Biomechanics Instrumentation Design Laboratory II

Occupational Biomechanics

Abstract

There are four different postures to study effects on compressive forces in the L5/S1 disc. The first three lifts use various distances between subject and weight, such as between feet, 6 inches, and 12 inches. The last posture is lifting weight without bending knees. The results supports that using leg muscles and bending knees help to reduce compressive loading of the L5/S1 disc. Also lifting weight from between one's feet create a lot of compressive and shear force to L5/S1 disc. The best way to lift weight is using knees, leg muscles, and choosing distance between 6 and 12 inches away from body.

Introduction

Low back pain and injuries attributed to manual lifting activities continue as one of the leading occupational health and safety issues facing preventive medicine. Therefore, it is very important to biomedical engineers to understand mechanics of spine to reduce and prevent injuries of discs. The objective of this lab is to study the effects of different postural lifting configurations and their effects on compressive forces in the fifth lumbar and first sacral intervertebral disc. Compressive and shear forces in the L5-S1 intervertebral discs over the course of four different lifting activities. These forces will then be compared to data obtained from previous studies to see which lifting posture minimizes the risk for injury.

According to the National Institute for Occupational Safety and Health (NIOSH) identifies 3400N as potentially hazardous for some workers and the maximum permissible limit is 6400N. The Department of Labor's Bureau of Labor Statistics suggests that back injuries account for 20% of workplace injuries and illnesses and similarly to 25% of workman's compensation paid. Because the L5/S1 is major injured disc by lifting heavy load, L5-S1 intervertebral disc has been extensively researched by researchers. The compressive force exerted on the L5/S1 disc which can be reduced by lifting with back upright with proper posture. There are ways of reducing compressive forces on the L5/S1 such as reducing angle between cutting plane and horizontal plane and reducing moment arm in other words, keep the weight close to the body. To reduce moment arm it is important to bend knees and use leg muscles while lifting heavy objects which also helps to reduce angle between cutting plane and horizontal plane.

The NIOSH suggests the recommended weight limit (RWL) which is the weight of the load that nearly all healthy workers could perform over a substantial period of time without an increased risk of developing lifting-related lower back pain. RWL is equal to the production of LC (load constant), HM (Horizontal multiplier), VM (Vertical multiplier), DM (Distance multiplier), AM (Asymmetric multiplier), FM (Frequency multiplier), and CM (Coupling multiplier). The values of each are defined in the document, Revised lifting equation, from the NIOSH.

The lifting index (LI) is a relative estimated physical stress associated with a manual lifting job. The LI is equal to

$$LI = \frac{Load\_Weight}{\mathrm{Re}commended\_Weight\_Limit} = \frac{L}{RWL}$$, where L is the weight of an object lifted.

All equations and sample calculations (by Chaffin and Anderson) of this lab are in the result section. The calculations were all performed within Microsoft Excel. Microsoft Paint was used to determine positions of markers.

Method

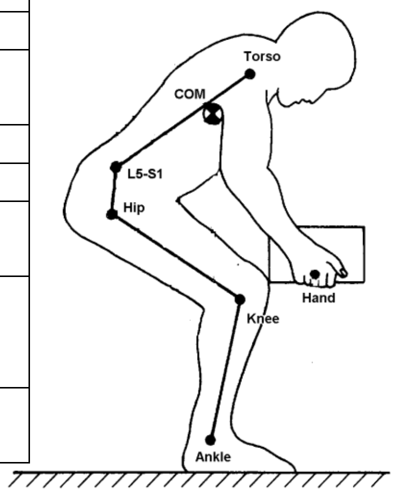
A subject needs to attach seven markers on their body to identify interest points of mechanics of body system. Find a subject wearing dark clothing so that the white markers will strongly contrast with the background. This will help to identify markers during analysis process. Marker #1 is placed on right lateral malleolous, which is right outer an ankle bone. Marker #2 is placed on right lateral femoral condyle, which is right knee joint center. Marker #3 is placed on right greater trochanter, which is right hop joint. Marker #4 is right glenohumerol joint, which is right shoulder joint. Marker #5 is center of mass of upper body for the head, arms, and trunk (HAT), which is calculated distance from the top of the head and center of the torso with equations, mass of HAT is 0.678(total body mass) and center of mass of HAT is 0.374(0.626(total height)). Marker #6 is placed on lumbrosacral joint, which is 20% of distance from center of the torso marker to the center of the hip marker. Then on the subject's back, find the location of the L5 vertebrae which is the place of the marker #6 and center of the L5 – S1 disc. Take a ruler and project it from the hip marker to that location. Marker #7 is placed on the right distal third metacarpal which is middle of the weight. The positions of markers are critical because movement of subject moves markers at the same time. Thus, attach markers as adhesive as possible.

