METHODS:

An intact osteoligamentous L3-disc-L4 finite element model (FEM) was used as the baseline case (figure 1); validation was done by comparing the predicted intradiscal pressure and axial stiffness with the experimental data from published literatures. For our specific study purpose, our meshed model included the major features of the endplate-disc-endplate structure: an anteroposterior wedge shaped disc, with biconvex interface, was well fitted with the biconcave endplate (curvature in both anteroposterior and mediolateral directions). A uniform thickness of 1mm was set for the endplate, which was similar to that of the cortical bone shell. While simulating the systematic change accompanied by aging process, another two degenerated models were then created by modifying the intact model. The degenerated disc was simulated in two fashions by either assuming it to be void of nucleus pulposus, or removing the hydrostatic properties of the nucleus and making it “stiffer” by doubling its Young’s modulus. On the other hand, the effects of possible alterations in material properties due to osteoporosis were incorporated by means of a considerable loss in elastic modulus. Compared to the “normal” bone, a decrease by 66% in elastic modulus for cancellous bone and by 33% for the rest of bony structures were considered in current osteoporotic model.

RESULTS:

With 2000N axial compression, the maximum principal stress distributions in endplate along mid-saggital diameter when compared to the intact model were: as follows (figure 2.). For the models without “normal” discs, the “stiffer” case had a 82.4% decrease in tensile stress in posterior region, a 22.5% increase in compression in mid region respectively; meanwhile compressive stress was generated anteriorly. The other “nucleotomy” case showed reversed stress states in all regions correspondingly. As to the “osteoporosis” model, there were 32% and 50.6% increases in the tensile stress in posterior and anterior regions, respectively.

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FIGURE 1. FEM OF L3-L4 LUMBAR FSU WITH WEDGE-SHAPED INTERVERTEBRAL DISC

FIGURE 2. STRESS DISTRIBUTION AT THE INFERIOR ENDPATE OF L3, IN THE MIDSAGITTAL PLANE, FOR AXIAL UNIFORM COMPRESSION OF 2000N

FIGURE 3. MAXIMUM PRINCIPAL STRAIN DISTRIBUTION IN ENDPATE-DISC-ENDPATE STRUCTURE UNDER AXIAL UNIFORM COMPRESSION OF 2000N

DISCUSSION:

Under axial compression, the stress distribution in the endplate was highly sensitive to the changes in the state of the adjacent disc and vertebral body. In the models with “normal” discs (intact and osteoporosis model), both posterior and anterior regions of the endplate were highly pulled by annulus fibers, while the central endplate was under compression due to axial bulging of hydrostatic nucleus pulposus and bony pressure of vertebral cancellous bone. A typical “three point” bending could address the possible central failure of endplate in these cases with normal discs. But it seems that the weaker osteoporotic bone gave “softer” support so that tensile stress generated in the central endplate, which might be the cause of the more concaved endplate observed in osteoporotic patients. After removal of the nucleus pulposus, the central endplate became the only structure supporting the above corresponding cancellous bone like an “arch bridge”, a high tensile stress was found in central region while the anterior and posterior annulus matrix acting as “supporting points”. The compression force was mainly transmitted by the way of annulus fibrosus. And we found that the compressive stress was much larger in anterior region. Fractures might initiate anteriorly. When the disc was made stiffer and compressible, the annulus fibers was no longer as intense as it was in normal discs because of the reduced horizontal bulge of the nucleus pulposus, however, the central endplate was pressed severely.

We concluded that the stress and strain distributions in endplate under axial loading were dominated by its adjacent structures. Both the degenerated disc and osteoporotic changes in vertebral body may have a pronounced impact on the structural failure of the endplate.