

Integrative Spine Dynamics

A Major Qualifying Project Report

Submitted to the Faculty of

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for the

Degree of Bachelor of Science

By

Sarah Doyon

Richard Henley

Ashley Zalucky

Date: April 27, 2006

Approved: _____

Professor Mustapha Fofana, Advisor

Abstract

This project originated due to the increasing concern involving spinal injury in the manufacturing environment. There is an average loss of 7 days away from work a year because of spinal overexertion and 18 days a year are lost due to repetitive motion. The MQP took particular interest in the activities of sitting, standing and walking in the workplace.

The intent was to help reduce spinal injuries within the manufacturing environment by providing stability indices. The indices would provide values which one can sustain various loadings before experiencing injury. The process began by examining the physiology, biomechanics and dynamics of the spine. With this information a mathematical model was formulated which would produce results involving the various factors that play significant and minor roles in determining spinal injury. Ideally, the model predicts a range of forces and motion trajectories with respect to sitting, standing and walking. The mathematical model is represented by a differential equation with multiple delays:

$$f(t) = \ddot{\theta} + 2\omega \cdot \delta \cdot \dot{\theta} + \omega^2 \cdot \theta + \mu_1[\theta(t - \tau_1) + \dot{\theta}(t - \tau_1)] + \mu_2[\theta(t - \tau_2) + \dot{\theta}(t - \tau_2)]$$

A physiological model was then created using an inverted pendulum to assist in determining the unknown values of spinal exertion. The model used representative variables to substitute for internal forces such as stiffness and damping. The flexor and extensor muscles were characterized by spring and dampers in the model.

These models were used to determine if the spine was dynamically stable with respect to the various activities. The proposed model sets the groundwork for safety guidelines in the manufacturing environment.

Acknowledgements

We would like to thank the following people, without their efforts, this project would not have been possible: Mustapha Fofana-WPI Associate Professor, Jacek Cholewicki Ph. D, Associate Professor of Orthopedics and Rehabilitation and Biomedical Engineering- Yale University

TABLE OF CONTENTS

<i>Abstract</i>	<i>ii</i>
<i>Acknowledgements</i>	<i>iii</i>
<i>Table of Contents</i>	<i>iv</i>
<i>List of Figures</i>	<i>vi</i>
<i>List of Tables</i>	<i>viii</i>
CHAPTER 1. INTRODUCTION	1
CHAPTER 2. PHYSIOLOGY OF THE SPINE	3
2.1 THE SPINE.....	3
2.1.1 <i>Vertebrae</i>	3
2.1.2 <i>Spinal Discs</i>	5
2.1.3 <i>Ligaments and Tendons</i>	6
2.1.4 <i>Muscles</i>	7
2.1.5 <i>Joints</i>	8
2.1.6 <i>Nerves</i>	9
2.2 CERVICAL SPINE REGION.....	11
2.2.1 <i>Vertebrae of the Cervical Spine</i>	11
2.2.2 <i>Ligaments of the Cervical Spine</i>	15
2.2.3 <i>Muscles of the Cervical Spine</i>	16
2.2.4 <i>Nerves of the Cervical Spine</i>	18
2.2.5 <i>Joints of the Cervical Spine</i>	19
2.3 THORACIC SPINE REGION.....	19
2.3.1 <i>Vertebrae of the Thoracic Region</i>	20
2.3.2 <i>Discs of the Thoracic Region</i>	23
2.3.3 <i>Ligaments of the Thoracic Region</i>	24
2.3.4 <i>Muscles of the Thoracic Region</i>	24
2.3.5 <i>Nerves of the Thoracic Region</i>	27
2.4 LUMBAR SPINE REGION.....	28
2.4.1 <i>Vertebrae of the Lumbar Spine</i>	28
2.4.2 <i>Discs of the Lumbar Spine</i>	31
2.4.3 <i>Joints of the Lumbar Spine</i>	31
2.4.4 <i>Ligaments of the Lumbar Spine</i>	31
2.4.5 <i>Muscles of the Lumbar Spine</i>	32
2.4.6 <i>Nerves of the Lumbar Spine</i>	39
CHAPTER 3. SPINE MECHANICS	42
3.1 MOTIONS OF THE SPINE.....	42
3.2 FORCES OF THE SPINE.....	43
3.2.1 <i>Compressive Force</i>	44
3.2.2 <i>Tensional Force</i>	44
3.2.3 <i>Shear Force</i>	45
3.2.4 <i>Torsional Force</i>	45
3.3 SITTING.....	46
3.4 STANDING.....	51

3.5 WALKING.....	56
CHAPTER 4. SPINE DYNAMICS.....	61
4.1 STABILITY OF THE SPINE.....	61
4.2 PHYSIOLOGICAL MODEL OF THE SPINE.....	62
4.3 MATHEMATICAL MODEL OF THE SPINE.....	63
4.2.1 <i>Forces of the Equation</i>	63
4.2.2 <i>Reflex Delays</i>	66
4.2.3 <i>Corrective Measures</i>	67
4.2.4 <i>Extensor and Flexor Muscles</i>	69
4.4 LINEARITY AND NON-LINEARITY OF THE SPINE.....	70
CHAPTER 5. STUDIES ON THE SPINE RELATED TO THE MANUFACTURING ENVIRONMENT.....	72
5.1 SITTING STUDY.....	72
5.2 STANDING STUDY.....	75
5.3 WALKING STUDY.....	76
CHAPTER 6. RESULTS AND DISCUSSION.....	81
CHAPTER 7. CONCLUSION.....	84

LIST OF FIGURES

FIGURE 1: SPINE - FRONTAL AND PROFILE VIEW	4
FIGURE 2: SACRUM AND COCCYX.....	5
FIGURE 3: SPINAL DISC - TOP VIEW.....	6
FIGURE 4: SPINAL SEGMENT - LANDSCAPE VIEW	7
FIGURE 5: FACET JOINTS	8
FIGURE 6: SPINAL CORD IN DIFFERENT SECTIONS OF THE SPINE	9
FIGURE 7: SPINAL CORD LAYOUT.....	10
FIGURE 8: CERVICAL VERTEBRA - TOP VIEW.....	11
FIGURE 9: CERVICAL VERTEBRA - SIDE VIEW.....	12
FIGURE 10: ATLAS	13
FIGURE 11: AXIS.....	14
FIGURE 12: SEVENTH VERTEBRA - TOP VIEW	15
FIGURE 13: KYPHOSIS CURVE OF THE SPINE.....	20
FIGURE 14: INDIVIDUAL VERTEBRAE OF THE THORACIC SPINE.....	21
FIGURE 15: 1ST THROUGH 12TH THORACIC SPINE	22
FIGURE 16: TRANSVERSE THORACIC.....	26
FIGURE 17: LUMBAR REGION OF THE SPINE	28
FIGURE 18: LOCATION OF PROCESSES ON LUMBER VERTEBRAE.....	30
FIGURE 19: ERECTOR SPINAE MUSCLES.....	34
FIGURE 20: INTERTRANSVERSII MUSCLES AND INTERSPINALES MUSCLE	34
FIGURE 21: MULTIFIDUS MUSCLE.....	35
FIGURE 22: INTERNAL OBLIQUE MUSCLE.....	36
FIGURE 23: EXTERNAL OBLIQUE MUSCLE.....	36
FIGURE 24: TRANSVERSES ABDOMINUS MUSCLE	37
FIGURE 25: SIDE AND BACK VIEW OF RECTUS ABDOMINUS MUSCLE	37
FIGURE 26: PSOAS AND QUADRATUS LUMBORUM MUSCLES.....	39
FIGURE 27: LUMBAR PLEXUS	40
FIGURE 28: MOTIONS OF THE SPINE WHEN STANDING.....	43
FIGURE 29: COMPRESSIONAL FORCE FROM SIDE VIEW AND FRONT VIEW	44
FIGURE 30: TENSION FORCE FROM THE SIDE VIEW AND FRONT VIEW	45
FIGURE 31: SHEAR FORCES ACTING ON A VERTEBRAE	45
FIGURE 32: TORSIONAL FORCES ACTING ON A VERTEBRAE.....	46
FIGURE 33: FREE BODY DIAGRAM OF PERSON SITTING	47
FIGURE 34: SEATED POSITION WITH HIP FLEXION.....	48
FIGURE 35: CURVES OF THE LUMBAR REGION.....	49
FIGURE 36: SPINE WHEN SITTING	49
FIGURE 37: ANTERIOR SHEAR	50
FIGURE 38: SITTING AT VARIOUS ANGLES	51
FIGURE 39: ANGLE OF LUMBOSACRAL DISC WHEN STANDING ERECT	53
FIGURE 40: FORCES ACTING ON THE HUMAN BODY WHEN STANDING ERECT.....	53
FIGURE 41: COMPRESSIVE FORCES VS. VARIOUS POSITIONS OF THE SPINE.....	54
FIGURE 42: FORWARD FLEXION OF THE HUMAN SPINE.....	55
FIGURE 43: PERCENTAGES OF DISC PRESSURE IN THE SPINE	56
FIGURE 44: FREE BODY DIAGRAM OF PERSON WALKING	57

FIGURE 45: GAIT PERIOD.....	57
FIGURE 46: GAIT PERIOD WITH MOVEMENTS	58
FIGURE 47: HIP BALANCE	59
FIGURE 48: HIP EXTENSORS/ FLEXORS	60
FIGURE 49: INVERTED PENDULUM MODEL.....	62
FIGURE 50: GRAPH MODELING MOTION DECAY FOR DAMPING.....	65
FIGURE 51: END RESULT OF SPINAL FUSION SURGERY ON THE SPINE.....	68
FIGURE 52: ALTERNATE LEG RAISE EXERCISE.....	69
FIGURE 53: NON-LINEAR ANALYSIS	70
FIGURE 54: DYNAMIC STABILITY CHART	77
FIGURE 55: 3-D WALKING MODEL	79
FIGURE 56: STEP WIDTH VERSUS METABOLIC COST.....	80
FIGURE 57: REGIONS OF STABILITY INDICIES	81
FIGURE 58: LOCATION OF EIGENVALUES IN COMPLEX PLANE.....	83

LIST OF TABLES

TABLE 1: CERVICAL MUSCLES OF THE SPINE 17

Chapter 1. Introduction

In any workplace, large or small, employees are the most valuable asset. Particularly in the manufacturing environment, the primary asset the employee brings to the workplace is the ability to perform physical activities. The human body's overall function is contingent upon its core component, the spine. The spine provides the most essential components for mobility and operation of physical activities. Alarming, over eighty percent of employees will experience a spinal related issue throughout their working lives.

Within the United States, back pain is the most common work related disorder. Back pain results in unsatisfied employees and loss of profit for the workplace. Whether the injury is non-accidental (i.e.: where pain arises as a consequence of normal activities and requirements of the task) or accidental (i.e.: where an unexpected occurrence arises resulting in an injury during the task), workplaces suffer from loss of profit and productivity. In recent years, the costs related to back injury are a staggering twenty billion dollars or more, annually. As the leading contributor to missed work, as many as one hundred million working days are lost each year.

Through extensive research of the anatomy, physiology, and biomechanics of the spine, this Major Qualifying Project will explore the various ways to reduce work related injury to the spine. By taking particular interest in sitting, standing, and walking, mathematical models will be created to represent these everyday motions and forces the spine undergoes in the manufacturing environment. The end result will produce stability indices. An evaluation will be produced which will provide numerous solutions to minimize this ongoing billion dollar issue within the United States.

In order to accomplish the end result, this project will highlight certain essential components. Chapter 1 establishes the problem statement and objectives. An in depth look at the physiology of the spine is discussed in Chapter 2. Chapter 3 goes into detail about the mechanics of the spine. Next, Chapter 4 reports on field studies that have been done previously related to sitting, standing and walking in the workplace. Chapter 5 is a detailed look at the dynamics of the spine including the model formulation of the spine. Chapter 6 then leads into the results and discussion of this MQP. The last chapter contains the conclusion.

Chapter 2. Physiology of the Spine

2.1 The Spine

The spine is primarily made up of eight unique parts. The first component consists of many small bones called vertebrae which comprise the vertebral column, serving as the core of the spinal column. In between the vertebrae, soft pieces of cartilage known as the spinal discs. They are held together by ligaments and the spinal muscles are attached to the bones by tendons. Spinal muscles control all back movements. These movements are regulated by two sets of joints which support the movements and prevent damage that can be caused by extreme movement. All actions, being involuntary, passive or voluntary actions are directed by the nervous system, whose roots course down and throughout the spine.¹

2.1.1 Vertebrae

The bones in the spinal column are referred to as vertebrae. They are separated into five distinct regions, cervical, lumbar, thoracic, sacrum and coccyx and can be seen in Figure 1 below. The cervical is the top region of the spine, incorporating the first seven bones. This region is primarily responsible for neck and head support, making up the first curve in the spine. Bones one and two from the top, known as atlas and axis are responsible for allowing rotation of the head around the x-axis and y-axis. The thoracic section makes up the next twelve bones in the spine. These are a bit bigger than the cervical vertebrae and compromise the second curve in the column. Vital organs in the body depend on the rib cage for support and safety, and the thoracic region is where the back side of the ribcage is anchored. The lumbar region is the next five sometimes six bones forming the third spinal curve. The biggest vertebrae in the spine, most of the back

muscles are attached to this region. It is this region which supports most of the body's weight and therefore is subject to many stresses. The sacrum is the next region of the spine and exists in two phases. During juvenility is the first, in which the sacrum exists as four to five small vertebrae.² This changes somewhere in the mid-twenties, when the sacrum bones fuse to become one triangular bone mass. Squeezed between the two iliac bones, the sacrum exists as the back of the pelvis. It is between the sacrum and lumbar zones that much of the back injury occurs due the massive amount of stresses it endures.³

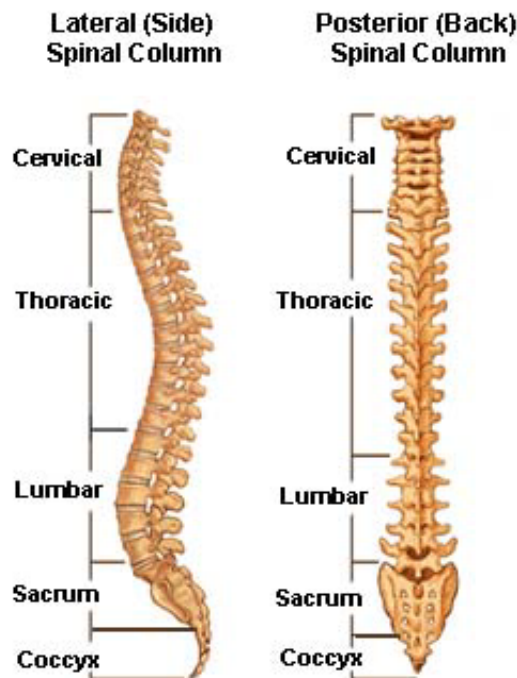


Figure 1: Spine - Frontal and Profile View
Eidelson, Stuart. "Thoracic Spine." *Spine Universe*. 5 Jan. 2002. 02 Feb. 2006
<<http://www.spineuniverse.com/displayarticle.php/article1397.html>>.

Figure 2 illustrates, a section known as the coccyx. It is the final bone mass in the spine . Commonly known as the tailbone, the coccyx is the fusion of four or five tiny bones. This is the only part of the spine that nerves do not enter. It is held to the sacrum by many ligaments and serves as the anchor point for some muscles in the body.⁴

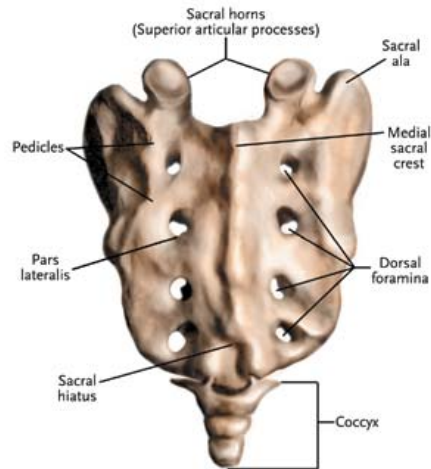


Figure 2: Sacrum and Coccyx

Portfield, Derose. "Anatomy of the Spine." Back.Com. 31 Oct. 2001. 02 Feb. 2006
<<http://www.back.com/anatomy-sacral.html>>.

2.1.2 Spinal Discs

Spinal discs fill in the gaps between each of the vertebrae. Their composition is that of a soft core with a hard outside. The outer surface consists of cartilage fibers called annulus fibrosus, while inside is a jelly substance known as nucleus pulposus. End plates of the vertebrae hold the discs firmly in place. The purpose of spinal discs is support for the bone. When the body undergoes stressful activities, extreme pressure is put upon the spine. Spinal discs act as shock absorbers for the body allowing for less of the concussion to be felt by the back.⁵ Spinal discs also support simple back movements. It's due to these discs that bending and twisting of the back is possible. Figure 3 demonstrates a top view of a spinal disc.

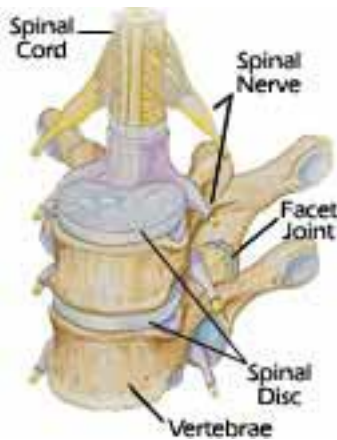


Figure 3: Spinal Disc - Top View
"THE INTERVERTEBRAL DISCS." *Your Spine*. 1999. 03 Feb. 2006
<http://www.dcdotor.com/pages/rightpages_healthconditions/yourspine/yourspine_disc.html>.

2.1.3 Ligaments and Tendons

Ligaments are fibers that attach different bones to each other, while tendons attach bone to muscles. Made of tightly packed collagen fibers, it is these two items that hold the parts of the body together. The spine contains two sets of ligaments, intrasegmental and intersegmental. Intrasegmental ligaments are responsible for holding the individual vertebra together. This group contains three main ligaments the interspinous ligament the ligamentum flavum and the intertransverse ligament.⁶

Intersegmental ligaments hold all of the vertebrae together. This group is comprised of three main ligaments, the anterior longitudinal ligament, the posterior longitudinal ligament and the supraspinous ligament. These sets of tissue run from the top to the bottom of the spine, helping to prevent radical movement that may cause injury or trauma. Through holding the bones together, ligaments provide a high level of stability for the body to function on. However, ligaments are not very strong and under constant high stress will suffer damage and unfortunately, due to their minute blood supply, when injury occurs, they suffer from slow healing times. Spinal tendons simply hold the

muscles in the spine to the bone allowing for movement. ⁶ The ligaments of the spine and their location, can be seen in Figure 4 below.

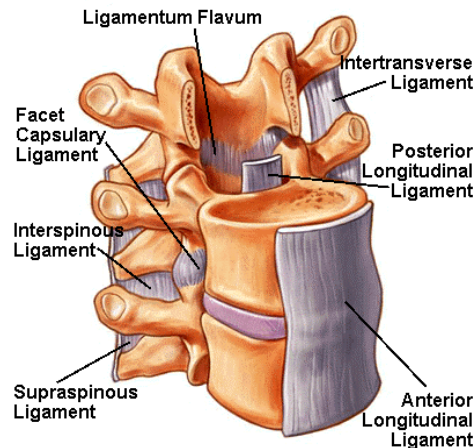


Figure 4: Spinal Segment - Landscape View
Eidelson, Stuart. "Spinal Ligaments." *Spine.Com*. May 2002. 03 Feb. 2006
<<http://www.spineuniverse.com/displayarticle.php/article1393.html>>.

2.1.4 Muscles

Spinal muscles are a group of muscular tissue, which connect up and down the spinal column. These thirty plus muscles are responsible for poise, mobility and strength. The muscles in the spine exist in four different groups, extensors, forward flexors, lateral flexors and rotators. Found at the rear of the spine, the extensors are responsible for such actions as lifting items and standing. The flexors make for forward bending, flexing and control of the back arches. These muscles are located in front of the spine (forward) and in the abdominal area (lateral). They extend down and attach to the pelvis and femur. Rotators, also known as paraspinal muscles allow for body rotation and support upright posture. Working in groups, they contract and relax opposing each other to allow for

movement while sustaining a certain level of strength. Fascia, layered fibrous tissue, covers all the muscles in the spine and turns into tendon which anchors to the bones.⁷

2.1.5 Joints

The spine has two types of joints in it, facet and sacroiliac joints. Facet joints, shown in Figure 5 are considered to be the primary source of back discomfort by many experts, are present in pairs, twice on each vertebra. With one above the vertebra and one below, these joints hold the vertebrae together, and guide their individual motion. Located at the posterior of the spine, these joints allow for much flexibility.⁸

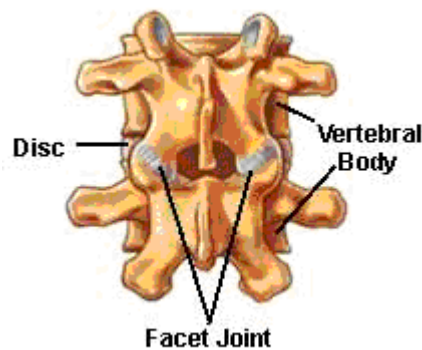


Figure 5: Facet Joints

**Bridwell, Keith. "Facet Joints of the Spine Anatomy." Spine.Com. 7 June 2001. 22 Feb. 2006
<<http://www.spineuniverse.com/displayarticle.php/article1293.html>>.**

These joints are synovial joints, covered on the ends of the bone with a slick layer cartilage, allowing for the bones to slide against each other with little to no friction. This soft surface is kept lubricated by synovial fluid which surrounds the ends of both the knob and joint socket. The sacroiliac joint is the joint that connects the sacrum to the pelvic bone. Very small yet tough, this joint is the primary highway for forces to move from the spine down to the lower body. This joint is held in place by a number of ligaments and muscles that anchor to the buttocks.

2.1.6 Nerves

The spinal cord is much like a protective case for the nerves which flow down the spine through all of the vertebrae. Nerves beginning at the brain are encased by the spinal column and branch from the vertebral gap to every part of the body. The nervous system controls all body functions voluntary and involuntary from the heart beating to breathing or walking, the spinal cord is responsible. As the spinal cord descends through the body, nerve roots split off from the vertebrae and spread to the rest of the body. At this point, nerves serve another key role, independent of the brain, which are reflexes.

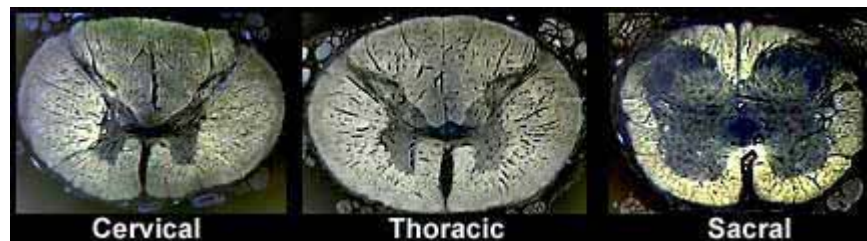


Figure 6: Spinal Cord in Different Sections of the Spine
Chudler, Eric H. "Neuroscience for Kids." The Spinal Cord. 17 Apr. 2006. 10 Oct. 2005
<<http://faculty.washington.edu/chudler/spinal.html>>.

Figure 6 indicates various regions of the nervous systems. The gray region in the center is known casually as “grey matter”. This matter is made up of dendrites and nerve cell bodies. The lighter region is bundled interneuronal axons which act as tracts for the axons to carry messages to and from the brain. As the nerves progresses down the body, the grey matter increases in size. The increase supports the need for more nerve cells in body parts with high levels of motor function, such as the legs.

The nerves are the body’s pathway for sending messages to the body’s different sections. Serving as one of the three sections of the central nervous system, it controls both voluntary and involuntary bodily functions. The immune system, blood flow and

cognition are some examples of this as well as the five senses, touch, taste, sight, hearing and smell. As the cord flows down the spinal encasing, the roots of nerve clusters branch off flowing into the different areas of the body. Intervertebral foramens serve as pathways in between the spinal bones, allowing for a safe throughway from spinal cord to body segment, thus allowing bodily organs to carry out their desired functions.

Whilst there are millions upon millions of nerves sending data back and forth about any and everything, just like the spine itself, the spinal nerves are split into sections. These are the cervical nerves, thoracic nerves as well as the lumbar and sacral nerves. Cervical nerves can be found in the neck. Their purpose is to supply abilities of motion and feeling to the arms and upper torso. Thoracic nerves reside in the upper back. They supply the nerve clusters in the abdomen handling organ function. The lumbar and sacral nerves split out of the lower back. They link the brain to the legs, excretory system and sexual organs.⁹ The location of the nerves to their respective component of the spine can be seen in Figure 7.

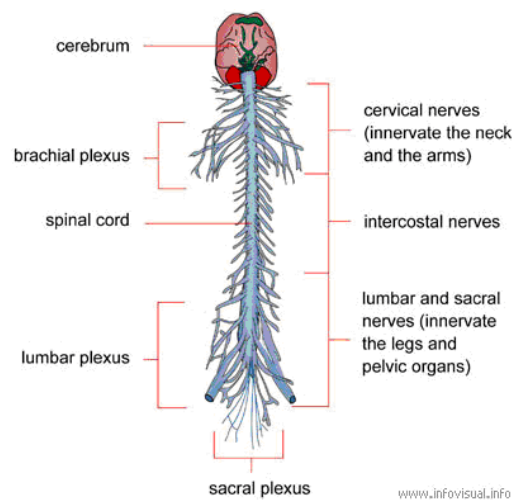


Figure 7: Spinal Cord Layout
Dery, Bernard. "Nervous System." InfoVisual.Visual. 2006. 11 Feb. 2006
<http://www.infovisual.info/03/039_en.html>.

2.2 Cervical Spine Region

The cervical spine is best known as the portion of the vertebral column contained in the neck, which consists of seven cervical vertebrae between the skull and the rib cage.

2.2.1 Vertebrae of the Cervical Spine

The cervical spine consists of seven vertebrae commonly known as C1 through C7. A top view is shown of the cervical vertebrae in Figure 8, followed by the side view shown in Figure 9. Out of the seven, C3 through C6 are of common construction, while C1, C2, and C7 possess unique structures. The four vertebrae that are of similar construction are still unique to the cervical section, because of their smaller size in comparison to the vertebrae of the thoracic and lumbar regions. These four vertebrae also are composed of a foramen in the transverse process. The basic parts of these four vertebrae are the body, pedicles, laminae and spinous processes and are represented in Figure 8.

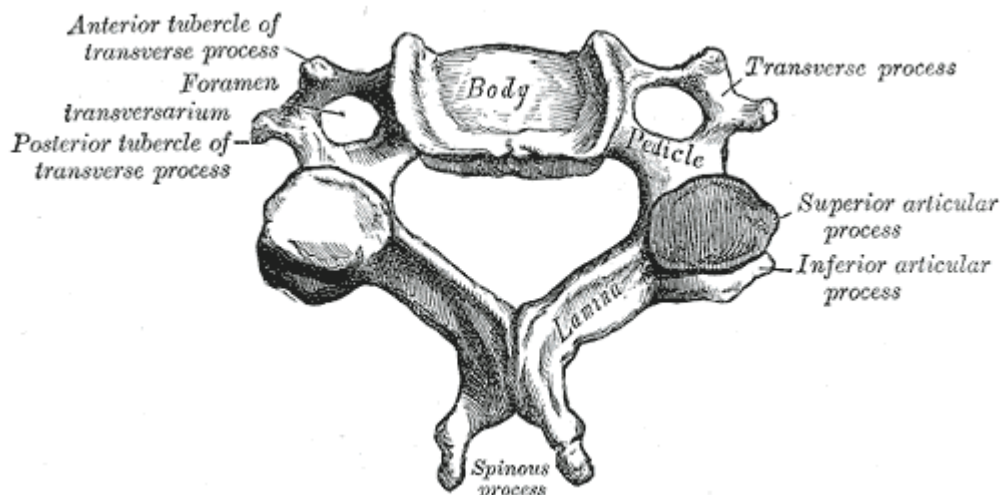


Figure 8: Cervical Vertebra - Top View

Gray, Henry. "The Cervical Vertebrae." *Gray's Anatomy*. Mar. 2001. 09 Jan. 2006
<<http://education.yahoo.com/reference/gray/subjects/subject?id=21>>.

