BIOMECHANICAL RELATIONSHIP BETWEEN THE PROPERTIES OF COLLAGEN FIBERS IN DIFFERENT REGIONS OF ANNULUS MATRIX AND THE DECOMPRESSIVE RESPONSE OF DISC TISSUES

Mozammil Hussain

Logan University, Division of Research, Chesterfield, MO, USA
email: mozammil.hussain@logan.edu

INTRODUCTION

Degeneration related neck and low back pain involving abnormal disc pressures/herniations has been shown to be relieved by spinal decompression therapy that widens intervertebral disc space, spinal canal, and neural foramen [1]. The underlying physiological mechanism that has been theorized behind this discogenic pain relief is the decrease in disc stresses [2,3] and dead cells [4], leading to an overall increase in the disc tissue metabolism [5] and the endplate vascular channels necessary for disc nutrient transport [6]. How the traction forces used in decompression therapy benefit disc health through stress re-distribution in discs is still not fully understood. Do the surrounding fibers in disc extracellular tissue matrix have any major role in the stress re-distribution?

Degeneration in discs begins in inner nucleus pulposus (NP). As degeneration advances, the load is shifted from inner NP to outer annulus fibrosus (AF). Degenerative signs are noted not only in the AF tissue matrix in the form of tears and delamination, but they also involve changes related to the annular fibers [7,8]. By resisting tensile loads, these fibers affect the mechanics of the discs through re-orientation and bulging. Despite past research have reported the annular stresses in degenerative discs, the relative contributions of degenerative properties in annular fibers, such as incompleteness and slackness, to the overall degenerative disc response are not completely known.

The aim of the present study is to understand the re-distribution of stresses in the discs consisting of degenerative fibers when the traction forces are applied on the compressed discs.

METHODS

The current study used an intact finite element (FE) model of a normal C5-C6 disc segment that was validated under axial forces [3]. Cortical bone, cancellous bone, endplates, AF, NP, and 6 layers of collagen fibers were included in the model. The collagen fibers were embedded into AF tissue matrix between the superior and inferior disc-endplate interfaces, arranged in a zigzag (X) fashion, and oriented at an angle of ±70° with respect to the horizontal plane. AF tissue matrix was divided into 3 regions – outer, middle, and inner – with 2 fiber layers in each of the AF regions. Tissue material properties of the spinal structures were referenced from the literature.

5 FE models (Model O, Model M, Model I, Model OM, and Model MI) were developed from the intact model with degenerative fiber modifications in different AF regions, respectively (outer AF, middle AF, inner AF, outer-middle AF, and middle-inner AF). First, incompleteness in fibers was modeled as a morphological modification by reducing the fiber length by 50% (in a wedge (>) fashion) originating from superior or inferior disc-endplate interface up to mid disc-height, compared to the complete length of fibers running between the superior and inferior disc-endplate interfaces in the intact model. Second, slackness in fibers as a tissue material modification was modeled by decreasing the fiber elasticity, by 30%, compared to the fiber elasticity in the intact model.

To simulate the in vivo disc pressure under upper body weight (50 N); the FE models were subjected to compression (C), by applying a pressure load on the superior C5 surface. Next, the models were decompressed (17 N), by applying a traction force (T). The inferior C6 surface was constrained in 3
perpendicular planes. Meshing and analysis were performed using the FE software ABAQUS (Dassault Systemes Simulia Corp, Providence, Richmond, USA). At the end of compression and decompression, stress profiles in AF and NP tissues were investigated and normalized with respect to the normal intact FE model. Normalized stress changes were used to formulate a NP/AF ratio – a parameter representing greater changes in NP than in AF, for the ratio greater than 1 and vice versa.

RESULTS AND DISCUSSION

For both incompleteness and laxity in annular fibers, a ratio (NP/AF) value of greater than unity was found (Figure 1) that indicated the NP stress changes are higher than the AF stress changes. With fiber modifications (incompleteness, laxity), ratio of NP/AF compressive stress changes were: Model O (2.17, 1.24), Model M (1.68, 1.60), Model I (4.04, 2.46), Model OM (4.55, 2.72), and Model MI (3.25, 2.09); and that of decompressive stress changes were: Model O (2.25, 6.12), Model M (1.72, 6.52), Model I (4.04, 5.45), Model OM (3.15, 4.80), and Model MI (3.27, 4.90).

NP tissues appeared to be more responsive than AF tissues. The load sharing between NP and AF was more affected by incomplete fibers than lax ones in compression; whereas, it was more affected by lax fibers than incomplete ones in decompression.

At the end of compression and decompression, no significant changes in NP/AF ratio were observed with incomplete fibers; however, an increase in the NP/AF ratio was noted with lax fibers. Therefore, elasticity of fibers played an important role in tissue decompression than that in tissue compression.

One of the limitations in the present study includes the development of the FE model from the anthropometric spinal dimensions, rather than from the computed tomographic image scans. Also, only 6 concentric rings of fibers were modeled, compared to the 15-20 rings of fibers. It is recommended the findings of this computational analysis be verified with other comparable biomechanical studies.

CONCLUSIONS

Spinal decompression technique used as a non-surgical interventional procedure for the discogenic pain relief may be more beneficial in the disc regions that have complete length of collagen fibers, although the fiber elasticity should also be taken into subsequent consideration when this intervention is applied to the degenerated discs.

REFERENCES