Minimally Invasive Spine Fracture Risk Prediction Based on QCT and Image Analysis

Zhong Fang[1], Jon J. Camp[2], Heng Zeng[1], Hugo Giambini[3], Mahrokh Dadsetan[1], Kai-Nan An[3], Richard A. Robb[2], Michael J. Yaszemski[1], Lichun Lu[1]

[1]Biomaterials and Tissue Engineering Laboratory, [2]Biomedical Imaging Resource, [3]Biomechanics Laboratory, Division of Orthopedic Research, Mayo Clinic College of Medicine, Rochester, Minnesota, USA

Statement of Purpose: Vertebrae that contain metastatic tumor tissue, and that subsequently fracture, pose several problems for the patient. The two most significant problems that occur are pain and paralysis. Pain occurs from the fracture itself and from compression of spinal nerves by displaced tumor tissue and fracture fragments. Neurologic injury occurs from spinal cord and/or spinal nerve compression by tumor and fractured bone. Patients who receive spinal surgery to mitigate against these sequels of pathologic vertebral fracture spend a significant amount of time recovering from the surgery. These patients' care would be enhanced by an accurate prediction regarding their spine's risk of structural failure, so that surgery of any sort will be avoided whenever possible, and minimally invasive tumor removal and spinal reconstruction when surgery is necessary. In this study, we developed an automated vertebrae structural analysis program using axial computerized tomography to calculate the vertebra's residual load bearing capacity. This Spine Cancer Analysis (SCA) program was used to assess the mechanical properties of the vertebral bodies and to calculate the corresponding fracture risk index (FRI) in a simulated metastatic lytic lesion model in human cadavers.

Methods: To simulate metastatic lytic lesions, an approximate 25% v/v of a central core of the trabecular bone in each vertebral body was removed. The defects were either left untreated (negative control), filled with poly(propylene fumarate-co-caprolacton) (PPF-co-PCL) (copolymer group), or filled with poly(methyl methacrylate) (PMMA group). The results were also compared to intact vertebral bodies (positive control). A total of forty vertebral bodies from fresh-frozen cadaveric thoracolumbar spines were used and divided into the above four experimental groups in a random fashion.

The spine was then imaged using qualitative CT scan (QCT) (LightSpeed Ultra, General Electric Medical Systems, Waukesha, WI, USA) in the presence of a calibration phantom with known hydroxyapatite densities. Reconstructed 3D images from QCT scans were then imported into Analyze™ program (Biomedical Imaging Resource, Mayo Clinic, Rochester, MN, USA), and the volume of each defect (filled or unfilled) was manually segmented. In the SCA program, the moduli of the selected volumes representing the defect, the copolymer, or PMMA were specified and the corresponding image densities were automatically adjusted to fit the regression curve obtained from calibration density standards.

To analyze the vertebrae in the SCA program (Fig. 1), we first selected the vertebrae of interest, then oriented and placed the vertebrae body along the transverse axis. Aggregate data were generated with each row representing a single measurement of a single vertebra taken at 0-100% of the vertebra height in 5% increments. The FRI was calculated by $FRI=F_p/F_n$ where Fp is the maximum expected applied load and Fn is the calculated load bearing capacity. The maximum expected applied load selected was the vertebral load that occurs when holding a 10kg weight in front of the body at arm's length, which was estimated to be 1757 N [1].

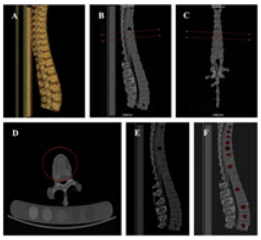

Figure 1: (A) 3D reconstructed spine model from QCT scans. (B, C) Sagittal views of the vertebral segment. (D) Coronal view of the vertebral segment. (E, F) Simulated lytic defects with or without filling materials are shown in red.

Results and Discussion: Using the SCA program, we were able to calculate the average area, average height, volume, maximal force (Fmax), modulus (both trabecular and cortical), and FRI for each vertebral body. The PMMA group showed a maximal force of 4156 N, about 2.2, 1.4, and 1.3 times greater than that of the negative control, the positive control, and the copolymer group, respectively (Fig. 2A). The modulus values followed a similar trend for the four groups.

The corresponding FRI for the negative control, positive control, copolymer, and PMMA groups was 0.61, 0.35, 0.32, and 0.25, respectively (Fig. 2B). The defects treated with the copolymer restored mechanical properties similar to the intact bone.

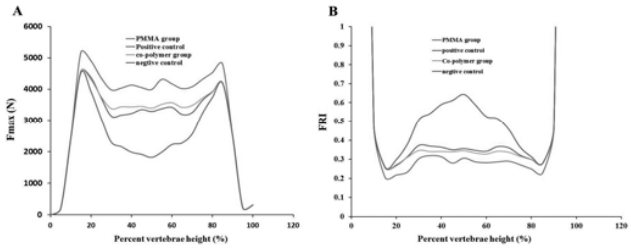

Figure 2: (A) Fmax and (B) FRI of the vertebral body for different experimental groups.

Conclusions: The Spine Cancer Analysis (SCA) program was able to calculate the residual load-bearing capacity in vertebrae with simulated metastatic lytic defect with or without treatment from QCT scans. This information was then used to calculate the fracture risk index for certain activity level. This quantitative program may allow better prediction of fracture risk in patients and provide more reliable guidelines for physicians to select appropriate treatment options.

Reference: [1] Camp JJ, et al. Proc. SPIE, 2004, 5369:74-88.

Acknowledgements: This work was supported by the Mayo Foundation and NIH grant R01 AR056212.