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Finite Element Simulation of the Effect of Anti-whiplash Mechanism on Human Spine

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Abstract—*During a rear impact collision, the passenger's head is first thrown backward and then thrown forwards. Such a motion can cause excessive strain on the neck and the spine which can manifest as a whiplash injury. The pneumatic automation discussed here is aimed at addressing this issue. This automation system consisting of a fluid driven assembly is energised by the fluid driver assembly to cause the actuation of the head restraint's pivoting mechanism. Fluid driver actuator in the driver assembly is coupled to the seat track and is designed for operation based on the input sensed by the limit switches that are attached to the seat portion. This pneumatic automation is designed to restrict the motion of head relative to the torso thereby minimizing the effect of whiplash during a rear end collision. Non-linear hyperelastic model of the lumbar spine L4-L5 was developed using finite element solver ABAQUS to evaluate the peak failure forces and parameters that cause the rupture in the anterior longitudinal ligament. Kinematics of the spine were recorded and response of spine section to the impact before and after the installation of this head restraint mechanism was studied to validate its effectiveness.*

1. INTRODUCTION

Whiplash is a non-medical term describing a range of injuries to the neck caused by or related to a sudden distortion of the neck associated with extension. It is often defined as ligamentous strain or sprain of the spine segment without any fractures and dislocations [2]. From citing the research [1], it was found that whiplash is commonly associated with motor vehicle accidents, usually when the vehicle has been hit in the rear. It is one of the main injuries covered by insurance. For example, in the United Kingdom, 430,000 people made an insurance claim for whiplash in 2007, accounting for 14% of every driver's premium. More than 20% of car-to-car accidents in the U.S. are believed to be rear-end collisions, and approximately 10% of the whiplash injuries resulting from rear-end impacts require longer term therapy. Thus, the societal cost of whiplash injuries is a common problem worldwide, and its prevention a hot topic globally. In the present work, an attempt has been made to reduce injuries due to whiplash in the cervical spine and lumbar spine region by designing a pneumatically actuated automation that restricts the motion of the head relative to the torso. Actuation was made smarter and faster with the response speed of 35 microseconds and was thus able to reduce the severity of injury caused.

2. INJURY MECHANISM OF WHIPLASH

Lumbar region of the spine consists of five vertebrates connected by facet joints which aid in the forward, backward and twisting movements. The lower back of spine system consists of muscles which supports the back and helps in the movement in the trunk of the body. We have recorded the stress response in L4-L5 vertebrate segment of the Lordosis system and observed that the strain induced in these muscles due to stress caused excessive lower back pain. Since the L4-L5 segment forms the lower most part of the spine, it is subjected to compressive load and moments which makes it injury prone. Spinal discs acts as a cushion and provides support to the vertebrates and it has been observed that these invertebral disc are likely to herniate or degenerate which causes the pain in lower back during rear end collisions. In addition to this, whiplash injuries also cause hyperextension in the cervical spine region causing rupture in the anterior longitudinal elements.

3. WORKING OF ANTI-WHIPLASH MECHANISM

The mechanism developed restricts the motion of the head relative to the torso. This mechanism prevents injuries due to hyperextension of the cervical spine and minimizes the spine straightening during rear end impacts which forces the spine to straighten and can cause a possible injury. This mechanism consists of three double acting reciprocating cylinders, one bidirectional limit switch, one FLR unit, two 5/2 valves, a solenoid valves and a push button. Most of the mechanisms consist of head restraints that gets actuated only after the receiving the input from the crash sensor. This pneumatic automation is designed to overcome this issue by making the mechanism more responsive and effective. In [5], the anti-whiplash mechanism developed involves use of hook like structure that is designed based on impact calculations. Main disadvantage of this model is that, the hook needs to be replaced after the collision and has to be replaced from time to time. This is overcome by means of a simple push button in this proposed automation. The proposed anti-whiplash mechanism consists of two main parts: Fluid driver assembly and Fluid driven assembly. Fluid driven assembly primarily consists of locking mechanism which gets unlocked to actuate the sliding motion of the seat on its track upon receiving signal from crash sensors. Bi-directional limit switch is positioned at a predetermined distance which was determined from impact calculations. During a rear impact, limit switch senses the disturbance and sends the signal to DC solenoid switch. Now air from the compressor passes through the FLR unit and enters the 5/2 valve which regulates the air flow. Pneumatic cylinder in the fluid driver assembly is now actuated and this causes the motion of piston towards its top dead center. Compressed air obtained from other end of fluid driver assembly is fed to the pneumatic cylinder at the fluid driven assembly. The cylinder is now energized to cause the actuation of head restraint which causes the pivoting action. This mechanism reduces the whiplash injury by effectively reducing the compressive moment induced by rear impact on intervertebral discs of Lumbar spine and hyperextension that causes rupture in the anterior longitudinal ligament due to flexion in the Cervical spine region.

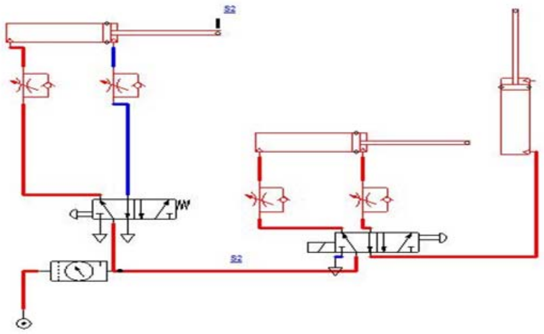

Fig. 1: Actuation of Anti-whiplash mechanism during rear end collision.

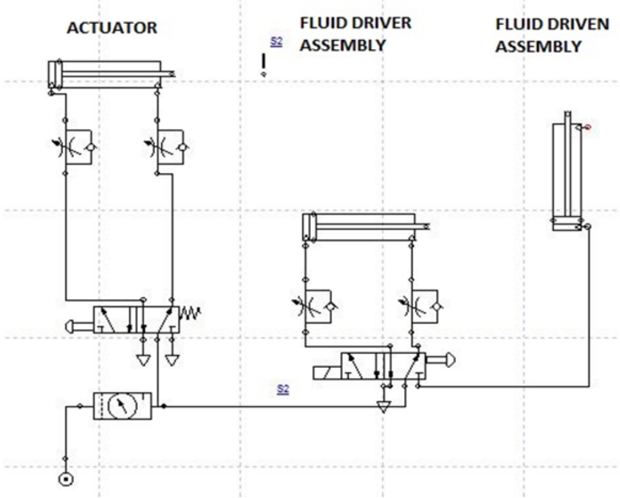

Fig. 2: Automation layout of the anti-whiplash mechanism created using automation studio.

4. DESCRIPTION OF THE FINITE ELEMENT MODEL

Hyperelastic non-linear finite element model of the healthy lumbar spine L4-L5 segment was developed using finite element solver ABAQUS. FE model containing ligaments, invertebral disc, annulus, nucleus, facet joints was modeled. In order to assess the behavior, Mooney-Rivlin material model was used for hyperelastic materials in annulus and nucleus pulpous.

Eight different constraints were used to define the relation between components after clear kinematic study. Kinematic coupling was created for the loading point and tie constraints was created between the master and slave surface. Fibers in the outer layer of the invertebral discs were embedded by using embedded region option by choosing the appropriate embedded and host regions.

Numerical model was developed with 27586 elements, 53 linear line elements of type T3D2 (2-node linear 3D truss, hybrid), 2688 linear elements of type T3D2H, 22101 linear hexahedral elements of type C3D81 (8-node linear brick, incompressible), 2520 linear hexahedral elements of type C3D8 and 224 linear wedge elements of type C3D6.

It consists of twenty different components and each individual component was defined as individual set. Some 3D components were used to represent bones and truss components were used to represent ligaments.

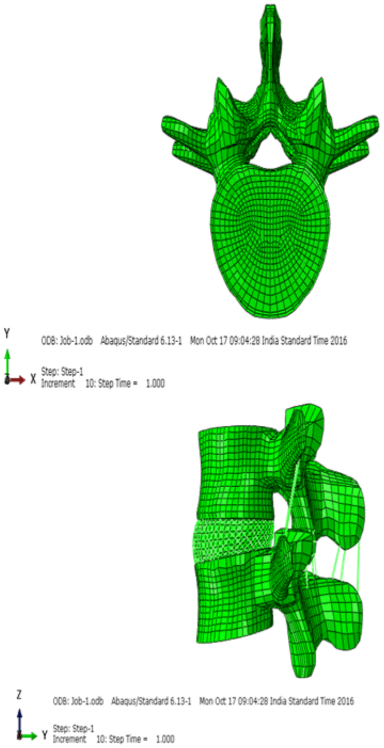

Fig. 3. Finite Element Model of Lumbar spine L4-L5 section Top view (X-Y) and side view (Z-Y) generated using ABAQUS viewport.

In order to apply axial load as follow load, two reference points were created and each point was connected to the cortical shell by means of beam type MPC Constraints. In this analysis, bottom surface of the L5 was fixed to simulate equivalent effects after kinematic study of the spine section.

For lateral bending, 7.5Nm was applied on RF-2 and axial load of 500N (Upper body forces) was applied on axial connectors.

5. MATERIAL PROPERTIES OF LUMBAR SPINE MODEL

Elastic constants of the hyperelsatic material was extracted from the curve that fits the available test data by using Mooney-Rivlin theory for hyper-elastic material [6]. The properties of the material and the constants obtained were fed in hyperelastic (N=1) material input box in ABAQUS window.

Table 1: Material properties assigned to various spinal components in the finite element model

Part	Young's Modulus(MPa)	Poisson Ratio
Cortical bone	12000	0.3
Interspinous Ligament	10	0.3
Liagmentum Flavum	15	0.3
Capsular Ligament	7.5	0.3
Supraspinous ligament	8	0.3
Transverse Ligament	15	0.3
Posterior Ligament	10	0.3
Cancellous Bone	3500	0.25
Part	C10, C10	D1
Nucleus Pulposus	-0.219197, 0.43494	0.000927066
Annulus	-0.117485, 0.273737	0.66206

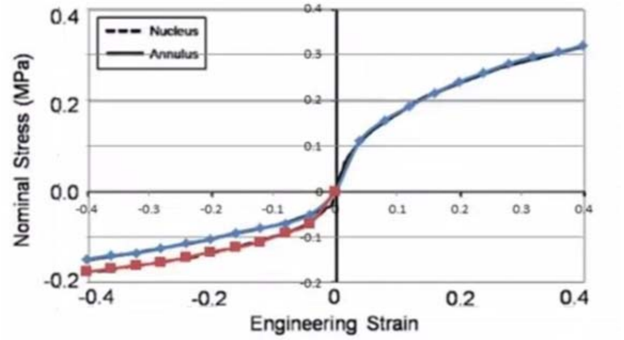

Fig. 4. Stress-strain curve of the constitutive laws adopted for the nucleus pulpous and the annulus drained ground substances, which resulted in the best fit between numerical and experimental results under axial compression as well as flexion and extension. These curves were used to determine the material parameters. [3]

6. FINITE ELEMENT SIMULATION OF THE SPINE SUBJECTED TO IMPACT LOAD

During rear end collision, the lumbar spine experiences impact force which results in straightening of the spine. This straightening effect, imparts pressure on the front of the vertebrates in the lumbar region. This pressure is exerted in the form of compressive load on the invertebral disc that is sandwiched between L4 and L5 portion of the spine column. This results in disc herniation which pushes the nerves exiting the spinal cord leading to radiating pain. This was observed by [4] and was concluded that the compressive load causes the protrusion of the invertebral disc when the passenger is subjected to rear end accidents. Numerical model of the L4-L5 segment was developed using finite element solver and was analyzed to understand of the von-mises stress distribution before and after the installation of anti-whiplash mechanism to validate its effectiveness. These results were recorded and have been presented in Fig. 6 and Fig. 5 respectively.

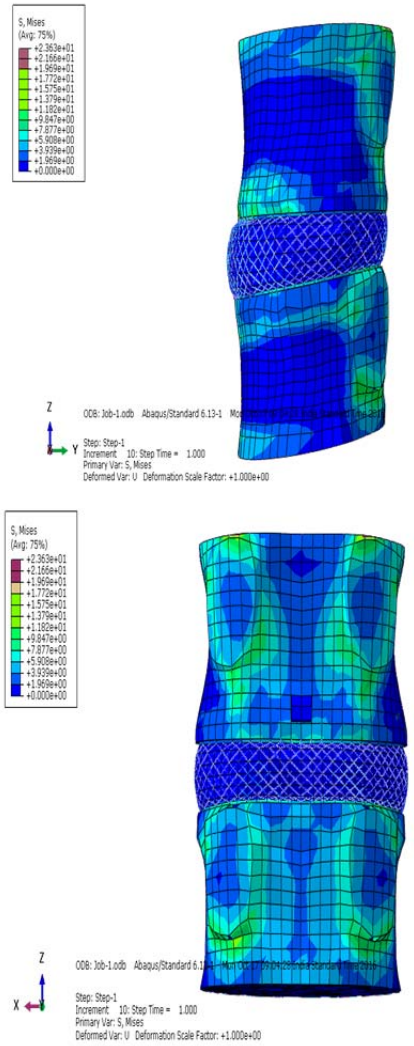

Fig. 5. Response of L4-L5 segment after the installation of anti-whiplash mechanism.

It can be observed that, with the installation of anti-whiplash mechanism stress induced was less severe and by visual inspection it is quite evident that the pattern of stress distribution is symmetric and there is no stress concentrated region which indicates the lack of straightening effects in the lumbar spine segment. Without the installation of this pneumatic mechanism, it was found that the magnitude of stress buildup was much higher and from Fig. 6 it can be observed that the stress remains concentrated near the invertebral disc which resulted in disc bulging and hence increasing the risk of whiplash injury.

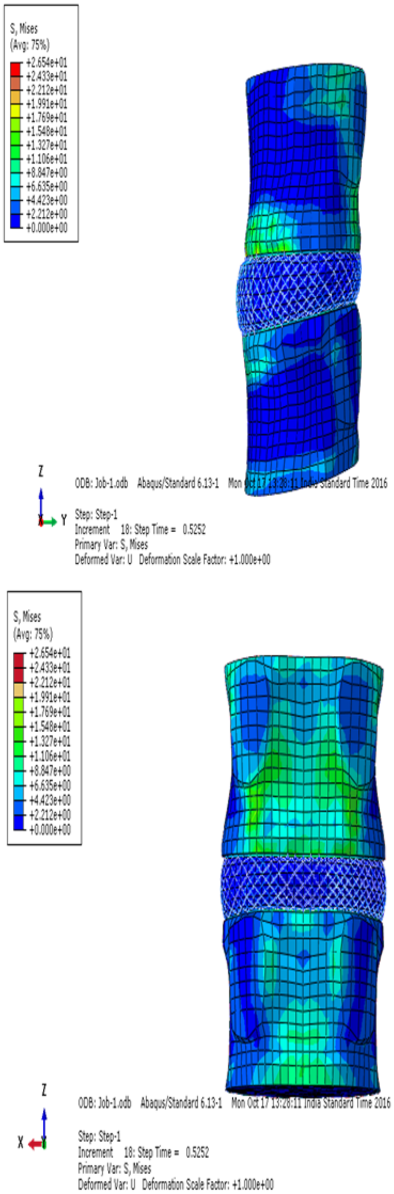

Fig. 6. Response of L4-L5 segment without the installation of anti-whiplash mechanism.

7. CONCLUSION

From the finite element analysis, effectiveness of the anti-whiplash mechanism was validated and it has been found that installation of this active head restraint mechanism reduces the ligamentous rupture and disc bulge during rear end collisions. From the results it can be concluded that installation of active head restraints can effectively alleviate back pains and the effects of neck injuries caused due to whiplash.

REFERENCES

[1] Hasegawa, Shiomi, "Study of whiplash injury occurrence mechanisms using human finite element model.pg:195.

[2] Ella Yeung, 'Whiplash Injuries' of the cervical spine: The relationship between the mechanism of the injury and the Neural Tissue involvement.

[3] Schmidt, Shirazi-Adl, Galbusera, JoachimWike, "Response analysis of the lumbar spine during regular daily activities—A finite element analysis".

[4] Sansone, "Mechanism of Injury to the lower back".

[5] Gaurav Nilakantan, US patent: Anti-whiplash vehicle system with active head restraint. US20090108645.

[6] William W.Feng "On Mooney-Rivlin Constants for Elastomers