this fashion, there are no assumptions made regarding material properties, host anatomy or implant motion as with a finite element model. In addition to assessing the motion of facet joints, the specimen-specific model can be also used to make quantitative measurements of facet joint gapping, area of intervertebral foramen and spinal canal, and ligament stretch in the specimen's intact state and after TDR.