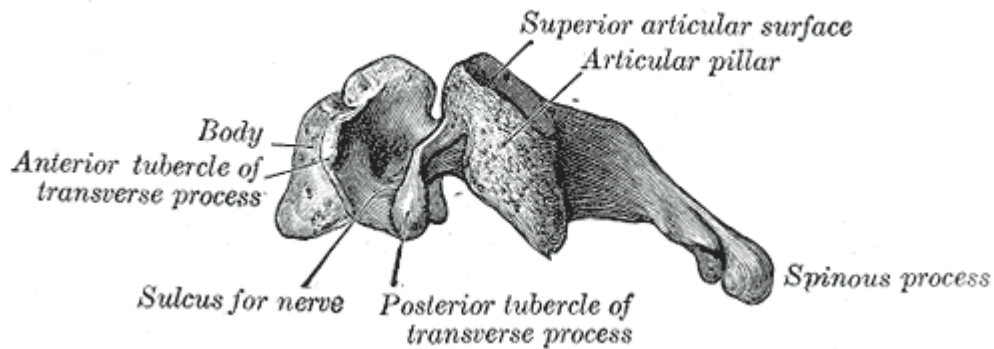
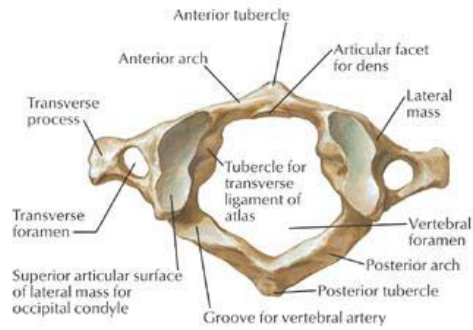


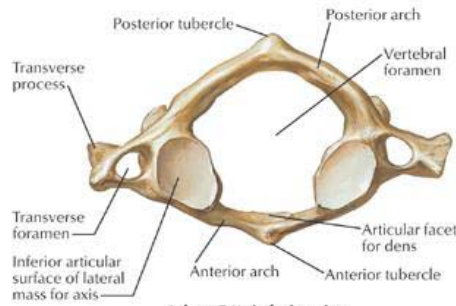
Figure 9: Cervical Vertebra - Side View
 Gray, Henry. "The Cervical Vertebrae." *Gray's Anatomy*. Mar. 2001. 09 Jan. 2006
 <<http://education.yahoo.com/reference/gray/subjects/subject?id=21>>.

The vertebral body is small, and is wider than it is long. The pedicles, which are short rounded pieces of cortical bone can be found laterally and backward, and are attached to the body midway between its upper and lower borders. The laminae, which extend off of the pedicles, are narrow, and thinner above than below; the vertebral foramen is large, and of a triangular form. The laminae form the posterior wall of the foramen.¹⁰ The spinous process is short, the two divisions being often of unequal size.¹¹ The transverse processes are each pierced by the foramen transversarium, which, in the upper six vertebrae, gives passage to the vertebral artery vein as well as a plexus of sympathetic nerves. Each process consists of an anterior and a posterior part.¹¹

The first vertebra in the cervical region is referred to as the Atlas and its purpose is to support the skull. It was given the name Atlas in reference to the Greek God Atlas who was given the weight of the world on his shoulders. The atlas is unique from the rest of the seven cervical vertebrae due to its lack of body. Other distinctive features are its lack of a spinous process, its ring-like structure, and presence of an anterior and a posterior arches with two lateral masses. The superior and inferior view of the atlas can be seen in Figure 10.



Atlas (C1): superior view

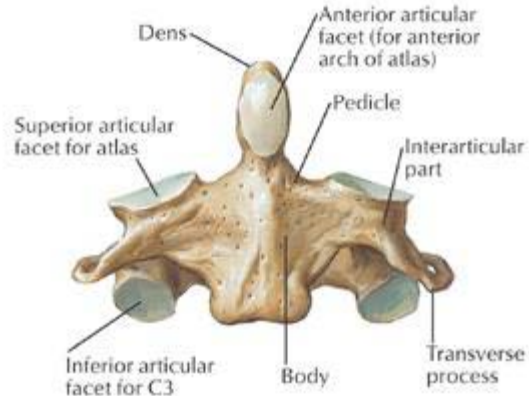


Atlas (C1): inferior view

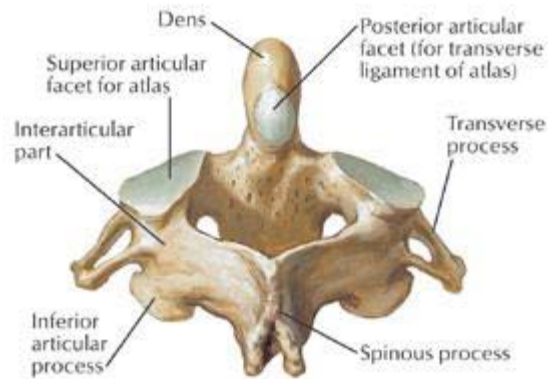
Figure 10: Atlas

**Gray, Henry. "The Cervical Vertebrae." *Gray's Anatomy*. Mar. 2001. 09 Jan. 2006
 <<http://education.yahoo.com/reference/gray/subjects/subject?id=21>>.**

The second vertebra is the axis vertebra, otherwise known as C2. This vertebra forms the pivot joint with the atlas vertebra (C1) that supports the head and allows for pivotal movement. Figure 11 exemplifies the anterior and posterior axis.



Axis (C2): anterior view



Axis (C2): posterosuperior view

Figure 11: Axis

Gray, Henry. "The Cervical Vertebrae." *Gray's Anatomy*. Mar. 2001. 09 Jan. 2006
 <<http://education.yahoo.com/reference/gray/subjects/subject?id=21>>.

The most unique part of the axis construction is the odontoid process that protrudes perpendicularly to the vertebral structure. This process articulates the anterior arch of the atlas and axis. The axis body is deeper in front than behind, and is prolonged downward anteriorly, causing an overlap in the upper and fore part of the third vertebra. This presents a longitudinal ridge, separating two lateral depressions for the attachment of the Longus colli muscles, which is situated on the anterior surface of the vertebral column, between the atlas and the third thoracic vertebra. The under surface is concave

from the back and convex from side to side.¹¹ The pedicles are broad and strong, especially in front, where they join together with the sides of the body and the root of the odontoid process. The laminae are thick and strong, and the vertebral foramen large, but smaller than that of the atlas. The transverse processes are very small, and each ends in a single tubercle; each is touched by the foramen transversarium, which is directed obliquely upward and laterally.¹¹ The spinous process is large, very strong and deeply channeled on its under surface.

The seventh vertebra is unique from the six preceding it because of its larger and longer spinous process. This process is thick, and nearly horizontal in direction as can be seen in Figure 12. This vertebra is also referred to as the prominent vertebra because the existence of a long and prominent spinous process

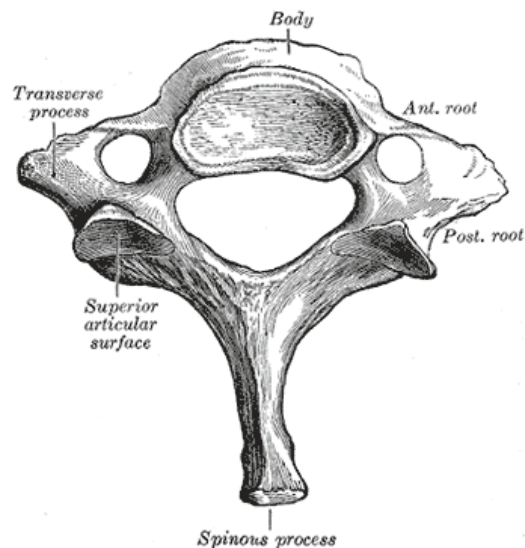


Figure 12: Seventh Vertebra - Top View
Gray, Henry. "The Cervical Vertebrae." *Gray's Anatomy*. Mar. 2001. 09 Jan. 2006
<<http://education.yahoo.com/reference/gray/subjects/subject?id=21>>.

2.2.2 Ligaments of the Cervical Spine

Both the main ligaments of the spine, the intraspinal and the interspinous systems are located in the cervical region. There are ligament systems that exist only within the

cervical region, one of these systems is the Cruciform Ligament. The Cruciform ligament connects the occiput and C1 with C2, consisting of 4 different ligaments; left and right transverse ligaments and superior and inferior longitudinal fascicles. The transverse ligaments attach from one side of C1, around the dens, to the other side of C1. The longitudinal fascicles run from the anterior aspect of the foramen magnum to the body of C2.¹² The cervical spine also consists of the Alar ligaments which are used to stabilize and limit movement between the dens and the occiput.

The posterior longitudinal ligament plays an important role in the cervical region by attaching to the anterior aspect of the foramen magnum and running downward behind the vertebral bodies. This runs the length of the spine and forms the front of a tube created by the vertebrae called the Spinal Canal (that contains the spinal cord). The Anterior Longitudinal Ligament runs downward on the opposite side of the vertebral body from the posterior longitudinal ligament. It runs the length of the cervical spine on the front of the vertebrae.¹²

2.2.3 Muscles of the Cervical Spine

Table 1 relates each of the muscles within the cervical region to their corresponding nerve and function.

CERVICAL MUSCLES	FUNCTION	NERVE
Sternocleidomastoid	Extends & rotates head, flexes vertebral column	C2, C3
Scalenus	Flexes & rotates neck	Lower cervical
Spinalis Cervicis	Extends & rotates head	Middle/lower cervical
Spinalis Capitus	Extends & rotates head	Middle/lower cervical
Semispinalis Cervicis	Extends & rotates vertebral column	Middle/lower cervical
Semispinalis Capitus	Rotates head & pulls backward	C1 – C5
Splenius Cervicis	Extends vertebral column	Middle/lower cervical
Longus Colli Cervicis	Flexes cervical vertebrae	C2 – C7
Longus Capitus	Flexes head	C1 – C3
Rectus Capitus Anterior	Flexes head	C2, C3
Rectus Capitus Lateralis	Bends head laterally	C2, C3
Iliocostalis Cervicis	Extends cervical vertebrae	Middle/lower cervical
Longissimus Cervicis	Extends cervical vertebrae	Middle/lower cervical
Longissimus Capitus	Rotates head & pulls backward	Middle/lower cervical
Rectus Capitus Posterior Major	Extends & rotates head	Suboccipital
Rectus Capitus Posterior Minor	Extends head	Suboccipital
Obliquus Capitus Inferior	Rotates atlas	Suboccipital
Obliquus Capitus Superior	Extends & bends head laterally	Suboccipital

Table 1: Cervical Muscles of the Spine
Montazem, Abbas. "The Cervical Spine." 21 Jan. 2006
http://www.montazem.de/english/html/body_cervical_spine.html.

The cervical spine is stabilized and supported by a system of four muscles groups. Ligaments assist these muscles in an attempt to prevent any injury that can possibly occur. Muscles enable movement and provide back balance and stability. Nerve impulses from the brain send messages to these tissues allowing them to relax and contract when necessary. Some muscles act together while others work as opposites for further strength,

such that when one muscle contracts another relaxes proportionally. The four types of muscles are forward flexors, lateral flexors, rotators, and extensors.¹³

2.2.4 Nerves of the Cervical Spine

The nerves of the cervical spine can be divided up into two groups: the posterior divisions, and the anterior divisions. The posterior divisions are as a rule smaller than the anterior. The anterior divisions of the spinal nerves supply the antero-lateral parts of the trunk, and the limbs; they are for the most part larger than the posterior divisions. In the thoracic region they run independently of one another, but in the cervical, lumbar, and sacral regions they unite near their origins to form plexuses.¹⁴

The posterior division of the first cervical nerve is larger than the anterior division, and emerges above the posterior arch of the atlas and beneath the vertebral artery. The second cervical nerve in the posterior divisions are much larger than the anterior division, and is the greatest of all the cervical posterior divisions. It emerges between the posterior arch of the atlas and the lamina of the axis, below the Obliquus inferior. It supplies a twig to this muscle, receives a communicating filament from the posterior division of the first cervical, and then divides into a large medial and a small lateral branch. The posterior division of the third cervical is intermediate in size between those of the second and fourth. The posterior divisions of the lower five cervical nerves divide into medial and lateral branches.¹⁵

The anterior divisions of the cervical nerves, with the exception of the first, pass outward between the intertransversarii anterior and posterior, lying on the grooved upper surfaces of the transverse processes of the vertebræ. The anterior division of the first nerve issues from the vertebral canal above the posterior arch of the atlas and runs

forward around the lateral aspect of its superior articular process. The anterior divisions of the upper four cervical nerves unite to form the cervical plexus. In the cervical plexus, each nerve, except the first, divides into an upper and a lower branch, and the branches unite to form three loops. The plexus is situated opposite the upper four cervical vertebrae.¹⁵

2.2.5 Joints of the Cervical Spine

The articulation of the atlas with the axis is of a complicated nature, comprising no fewer than four distinct joints. There is a pivot articulation between the odontoid process of the axis and the ring formed by the anterior arch and the transverse ligament of the atlas. Here there are two joints: one between the posterior surface of the anterior arch of the atlas and the front of the odontoid process; the other between the anterior surface of the ligament and the back of the process.¹¹ The opposed articular surfaces of the atlas and axis are not commonly curved; both surfaces are convex in their long axes. Therefore, the upper facet glides forward on the lower it also descends; the fibers of the articular capsule are relaxed in a vertical direction, and will then permit of movement in an antero-posterior direction. This means a shorter capsule would be sufficient and the strength of the joint is materially increased. This joint allows the rotation of the atlas upon the axis while the extent of rotation being limited by the alar ligaments.¹¹

2.3 Thoracic Spine Region

The thoracic region of the spine is the longest part of the back and is often referred to as the “middle back”. Although this region rarely experiences injury and is often overlooked by the more problematic areas of the back, it plays a vital role in the

function of the body.¹⁶ The thoracic region is located below the cervical and above the lumbar region of the spine. Its shape takes on a kyphotic, “C”- shaped curve which opens to the front, and contributes to the overall shape of the spine known as the “S”-shaped curve and shown in Figure 13.¹⁶

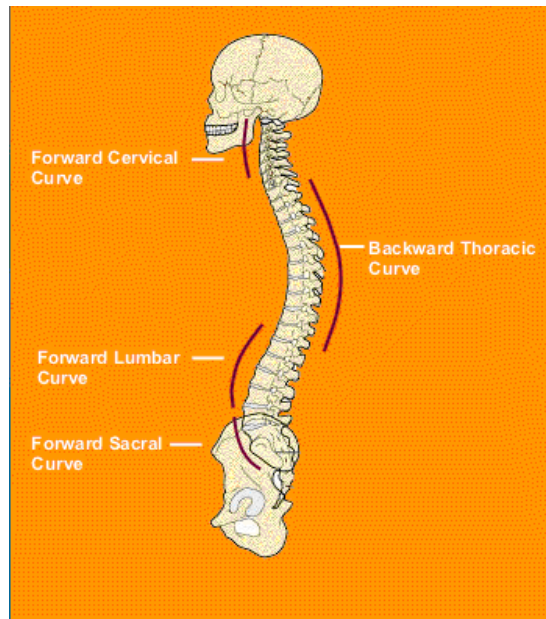


Figure 13: Kyphosis Curve of the Spine

"A Patient's Guide to Kyphoplasty." **Montana Spine Center**, Medical Multimedia Group, L.L.C..
<<http://www.eorthopod.com/eorthopodV2/index.php/fuseaction/topics.detail/ID/79791a8f7dd9f446b38653cbeab9a955/TopicID/775ab1f814d5190fb55685dbe1c6f7bd/area/4>>.

2.3.1 Vertebrae of the Thoracic Region

The thoracic spine is made up of the 12 middle vertebral bodies that allow very minimal motion because they are securely attached to the ribs and form part of the thorax wall. The vertebrae in this region are often referred to as T1 through T13. The vertebrae's firm connection with the rib cage and lack of motion offers the body stability and support. Its overall structure acts as a cage by protecting the fundamental organs of the heart and lungs.¹⁷ Figure 14 shows a detailed look at an individual thoracic vertebrae.

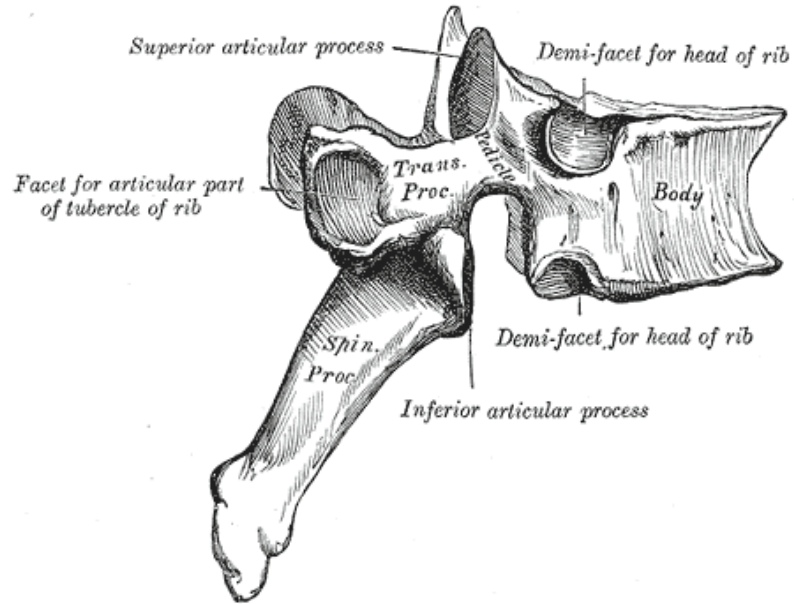


Figure 14: Individual vertebrae of the thoracic spine
 "Thoracic Vertebrae." [Wikipedia.Com](http://en.wikipedia.org/wiki/Thoracic_spine). 27 Feb. 2006. 09 Feb. 2006
 <http://en.wikipedia.org/wiki/Thoracic_spine>.

Overall, the vertebrae are intermediate in size, and they increase in dimension as you move down the spine. The upper vertebrae are much smaller than the lower regions vertebrae. Within the thoracic region, the vertebrae have their own regions, which correlate to different parts of the body. They can be distinguished by facets on the sides of the individual vertebrae bodies for articulation with the heads of the ribs.

The thoracic spine is comprised of numerous types of vertebrae that are designated by their location moving from the top of the region down. The first eight vertebrae in the thoracic region are the same, containing an entire articular facet, which serves as a connection point for the first rib. It also includes a demi-facet for the upper part of the second rib. Similar to the vertebrae in the cervical region, the surface is concave and lipped on both sides. The transverse processes in the thoracic spine's vertebrae are long, and the notches within the first through eighth vertebrae in these regions are much deeper than the remaining four.¹⁸

The ninth thoracic vertebrae often have no demi-facets, although it is possible in some cases, they can contain two demi-facets on either side. In this case, the occurrence of two demi-facets affects the tenth vertebrae by limiting it to only contain demi-facets on the upper part. The tenth thoracic vertebra has the major difference of having an articular facet on both sides. The tenth thoracic vertebra has the major difference of having an articular facet on both sides.

Unlike any of the previous vertebrae, the eleventh thoracic vertebrae begins to take on the size and form of the lumbar vertebrae. The articular facets, which allow room for the rib, are much larger, and are primarily located on the pedicles. The pedicles in the eleventh vertebrae are much thicker and stronger, and the transverse processes are very short and do not contain any articular facets. Much like the eleventh vertebrae, the twelfth thoracic vertebrae holds the same overall characteristics but is varied by its interior articular surfaces. This vertebrae appears to be convex and directed lateralward, similar to the lumbar vertebrae.¹⁹ Each of the twelve vertebrae are labeled in Figure 15 with their correlating facet.

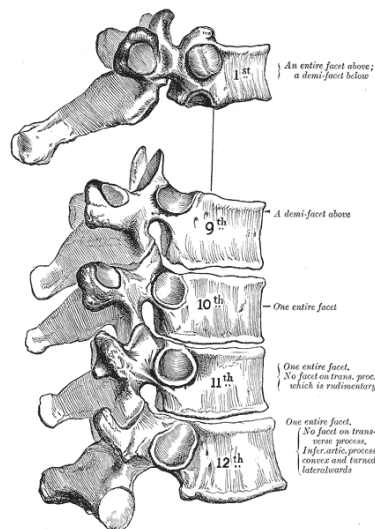


Figure 15: 1st through 12th thoracic spine
"Thoracic Vertebrae." [Wikipedia.Com](http://en.wikipedia.org/wiki/Thoracic_spine). 27 Feb. 2006. 09 Feb. 2006
<http://en.wikipedia.org/wiki/Thoracic_spine>.

The ninth thoracic vertebrae often have no demi-facets, although it is possible in some cases, they can contain two demi-facets on either side. In this case, the occurrence of two demi-facets affects the tenth vertebrae by limiting it to only contain demi-facets on the upper part. The tenth thoracic vertebra has the major difference of having an articular facet on both sides.

Unlike any of the previous vertebrae, the eleventh thoracic vertebrae begins to take on the size and form of the lumbar vertebrae. The articular facets, which allow room for the rib, are much larger, and are primarily located on the pedicles. The pedicles in the eleventh vertebrae are much thicker and stronger, and the transverse processes are very short and do not contain any articular facets. Much like the eleventh vertebrae, the twelfth thoracic vertebrae holds the same overall characteristics but is varied by its interior articular surfaces. This vertebrae appears to be convex and directed lateralward, similar to the lumbar vertebrae.²⁰

2.3.2 Discs of the Thoracic Region

The intervertebral discs of the thoracic spine are very narrow and thin; and restrict movement throughout the mid back. The smaller discs also allow for less space within the spinal canal. They are located between adjacent vertebrae and function as spacers allowing room for spinal nerves to act as links and provide movement. Their main purpose is to act as a spinal shock absorber to minimize the risk of injury.

It is unlikely that the discs of the thoracic spine become injured. In fact, injury to this area only makes up for 2% of all intervertebral disc damage. This can be attributed to the rib articulations made by the vertebrae that considerably amplify the stability of the thoracic region of the spine.²¹

2.3.3 Ligaments of the Thoracic Region

The ligaments within the thoracic spine, like any other fibrous sheets of tissue, link two or more bone structures together. Five primary ligaments appear within the thoracic spine, beginning with the anterior longitudinal ligament. This tissue extends along the length of the vertebral column and assists in the prevention of hyperextension. The posterior longitudinal ligament also extends along the entire length of the vertebral column from the sacrum to the cervical region. This ligament is attached to the anterior border of the foramen magnum.²²

The ligamenta flava are elastic tissue bands that extend between the laminae of vertebrae while attaching to the anterior surface. These ligaments help to preserve the vertebral columns original curve and assist to straighten it when it is flexed. The interspinous ligaments are considered to be very weak and extend between the spinous process. The supraspinous ligaments appear only at their tip; these ligaments are often strong, tough fibrous tissues. Lastly, the intertransverse ligaments extend between the transverse process and adjacent vertebrae. Overall, they carry little significance within the thoracic region, yet offer a much more significant purpose within the lumbar region.¹⁸

2.3.4 Muscles of the Thoracic Region

The muscles that run through the thoracic spine are arranged in layers that run from the back of the vertebrae to the shoulder blades. The other muscles of this region wrap around the rib cage and connect to the shoulder. The middle layer of muscles through the thoracic spine are strap-shaped and run up and down over ribs and lower part of the thorax. The deepest layer attaches along the back of the spinal bones and connects to the vertebrae.²³

The muscles that belong to the thoracic spinal group are: intercostals externi, intercostals interni, subcostales, transversus thoracicus, levatores costarum, serratus posterior superior and the serratus posterior inferior. The intercostals externi extend from the tubercles of the ribs to the cartilage in front of the ribs. They end in thin membranes called anterior intercostals membranes. These muscles are fairly thick and contain fibers that are directly obliquely downward on the thorax.

The intercostals interni muscles of the thoracic region come together anteriorly at the sternum between the cartilage of the ribs and extend into the vertebral column. Once they reach the vertebrae, they are called posterior intercostals membranes. Like the intercostals externi, they have oblique fibers, but are thinner and pass in the opposite direction. The subcostales are made up of muscular fasciculi that are primarily located in the lower part of the thorax. Similarly, they pass in the same direction as the intercostals interni.²⁴

The more tendinous muscles of the thoracic spine are the transverses thoracis, shown in Figure 16. This fibrous group is located on the inner surface of the front wall of the chest. The fibers are arranged horizontally and are attached to the transversus abdominis.

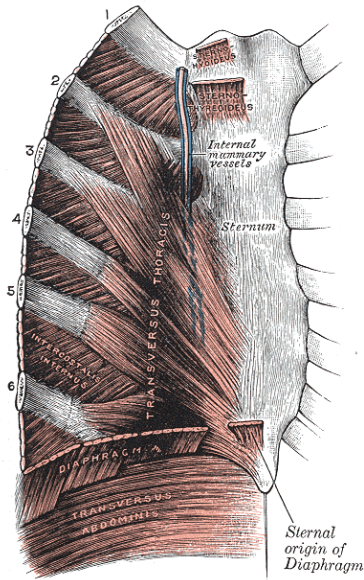


Figure 16: Transverse Thoracic

Gray, Henry. "The Muscles of the Thorax." Gray's Anatomy of the Human Body. Feb. 2004. 10 Nov. 2005 <<http://education.yahoo.com/reference/gray/subjects/subject?id=117>>.

Overall, this muscle differs by the person; it also appears on opposite sides of the same person. The next muscle of the thoracic spine is the levatores costarum which consists of small tendinous, fleshy bunches located between the transverse process of the upper eleven vertebrae. Like the intercostals externi, each fiber is attached to the surface of the rib.

The thin quadrilateral muscle known as the serratus posterior superior is located in the upper back part of the thoracic spine. As the muscle moves downward, it becomes stronger and fleshier. The serratus posterior inferior is located in the thoracic and lumbar region of the spine. It has a rather irregular form, with more broad muscles that are widely separated. As it moves downward, it also becomes more fleshy and separates into four flat muscles that travel to the borders of the ribs.¹⁸

2.3.5 Nerves of the Thoracic Region

The spinal nerves of the thoracic spine assist in the protection of many muscles of the back as well as many vital organs and tissues of the abdomen and chest. Nerve pain within the thoracic region often roots to intercostals pain and irritation. Although it is not common to injure areas of the thoracic spine, nerve damage is one of the leading causes of pain within this region.

The nerves of the thoracic region are divided into the sections in which they are located. The first intercostal nerve runs along the intercostals space (between the ribs) and ends at the front of the chest. The second through sixth thoracic nerves are the thoracic intercostals nerves which are smaller in size and stem from the thorax.¹⁸ The nerves of the lower thoracic region have a larger consistency than the others that deal with this part of the spine. These are the seventh through the eleventh thoracic nerves, which travel anteriorly from intercostals spaces through the abdomen walls; they are termed thoracicoabdominal intercostals nerves. The twelfth thoracic nerve is larger than any other thoracic nerve in the region; it runs along the rib offering communication to the lumbar region. The lateral cutaneous branch of this nerve is large, and unlike others, does not divide into an anterior or posterior branch.¹⁷

The lower thoracic regions nerves often overlap with nerves of the lumbar region. Due to their connection in the spine, these nerves are more likely to experience damage. Many of the most important messages will be sent through these nerves and be received by the brain. The general makeup of these nerves serves a vital role in the spinal communication with the brain.¹⁸

2.4 Lumbar Spine Region

The section of the spine that makes up the lower back is called the lumbar spine and is highlighted in blue in Figure 17. The front of the low back is called the anterior lumbar area and the back of the lumbar spine is called the posterior lumbar area. The lumbar area supplies a number of important functions for the human body. This region functions include structural support, movement, and protection of certain body tissues. When the human body is standing, the lower back is functioning to hold most of the weight of the body. Likewise, when the human body is bending, extending, or rotating at the waist, the lower back is involved in such movements. The normal makeup of this region includes important structures, such as: vertebrae, discs between the vertebrae, ligaments around the spine and discs, tendons, spinal cord nerves, muscles of the low back, internal organs of the pelvis and abdomen, and the skin covering the lumbar area.²⁴



Figure 17: Lumbar region of the spine
"Spine Physiology." All About Back Pain. 18 May 2004. 10 Oct. 2005
<http://www.allaboutbackpain.com/html/spine_luoo>.

2.4.1 Vertebrae of the Lumbar Spine

This region is made up of five vertebrae, although it is not unusual for a human to have six vertebrae. Starting at the top of this region, where it connects to the thoracic

region, the first vertebrae is normally labeled as L-1 and continuing L-2, L-3, L-4 down to the last vertebrae of the lumbar area L-5. The lumbar vertebrae are the five lowest and five largest bones of the spinal column. The lumbar vertebrae have sturdy lamina and there is an absence of costal facets, as well as an absence of foramen, in the transverse process.²⁵ Also, the lumbar vertebral bodies are taller and bulkier compared to the rest of the spine. This is partly because the low back has to withstand pressure from the body weight and from movements such as lifting, carrying, and twisting. Also, large and powerful muscles attaching on or near the lumbar spine place extra force on the lumbar vertebral bodies. The 5th lumbar or L-5 carries more weight than any other vertebral joint in the spinal complex. L5 has its own unique characteristic compared to that of L1-L4; that is, its vertebral body is much deeper in front than behind. The vertebral bodies of the lumbar spine also have four additional processes compared to the rest of the spine, two mamillary and two accessory.¹⁸

The composition of the body of the lumbar vertebrae is large and wider from side to side than from front to back. The vertebrae are also thicker in the front than behind. They are flattened above and below, concave behind and deeply restricted in front and at the sides. Its pedicles are very strong, directed backward from the upper part of the body, and as a result, the inferior vertebral notches are of significant depth. The laminae are broad, short and strong. The vertebral foramen is triangular and larger than in the thoracic, but smaller than in the cervical region.¹⁸

The processes of the vertebrae are similar to that of the other regions. The processes present are spinous, superior articular, inferior articular, transverse, mamillary process and transverse. The spinous process is thick, broad and somewhat quadrilateral

and projects backward and ends in a rough, uneven border, thickest below where it is occasionally notched. The superior and inferior articular processes project upward from the junction of the pedicles and downward from the junction of the laminae. The superior processes facets are curved in and look backward. The facets on the inferior process are convex and are directed forward. The transverse processes are long, slim and horizontal in L1 to L3. Here they arise from the intersection of the pedicles and laminae. The processes incline slightly upward in L4 and L5 and are set farther forward and spring from the pedicles and posterior parts of the bodies. The transverse processes are located in front of the articular processes, instead of behind them, as in the thoracic vertebrae. There are three knob like projections in connection with the transverse processes of the lower thoracic vertebrae. The superior one is connected in the lumbar region with the back of the superior articular process, and is named the mammillary process. The inferior is situated at the back part of the base of the transverse process, and is named the accessory process.¹⁸ Figure 18 below depicts the processes of a lumbar vertebral body.

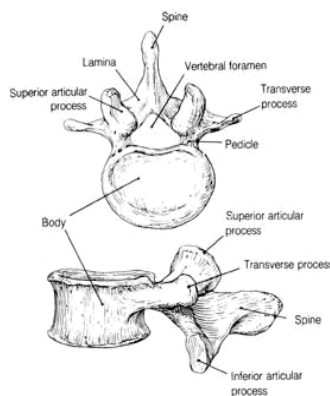


Figure 18: Location of Processes on Lumbar Vertebrae
 "The Vertebral Column and Spinal Cord." Human Anatomy. 5 Feb. 2004. 15 Oct. 2005
 <<http://www.emory.edu/ANATOMY/AnatomyManual/back.html>>.

2.4.2 Discs of the Lumbar Spine

The discs of the lumbar region play the same role as the discs of any other region, acting as shock absorbers, and assist in helping the spine to move. However, the discs in this region are larger, about 1/4" to 3/4" thick due to the extra pressure put on this region. There is an enormous amount of pressure placed on these discs when flexing.²⁵ Disc herniations are most common in the low back, especially discs between L4 and L5, as well as between L5 and the 1st sacral vertebral body. Disc herniations here account for more than 90% of lumbar disc herniations.¹⁸

2.4.3 Joints of the Lumbar Spine

The lumbar region has 5 facet joints. The alignment of the facet joints of the lumbar spine allows freedom of movement as you bend forward, backward and from side to side. They prevent rotation in the upright position by one half of a joint contacting the other half. They allow rotation when the spine is fully flexed forward which leaves great vulnerability to straining the back. The joints change orientation from L1 to L5. At L1 they lay perpendicular, and as they continue down the spine, they become angled. At L5 they are angled out at about twenty degrees, preventing the L5 vertebrae from slipping forwards into the sacrum.¹⁸

2.4.4 Ligaments of the Lumbar Spine

The ligaments of the lumbar spine include similar ligaments as the other regions. The six ligaments in the region are the anterior longitudinal ligament, the posterior longitudinal ligament, ligamentum flavum, interspinous ligament, supraspinous ligament, and the intertransverse ligament. In addition, the lumbar spine has an iliolumbar

ligament and a thoracolumbar fascia ligament. The iliolumbar ligament has a very important function, to restrain movement at the lumbosacral junction. The iliolumbar ligament attaches the fifth lumbar vertebrae to the pelvis and it has five bands.¹⁸

The thoracolumbar fascia, also known as the lumbodorsal fascia, is in three layers. There is an anterior, middle and posterior layer which enclose the erector spinae and quadratus lumborum muscles and unite laterally to give origin to the internal oblique, external oblique and transverses abdominus muscles. The anterior layer is thin but strong and covers the anterior aspect of the quadratus lumborum. The middle layer separates the erector spinae from the quadratus lumborum. The posterior is the strongest. Together these layers make a very strong ligament that help to resist flexion forces. They arise from transverse processes and spinous processes.

2.4.5 Muscles of the Lumbar Spine

This region has some of the largest muscles throughout the human body supporting it. The deep trunk muscles, including the multifidus, anterior and lateral wall abdominal muscles, posterior abdominal wall muscles, paraspinal muscles, and the pelvic floor, are key muscles to the active support of the lumbar spine. Contraction of these muscles produces forces which help to stabilize the lumbar spine. The paraspinal and multifidus muscles act directly to resist the forces acting on the lumbar region.¹⁸

The muscles of the deep trunk are arranged by layers. Those closest to the skins surface, the superficial layer, are covered by a thick tissue called fascia. There are no muscles associated with this layer in the lumbar region. The middle layer, called the erector spine, has strap-shaped muscles that run up and down over the lower ribs, chest and low back. They join in the lumbar spine to form a thick tendon that binds the bones

of the low back, pelvis, and sacrum. The muscles of this layer include the longissimus lumborum and the iliocostalis lumborum. The deepest layer of muscles attaches along the back surface of the spine bones, connecting the low back, pelvis and sacrum. These deepest muscles coordinate their actions with the muscles of the abdomen to help hold the spine steady during activity. The muscles of the deep layer are the interspinales, intertransversarii lateralis, and multifidus. These muscles are in charge of keeping the body erect when either sitting or standing.¹⁸

A muscle of the erector spine, the longissimus lumborum, originates on the ilium and L1 to L5, and inserts on the angle of the ribs. The longissimus lumborum is the largest of the continuations of the sacrospinalis. It is blended with the iliocostalis lumborum. Its fibers are attached to the whole length of the posterior surfaces of the transverse processes and the accessory processes.¹⁸ This muscle serves to extend and rotate the vertebral column.²⁵

The other muscle of the erector spine, the iliocostalis lumborum muscle, is an anterior surface of a broad and thick tendon which originates from the sacrum, spinous processes of the lumbar vertebrae, and the inner lip of the iliac crest. It inserts into the inferior borders of the angles of the lower 6 or 7 ribs. This muscle acts to extend and rotate vertebral column by drawing the trunk to the same side or to depress the ribs. Its nerve supply comes from the posterior rami of the spinal nerves.¹⁸ Figure 19 illustrates the location of the iliocostalis lumborum.

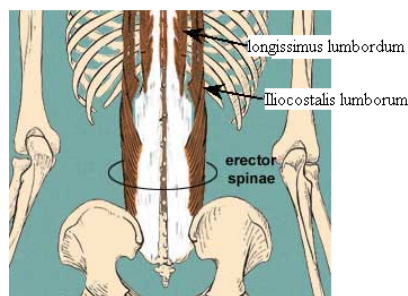


Figure 19: Erector Spinae Muscles
 Suckerman, Solley. "Intermediate and Deep Muscle Layers of the Back." The Anatomy Lesson.
 1999. Mosby Company. 13 Oct. 2006

A muscle of the deepest layer, the interspinales, are short muscular bundles, placed in pairs between the spinous processes of the contiguous vertebrae, one on each side of the interspinalis ligament. The muscle extends from L1 to the sacrum. In the lumbar region there are four pairs. Its action is to extend and hyperextend the spine. There nerve supply comes from the posterior rami of the spinal nerve. Figure 21 points out the interspinalis muscles.

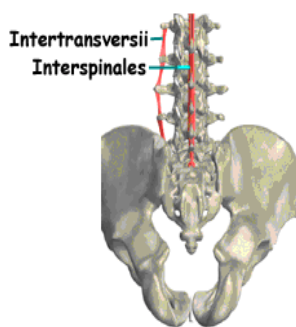


Figure 20: Intertransversarii Muscles and Interspinales muscle
 FotoSearch. 18 May 2005. 15 Oct. 2005 <<http://www.fotosearch.com>>.

The intertransversarii lateralis are small muscles placed between the transverse processes of the vertebrae. Intertransversarii lateralis are arranged in pairs, on either side of the vertical column, one set occupying the entire interspace between transverse processes of the lumbar vertebrae.¹⁸ The intertransversarii lateralis function is to laterally flex the vertebral column.²⁵

The multifidus muscle, seen in Figure 21 is located in the deepest layer of the vertebrae, under the erector group, and is often missed. However, it is one of the most important muscles regarding lower back pain. It is the only muscle that has fibers that actually attach to the posterior part of the sacrum. It serves to extend and rotate vertebral column. The multifidus bilaterally extends the vertebral column, controls lateral flexion to side opposite contraction, and unilaterally rotates vertebral bodies to opposite side. The multifidus gets its nerve supply from the dorsal rami of spinal nerves.

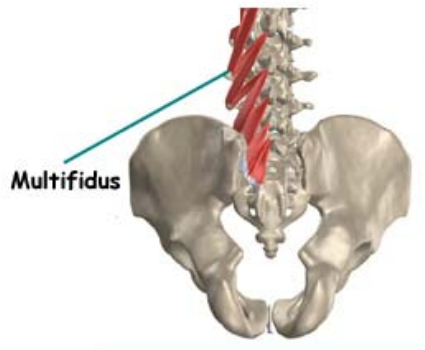


Figure 21: Multifidus Muscle
FotoSearch. 18 May 2005. 15 Oct. 2005 <<http://www.fotosearch.com>>.

The next group of muscles the lumbar region is concerned with are the abdominal muscles. There are four abdominal muscles located within the anterior and lateral abdominal wall closely associated with the lumbar spine. The muscles are the internal oblique, external oblique, transverse abdominus, and the rectus abdominus. These muscles are located between the ribs and the pelvis on the front of the body. They combine to completely cover the internal organs. They support the trunk, allow movement and hold organs in place by regulating internal abdominal pressure as well.

The internal oblique muscle depicted in red in Figure 22 arises from the lumbar fascia and the iliac crest. The internal oblique muscle acts to support the abdominal wall,

flex and rotate the trunk, raise intra-abdominal pressure and support the posterior wall of the inguinal canal. Basically, it works to rotate the trunk and stabilize the abdomen.¹⁸



Figure 22: Internal Oblique Muscle
FotoSearch. 18 May 2005. 15 Oct. 2005 <<http://www.fotosearch.com>>.

The external oblique muscles highlighted in red in Figure 23 are on the border of the rectus abdominus muscles. It arises from the anterior angles of ribs 5 through 12. The external oblique muscle allows the trunk to twist but to the opposite side of whichever external oblique is contracting.⁸

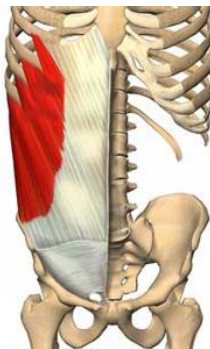


Figure 23: External Oblique Muscle
FotoSearch. 18 May 2005. 15 Oct. 2005 <<http://www.fotosearch.com>>.

The transversus abdominus shown in Figure 24, acts as a natural weight belt, keeping your muscles inside. Its main roles are to maintain abdominal pressure and stabilize the trunk.

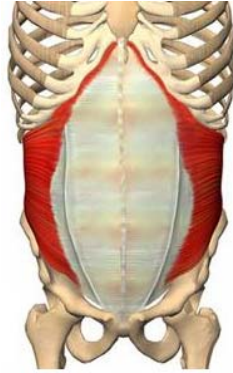


Figure 24: Transverses Abdominus Muscle
FotoSearch. 18 May 2005. 15 Oct. 2005 <<http://www.fotosearch.com>>.

The rectus abdominus is between the ribs and the pubic bone at the front of the pelvis. This muscle has the characteristic bumps or bulges, when contracting, that are commonly known as “the six pack.” Its main function is to move the body between the ribcage and the pelvis. The red regions in Figure 25 display a side and back view of the rectus abdominus muscle.

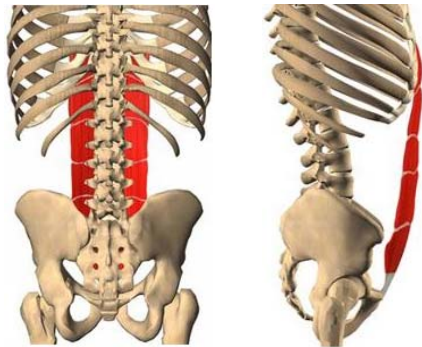


Figure 25: Side and Back view of Rectus Abdominus Muscle
FotoSearch. 18 May 2005. 15 Oct. 2005 <<http://www.fotosearch.com>>.

The next two muscles are muscles of the posterior abdominal wall muscles. The first is the quadratus lumborum. It originates from the inferior border of the 12th rib, then it descends and broadens, and inserts into the transverse processes of L1 to L4, posterior third iliac crest, and iliolumbar ligament in continuity with the iliac crest. It is innervated by the anterior primary rami of spinal nerves T12 to L3. The quadratus lumborum has several actions, including lateral flexion of the trunk, upon a contraction on the same side, and extension of the lumbar vertebral column, upon bilateral contraction. It aids in the functions of respiration by fixing the twelfth rib in relation to the pull of the diaphragm and is a muscle of inspiration, as it also increases the vertical height of the thorax. Its major contribution is attaching to the lumbar spine and compensating for hip functions.¹⁸

The other muscle of the posterior abdominal wall which correlates with the lumbar region is the psoas muscle, which includes the iliopsoas, psoas major and psoas minor muscle. The muscle lies behind the abdominal contents running from the lumbar spine to the inner thighs near the hip joints. The psoas muscle connects the spine to the legs. The iliopsoas muscle is a very strong muscle that lifts the knee up. It starts at the lower back and inserts into the thigh bone. The psoas major is a long muscle placed on the side of the lumbar region of the vertebral column. It arises from the anterior surfaces of the base and the lower borders of the transverse processes of all the lumbar vertebrae. It is a powerful flexor muscle of the thigh at the hip joint. If both psoas major muscles are fixed from below, they act as important flexors of the trunk on the hip, as in sitting up from a lying-down position. The psoas minor is also long and slender, and lays in front of the psoas major. It arises from the bodies of the twelfth thoracic and first lumbar

vertebrae. The psoas minor is a weak flexor of the trunk and the lumbar spinal column. It is supplied by a branch of the first lumbar nerve. These three muscles, which form the psoas muscle, are often portrayed as the villain of back pain.¹⁸ All three of the psoas muscles can be seen in Figure 26.

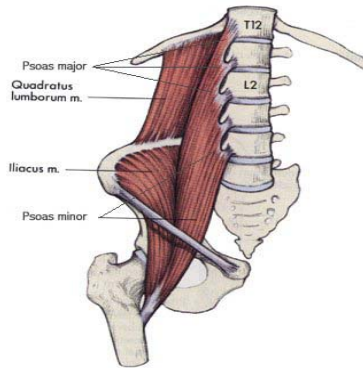


Figure 26: Psoas and Quadratus Lumborum Muscles
"Anatomy for Medical Students." 17 Oct. 2005
<<http://www.med.mun.ca/anatomyts/index/first.htm>>.

The muscles next to the spine are called the paraspinal muscles. These muscles attach to the spinal vertebrae and the pelvis to provide the torso with movement. Also, these muscles must be strong to control the upper torso about the pelvis and thus are frequently overworked and injured.

2.4.6 Nerves of the Lumbar Spine

The lumbar spine has five pairs of spinal nerves. The nerves of this region exit the lumbar region and control very large muscles. Also, many organs and tissues get their nerve supply from nerves exiting this region. Compared to the cervical and thoracic regions, the lumbar nerves have very long roots and much longer to travel before they reach their respective intervertebral foramina. Since the spinal cord ends in the lumbar

region, nerves of the lumbar have nerve extensions and are collectively called caudae equine. The nerves linked to L1 through the greater part of L4 make up the lumbar plexus. The lumbar plexus is on the internal surface of the posterior abdominal wall and its branches pierce the psoas muscle. The L5 nerve supplies the nerves to the muscles that raise the foot and big toe.¹⁸

The branches of the lumbar plexus are the iliohypogastric nerve, ilioinguinal nerve, lateral cutaneous nerve, femoral nerve, genitofemoral nerve, and the obturator nerve. Figure 27 is a detailed view of the lumbar plexus and the location of the different nerve branches.

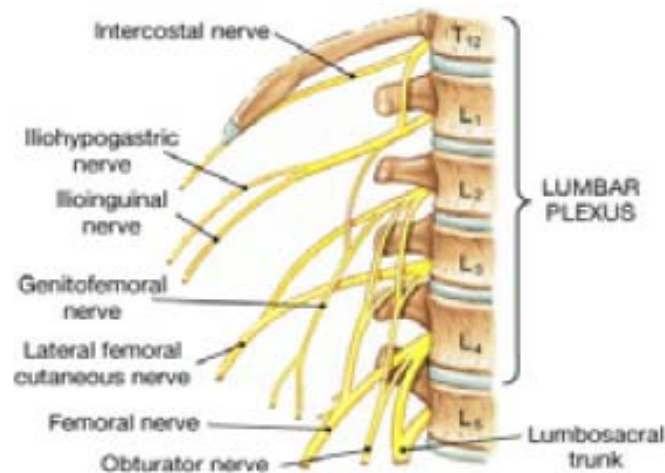


Figure 27: Lumbar Plexus
Martini, Frederic H. Fundamentals of Anatomy and Physiology. 6th ed. Benjamin Cummings, 2004.

The iliohypogastric nerve is formed by fibers from L1 with some contribution from T12. This nerve runs diagonally across the quadratus lumborum muscle. It pierces the internal oblique, external oblique and transverse abdominal muscles. It supplies the skin above the pubis. The ilioinguinal nerve is formed by fibers from L1 with some contribution from T12, same as the iliohypogastric nerve. The nerve lies on

the quadratus lumbordum between the internal and external oblique. It distributes sensory fibers to the thigh. The lateral femoral cutaneous nerve branches from L2 and L3. It supplies the skin of the lateral, anterior and posterior thigh. The genitofemoral nerve is formed from L1 and L2 and passes through the psoas to emerge on its anterior surface. It runs down the psoas and divides into genital and femoral branches. It supplies the skin of the genitalia and the femoral triangle. The femoral nerve connects from L2, L3 and L4 and supplies the knee extensors, thigh flexors and skin of the thigh, hip and medial lower leg and foot. The obturator nerve connects to L2, L3 and L4 and supplies the thigh adductors.

Chapter 3. Spine Mechanics

The biomechanics of the spine involves motion and forces. There are four motions and four forces associated with the spinal column. These motions and forces play a major role in the everyday movement of the spine and the pain related to that movement.

3.1 Motions of the Spine

Movements of the spine are three dimensional. The motions of the spine are known as flexion, extension, side-bending and rotation. Flexion is the forward bending of the spine that occurs in the sagittal plane. Extension is the backward bending of the spine that occurs in the sagittal plane. The right or left bending of the spine that occurs in the frontal plane is known as side bending. The final motion, rotation involves the turning of the spine to the right or to the left on the central axis of the body. More rotation takes place in the cervical and thoracic spine than in the lumbar region. Each of these movements can be seen in Figure 28.

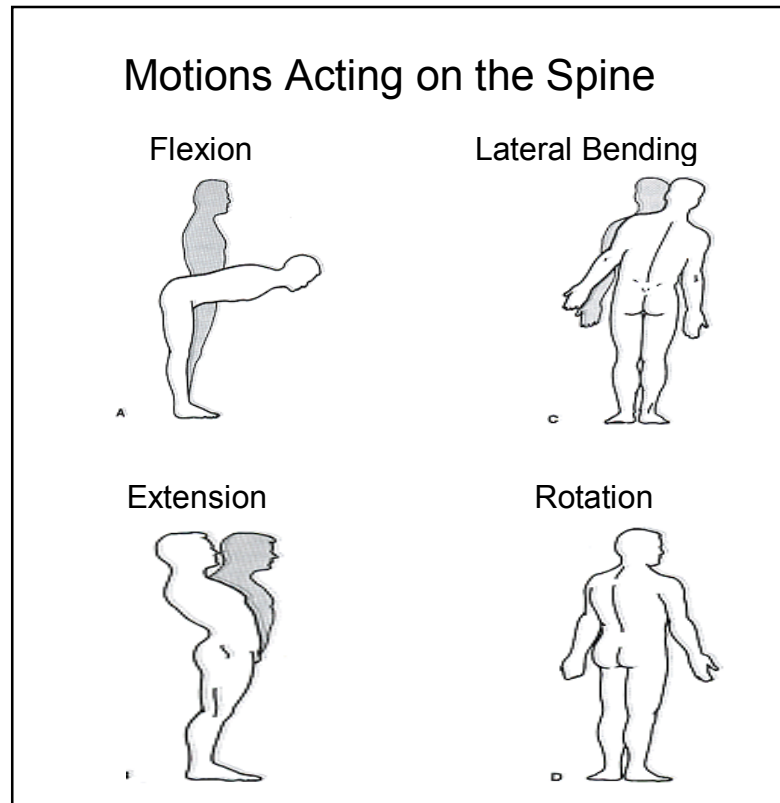


Figure 28: Motions of the Spine When Standing
 "The Spine." 22 Feb. 2002. Virginia Commonwealth University. 22 Nov. 2005
http://www.courses.vcu.edu/DANC291-003/unit_3.htm.

Using these four movements in isolation and in combination, allows one to achieve their activities of daily living. Having good body mechanics assists in aligning and running the spine properly. To minimize stress on the spine, the three natural curves in alignment should be maintained on a daily basis to prevent injury.

3.2 Forces of the Spine

Each segment of the spinal column lays prey to a variety of loads and forces. Various loads include the weight of body segments as well as the weights being handled. Spinal injury severity is directly related to the type and size of the forces present at time

of injury. The four types of forces acting on the spine are compression, tension, shear and torsional.

3.2.1 Compressive Force

A compressive force is a downward force on the vertebrae which compresses the discs and causes them to bulge or shorten and widen. Disc pressure increases as the compressive force increases until damage occurs to the disc structures. Lifting excessively heavy loads can cause injury due to compressive forces. Figure 29 displays compressional forces acting on the vertebrae.

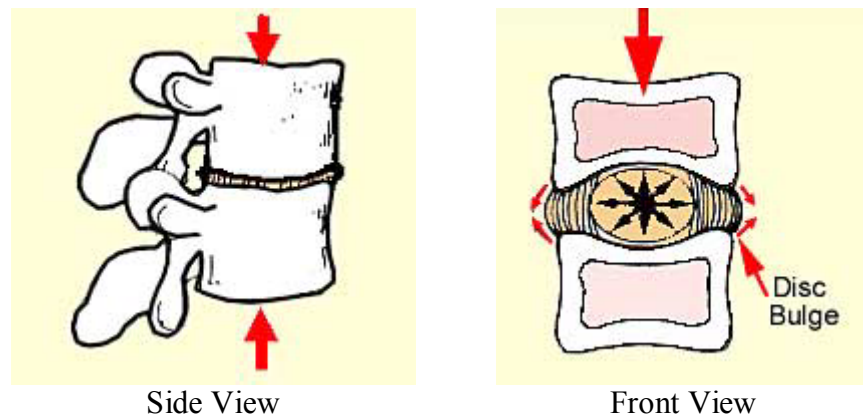


Figure 29: Compressive Force from Side View and Front View
"Basic Spinal Biomechanics." Department of Consumer and Employment
Protection. 23 Oct. 2005. SafetyLine Institute. 24 Nov. 2005
<http://www.safetyline.wa.gov.au/institute/level2/course17/lecture48/148_02.asp>.

3.2.2 Tensional Force

Tensional forces pull apart the structures being loaded and can be seen in Figure 30. Lengthening and narrowing are typically caused by ligaments under tension in the spine. When an individual overstretches their ligaments, a tear to parts or a tear to the entire ligament occurs. Tension force is often related to low back pain.

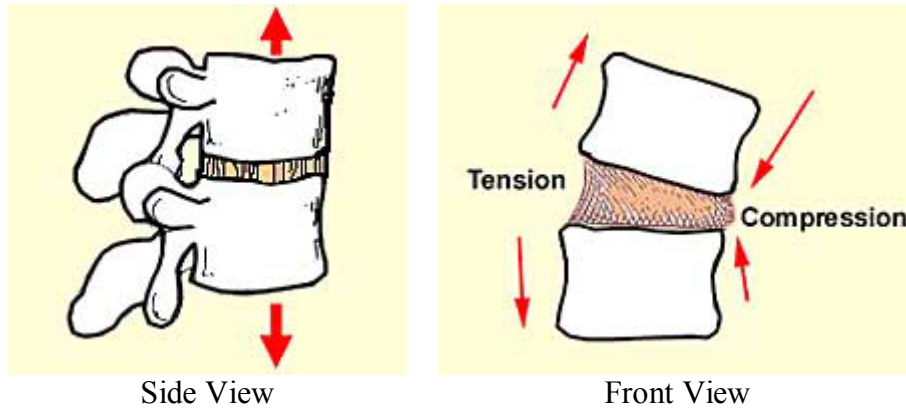


Figure 30: Tension Force from the Side View and Front View
 "Basic Spinal Biomechanics." Department of Consumer and Employment
 Protection. 23 Oct. 2005. SafetyLine Institute. 24 Nov. 2005
 <http://www.safetyline.wa.gov.au/institute/level2/course17/lecture48/148_02.asp> .

3.2.3 Shear Force

The application of a load parallel to the vertebral surface is known as a shear force shown in Figure 31. When bending forward there is often a tendency for a single vertebra to slide forward on the one below it. Most commonly, shear forces occur in the lumbosacral region and are linked to disc injuries.

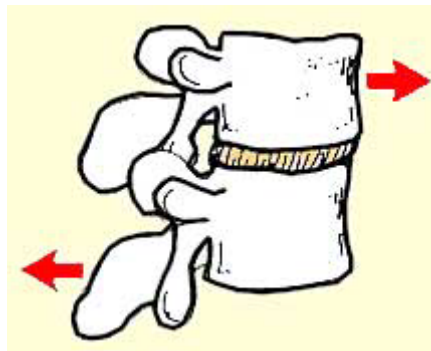


Figure 31: Shear Forces Acting on a Vertebrae
 "Basic Spinal Biomechanics." Department of Consumer and Employment
 Protection. 23 Oct. 2005. SafetyLine Institute. 24 Nov. 2005
 <http://www.safetyline.wa.gov.au/institute/level2/course17/lecture48/148_02.asp> .

3.2.4 Torsional Force

Twisting movements involve torsional forces and the direction of this force is illustrated in Figure 32. This force often causes soft tissue strain through large muscle forces and loads on the intervertebral discs. Twisting movement causes the soft tissues of the spine to be exposed to a combination of compression, shear and tension forces.

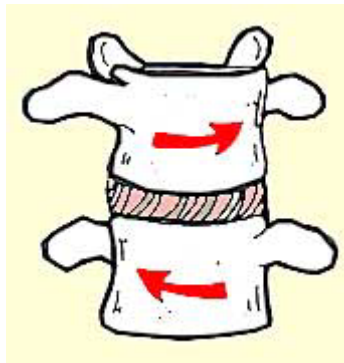


Figure 32: Torsional Forces Acting on a Vertebrae
"Basic Spinal Biomechanics." Department of Consumer and Employment
Protection. 23 Oct. 2005. SafetyLine Institute. 24 Nov. 2005
<http://www.safetyline.wa.gov.au/institute/level2/course17/lecture48/148_02.asp>.

3.3 Sitting

Sitting is a typical part of one's everyday course of events. It is a natural position that the body uses when doing numerous activities and is considered the most frequently assumed posture. Within the work environment, static work postures have become more prevalent causing musculoskeletal problems, particularly affecting the spine.

Surprisingly, approximately seventy-five percent of the workforces have sedentary jobs. Prolonged static sitting is frequently followed by spinal discomfort and complications. A free body diagram of a person sitting can be seen in Figure 33. Forces acting above the waist are shown, as the forces below add no bearing.

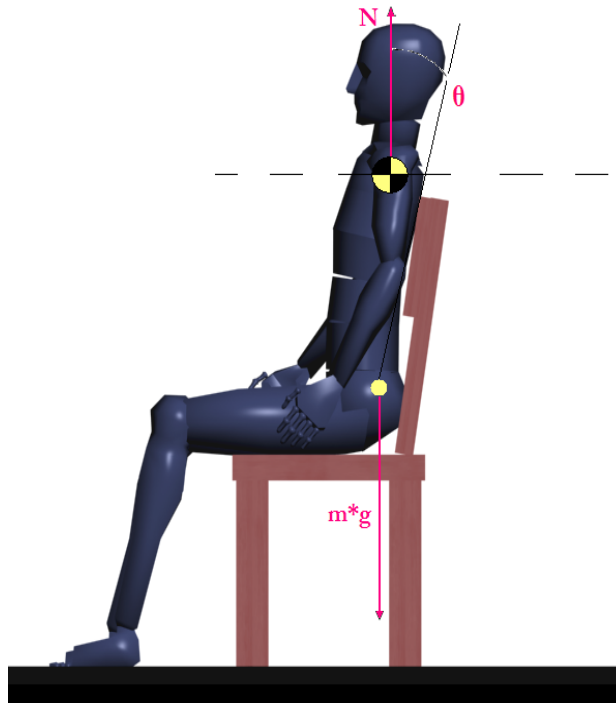


Figure 33: Free Body Diagram of Person Sitting

When sitting hamstring muscles pull on and rotate the pelvis, causing the lumbar spine to flatten. When the spine is straight during sitting, it puts additional pressure on the front of the spinal disks and creates additional strain on ligaments. Typically, when sitting, the lumbar spine is the most affected because it is at the base of the spine, yet some sitting positions do affect the thoracic region of the spine. The area which is most affected is circled in Figure 34.



Figure 34: Seated position with hip flexion
Mitchell, Jacqueline. "Keeping Your Spine in Line." *Scientific American Frontiers*. 4 Apr. 2002. 03 Dec. 2005 <www.pbs.org/saf/1210/images10/spine2.gif>.

When seated, the spine automatically conforms to the shape of the chair which causes bending in the spine, although in the majority of the cases, bending of the spine is generally not conducive to back health. Sitting often causes spine rounding, especially in situations where the person is leaning forward. A relaxed posture allows the spine to relax against the backrest which causes the opposite of rounding- flattening. Relaxed posture is actually the least conducive to spine health, as it causes the most repetitive injuries in the spine due to curvature and flattening. Figure 35 shows the curves that the spine undergoes when sitting.

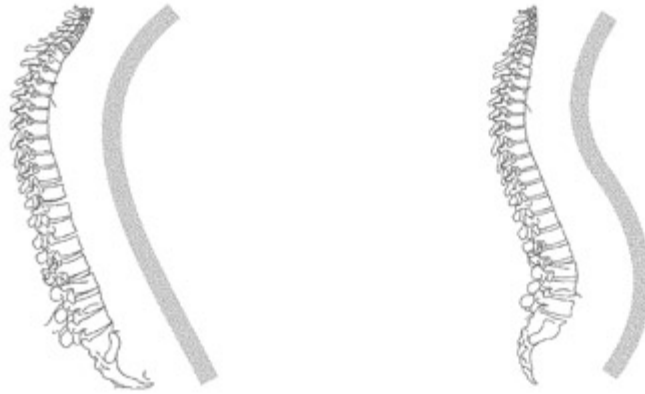


Figure 35: Curves of the lumbar region
 Allie, Paul. "Ergonomics - Seating." Steelcase. 02 Dec. 2005
 <www.steelcase.com>.

Sitting in a regular office chair causes the lumbar regions vertebral discs to flex. In this position, L4-L5 and L5-S1 pointed out in Figure 36 are most affected because they are brought to their flexed extremities. The discs open towards the back while the facet joints become separated and pulled open. The open facet joints allow the lumbar region to twist and bend.

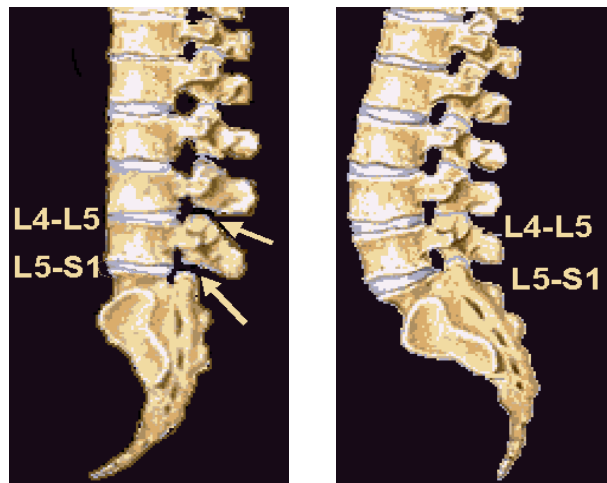


Figure 36: Spine when sitting
 Easy Vigour. 05 Dec. 2005
 <<http://www.easyvigour.net.nz/fitness/pLumbarSpineSitShrt.gif>>.

An anterior shear force occurs when sitting because the vertebra slips forward and off the vertebra below it. This occurs most commonly in L4-L5 of the spine. While sitting, the anterior shear force can promote disc injury such as a herniated disc or sciatic nerve pain. Figure 37 represents a person experiencing an anterior shear force as a picture of the resulting reaction of the vertebrae.

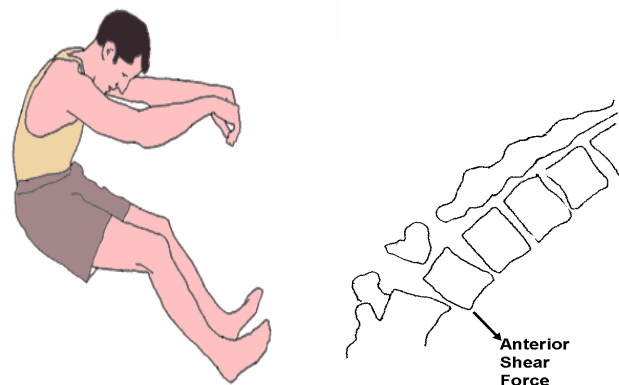


Figure 37: Anterior Shear
Easy Vigour. 05 Dec. 2005
<<http://www.easyvigour.net.nz/fitness/pLumbarSpineSitShrt.gif>>.

When moving from sitting upright to a reclining position, the spine experiences various changes. It first faces pressure changes on the thoracic and lumbar curve. It reduces the vertical loading of the upper trunk by 31%. The path of motion in each spinal region is independent, based on its vertebrae and their size. Figure 38 demonstrates the range of postures one may assume while sitting.

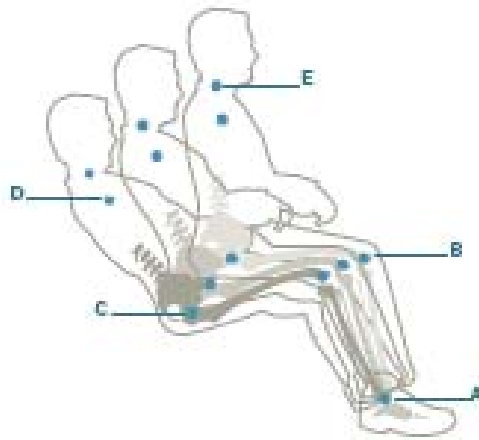


Figure 38: Sitting at various angles
"Dynamic Stabilization." 27 Oct. 2004. 06 Dec. 2005
<http://www.back.com/articles-motion_preservation.html>.

Although it is often overlooked, spinal injury is preventable by doing simple things to stabilize the spine. By sitting in a neutral position and then allowing constant movement by standing up frequently, the spine will experience much less strain. Sitting higher and allowing the legs to hang at a 90° angle will cause minimal curvature, leaving the spine in a more comfortable position.

3.4 Standing

Compared to sitting, standing is a much more unstable position which involves a relatively high center of gravity located over a relatively small base of support. Standing requires much more effort than sitting, especially muscular effort. Muscle effort is needed for fine motor control of repeated tasks in standing. When standing, there is an increase in load on the legs and more demand on the circulatory system. While standing, the spine can feel compression forces up to three times the weight of one's trunk.

When standing at ease, the back muscles may show slight activity, intermittent activity or no activity, and the amount of activity can be influenced by changing the position of the head or allowing the trunk to sway. These differences can be explained to the location of the line of gravity on relation to the lumbar spine in different individuals. In about seventy-five percent of individuals, the line of gravity passes in front of the center of the L4 vertebra, and therefore essentially in front of the lumbar spine. This results in gravity exerting a constant tendency to pull the thorax and lumbar spine into flexion. Conversely, when the line of gravity passes behind the lumbar spine, gravity tends to extend it, and back muscle activity is not required. Instead, abdominal muscle activity is recruited to prevent the spine from extending under gravity. To preserve an upright posture, a constant level of activity in the posterior sagittal rotators of the lumbar spine will be needed to oppose the tendency to flexion.

When the spine is erect or a person is standing up straight, the weight of the upper body (W) is directly over the legs. This position creates the need for erector spine muscles to be active, however, little force is exerted by the back and leg muscles. Most of the body's weight is supported by the skeleton and not by muscle action. A vertical line from the center of gravity of the upper body (C) passes through the middle of the foot. When standing upright, the lumbosacral disc, the disc next to the sacrum lies at an angle to the horizontal of forty degrees and can be seen in Figure 39. The weight of the head, trunk and arms is about six tenths times the total body weight and acts via the disc on the sacrum and pelvis. Newton's Law which states that to every action there is an equal and opposite reaction can be applied to the spine, therefore, the reaction of the pelvis and sacrum on the rest of the spine is also six tenths times the total body weight.

This reaction can be resolved by forces parallel and perpendicular to the direction of the spine where it meets the pelvis and is known as compressive and shear forces. When the back is in this erect position, the forces on support structures are more evenly distributed. Figure 40 illustrates the forces acting on the spine when a person is standing erect; the pivot in the figure represents the lumbosacral joint.

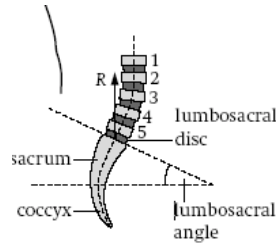


Figure 39: Angle of Lumbosacral Disc When Standing Erect
"Lumbosacral Spine." 5 Jan. 2003. 05 Dec. 2005
 <<http://connection.lww.com/products/hendrickson/documents/ch3.pdf>>.

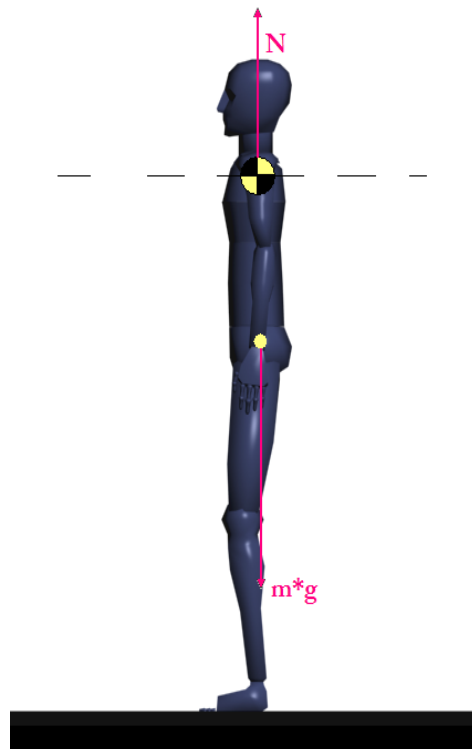


Figure 40: Forces Acting on the Human Body When Standing Erect

Static standing work postures or frequent bending and twisting greatly affect the spinal column. The shaded area in Figure 41 represents the compressive forces between the L3 and L4 vertebrae when standing. As illustrated, lying down creates the least force and the greatest force must be exerted when sitting slouched. This figure well exemplifies the idea that more forces are placed on the spine as one goes from standing erect to bending; the forces are especially applied to the lower part of the spine.

