Non-Invasive Fracture Property Analysis of Lumbar Vertebrae Affected by Osteoporosis

Marianna Oppenheimer Velez[1,2], Hugo Giambini, PhD[1], Sundeep Khosla, MD[4], Michael J. Yaszemski, MD, PhD[1], Lichun Lu, PhD[1,3].

1. Department of Orthopedic Surgery, Mayo Clinic, Rochester, MN; 2. University of Puerto Rico School of Medicine, San Juan, PR; 3. Department of Physiology and Biomedical Engineering; 4. Department of Endocrinology, Mayo Clinic, Rochester, MN.

Statement of Purpose: Osteoporosis is characterized by a progressive loss of bone mineral density over time. This process leads to an increased risk of fracture, particularly in the axial skeleton. It is associated with a reduction in the activities of daily living, chronic pain, neurologic involvement, depression, and a 10-20% increased mortality rate[1]. Currently, the gold standard for diagnosing osteoporosis is dual X-ray absorptiometry (DXA). It is routinely used in the clinical setting to assess the risk of fracture by providing a t-score value calculated from the measured areal BMD (aBMD) of the patient compared to standard values of young, healthy individuals. DXA outcomes are non-specific, do not consider bone geometry, are operator dependent, and are affected by physical artifacts, such as the thoracic vertebrae. Quantitative computed tomography (QCT) can delineate vertebral body geometry and quantitatively measure volumetric BMD (vBMD)[2]. Assessment of vertebral vBMD through QCT, together with consideration of vertebral body size, location and geometry can more accurately predict the vertebra's failure load, thus providing a personalized risk of fracture. The purpose of this study was twofold: 1) to perform an axial rigidity analysis on a population cohort using QCT images to evaluate vertebral fracture properties over time; 2) to investigate these differences based on sex.

Methods: A cohort of 120 patients from the Mayo Clinic Bone Health Study was obtained for the analysis. DXA imaging and fracture risk analysis using QCT were evaluated for each of the L1-L3 lumbar vertebrae over time: baseline and 6-year follow up, yielding a total sample size of 720 specimens. For each patient, the vertebrae of interest were selected and axial rigidity analysis using CT images and composite beam theory was performed to obtain fracture properties[2]. Briefly, the vertebrae were identified in the CT images and failure load was determined from the cross section with the lowest axial rigidity and calculated by: F_{max} (N)=0.0068 EA, where axial rigidity (EA) is defined by the material modulus, E (Pa), obtained by the conversion of Hounsfield Units from the CT image to BMD, and from the cross sectional area (A) of the bone, as follows: $EA=\int E_{BMD} da$, where *da* corresponds to the pixel area[2]. Failure load (F_{max}) and cancellous and cortical BMD for each lumbar vertebra was obtained at baseline and 6-years follow up. Predicted fracture properties were correlated with to the measured DXA clinical outcomes (BMD and t-scores). Paired t-tests were performed for the mean F_{max}, cortical vBMD, and trabecular vBMD of all vertebral samples (L1-L3) for comparison at both points in time. A t-test for unequal variances was also done to evaluate for significant differences in gender.

Results: QCT results showed a progressive loss of cortical and trabecular volumetric bone mineral density (vBMD) over time (mean cortical difference: 1.118 N, *p=0.569*; mean trabecular difference: 24.333 N, *p<0.001**). Vertebral failure loads, as described by F_{max}, also significantly decreased over time ($p<0.001$*; Fig. 1). Moreover, our data showed that women had an overall lower failure load when compared to men ($p<0.001$*; Fig.2).

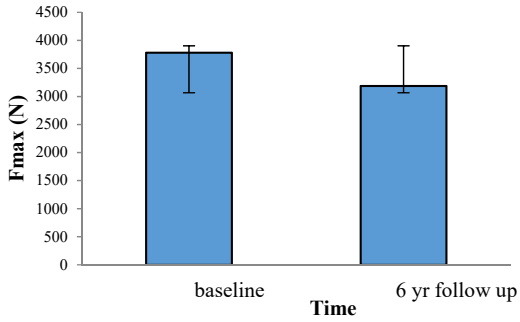

Fig 1. Vertebral failure load changes over time.

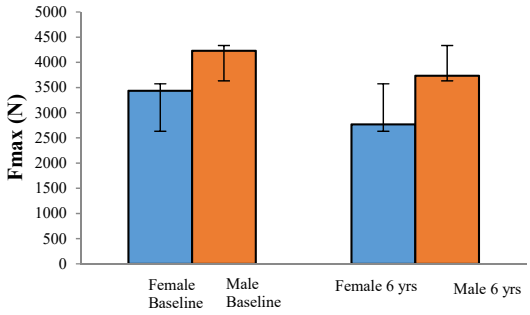

Fig 2. Vertebral failure load changes over time by gender.

Conclusions: This study shows that QCT can be used to quantitatively assess bone loss over time. Furthermore, axial rigidity analysis can be used to quantitatively predict vertebral fracture properties by providing approximate vertebral failure load from the measured vBMD and bony geometry. By obtaining a quantitative measure of predicted failure loads, we can determine vertebral propensity to fracture.

References: 1. Lewiecki EM. *UpToDate.* 2016. 1-15.
2. Giambini H. *Tissue Eng Part C Methods. 2016 Aug;22(8):717-24.*
Acknowledgments: This work was supported by the Mayo Foundation and NIH grant R01 AR056212.