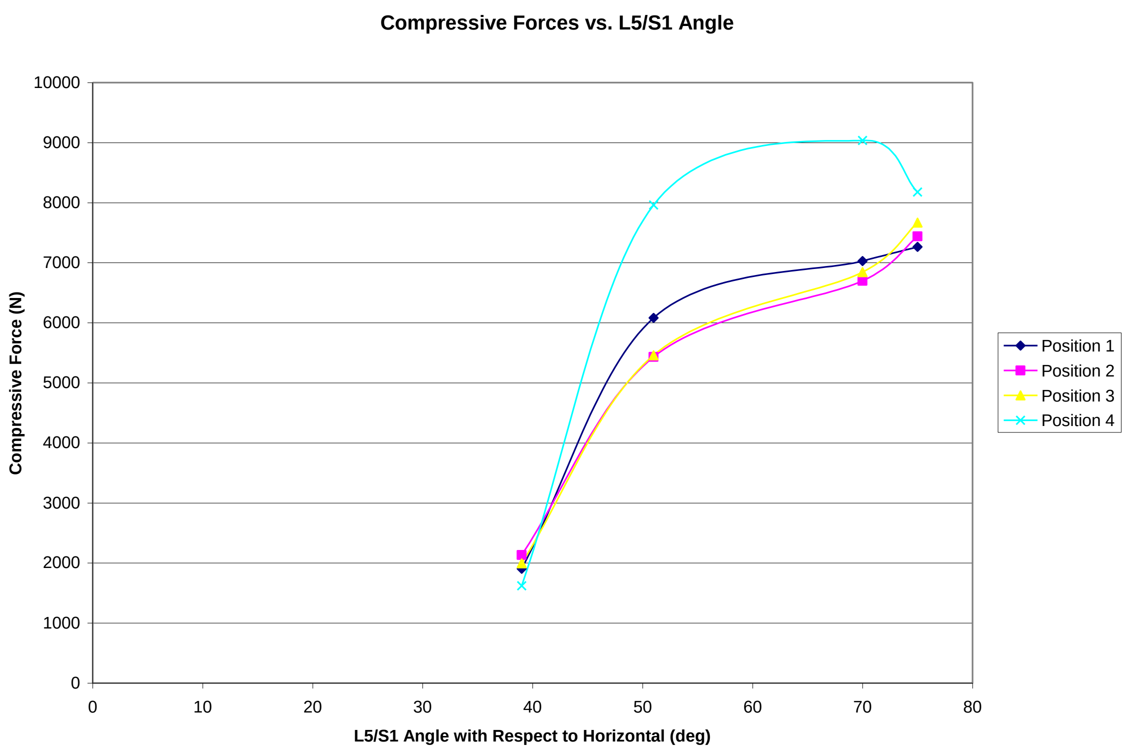
After markers are placed completely, students set camera approximately 8 feet from the walkway. Make sure that the field of view (FOV) is parallel to the walkway. The FOV should be large enough to capture the subject and all markers in both vertical and bent posture. Draw a 1 ft2 calibration square on the board that will be used in that data analysis to convert pixel values to measurement. The one-foot calibration square should also be in the camera's FOV. Make sure the digital camera is set to video mode. Subject begins squat and pick up the weight with a slow, steady motion making sure that the 20 lb weight is directly between the feet. Next, subject moves weight to 6 inches away from the body, and begins squat and pick up the weight with a slow, steady motion. Next, subject repeats same motion with 6 more inches away from the body (total 12 inches). The final lifting position will involve the subject bending about the waist with little to no knee flexion, and picking up the 20lb weight. Transfer video to a computer to gather data. Students pick four positions, which include initial lifting of the weight, two intermediate positions, and the final position when the subject is standing erect with the weight. When each position is copied and pasted into Microsoft Paint program, record the x and y axis of pixel positions of markers. Also do not forget to record the each corner of 1ft2 calibration square. After collect all data points, calculate forces, moment, angles, etc. (Chaffin and Anderson) with Microsoft Excel program.

Results

Table 1. Position of markers.

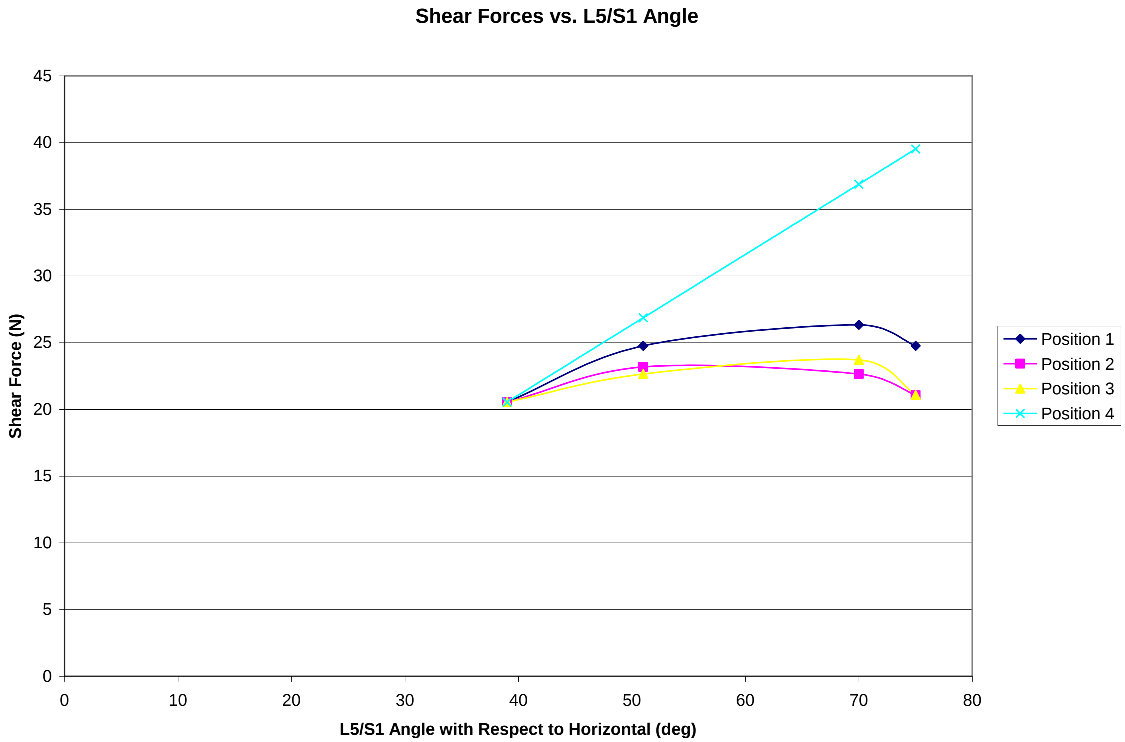
Marker #	Anatomical Landmark	Description
1	Right lateral malleolus	Right outer ankle bone
2	Right lateral femoral condyle	Right knee joint center
3	Right greater trochanter	Right hip pointer
4	Right glenohumerol joint	Right shoulder joint
5	Center of mass of upper body	Approx. 0.234*(total height) from top of head
6	Lumbrosacral joint	1/5 of the distance from the hip marker to the shoulder marker
7	Right distal 3rd metacarpal	Middle knuckle or weight





Graph 1. Compressive force vs. L5/S1 alpha angle

Position 1 is lifting weight between feet. Position 2 is lifting weight 6 inches away from subject. Position 3 is lifting weight 12 inches away from subject. Position 4 is lifting weight without bending knees.



Graph 2. Shear force vs. L5/S1 alpha angle

Position 1 is lifting weight between feet. Position 2 is lifting weight 6 inches away from subject. Position 3 is lifting weight 12 inches away from subject. Position 4 is lifting weight without bending knees.

Discussion

1. The highest stress on discs occurs when subject bends at the hips without any knee flexion. The other three postures show that compressive stresses are minimized with the distance between 6 inches and 12 inches which is from weight to subject. It is interesting to observe that the first posture, lifting weight between the feet, shows higher stress than between 6 and 12 inches postures even though moment arm is shorter with the first posture. In shear, it is difficult to compare which lifting position is better between lifting a load from between lifting between feet or 6 and/or 12 inches away from the subject. According to the shear vs. angle graphs, position 4, lifting weight without bending knees, created the most shear stress. Also, lifting weight 6 inches and 12 inches away from the subject shows similar pattern of stress with changing angles. Again, position 1 with lifting weight between feet shows greater shear stress than position 2 and 3 with 6 inches and 12 inches away from the subject.

2. When alpha angles, between horizontal and cutting planes, are 70 degrees, both the compressive and shear stresses show maximum value. This is expected because the larger value of alpha angle creates larger mg_{load} and mg_{HAT}. Fc and Fs are going to bigger with bigger values of mg_{load} and $mg_{HAT.}$ Stress is force over cross sectional area so that stress gets bigger with same cross sectional areas and bigger forces.

3. If EMG is used in this experiment, researchers can observe the muscle behavior of lower back. Also, EMG data might help researchers to determine which position excites muscle fibers to analyze the force and moment of lower back area. EMG helps to determine the proper lifting technique for individuals. Bending legs and using leg muscles reduce stress and force of lower back. Moreover, knowing when the back muscles are excited with EMG signal, it helps to identify magnitude of the stresses on the spine.

4. There are problems with subjects during the experiment. The subject used equations from Chaffin and Anderson to calculate the compressive and shear forces at the L5/S1 disc. Chaffin and Anderson developed equation really well but still because it is mathematical modeling equations, it might not fit into every single individual cases. Also, there is the moment arm for center of mass of the head, arms, and trunk, which is used instead of the actual weight and distance of each head, arms, and trunk or using integrations of the weight of those body parts. Another problem is the area of the abdomen which is assumed to be a constant value although it may vary depending on amount of flexion at the waist. In addition, markers sometimes move with clothes while subject is bending and lifting weights. This might gives errors to data which can lead false or inaccurate analysis.

5. The weight lifting belt would help reduce the amount of the compression loads at the L5/S1 disc. Weight lifting belts decrease the compression due to the lower back is forced to stay erect instead of allowing the back to bend as much. According to mechanics of spine, it makes the sacral shelf angle low to be stable and also results of the experiment supports the weight lifting belt. Thus, the weight lifting belt is reported effective in the

working environment or from personal opinions. However, weight lifting belt is helpful under the condition of using properly. The belt might give more stress and pain if the belt is very stiff or subject performs bending activities.

6. The rate of lifting is one of the critical factors of stress on L5/S1 disc. Inertia is a major part in the stresses on spine because the intervertebral disc requires time to account for changes. Thus, if the lifting weight happens very quickly then the changes do not occur which means the desired deformation does not occur. The force generated during lifting activities is a function of the mass and acceleration. However, inertia is a resistance of change in acceleration.

Conclusion

This lab is successful because students understand the effects of different postural lifting configurations and their effects on compressive forces of L5/S1 disc. The highest stress on discs occurs when subject bends at the hips without any knee flexion. The other three postures show that compressive stresses are minimized with the distance between 6 inches and 12 inches which is from weight to subject. It is interesting to observe that the first posture, lifting weight between the feet, shows higher stress than between 6 and 12 inches postures even though moment arm is shorter with the first posture. In shear, it is difficult to compare which lifting position is better between lifting a load from between lifting between feet or 6 and/or 12 inches away from the subject. According to the shear vs. angle graphs, position 4, lifting weight without bending knees, created the most shear stress. Also, lifting weight 6 inches and 12 inches away from the subject shows similar pattern of stress with changing angles. Again, position 1 with lifting weight between feet shows greater shear stress than position 2 and 3 with 6 inches and 12 inches away from the subject. Limitations and potential errors are presented in the lab. There is the moment arm for center of mass of the head, arms, and trunk, which is used instead of the actual weight and distance of each head, arms, and trunk or using integrations of the weight of those body parts. Another problem is the area of the abdomen which is assumed to be a constant value although it may vary depending on amount of flexion at the waist. In addition, markers sometimes move with clothes while subject is bending and lifting weights. This might gives errors to data which can lead false or inaccurate analysis. The lab can be improved by using EMG for muscle signals, measuring abdomen areas, and wearing clothes which do not stretch a lot while bending occurs.

Design a system component or process to meet desired needs with realistic constraints.

The microprocessor which is a small device with a replaceable adhesive so the device could be easily stuck to the system. The device is placed on to the stand would also contain an accelerometer, which would provide input to the microprocessor which would have a mathematical model for the deformation of the L5-S1 intervertebral disc to determine the differences in loading on the spinal segments in lifts of 1 sec, 500ms, and 100ms are different. Power system is convertible between normal outlet and lithium batteries. Lab view program is also needed to test the system if applicable or not.

Reference

[1] Harris, Gerald, ”BIEN 192, class notes”, Marquette University, Spring 2006

[2] National Institute for Occupational Safety and Health (NIOSH), http://www.cdc.gov/niosh/94-110.html, “Introduction 1. The Revised Lifting Equation”

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