INTRODUCTION: It has been well documented that multilevel anterior cervical corpectomy reconstructions are associated with significant rates of complication and failure. Strut graft dislodgment is a common complication for which the failure rate increases with the length of the reconstruction, particularly for reconstructions of three or more vertebral levels (1). The use of supplemental internal stabilization with rigid fixation has been advocated in the attempt to decrease the rate of graft dislodgment. Commonly reported fixation techniques include anterior plating, buttress plating, posterior segmental fixation, and circumferential stabilization. The biomechanics of rigid internal fixation in one- and, to a lesser extent, two-level reconstructions have been demonstrated with both physical and computational models. However, the same is not true for longer reconstructions where only a limited number of cadaveric experiments have been reported and computational models are conspicuously missing from the literature. Using a newly developed, validated, novel finite element computer model, we simulated several commonly performed internal fixation techniques used to stabilize a three-level corpectomy reconstruction. We specifically evaluated the biomechanical role of each of these fixation techniques in physiologic flexion, extension, and vertical compressive loading.

METHODS: A detailed, anatomically accurate finite element (FE) model of the ligamentous, subaxial cervical spine (C3-C7) was developed from CT scans of a 65 year old female and published biomechanical properties of the cervical vertebrae, discs, and ligaments. The vertebrae, including cortical, cancellous, endplate, and posterior bone regions, were modeled using solid isoparametric finite elements. The longitudinal ligaments, facet capsules, ligamentum flavum, and intraspinous ligaments were modeled using spring elements which provided stiffness only in tension. Facet articulation surfaces were modeled using low friction sliding contact elements. An intact version of the model included intervertebral discs but they, along with the longitudinal ligaments, were removed for the surgical simulations described here. The modeled vertebrae were aligned with 25.5 degrees of lordosis to reflect the physiological curvature of the cervical spine. To simulate corpectomy, a 16 mm wide section was removed from the vertebral bodies of C4, C5, and C6. The anterior strut graft was modeled as a hollow cylindrical shaft of cortical bone spanning from the inferior endplate of C3 to the superior endplate of C7. High friction sliding contact elements were used to model the graft-endplate interfaces. Modeled fixation techniques included a rigid, locking anterior cervical plate fixed with vertebral body screws in C3 and C7; a bilateral posterior rod/screw construct fixed with lateral mass screws in C3, C4, and C5, and a pedicle screw in C7; and a circumferential construct employing both the anterior plate and posterior rod/screw implants. The simulated loading scenarios included a 44.5 N downward vertical load applied at the superior surface of C3 to simulate the weight of the head. This vertical load was then maintained while flexion and extension moments of up to 1.25 Nm were applied at C3.

RESULTS: The vertical stiffness of the reconstructed spine is increased by 40% to 60% by adding either anterior plating or posterior rods while circumferential fixation nearly triples the vertical stiffness versus the strut graft alone (Figure 1). The peak stress in the strut graft is correspondingly reduced for each level of instrumentation (Figure 2). The rotational stiffness of the instrumented reconstructions are also higher than for the reconstruction without instrumentation. Posterior fixation alone is three times more stiff than anterior plating alone in extension but has a similar stiffness in flexion (Figure 1). The peak stress in the strut graft for extension loading is similar for all three instrumented reconstructions. In flexion, however, the peak stress with posterior fixation alone is 80% higher than for anterior plating alone and three times higher than for circumferential fixation, though it is still less than for the uninstrumented reconstruction (Figure 2). Finally, large increases (200% to 300%) in the pressure forces between the graft and the adjacent endplates were noted under extension loading with anterior plating alone and for flexion loading with posterior fixation alone.

CONCLUSIONS: This study clearly demonstrates that in all simulated scenarios, supplemental rigid internal fixation increases the rigidity of the construct while decreasing the peak stress in the strut graft. Circumferential rigid fixation provided the greatest stability in all modes of loading. Interestingly, isolated rigid posterior fixation without supplemental anterior fixation resulted in significantly higher graft stresses under flexion than with the other instrumented constructs. This suggests that although isolated posterior segmental rigid fixation clearly improves implant stability, it may be more prone to graft related complications associated with flexion. Therefore, under these physiological conditions, graft dislodgment, graft subsidence, and graft fracture may be issues due to increased pressure between the graft and the vertebral endplates. In this clinical scenario, not only is careful intraoperative technique important, but the role of external immobilization should be considered, and close postoperative follow-up is required.

REFERENCES:
** University of Virginia School of Medicine, Charlottesville, VA
*** Rothman Institute, Philadelphia, PA

Figure 1. Stiffness of strut graft reconstructions with varying levels of instrumentation

Figure 2. Peak stress intensity in strut graft for varying levels of reconstruction instrumentation