Effect of Implant Rigidity on the Recovery of Spinal Kinematics after Dynamic Stabilization

INTRODUCTION:
More than 200,000 U.S. patients undergo spinal fusion surgery every year. To avoid a common side effect of spinal fusion (transition syndrome), dynamic stabilization has been introduced as an alternative. Past experiments on dynamic stabilization were conducted on asymptomatic cadaver specimens or with numerical models derived from normal subjects. As such, these studies were designed to compare devices without consideration of actual patient characteristics. The objective of this study was to evaluate the efficacy of dynamic stabilization on a patient specific basis. The rigidity of the implant was considered the primary variable affecting spinal kinematics. Our long-term goal is to influence a physician’s decision for selecting a proper implant based on a patient’s spinal kinematic characteristic as can be obtained from triple radiographic analysis.

METHODS:
Six patients suffering from L3-L4 disc degeneration and spondylolisthesis were included in this study (66 ± 13.36 years). Spinal geometry and range of motion (ROM) were obtained from pre-surgical radiographic images at flexion, extension and neutral standing. Based on ROM, the patients were divided into two groups: hypo-mobility and hyper-mobility. Additionally, anterior translation (X) and disc height (Y) at L3-L4 in the neutral standing position were measured.

3D finite element models of the L2-L5 segment were generated from Computed Tomography (CT) images. The model was composed of a four-level spinal segment containing vertebral bodies, end-plates, and the annulus and nucleus of the disc. Seven spinal ligaments were attached: anterior longitudinal ligament, posterior longitudinal ligament, ligament flavum, transverse ligament, capsular ligament, interspinous ligament and supraspinous ligament. Since this study was focused on the flexibility of the intervertebral discs and spinal kinematics attributed mainly to disc deformation, we homogenized the vertebral bodies and considered them as rigid bones. Mechanical properties such as Young’s modulus, Poisson’s ratio, and the cross-sectional areas of the nucleus, annulus, ligaments and vertebrae were based on values published in the literature. For the nucleus, annulus and vertebrae, 3D tetrahedral elements were used and the ligaments were represented by tension-only bar elements. Contact and target elements were placed within the facet joints. The models were calibrated to patient’s characteristic ROM and a model validation study conducted. Subsequently, dynamic stabilization devices were implanted within the models. As the rigidity of the device was changed, flexion and extension were simulated. Each level’s ROM and maximum Von Mises stress in the disc were measured with each change of stiffness.

RESULTS:
As the rigidity of the dynamic stabilization implant increased, the ROM at the degenerated level decreased and the stress on the adjacent levels increased. Flexion and extension of the two models showed similar tendencies and patterns in the tests of ROM and stress. However, these results illustrated that the hypo-mobile spine and the hyper-mobile spine had different initial points, i.e. different values for ROM and disc stress without any stabilization device. In the case of the hypo-mobile spine, the simulation involving no device implant indicated an increase in ROM at the degenerated level while the adjacent levels had a decrease in ROM. However, the hyper-mobile model showed the opposite trend in that the no device simulation indicated an increased ROM at L3-L4 and decreased ROM at L2-L3 and L4-L5. Furthermore, stiffness saturation was evident as the ROM and disc stress were only marginally increased beyond an implant stiffness of 1.1 Gpa (yellow bar in Figure 4). Even though the stiffness of the implant increased, ROM and disc stress were not significantly increased.

DISCUSSION:
This study demonstrated the effects of varying levels of rigidity in dynamic stabilization devices on the spinal kinematics of patients. The findings of the study further indicated an advanced benefit of patients with hyper-mobility in the spine undergoing dynamic stabilization. As the stiffer device further limited mobility at the degenerated level, the above and below segments were forced to work harder to compensate for the loss of motion in L3-L4, thereby increasing the disc stress in the adjacent levels. Often, patients reduce their motion due to severe back pain, however, if we assumed that the patient desires to maintain the pre-fusion level of spinal motion, we can infer from these results that the stiff device could cause transition syndrome leading to further disc degeneration. Depending on an individual patient’s symptoms, devices will provide different outcomes and the stiffness of a device will have different effects on spinal kinematics. Consideration of the patient’s characteristics is important in choosing a proper dynamic stabilization device. There tends to be a significant influence of individual patient characteristics in choosing an appropriate stabilization device. Clinical outcome of dynamic stabilization may be improved through the incorporation of stabilization devices of varying rigidity.

REFERENCES: