RELATIONSHIP BETWEEN FAILURE PROGRESSION IN A LUMBAR DISC AND MANUAL LIFTING - A POROELASTIC FINITE ELEMENT MODEL STUDY

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INTRODUCTION

The degenerative process of the intervertebral disc is a cascading event which is often attributed to cumulative damage. Macroscopic autopsy studies have shown that nuclear clefts form first later followed by annular tears. Repetitive loading advances this damage process since the cyclic loadings does not allow the time necessary for discs to recover between load applications thereby leading to cumulative damage. Understanding how motion segments react to cyclic loading is important to understand the initiation and progression of the failure processes. The aim of the current paper was to develop a non-linear poro-elastic finite element model that included the physiological parameters such as osmotic pressure and the effect of change in permeability in the disc due to strain and use it to predict the failure initiation and progression in a lumbar disc due to repeated loadings that corresponded to three different commonly occurring lifting activities. It is hypothesized that failure progression in a lumbar disc will be fastest under lifting that involves lateral bending of the trunk.

METHODS

An existing model of the L4-L5 motion segment was modified to include the physiological parameters such as swelling pressure P_{swell} in the disc tissues and the effect of change in permeability of the disc tissue due to strain $P_{permeability}$ (1). To accommodate the variation in concentrations of proteoglycan as well as the porosity, permeability and aggregate modulus with in the disc, regional variations of the tissue properties were included in the analyses. Failure initiation and progression under cyclic loading was monitored using a custom-written failure rule. Failure at any point in a single element was predicted to occur if the internal stress at that point exceeded an assumed failure stress value. The elastic material property at the failure location was reduced by a percentage of the intact elastic modulus for subsequent analyses thus controlling the growth of failure progression in the model.

The loading conditions used in this investigation involved lifting a box weighing 30 pounds (Natarajan, 2004) from mid-shank level to elbow height simulating trunk extension from flexed to upright posture (task 1), (2) lifting the box from elbow height on the right side and placed on the left side simulating trunk twisting posture (task 2) and (3) lifting the box from a maximally lateral flexed posture up to waist level simulating trunk lateral bending motion (task 3). The time history data of spinal loads during the three lift modes were input into the poro-elastic finite element model to determine the corresponding biomechanics of the disc.

RESULTS

The lifting activity that required lateral bending of the trunk (task 3) produced largest disc translational and rotational

motions. Task 3 produced a disc compression of 6.4 mm while task 1 and 2 produced 5.6 mm and 3.1 mm compression respectively. Shear motion of the disc directed along right lateral direction was 4.0 mm for task 3 while a much smaller shear motion was seen during the other two lift activities (2.0 mm for task 1 and 1.8 mm for task 2). A flexion motion of 10^0 was seen during task 3, while task 1 and task 2 produced 5.8^0 and 3.6^0 of flexion respectively. Twisting motion to the right as well as lateral bending rotation was highest for task 3 (4.4^0 and 4.0^0 respectively). The largest von Mises stress of 6.5 MPa was observed in the right lateral quadrant of the annulus during task 3. Both the superior and the inferior end plates experienced a maximum von Mises stress of 12 MPa during the lateral lift task.

In all the three lift cases, failure in the endplate was observed even in the first cycle (Figure 1) with maximum failure occurring under task 3 (4.5% of endplate volume). As the load cycle progressed, endplate failure volume increased. Highest rate of endplate failure volume was observed during task 3. The failure volume reached a plateau quickly under task 2 (5 cycles) while under task 3 it took 15 cycles to reach a maximum endplate failure volume of 8%.

CONCLUSIONS

The analyses conducted here showed that of all the three lift conditions considered in the current study, task 3 produced greatest motions in all the three principal directions as well as largest stresses in the disc tissues leading to highest failure volume due to repeated loading. This conclusion agrees well with those obtained by Schmidt et al., (Schmidt, 2006) who with the help of a finite element model study showed that the risk of disc failure mostly occur in the posterior annulus under a load combination of lateral bending + axial rotation. Costi et al., (Costi, 2006) also showed from their studies on cadaver specimens that lateral bending produced highest motions that induced high physiological maximum shear strain that place the disc at greatest risk for failure and injury. These conclusions agree very well with the results from the current study which showed that task 3 which involved lateral bending of the trunk produced largest motions in the disc, induced largest disc tissue stresses and as a consequence produced largest volume of failure in the disc tissues.

REFERENCES

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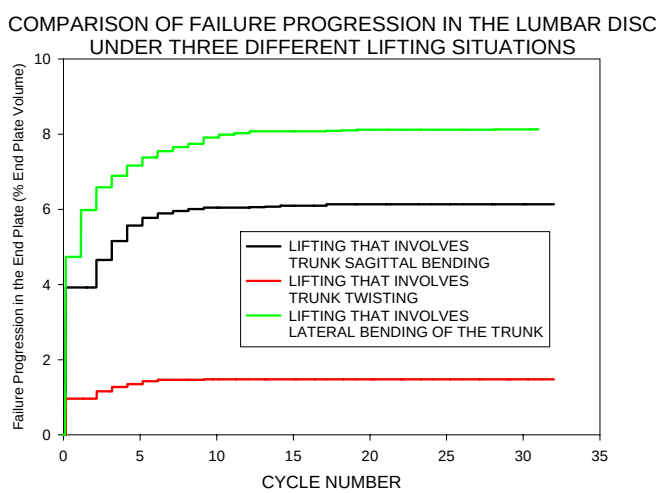

Figure 1: Failure progression in a lumbar disc under three different lifting modes.