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. Nevertheless, the effects of patient conditions, such as physiological loading and spinal mobility, on the recovery of normal spinal kinematics after dynamic stabilization are still unknown.

The goal of this study was to examine the significant influence of patient characteristics on dynamic stabilization and to investigate rigidity of the dynamic stabilization device to recover normal motion depending on patient's body weight and segmental instability. Our long-term goal is to influence a physician’s decision for selecting a proper implant based on a patient’s spinal kinematics obtained from radiographic analysis and body build/weight.

METHODS:
Fifty-five patients suffering from L4-L5 intervertebral disc degeneration, spondylolisthesis, or spondylosis were included in this study (Age: 55.85±13.36 years, BMI: 24.73±0.456). Spinal geometry and range of motion (ROM) were obtained from pre-surgical and post-surgical radiographic images at flexion, extension and neutral standing (Figure 2). Based on ROM, 33 patients (54.8 ± 2.29) exhibited hypermobility. The average body weight of this group was 65.14 kg. At L4-L5, disc height in the neutral standing position and anterior translation at flexion and extension were measured.

Model Generation: A 3D finite element model of the L3-S1 segment was generated from Computed Tomography (CT) images. The model was composed of a four-level spinal segment containing vertebral bodies, end-plates, and the discs (Figure 3). The discs consisted of annulus ground, annulus fibers and nucleus pulposus. Seven spinal ligaments were attached. The ligaments incorporated non-linear force-deformation behavior. Since the focus of this study was mainly on the flexibility of the intervertebral discs and spinal kinematics attributed mainly to disc deformation, the vertebral bodies were homogenized and considered as rigid bodies. Mechanical properties such as Young’s modulus, Poisson’s ratio, and the cross-sectional areas of the nucleus, annulus grounds, annulus fibers, ligaments, endplates and vertebrae were based on literature values. For the nucleus, annulus grounds, screws and rods, 3D 8-nodes hexahedron elements were used and the endplates and vertebrae were constructed by 3D tetrahedral elements. The ligaments were represented by tension-only bar elements. Contact and target elements were placed between the superior and inferior facet joints. The facet joint articulation was represented as a nonlinear, frictionless contact.

Numerical Simulation: The models were calibrated to hypermobile patient’s characteristic preoperative ROM. A model validation study was conducted with postoperative patient data. Subsequently, dynamic stabilization devices were implanted within the numerical models. To study effect of L4-L5 mobility on recovery of spinal segmental motion by dynamic stabilization, two additional hyper-mobility models based on the validated model were generated. Through manipulating the material property of the anterior longitudinal ligament, supraspinous ligament, and interspinous ligament between L4 and L5, the models exhibited the recorded patient’s mobility. To examine effect of physiological loading, five different compressive loadings were applied. 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 stiffness set for the dynamic stabilization implant.

RESULTS:
As expected, the ROM of the degenerated spinal levels decreased as the stiffness of the implant increased. The Von Mises stress and ROM of the adjacent levels increased to compensate the reduction of mobility at the degenerated level. These results were comparable for all patients. For hyper-mobility patients, higher rigidity of the implant was required to recover normal spinal kinematics for both flexion and extension. However, spinal kinematics reached a minimum when the implant stiffness was greater than 1.0 E+09 Pa.

In general for pre-surgical cases, higher compressive loading reduced the L4-L5 mobility and increased ROM at the adjacent levels. However, as loading and rigidity increased, mobility at the degenerative level was less constrained. Consequently, to recover normal kinematics higher rigidity of the implant was needed. As the compressive axial load (body weight) increased, the implant limited more extension motion at L4-L5 then flexion (Figure 4). An implant stiffness of 1.0 E+08 or 1.0 E+09 Pa induced less ROM than 1.0 E+11 Pa, which is equivalent to the elastic modulus of Titanium.

DISCUSSION:
This study is the first to demonstrate the effects of varying levels of implant rigidity in a dynamic stabilization device on the spinal kinematics of patients. The findings of the study indicated that hypermobility in the L4-L5 spinal region required stiffer implants to recover normal segmental motion. Furthermore, heavier patients needed stiffer implants to recover spinal kinematics in flexion. However, the effect of implant rigidity on spinal kinematics was reversed in extension compared to flexion. This is still under investigation but we believe that buckling plays a role. Axial loading applied to the anterior column caused the device to buckle and the convex shape strongly limited extension motion.

Depending on an individual patient’s characteristics (e.g. spinal mobility and body weight), different spinal implants will provide different clinical outcomes and the implant rigidity will have different effects on the recovery of the spinal kinematics. Consideration of the patient’s physiology is important in choosing a proper dynamic stabilization device.

REFERENCES: