Introduction: Up to 1/3 of all cancer patients develop metastases to the spinal column. However, no objective criteria presently exist to estimate the risk of burst fracture and neurologic compromise in the metastatically involved spine. A comprehensive clinical guideline should be based on both the patients’ load-bearing capacity and load-bearing requirement. The objective of this study was to develop a semi-quantitative measure of the risk of burst fracture based on the biomechanics of the metastatically involved spine that may, in the future, serve as a basis for clinically-applicable guidelines.

Methods: We developed a three dimensional poroelastic finite element model of the first lumbar vertebra and adjacent intervertebral discs, symmetric about the sagittal plane, incorporating anatomical vertebral body curvature and material properties based on average values reported for L1. The model was designed to include a centrally located hemi-elliptical tumor occupying 0, 15, 30 or 45% of the trabecular bone centrum by volume.

To validate the model we experimentally tested 12 fresh-frozen thoracic and 2nd lumbar vertebrae. The specimens and model were similarly prepared and tested for load induced canal narrowing, axial and endplate displacement. The experimental results were compared to the finite element model results for failure. The ratio of VHN* to VB N* was also calculated to describe the relationships using a power law. Loading rate (RT), pedicle status (PED) and disc status (DISC) were represented as categoric variables, and tumor size (TS), bone mineral density (BD) and load (PLD) were represented as continuous variables. The results from the parametric analyses (normalized vertebral bulge, VBN*, and vertebral endplate axial displacement, VHN*, respectively) were correlated with the experimental results.

Results: The finite element model results compared well to the results of the experimentally tested specimens for load induced canal narrowing, axial and tensile hoop strains, and pore pressure and validated the model for use in parametric analyses. The results from the model yielded a linear correlation between vertebral bulge and canal narrowing, tensile hoop strain values, and maximum pore pressure, thus vertebral bulge and vertebral axial displacement were chosen as the main outcome parameters in the finite element analyses.

Discussion: The objective of this study was to develop guideline equations that reflect the risk of burst fracture in the metastatically involved spine. Because of structural complexity, the clinically relevant features of burst fracture cannot be related to known risk factors via a simple mathematical relationship. To overcome this, we parametrically varied a validated finite element model to elucidate functional relationships. Our results demonstrate, in concurrence with clinical findings, that the most important risk factor for burst fracture in the metastatically involved spine is tumor size. Increased tumor size, lower bone mineral density, increased load and pedicle involvement elevate the risk of burst fracture prior to endplate failure. Each of these factors and an increased rate of loading elevate the risk of burst fracture following endplate failure. Disc degeneration reduces the likelihood of burst fracture by both mechanisms.

Bone mineral density was found to have an effect on the expected mechanism of fracture. The ratio of VHN*/VBN* was found to increase with BMD, thus specimens with normal BMDs would be more likely to experience burst fracture resulting from endplate failure, in contrast to low BMD specimens which would have an increased likelihood of burst fracture prior to endplate failure. Distinguishing these mechanisms of failure may ultimately have clinical importance, if the two mechanisms yield different amounts of reparative force into the spinal canal which may affect the potential for neurologic compromise. The algebraic approach utilized here provides a basis for further development of guidelines where the variables are set for a particular patient based on clinically available data. Validation through a clinical study of patients with vertebral metastases is necessary to establish the validity and utility of these guidelines and to determine a definitive threshold level. It is hoped that this methodology of guideline equations will provide useful information to be used in recommending treatment for patients who have metastatic involvement of the spine.

Acknowledgements: USAMRMC DAMD17-97-1-7325 & NSERC (Canada).