Introduction
Vertically unstable sacral fractures have an associated risk of hardware failure when using iliosacral screw fixation. The purpose of this project is to evaluate the biomechanical stability of trans-sacral and trans-alar screw fixation versus standard iliosacral screw constructs for stabilization of comminuted transforaminal (Denis Zone II) sacral fractures.

We hypothesize that the bone-implant interface resistance to bending moments and the associated bony parameters are the primary factors influencing the stability of different pelvic fixation techniques. The iliosacral ilium-screw interface is critical as the foundation for the iliosacral screw acting as a cantilever beam and is the location of the highest bending moment during ipsilateral single-leg stance. As failure occurs, rotation about the ipsilateral screw-compromised interface continues until the ipsilateral rami fractures close anteriorly which leads to the screw becoming a beam supported by the bone interface at the iliosacral ilium on one end and the contralateral sacrum-ilium on the other leading to a potentially more stable construct. The magnitude of bending moment that occurs at these two interfaces depends upon the relative motion in the pelvic ring and resistance to it allowed by the closed (or instrumented) rami fractures. With improved resistance to bending moments at the contralateral end, we hypothesize that one trans-sacral/alar and one iliosacral screw will be more stable than two iliosacral screws in comminuted transforaminal sacral fractures.

Null Hypothesis: The trans-sacral/alar construct will not be significantly more stable than the standard iliosacral screw construct to bending moments.

Methods
A synthetic pelvis model was used to eliminate the uncontrolled variability in significant bone-implant interface parameters present in cadaveric pelvis–ilium width, cortical bone thickness at the screw insertion site, and bone mineral density. A comminuted transforaminal sacral fracture was created since it has rotational and vertical instability. A 0.5 cm gap was created through the sacral foramina to simulate comminution. Ipsilateral rami 0.5 cm gaps were created to simulate anterior pelvic ring instability.

Each pelvic model was tested using a physiological single-leg stance position with applied unconstrained axial load and torsional stiffness was determined as the average of the slope of the third, fourth and fifth cycles of the first five cycles of the corresponding mode of loading.

The 3-D motion of the sacrum relative to the ipsilateral ilium was measured using an ND1 Certus optical tracking system. Relative rotation about three axes was graphed as a function of applied load. In addition, relative motion at the fracture site was determined at select points on the perimeter of the sacral and rami fractures by digitization of their location. To do this, LED’s were attached to the ipsilateral ilium, both segments of the sacrum, the contralateral ilium, and the rami surfaces.

Results
Relative motion of pelvic components depended upon fixation type and the inclusion of external fixation. Motion at the rami fracture was significantly reduced (P<0.05) with the inclusion of external fixation. Initial failure included rotation of the sacrum relative to the iliosacral ilium.

Small relative motion was measured between the screw and the sacrum for all points of interest and for all tested fixation configurations when loaded in axial compression. These results indicate that the fixation in the sacrum remains intact throughout the loading. All relative motion was measured less than 1 mm, with most below 0.5 mm.

Small relative motion was measured between the screw and the sacrum for all points of interest and for all tested fixation configurations when loaded in torsion for the x direction (A-P motion) and the y direction (pullout along the screw axis). These results indicate that the fixation in the sacrum remains intact throughout the loading in those two directions. However, the relative motion in the z direction (C-C), when loaded in torsion is greater than 1 mm at the fracture site and increases substantially along the length of the screw. Relative motion in the z direction is between 2 and 3 mm at the 80 mm point of interest.

We expect that relative motion of greater than 2 mm would have a clinical impact on the performance of the fixation instrumentation. Relative motion in the z direction increases again at the 120 mm point of interest with some configurations showing as much as 10.5 mm of relative displacement. Differences in stiffness were not statistically significant.

Discussion
Screw-bone interface failure appeared similar to clinical cases, inferring realistic simulation of in vivo fixation testing. From this data, we can conclude that the gross motion measured for the sacrum relative to the iliosacral ilium is likely not due to a degradation of the bone screw interface in the sacrum, but rather due to localized failure at the screw head/ipsilateral ilium junction. There are no measured or statistical differences between or among the different fixation configurations for fixation screw motion when loaded in axial compression.

From this data, we can conclude that the gross motion measured for the sacrum relative to the iliosacral ilium is potentially due to a degradation of the bone screw interface in the sacrum leading to increased motion in the z direction under torsional loading. Fixation configurations with external fixation demonstrated less relative motion in the z direction at the 60 and 80 mm points of interest, but the difference was not significant. The addition of the anterior external fixator allowed significantly less (p<0.05) relative motion in the z direction at the 120 mm point of interest for fixation screws tested in torsion. Therefore anterior pelvic ring fixation either with external fixation or internal fixation should be considered in patients with comminuted transforaminal sacral fractures.