INVESTIGATION OF LUMBAR INTERBODY FUSION AND ITS EFFECT ON THE ADJACENT LEVELS – A FINITE ELEMENT STUDY

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SUMMARY

Disorders involving spinal column are the most prevalent cause of chronic disability. Low back pain is one of the major problems facing the workforce in the world today. According to American Association of Neurological Surgeons (AANS) more than 65 million Americans suffer from low back pain annually. It is widely believed that severe intervertebral disc degeneration is one of the major causes of low back pain. According to Chicago Institute of Neurosurgery and Neuroresearch (CINN) report, by the age of fifty 85% of the population will show evidence of disc degeneration. Lumbar fusion is one of the most commonly performed operative procedures when there is severe degeneration or instability, which causes significant low back pain. It is estimated that more than 70,000 lumbar fusion procedures are done annually in the U.S. Biomechanically interbody fusion is the most stable of all fusions, because of its effectiveness in eliminating multidirectional segmental motion. But it is well known that after bony fusion biomechanical behavior of the spinal structure is altered.

Many studies indicate that various pathologic conditions were observed in the segments adjacent to the fused segment. Spinal stenosis was the most common finding encountered at the adjacent segments according to an adjacent segment study conducted with fifty-eight patients. Alterations of biomechanical behavior are believed to be responsible for spinal stenosis in the adjacent levels but no biomechanical investigation has been done in this regard according to the literature at our disposal.

Multilevel disc degeneration is quite common in patients with back pain. It is also known that spinal fusion of one motion segment leads to the degenerative changes and instability in the adjacent intact discs. The combined effect of interbody fusion and degeneration of the adjacent disc which is a common occurrence has not been studied. It is also observed that the segment adjacent to the adjacent segment of fused segment was almost as likely to breakdown as the adjacent segment itself. But no data quantitative data is available to describe the biomechanical changes that lead to these pathological conditions.

Osteoporosis is currently estimated to be a major public health threat. It is estimated that by the year 2010 over 52 million U.S. women and men aged 50 and older will be affected by osteoporosis. Both intervertebral disc degeneration and osteoporosis of the vertebra have been studied extensively using in-vitro experiments and analytical models. However, very little is known of the combined effects of osteoporosis and disc degeneration, which is a common clinical scenario particularly in the elderly.

It is difficult and expensive to conduct experimental studies to investigate the combined effects of fusion, disc degeneration and osteoporosis. On the other hand mathematical models permit to simulate the spine behavior in different situations (sound, pathological

and instrumented) in an easier and cost effective way. Finite element analysis is widely accepted and versatile tool for biomechanical studies. Finite element model of lumbar spine has been used in many studies for biomechanical analysis.

To develop a three dimensional finite element model of the lumbar spine, a parametric solid model of the lumbar spine was developed in ProEngineer. The model was then meshed in ANSYS to obtain the finite element model. The finite element model consisted of all the critical components of the lumbar spine. The model was then validated by comparing the results with previous experimental and finite element studies. Interbody fusion and pathological conditions like disc degeneration, osteoporosis were simulated in the model. The model was then analyzed under various loading conditions in ANSYS with the following objectives:

1) To investigate the influence of lumbar interbody fusion at the adjacent levels by simulating interbody fusion at different levels.
2). To analyze the combined effects of disc degeneration and osteoporosis.
3) To study the combined effects of interbody fusion and adjacent disc degeneration on the lumbar spine under different physiological loading conditions using the validated 3D parametric finite element model of the lumbar spine and
4) To establish the capability of analyzing the fusion procedure with interbody cages, using parametric finite element models.

Interbody fusion was simulated at different levels to investigate its influence at the adjacent segments. Fusion was simulated by modifying the intact lumbar spine model assuming complete fusion. This study simulated both single level and multi level fusions at various disc levels: L1-L2 Fusion, L2-L3 Fusion, L3-L4 Fusion, L4-L5 Fusion, L2-L3-L 4 Fusion, L3-L4-L5 Fusion.

Both the intact and fused models were then subjected to axial compressive loads and saggital, lateral bending and torsional moments. The finite element model results demonstrate significant increases in vonmises stress in the vertebral body and pedicles adjacent to the fused segments. This increase in stress according to Wolff’s law may be the underlying cause for osteophyte formation, which may lead to canal and foraminal stenosis. The largest increase in the cancellous bone stress occurred immediately above the multi-level and lower level fusions. Furthermore after fusion, significant increases in annulus stress and nucleus pressure in adjacent segments were observed which may accelerate adjacent disc degeneration. It was also observed that the disc above the fused segment had more stress increase than the disc below the fused segment.

Combined effects of disc degeneration and osteoporosis were studied using the finite element model of L4-L5. Various stages of disc degeneration and osteoporosis were simulated in the intact model. Under axial compressive loading the stiffness of the disc-body unit increased as the disc degeneration progressed irrespective of the bone condition. On the contrary osteoporosis of the bone decreased the stiffness of the spinal segment irrespective of the disc condition. With increase in osteoporosis, the effects of disc degeneration in terms of stiffness, disc bulge, stresses in annulus, pedicle and cancellous bone was found to be diminished. As the osteoporosis progressed, maximum vonmises stress in the annulus ground substance increased. This increased stress may accelerate disc degeneration. Hence by preventing osteoporosis of vertebra by appropriate screening and treatment, the intervertebral disc may be better protected from degeneration.

The finite element model of the lumbar spine was also utilized to study the stress changes in the intact disc(D) above the adjacent segment due to the combined effect of interbody fusion and adjacent disc degeneration. Single level and multilevel Interbody fusion were simulated at various levels. Disc degeneration was also simulated in the discs adjacent to the fused segments. These models were then analyzed under different physiological loading conditions. The presence of degenerated disc above the fused segment increased the vonmises stress both in the degenerated disc and in the intact disc(D) above the degenerated disc under all loading conditions.

Finite element analysis is also being used to investigate the fusion process using instruments like interbody cages, plates, pedicle screws etc. With the objective to investigate the sensitivity of various parameters of the instruments to the biomechanical response and to aid the physician in selecting the instrument, finite element models of two interbody cages (LT Cage & Ray cage) were developed by parametric modeling. Interbody fusion was performed by inserting cages in the spine model. The parametric nature of the cages allows us to compute the optimum design parameters that keep the micromotions and stress shielding effect within the desirable range.

Thus the parametric FEM of the lumbar spine serves as a test bed to simulate the biomechanical effects of different types of injury and stabilization. It reduces the dependence on animal and cadaveric experiments and is an invaluable complement to clinical studies. The present work can be extended to create patient specific models of lumbar spine along with parametric models of instruments to decide the type and size of the instrument required for a particular patient.