INTRODUCTION: Pedicle screw fixation has become one of the most commonly used surgical techniques to stabilize the spine. Despite advances in screw design, purchase and loosening of pedicle screws in osteoporotic bone still presents a significant clinical problem. Optimizing screw purchase can be achieved with increased screw diameter, screw depth, and screw design, but has to be balanced against anatomical considerations. There are currently two main pedicle screw designs on the market: cylindrical and conical core screws. As opposed to the traditional cylindrical screw, the conical core screw was developed to maximize purchase in both the cortical and cancellous portions of the pedicle screw path. It has a constant outer diameter while the inner core diameter decreases distally. Simulating the physiologic loading conditions on a pedicle screw has been difficult to determine and therefore an axial pullout model has been adopted as a basis for comparing screw designs. Previous studies have shown the differences in pullout load between a 6mm conical and cylindrical core screw. In addition, the effect of backing out a conical or cylindrical core screw on the biomechanics has been described using porcine vertebrae with sufficient bone density and a single diameter screw. The objective of this experimental study was to examine the biomechanics of conical and cylindrical pedicle screws in a simulated spinal model and focused on the effects of screw diameter, density, and screw backout.

METHODS: In order to examine the differences in pedicle screw design, an experimental pullout test as well as an analytical analysis was conducted on each screw. Four conical core pedicle screws (same type, length of 40mm, outer diameters of 4.5mm, 5.5mm, 6.5mm, and 7.5mm) and four cylindrical pedicle screws (same type, length of 40mm, and diameters of 4.35mm, 5.0mm, 6.0mm, and 7.0mm) were compared in this study. The biomechanical testing was performed using a materials testing machine and a tensile testing displacement protocol (5mm/sec). Cellular polyurethane foam was used to simulate cancellous bone from a vertebral body at various densities (0.12g/cc, 0.20g/cc, and 0.32g/cc). Pullout tests were performed for each screw and each density of foam under two conditions – fully inserted and backed out (2 rotations or 720 degrees). Peak force to failure was analyzed from the pullout tests. An analytical analysis of the flank overlap area (FOA) was used to determine the projected area of the bone that is covered by the threads of the screw. FOA was calculated by taking the difference between the outer screw diameter ($D_{outer}$) and the inner core diameter ($D_{inner}$) and multiplying by the ratio of shaft length ($l$) and thread pitch ($p$). Total FOA was computed by the following formula:

$$\text{FOA} = \left( \frac{1}{4} \pi \left( D_{outer}^2 - D_{inner}^2 \right) \right) \frac{l}{p}$$

RESULTS: The data from this study has demonstrated statistically significant differences in the mean pullout strength for all screws tested as the density of polyurethane foam increases from 0.12g/cc to 0.20g/cc, 0.12g/cc to 0.32g/cc, and 0.20g/cc to 0.32g/cc (p<0.05) (Figure 1). Statistically significant differences in pullout strength were also obtained between fully inserted screws and those backed out 720 degrees in all foam densities (p<0.05). A comparison of all conical screws fully inserted vs. all cylindrical screws fully inserted, as well as all conical screws backed out vs. all cylindrical screws backed out yielded statistically significant differences in pullout strength in all foam densities (p<0.05) (Figure 2). These results showed there were differences between conical and cylindrical core screws, most significantly for the smaller diameter screws. This result also concurred with the FOA analysis, which showed differences in FOA between conical and cylindrical core screws for the smaller diameter screws (Figure 3).

DISCUSSION: Polyurethane foam as a model for cancellous bone in biomechanical testing is an inexpensive substrate that provides a more uniform material than cadaveric bone. In our study, and consistent with other papers of similar design, material density was a significant factor in determining the pullout strength of pedicle screws inserted in polyurethane foam. A 60-80% loss in pullout occurred when similar type screws were used in lower density material (representing osteoporotic cancellous bone) in comparison to the mid to higher density material (representing typical cancellous bone).

REFERENCES:
3. Abshire et al., The Spine Journal, 2001

Backout of a screw by two turns also had a substantial impact (25-30%) on decreasing pullout strength. However, even backed out, screws inserted in blocks of 0.32g/cc foam required on average 4.06 times more force to reach pullout failure than screws fully inserted in blocks of 0.12g/cc foam. More interestingly, we found the (pullout strength)/(screw diameter) ratio was smaller in the conical core screw group, suggesting conical core screws are better in retaining their pullout strength at smaller screw diameters when compared to their cylindrical core screw counterparts. This finding also correlated well with the FOA/Screw diameter ratio. The clinical significance of these findings is that smaller diameter conical screws, which would be less susceptible to a breach of the pedicle wall in comparison to larger diameter screws, would have similar resistance to pullout.