Introduction: Osteoporotic vertebral compression fracture is one of the most common diseases that attack the elder population especially in postmenopausal women. Percutaneous vertebroplasty (PVP) has been reported to be an effective treatment for indicated compression fracture patients. However, new vertebral fractures in adjacent vertebrae after PVP were often reported in literature. The detailed mechanism of the altered biomechanics in the treated vertebra and untreated adjacent vertebra were still unclear. Therefore, the optimal cement volume in terms of the percent fill of the vertebral body volume is lacking and no literature discusses on the effects of bone stiffness and the vertebral body height loss. The objective of the current study was to use a computational finite element method to investigate the effects of bone quality, cement volume and body height loss on the overall stiffness of the treated vertebra and the load transfer changes of adjacent vertebrae following percutaneous vertebroplasty.

Materials and Methods: A finite element model of the vertebral body was generated from the digitized CT scans using the image software-Amira (Mercury Computer Systems, Inc., Massachusetts, U.S.A.). The surface models of the vertebral bodies and discs were transferred to a finite element pre-processing program – Mentat (MSC Software Corp., Los Angeles, U.S.A.) and the finite element mesh of the intact T10-L2 vertebrae was generated with 78,000 8-node hexahedral elements. In order to simulate the collapsed vertebral body with different levels of body height loss, the intact T10-L2 finite element model was modified with four different anterior body height losses (20%, 40%, 60% and 80%). Four different volumes of bone cement were considered for each model with different body height loss. A 300 N axial, compressive load was applied evenly on the upper endplate nodes of T12 (or T10 for the five-segment model) while the bottom surface nodes of the T12 (or L2 for the five-segment model) were constrained. Commercially available FEA software – MARC (MSC Software) was used as a solver for these analyses. Analyses were performed using the computing facilities at the National Center for High-Performance Computing (NCHC, Taiwan) via internet connection.

Results: Single level model. Vertebral stiffness was strongly influenced by more cement volume and higher cancellous bone density. By increase cement volume with 2ml., 4ml, 6ml and 8ml, the percentage of increment in vertebral stiffness of poor bone density were 5.3%, 36.5%, 85.6% and 106.5% respectively. There is a noticeable change of vertebral stiffness by increasing cement volume in poor bone density. In poor bone density (100MPa), thirty percent fill (6ml) restored the vertebral stiffness to healthy one value. In largest body height loss, the vertebral stiffness decreases 64% with no cement injected. When the body height loss is 20%, the least amount of bone cement (10% fill) restored the vertebral stiffness to its initial value. Twenty percent fill (4cc.) restored the vertebral stiffness to its initial value in the 40% and 60% body height loss cases.

In the highest body height loss case, thirty percent fill (6cc.) restored the vertebral stiffness to its initial value. Five level model. The load shifting to the adjacent vertebrae had positive relationship to the collapse angle, the percentage changes of adjacent vertebra stress increased several times. The load shifting was reduced by cement injection while the fractured vertebra has higher stress accumulation, the percentage changes of adjacent vertebra stress decreased only 2%-3%. On the severity of the collapse, bone stress was reduced 25% after inject cement. The cement amount did not show significant effect on the alteration of load shifting. Furthermore inferior level (L1) was shared more stress than superior one (T10).

Discussion: Our results suggest that if the goal is to restore vertebral stiffness to its pre-damaged level in poor cancellous bone quality, the cement has to be injected by 6ml. A wedge-shaped fracture of a vertebral body decreases vertebral stiffness and increases maximum von Mises stress of cortical bone and cancellous bone. The vertebral body may be fractured due to high stress concentration. However, to inject more cement volume will not restore the vertebral stiffness. We also found that inferior level (L1) was shared more stress than superior one (T10) due to the loading position was changed.

It is more sensitive for vertebral stiffness and bone stress by increasing cement volume in poor cancellous bone quality. For the wedge-shaped fracture case, not only bone cement injection but also reconstruction of lordotic curvature of spine is necessary.