INTRODUCTION
Graft healing and subsidence are both clinically relevant issues related to the use of an anterior plate with bone graft. Our hypothesis is that these issues are related to load sharing and stresses observed among the plate, graft, and endplates. The reported load sharing data between the plate and bone graft using the in vitro approach is sparse and in vitro protocols are not well suited to address this issue. The finite element (FE) technique can be exploited for an in depth understanding of load sharing between plate and graft and potential sites for graft subsidence.

PROCEDURES
A ligamentous, non-linear, three-dimensional FE model of the C4-C6 motion segments was developed from 1.5 mm thick serial computed tomography (CT) scans. Material properties for the intact model were taken from our previously validated C5-C6 FE model (Goel and Clausen, 1998). Validation of the intact model was performed by comparing model predictions to published cadaveric load-displacement characteristics and our own in vitro experiments. The intact model was modified at the C4-C5 level to simulate an anterior plate and bone graft. The bone graft was assigned three different material properties: cancellous bone, cortical bone, and titanium. A bone graft healed (BGHL) case and bone graft not healed (BGNH) case were simulated. All models were subjected to compressive loading of 73.6 Nm with and without flexion/extension, right lateral bending (RLB), and left axial rotation (LAR) moments of 1.5 Nm. C4-C5 and C5-C6 rotations were determined for all cases. Loads in the plate and graft were computed. Von Mises stresses were observed to identify loading patterns and possible subsidence locations.

RESULTS AND DISCUSSION
Model predictions demonstrated good agreement with the in vitro data. C4-C5 rotations in the stabilized models were an order of magnitude lower than intact rotations.

In BGHL and BGNH compression, the graft took a majority of the load in all simulations while the anterior plate and facets were minimally loaded, Figure 1A, 1B. In BGHL flexion, the plate was in compression, while the graft was in tension. In BGNH flexion, the plate was in compression and the graft was unloaded. In BGHL and BHNH extension, the plate was in tension, while the graft was in compression. In BGHL RLB the graft and plate were in compression, while in BGNH RLB the graft was in compression and the plate was in compression or tension, depending upon graft type. In both BGHL and BGNH LAR the graft and plate were in compression.
The Von Mises stress patterns observed at the endplates equaled the load distribution and followed the load sharing mechanism. In cases of no or minimal load transfer through the graft (i.e. flexion), endplate stresses were decreased compared to the intact case. In cases where the graft load increased greatly (i.e. extension), the maximum endplate stresses increased by as much as 425% compared to the intact case (21.8 MPa in BGHL titanium graft case versus 5.12 MPa in the intact case), Figure 2. Trends indicated higher stresses in the BGHL cases than in the BGNH cases and stresses tended to increase with increasing graft modulus. The higher endplate stresses tended to occur in the inferior endplate.

The data indicate that the plate load is very sensitive to motion segment rotations. The graft will experience high compressive loads in extension. The plate will stress shield the graft in flexion. Model predictions indicate that the magnitude and nature of loads (tensile or compressive) seen by the plate and graft is dependent upon several factors: the axial compressive load that simulates the head weight and the accompanying flexion/extension rotation, the degree of lordosis, compression induced on the graft via distraction, graft stiffness, and degree of graft consolidation. Higher stresses are expected to occur after fusion, with increasing graft modulus, and at the inferior endplate region. Stress patterns can also be expected to change with endplate bone quality, thickness, and morphology. Under distraction and re-compression, these stresses can be expected to be increased, possibly enough to cause subsidence or pistoning of the graft, both of which are observed clinically.

**SUMMARY**

Using an FE model of C4-C6, the load sharing between an anterior plate and bone graft was investigated. Endplate stress patterns under various loading modes were investigated to determine locations of graft subsidence. Results indicated that the graft will experience high compressive loads in extension and the plate will stress shield the graft in flexion. Endplate stress patterns indicated potential subsidence would occur at different endplate locations, depending upon loading modality.

![Graph](image)

**Figure 1:** (A) Ratio between predicted load in the graft vs. applied compressive load (B) Ratio between predicted load in the plate vs. applied compressive load

**Figure 2:** Von Mises stress plot of stresses observed in the C4-C5 endplates during extension with a titanium graft (BGHL)

**REFERENCES**