Introduction:
Despite widespread use of pedicles in lumbar spine fixation, relatively little is known regarding variations in pedicle structure particularly in osteoporosis. It is valuable to understand this relationship because pedicles provide an important area for screw fixation and a point of complication when screws penetrate through weak pedicle walls into adjacent structures.

Hirano et al. compared DEXA measurements of bone mineral density (BMD) between cadaveric lumbar spines to define groups of normal and osteoporotic spines. The proportion of pedicle cortical to cancellous bone was determined using peripheral quantitative CT. In the osteoporotic group the pedicle cortex represented a smaller proportion of the pedicle on cross-section. Inceoglu et al. used microCT to evaluate lumbar pedicle cancellous structure and suggested that the trabecular thickness may decrease with osteoporosis while the trabecular number remains constant. However, in this study there were no pedicles from osteoporotic lumbar spines.

The objective of the present study is to characterize the variation in lumbar pedicle structure and to clarify how pedicle structure is related to lumbar spine and pedicle BMD.

Methods:
Twenty-two lumbar spines with intact L3 pedicles were dissected from embalmed cadavers. Eleven were from male donors and 11 from female donors. The median age was 81 with a range from 55 to 99. The right L3 pedicles were removed from the vertebral body and posterior elements with an oscillating saw and labeled.

AP and Lateral DEXA scans of the 22 lumbar spines were performed in a 15 cm deep water bath to simulate soft tissue. A micro-CT scan of each right L3 pedicle was obtained using 47 micron resolution. Images were reconstructed to include the entire pedicle and then reoriented to align the pedicle for a true cross sectional view. Phantoms of air, water, and bone density were included in each scan to calibrate BMD measurements.

GE microview software was used to study the pedicle structures. All measurements were performed by a single investigator. The inner and outer extents of the pedicle cortex were manually marked on successive axial cuts to obtain a 3D model of the pedicle cortex. This allowed measurements of the inner (cancellous) volume, the outer (entire pedicle) volume and the cortical volume. The isthmus was easily distinguished as the smallest area of the pedicle in cross section. Measurements at the isthmus included: inner and outer cortical areas, outer height (largest dimension of the cortical surface on cross section), inner height (largest endosteal dimension), outer width (width perpendicular to the long cross-sectional axis), and inner width (endosteal width). Superior, inferior, medial, and lateral wall thicknesses were measured in line with the principle and minor axis on the isthmic cross-section. Bone mineral densities were measured from several 3D regions of interest including the cortex, cancellous and inner cancellous regions. In the cancellous volumes, the following structural values were calculated: bone volume fraction, trabecular number (Th.N), trabecular thickness (Th.Th), and trabecular spacing (Th.Sp). Several microCT measurements were repeated to allow calculation of interclass correlation coefficients. Statistical analysis was performed using SAS software to calculate Pearson correlation coefficients and inner-class correlation coefficients.

Results:
Inner class correlation coefficients (ICC) demonstrated high measurement reproducibility for all measures. The highly reproducible measurements included: the inner area and width; outer area height and width, full pedicle BMD, cortical BMD, and cancellous BMD measurements (all ICC’s greater than 0.95). Slightly less reproducible measures included: outer volume (ICC -0.77), inner volume (ICC -0.84), inner height (ICC-0.84), Th.th (ICC-0.94), Tb.Sp (ICC-0.91), and Tb.N (ICC-0.88).

AP DEXA T-scores ranged from -5.9 to 0.7 with a median of -4.1. Five specimens had T-scores greater than -2.5. The AP DEXA results averaged in the 70th percentile for age, ranging from 49 to 114th percentile. AP and lateral DEXA BMD values were correlated (R=0.83). No relationship could be detected between the pedicle BMD and the AP or Lat DEXA results (R=0.41 and 0.23 respectively).

Similarly, there was not a significant relationship seen between donor age and AP BMD (R=0.36), lat BMD (-0.53), and pedicle BMD (R=0.31). Cortical, cancellous and whole pedicle BMD’s were directly proportionate (cortical vs cancellous R=0.83, full pedicle vs cortical R=0.9, and full pedicle vs cancellous R=0.89).

The percent cancellous bone on isthmic cross section (inner/outer area) demonstrated an inverse linear relationship to the BMD of the entire pedicle (R=-0.86, p<0.0001). This relationship maintained significance after controlling for subject age and sex. Furthermore, within each of the groups of 10 males and 10 females, the same relationship remained statistically significant (R=-0.9, p=0.0004; R=-0.77, p=0.0087). The pedicle cancellous BMD also demonstrated an inverse linear relation to the inner/outer area (R=-0.67, p=0.0011). Such a relationship between cortical BMD and inner/outer area fell just shy of statistical significance (R=-0.63). No relationship could be found between isthmic inner/outer area and subject age, sex, or lumbar DEXA BMD.

The inner/outer volume ratio (volumetric proportion of cortical bone) also correlated with the pedicle BMD (R=0.067, p=0.0011). A similar relationship of inner/outer volume compared to cortical and cancellous BMD did not reach statistical significance (R=0.43 and R=0.52). Both the inner/outer height and width ratios correlated with pedicle BMD (R=-0.82, p<0.0001; and R=-0.77, p<0.0001). Superior and inferior cortical thickness was directly related to pedicle BMD (R=0.67, R=0.69). Such a relationship with medial and lateral cortical thicknesses was not statistically significant.

No statistically significant correlations could be demonstrated between any of the measured densities and the trabecular number, thickness, spacing, or BS/BV. The cross-sectional geometry of the pedicles was highly variable and visually striking. Figure 1 demonstrates cross sections at the isthmus of pedicles with BMD’s ranging from high to low.

Discussion:
Lumbar pedicles at L3 have highly variable cross-sectional geometry. The density of a pedicle and the density of its cortical and cancellous sub-volumes are directly proportionate to each other. The proportion of cortical bone in the pedicle decreases in a linear fashion as the density of the pedicle and its sub-volumes decreases. There is not a strong relationship between lumbar bone mineral density measured with DEXA and pedicle regional density or structure measured by microCT. This suggests that standard lumbar DEXA may not be useful to estimate pedicle characteristics and hence pedicle screw fixation strength. A measurement of pedicle cortical proportion could serve as a reliable substitute for a measurement of pedicle density.

References: