Biomechanics Instrumentation Design Laboratory II

Spine

Abstract

In this lab, students are going to perform property testing with MTS machine under various situation such as ruptured disc and osteoporosis. The results are expected to have viscoelastic behavior of spine. According to results, injured spine shows less stiffness and less maximum value of extension. The MTS machine runs with two different speeds, 0.5 in/min and 0.05 in/min. With 0.5 in/min, spine shows stiffer than 0.05 in/min. Ruptured disk is easier to be broken by compressed load than osteoporosis due to lack of absorption of load. Non-linear regression fit is the most accurate for load vs. extension graphs. These regression results support the hypothesis of viscoelastic behavior which can be represented with Maxwell's model with dashpot and spring because dashpot does not respond as quickly as spring. So spring responses first which is damping region and dashpot responses later which is stiff region.

Introduction

The purpose of this lab is to introduce biomechanical mechanisms of the spine. Thus, the objective of this lab is to learn preparation of specimen, material testing, and responses of the spine to injuries such as disc rupture and osteoporosis. In this lab, calf spine, MTS machine and dental cement used for testing. Result of this lab is expected to have viscoelastic behavior of spine. For biomedical engineers, it is important to understand spine behavior to improve back disk replacement and surgery. The spinal column consists of individual bones called vertebrae, the building blocks, which provide support for the spine. These vertebrae are connected in the front of the spine by intervertebral discs. Discs help to support the spine and also allow it to move. The spinal column consist of seven cervical vertebrae (neck), twelve thoracic vertebrae (upper back), five lumbar vertebrae (lower back), five bones to form the bony sacrum, and three to five bones fused together to form the coccyx or tailbone. In general a typical vertebra consists of a large vertebral body in the front, two strong bony areas called pedicles connecting the vertebral body and the posterior arch, and an arch of bony structures in the posterior arch. The exterior vertebral body consists of cortical bone with more spongy bone cancellous bone and blood vessels inside. The vertebral bodies support 80 percent of all of the loads applied to the spine. The posterior arch consists of several bony structures. The main purpose of these structures is to protect the spinal cord, and to enable the connection of the vertebrae of muscles and ligaments. With sagittal view, there should be lordosis at the cervical and lumbar levels, and a kyphosis at the thoracic level. These curves allow the head to position over the pelvis in a sitting and standing position, while allowing for load bearing and shock absorption in the spine.

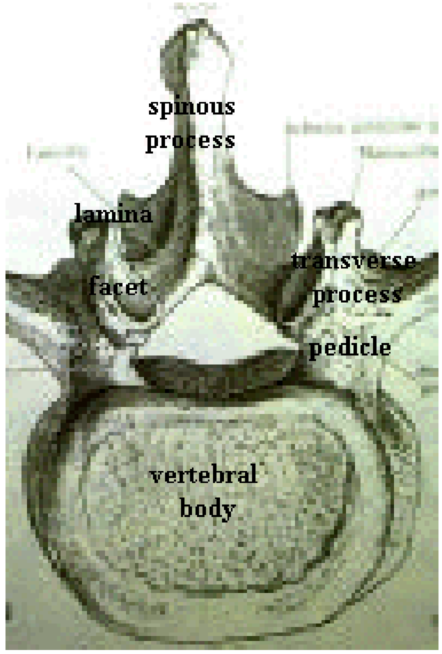

Figure 1. vertebral body

Osteoporosis is a disease characterized by low bone mass and deterioration of bone tissue. This leads to increased bone fragility and risk of fracture. Particularly of the hip, spine, and wrist areas are critical. Through degeneration or injury, the fibrous tissue constraining the soft disc material may tear. This may result in bulging of the disc or even extrusion of disc material into the spinal canal or neural foramen. However, ruptured disk is easier to be broken by compressed load than osteoporosis due to lack of absorption of load.

Methods

Obtain a pre-cut calf spine segment and measure and record the average diameter (medial-lateral and anterior-posterior), and height f the intervertebral disc. Then make dental cement with 2 cupts of the Die-Keen Green cement into a bowl along with approximately 140ml of water. Stir until mixture thickens. Pot the spine by pouring cement into the PVC pipe. Make sure that cement is not covering disk. Quickly place the superior end of the calf spine into the center of the PVC pipe. Press the spine segment into the cement and make sure that the cement surrounds the spine at the mid-level of the vertebral body. Also make sure that no cement surrounds the intervertebral disc. Hold the spinal segment in place until it is stable. Let it dry for 30 minutes. During waiting time, prepare more cement for other discs. Fill the mounting block with cement. Quickly place the inferior end of the calf spine into the center of the mounting block. Press the spine segment into the cement making sure that the cement completely surrounds the spine at the mid-level of the vertebral body. Also, make sure that no cement surrounds the intervertebral disc. Hold the spine segment in place until it is stable and again let it dry for 30 minutes. Students are preparing two specimens. Perform material testing with MTS machine with two speed 0.5 in/min and 0.05 in/min. For specimen #1, to simulate a disc rupture in the spine, a 0.25 in hole is drilled through the intervertebral disc in the mid-saggital plane, anterior to posterior. Before drilling, use calipers to make the necessary measurements such as disc height and diameter so that the area of the uninjured disc can be estimated. Subtract the area that will be removed by the drilling and record the new area of the ruptured disc. Simulate more serious rupture by drilling an additional hole perpendicularly to the original hole. Again, subtract the amount of disc area removed due to the drilling and record the new area of the ruptured disc. Repeat compression testing with two speeds, 0.5 in/min and 0.05 in/min. Make sure the break threshold is set to 700lbs. After gather the data, create a plot of load vs. extension. For specimen #2, to simulate an osteoporotic vertebral body, drill two holes through one vertebra, close to the vertebral end plate. Repeat compression testing with two speeds, 0.5 in/min and 0.05 in/min. simulate a more serious case of osteoporosis by drilling two holes through the other vertebra and repeat testing. After gather the data, create a plot of load vs. extension. After finished experiment, remove the spinal segments and hardened Die-Keen Green cement from the PVC pipe and mounting block. A hammer and screwdriver may be needed to loosen the cement from the pipe and mounting block. Dispose wastes and spinal segment. Sanitize area with paper towels, water, and disinfectant.

Results

Table 1. Measurement of Disc

disc	
diameter (in)	1.75
height (in)	0.245
volume uninjured (in^3)	0.5893
volume ruptured (1 hole)	0.568
volume ruptured (2 holes)	0.547

Table 2. Measurement of Vertebrae

vertebrae #1 for uninjured and two level osteoporosis testing	
diameter (in)	1.75
height (in)	1.486
volume uninjured (in^3)	3.574
volume ruptured (3 holes)	3.547
vertebrae #2 for uninjured and two level osteoporosis testing	
diameter (in)	1.75
height (in)	1.1555
volume uninjured (in^3)	2.779
volume ruptured (3 holes)	2.7517

Table 3. Linear and non linear fit information of R^2

	Linear fit	Non-linear fit
Uninjured spine at 0.05 in/min	0.9447	0.9995
Uninjured spine at 0.5in/min	0.8991	0.9989
Injured spine with initial rupture at 0.05 in/min	0.9284	0.9994
Injured spine with initial rupture at 0.5 in/min	0.8512	0.9947
Injured spine with additional rupture at 0.05 in/min	0.9402	0.9992
Injured spine with additional rupture at 0.5 in/min	N/A	
Spine with one osteoporotic vertebrae at 0.05 in/min	0.9265	0.9995
Spine with one osteoporotic vertebrae at 0.5 in/min	0.8729	0.9413

Spine with two osteoporotic vertebrae at 0.05 in/min	0.9265	0.9995
Spine with two osteoporotic vertebrae at 0.5 in/min	0.8729	0.9972

Table 4. Linear and non linear fit information of equation

	Linear fit Equation	Non linear fit Equation
Uninjured spine at 0.05 in/min	y = 5258.5x -53.568	$y = 63451x^2 + 303.83x + 11.472$
Uninjured spine at 0.5in/min	y = 10482x -78.89	$y = 250087x^2 -2271.5x + 20.692$
Injured spine with initial rupture at 0.05 in/min	y = 5326x -56.285	$y = 77976x^2 -287.48x + 9.732$
Injured spine with initial rupture at 0.5 in/min	y = 8317.4x + 109.33	y = 204567x2 -4844.3x + 30.117
Injured spine with additional rupture at 0.05 in/min	y = 4515.8x -49.464	$y = -51367x^2 + 222.09x + 9$
Injured spine with additional rupture at 0.5 in/min	N/A	
Spine with one osteoporotic vertebrae at 0.05 in/min	y = 5059.3x -47.239	$y = 75451x^2 -227.25x + 11.581$
Spine with one osteoporotic vertebrae at 0.5 in/min	y = 6445.4x + 77.136	$y = 75451x^2-227.25x+11.581$
Spine with two osteoporotic vertebrae at 0.05 in/min	y = 6445.4x -77.136	$y = 161088x^2 -3199.3x + 21.129$
Spine with two osteoporotic vertebrae at 0.5 in/min	y = 5059.3x + 47.239	$y = 7451x^2-227.25x + 11.581$

** y is load (lbf) and x is extension(in)

Non-linear regression fit is the most accurate for load vs. extension graphs. These regression results support the hypothesis of viscoelastic behavior.

Discussion

1. When calf spines are pre-potted, spine is dried out and dried spine does not show the viscoelastic behavior. Also students used dental cement instead of PMMA because dental cement is not toxic.
2. When the posterior elements of the spine removed, spine gets less stiff and the slope of load vs. extension plot has lower slope. In the experiment, posterior elements of the spine are removed to observe better behavior of disc.
3. With faster MTS speed crosshead (0.5 in/min), load vs. extension graph shows high value of slope and lower MTS speed crosshead (0.05 in/min), load vs. extension graph shows lower value of slope. Which explains that faster MTS speed of crosshead shows more stiffness than lower MTS speed of crosshead. However, extension while damping behavior is shown is similar in both speeds. Intervertebral disc have cartilaginous endplates at the top and bottom and are surrounded by the annulus. Through degeneration or injury, the fibrous tissue constraining the soft disc material may tear. This may result in bulging of the disc or even extrusion of disc material into the spinal canal or neural foramen.
4. The graph of the uninjured spine shows less damping region than the injured spine. Both can handle similar amount of load. However, the maximum extension of injured disc is less than uninjured disc. Injured disc shows less stiffness than uninjured one due to the slope after damping region. This can be represented as Maxwell's mathematical model. In Maxwell's model, when dashpot and spring are series, the behavior of damping and stiffness can be simulated from the results of compression and relaxation test.
5. Non-linear regression fit is the most accurate for load vs. extension graphs. These regression results support the hypothesis of viscoelastic behavior which can be represented with Maxwell's model with

dashpot and spring. Because dashpot does not respond as quickly as spring. So spring responses first which is damping region and dashpot responses later which is stiff region.

6. The mechanical properties of cadaveric spines reflect the properties in vivo, provided that preliminary creep tests are employed to reduce the hydration of cadaveric intervertebral discs (Keller). In vivo function and failure can be investigated in vitro only if physiologic loads and loading rates are employed. Adams compared between discs removed at surgery and discs removed several hours after death suggested that post-mortem changes in tissue water content involve a transfer of water from the outer to inner annulus. Also stress distributions in discs vary with age, and posture. (Adams). The motion segment consists of two whole vertebrae and all of the intervening soft tissue. It is the smallest repeating unit of the spine that preserves disc and vertebrae intact. As the results, motion segments are used in the majority of experiments (Adams). However, it led to a serious underestimation of the tensile strength of the ligaments due to the longitudinal and ligaments span several vertebrae so that many of their fivers are disrupted in a motion segment. Mathematical models depend on materials properties measured on cadaveric specimens (Adams). Also mathematical models obliged to make simplifying assumptions regarding the mechanical behavior of composite materials. Thus, it is critical to determine with estimated predicted contact stresses, shapes, spacing, etc. According to Adams, mathematical models are able to explain experimental results even though it has only a limited ability to make independent predictions. Their predictive ability will be enhanced when increased computing power reduces the need for simplifications and when the materials properties of spinal tissues are known in more detail. Eventually, finite element modeling should supplant mechanical testing for most applications (Adams).

In the lab, due to the limitation of size of specimen for MTS machine, it might not give as accurate results as Adams pointed out in this article. Also depends on how mount calf spine, covers disc or not, may cause errors of results. In the lab, MTS machine broke due to overload so it is very important to make sure cautions during the lab. Also the injured spine with additional rupture at 0.5 in/min is not available.

Conclusion

This lab is successful because students learned the biomechanical mechanisms of the spine. Students also gained experience in specimen preparation and material testing in various situations, such as rupture and osteoporosis. In this lab, students are going to perform property testing with MTS machine under various situations such as ruptured disc and osteoporosis. The results are expected to have viscoelastic behavior of spine. According to results, injured spine shows less stiffness and less maximum value of extension. The MTS machine runs with two different speeds, 0.5 in/min and 0.05 in/min. With 0.5 in/min, spine shows stiffer than 0.05 in/min. Ruptured disk is easier to be broken by compressed load than osteoporosis due to lack of absorption of load. Non-linear regression fit is the most accurate for load vs. extension graphs. These regression results support the hypothesis of viscoelastic behavior which can be represented with Maxwell's model with dashpot and spring because dashpot does not respond as quickly as spring. So spring responses first which is damping region and dashpot responses later which is stiff region. It is very important to pay attention to the MTS machine while the compression is applying to the specimens not to break MTS. Also the injured spine with additional rupture at 0.5 in/min is not available.

References

[1] Adams, M.A. Spine Update Mechanical Testing of the Spine.
[2] Keller, T.S. The dependence of intervertebral disc mechanical properties on physiologic condition.