INTRODUCTION: Vertebral fractures are often the result of a progressive deformation process. Structural brittleness parameters should be considered relevant for such failure processes. Much of the previous work has been concerned with vertebral stiffness and strength but measures of brittleness such as work to fracture and failure displacement largely remained unexplored. In a previous study examining the relationships of local stress distribution properties with vertebral strength and brittleness, it was observed that the finite element (FE) calculated whole vertebral stiffness ratio from two different models of the same vertebra was highly correlated with experimental displacement and strain to maximum load [1]. Because the only difference between the two models was in the elastic properties of the filler material that was digitally added to the microcomputed tomography (CT) image of the same vertebra, it was concluded that the differences in the ability of vertebral endplates to distribute stresses are a major determinant of vertebral brittleness. Because brittleness measures such as work to fracture or failure displacement and strain were not measured when investigating the distribution properties of human vertebral bodies, our finding that vertebral endplate geometry is associated with structural brittleness of a vertebra is significant in that it offers a potential mechanism for disease progression in addition to loss of bone mass and cancellous bone microstructural integrity.

METHODS: Eighteen thoracic and lumbar (T6-L3) vertebral bodies, extracted from 4 female and 5 male cadavers, aged 40-98 years were used for the study. The vertebral bodies were scanned using a µCT system. Details of the scans, axial compression testing using Wood’s metal as filler material, construction of voxel-based FE models, assignment of element material modulus to cancellous bone based on image gray value, digital addition of filler material and subsequent calculation of FE results have been presented before [2, 3, 4]. Structural stiffness (S), strength (maximum load, Fmax), work to fracture, U, and displacement at maximum load (Dmax) were calculated separately for superior and inferior endplates for human lumbar vertebrae [7]. Posterior elements reinforce the cortical shell of the superior endplate whereas no such reinforcement exists at the inferior end of the vertebral body which may explain the low strain to failure of vertebral bodies along these pockets that increase the fracture risk. The existence of these pockets perhaps explains the low strain to failure of vertebral bodies associated with low kurtosis values of inferior endplate topography.

RESULTS: Kurtosis of the inferior endplate topography was significantly correlated with experimentally determined work to fracture, U (R=0.64, p<0.005), displacement at maximum load, Dmax (R=0.73, p<0.0006), and strain to failure, εf (R=0.73, p<0.0006) (Fig.1). Of all the endplate surface topographical distribution parameters, kurtosis of inferior endplate topography had the highest correlation with W-layer to D-layer stiffness ratio (R=0.82, p<0.001). Kurtosis of the inferior endplate topography was also significantly correlated with W-layer to D-layer ratios of average von Mises stress, VMEp (R=0.82, p<0.0001), and von Mises standard deviation, VMSD (R=0.75, p<0.0003). Multiple regression analysis indicated that W-layer to D-layer VMCV ratio (p<0.018) and kurtosis of inferior endplate topography (p=0.034) independently contributed to strain to maximum load. µCT-BMD did not contribute in presence of these parameters (p=0.36).

DISCUSSION: We demonstrated that endplate topography of a human vertebra is associated with its structural brittleness. The distribution of stiffness, strength or brittleness parameters. In a recent study it was concluded that inferior endplates are stronger than superior endplates for human lumbar vertebrae [7]. Posterior elements reinforce the cortical shell of the superior endplate whereas no such reinforcement exists at the inferior end of the vertebral body which may explain the higher sensitivity of failure strains to the inferior endplate topography. It has been demonstrated that vertebral strength and brittleness are associated with the regional variations in cancellous bone properties in human vertebrae [4, 8]. It has also been shown that cancellous bone structure in a vertebra is associated with the thickness and cross sectional area of the adjacent endplate [9]. Further understanding of the mechanisms underlying vertebral endplate topography variations and their interaction with regional cancellous bone properties may provide insight into the aetiology of vertebral fractures.