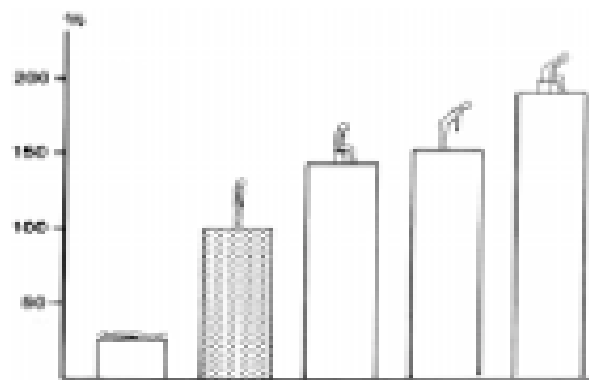


Figure 41: Compressive Forces vs. Various Positions of the Spine
Adams, Michael A. "Mechanical Initiation of Intervertebral Disc Degeneration." Spine Inc. 25 July 2003. 10 Dec. 2005
<<http://www.spine-inc.com/glossary/m/mechanical-initiation.htm>>.

When the spine begins to bend, your backs' alignment changes, as well as the center of mass in the abdomen. Flexion moments are exerted on the lumbar spine when the trunk leans forward. The force exerted is the weight (W) of the trunk above the lumbar spine. This force acts downward from the center of mass of the upper trunk (m). The moment arm (d) is the distance from the lumbar spine to the line of gravity acting on the upper trunk. The magnitude of the flexion moment (M) is the product of the force and the moment arm. The further an individual leans forward, the longer the moment

arm and the greater the resultant moment. Figure 42 portrays these forces acting on the spine when bending.

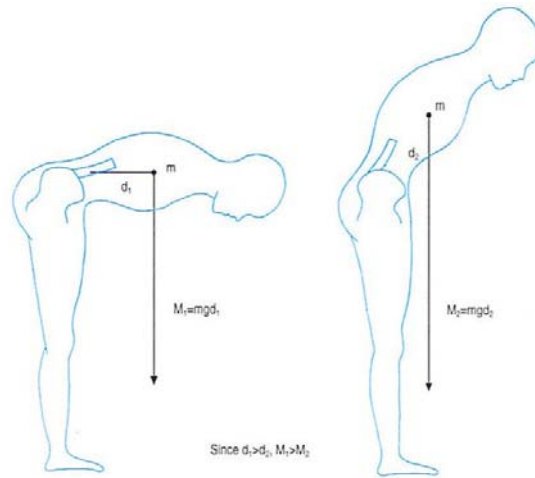


Figure 42: Forward Flexion of the Human Spine

In the standing position, forward bending causes the greatest increase in disc pressure and, lifting a weight in this position, raises disc pressure even further. The pressure will be greatly increased if bending additionally involves rotation. The percentages are shown in Figure 43 for the amount of disc pressure related to various activities. This increase in pressure proportionally leads to an increase in back muscle activity. However, the flexion of the lumbar spine does not compromise the strength of the back muscles. The moment arms of the fascicles are reduced by flexion, but the moment arms of others are increased, resulting in a little amount of change in the total ability to produce moments. However the fascicles however, are elongated which reduces their maximum force on active contraction, but increases the inactive tension in the muscles, resulting in no reduction in total tension. Upon flexion when standing, the total extensor moment of the back muscles and the compression load that they exert change little from those in the upright position. However, the shear forces change

immensely. The posterior shear forces on the upper lumbar segments are reduced by flexion, but the shear force on L5 reverses from an anterior shear force in the upright position to a posterior shear force in full flexion.

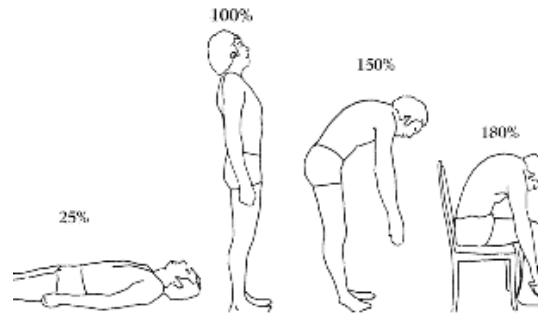


Figure 43: Percentages of Disc Pressure in the Spine
Marras, William S., and Kermit G. Davis. *Spine*. Vol. 26. Lipincott,
Williams and Wilkins Inc. 2566-2574.

3.5 Walking

Walking is defined as moving over a surface by taking steps with one's feet at a chosen pace. A free body diagram of a person walking can be seen in Figure 44. This action, though perpetuated by the legs, is actually governed by the spine. Not only does the spinal cord send the signal to the legs to induce movement, but the back itself powers the movement carried out by the legs.

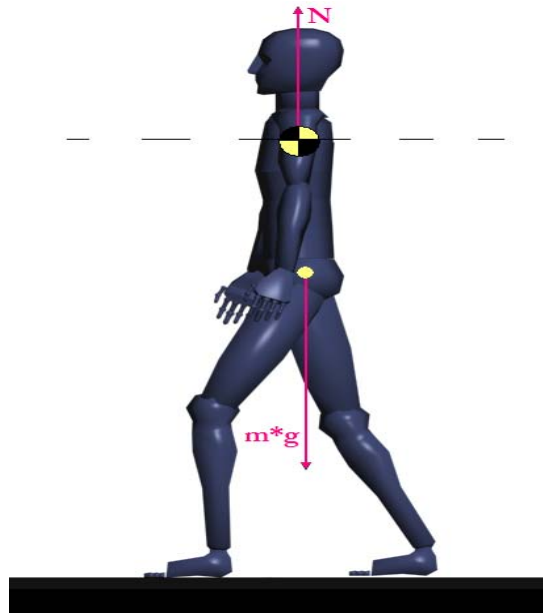


Figure 44: Free Body Diagram of Person Walking

Mainly, ambulation is governed by the lumbar region of the spine. During standard walking motion, the lumbar region is responsible for maintaining balance for all of the lower extremities. Per gait cycle, the lumbar region is extended and flexed twice. Peak extension is encountered during heel contact, peak flex at mid-stance.²⁶ Figure 45 displays a gait period.

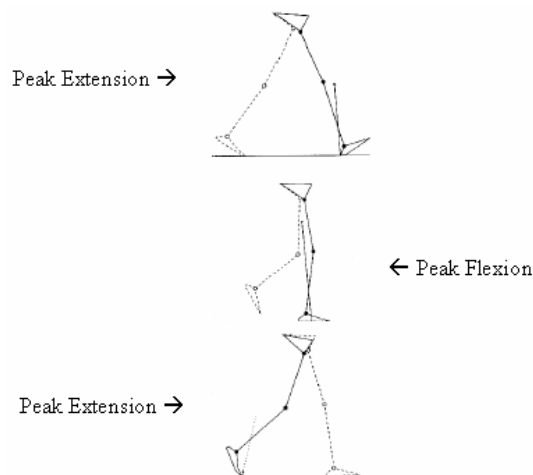


Figure 45: Gait Period

Callaghan, J P. Gait Period. 1999. Clin Biomech, Ontario. Low Back Three-Dimensional Joint Forces, Kinematics, and Kinetics During Walking.

A gait cycle is the period in which walking occurs. This cycle consists of several consecutive movements. For this example shown in Figure 46, assume the subject is facing to your right. First, the entire leg is swung forward by the hip muscles which anchor to the front of the legs. This results in counter-clockwise rotation around the hip joints. Rotating counter-clockwise about the knee joint, the upper leg carries the lower leg forward. As the leg approaches collision with the ground, the leg begins to decelerate. Rolling clockwise about the ankle, the foot rolls heel to toe and is once again lifted from the ground.

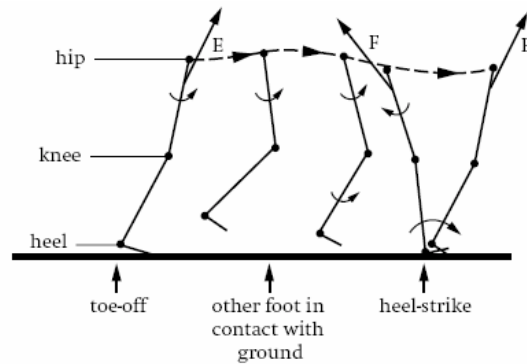


Figure 46: Gait Period With Movements
Goh, J H.. Gait Period Moments. 1998. Clin Biomech, Ontario. Low Back Three-Dimensional Joint Forces, Kinematics, and Kinetics During Walking.

Walking induces certain forces that are distributed throughout the body. When walking, kinetic energy from this motion travels up the spine. The spine then passes it off to the rest of the body. The main two receptors are the ribs and the shoulders. In the case of the shoulders, the force is delivered in a spiral-like shape towards the arms, forcing the torso to be turned.²⁷

There are several forces associated with the motion of walking. In the legs, the joints absorb and support these forces, which sum up to be more than double the actual body weight. The femur that meets the pelvis right below the hip and this is the major

joint carrying the load during walking. The flexors in this area are present as support, providing resistance to the upper body rotating about the femoral head. Flexors and extensors tug and release in a period due to the fluctuation in force, being less during the leg swing, and reaching its peak when the heel strikes contact. This acts in line with the ground reaction force, making parabolic force curve, with two points of maximum force and then a minimum in between. The two outer points of maximum force are experienced at heel strike and toe off, while the minimum force is experienced in between.

The specific forces in walking are as such. First there is potential energy. $PE = m \cdot g \cdot h$, which is simply the weight of the person multiplied by their height. In line with this is kinetic energy, $.5mv^2$, or half of their mass multiplied by their velocity squared. As one increases, the other decreases proportionally. Very little energy is lost to external work. The potential energy is at its maximum during mid-stance, the body's uprightness, putting its center of gravity at its highest. Once the body then progresses forward into the next step, the center of gravity falls, potential energy with it and kinetic energy rises.

Analysis into the flexors and extensors in the area shows a proportional relationship that keeps the body stable while moving. A frontal and side view can be seen here in Figures 46 and 47 respectively.

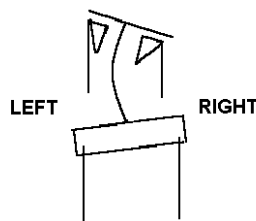


Figure 47: Hip Balance
Thompson, Dave. Hip Balance. 2001. Clin Biomech, Ontario.
Effects of chronic lengthening or shortening of muscle: "stretch weakness" and "adaptive shortening."

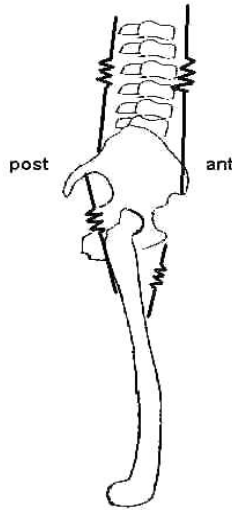


Figure 48: Hip Extensors/ Flexors
Thompson, Dave. Hip Extensors/Flexors. 2001. Clin Biomech, Ontario.
Effects of chronic lengthening or shortening of muscle:
"stretch weakness" and "adaptive shortening."

Due to constant movement, the pelvis is rarely ever level. And so, the body must compensate such that it can keep stability during this constant change. Flexor and extensor muscles throughout the region handle this. In order to provide balance the flexors in the right hip elongate in response to the right hip joint's extension. The humoral joint on the right is flexed and so the humeral flexors shorten. The left hip joint is flexed and so the flexor muscles in the left hip shorten. And finally, the left humeral joint is extended and so the humeral flexors elongate.²⁸

The ankle and knee also experience certain force equations about them during walking. To examine this, the point right after toe lift is examined. For the knee, the muscles in the upper leg push it forward, creating forces around the knee joint. Through basic physics, the movement can be observed and picked apart to recognize the different forces acting.

Chapter 4. Spine Dynamics

Dynamic modeling of the spine is associated with the relation between the forces acting on a body and the resulting movement. Musculoskeletal joint dynamics are generally non-linear, although for small displacements about a fixed point, the dynamic behavior is satisfactorily represented by a linear second-order model.

4.1 Stability of the Spine

Spinal stability is the ability of the spine to remain rigid and unchanged even in the presence of outside forces. The spine finds this rigidity through muscle co-activation. The muscle tissues in the spine complement each other through paired contraction and extension in an attempt to absorb shock and forces put on it and sometimes generate co-contraction to keep stability. In the lumbar spine, the majority of the spinal stabilizers can be found.²⁹

The lumbar spine is the main site for support in the back. Each joint in this region contains six degrees of freedom, three based on rotation and three based on translation. And so stability can be achieved when stiffness is created in the three rotations and translations. If this stability cannot be maintained during heavy loads, this is when instability occurs in the form of displacement or back pain.

The muscles and joints must work together to achieve this stability. Upon muscle contraction, spinal stiffness increases in both the muscle and joint. Therefore when a muscle group stiffens to sustain a load it is critical that they and the joints complement each other to reach the critical stiffness required. One of two problems can occur with this stiffness. When too great stiffness is applied, joint motion becomes severely limited restricting what can be done and when too little stiffness is applied, the system collapses

under the force. For maximum stability, spinal stamina is more important than spinal strength especially when sustaining heavy loads for lengthy periods.³⁰

4.2 Physiological Model of the Spine

The physiological model created represents the actions one's spine will experience through various force applications. An inverted pendulum acts at the spine, being held by springs which serve as the muscles that surround the spine. This is a simple model of spinal stability, including the trunk, flexor and extensor muscles. Static equilibrium is achieved when the moment caused by the external forces is balanced by the sum of the moments caused by the extensor and flexor muscle forces.³¹ Figure 49 is the physiological model created with all of the needed components included.

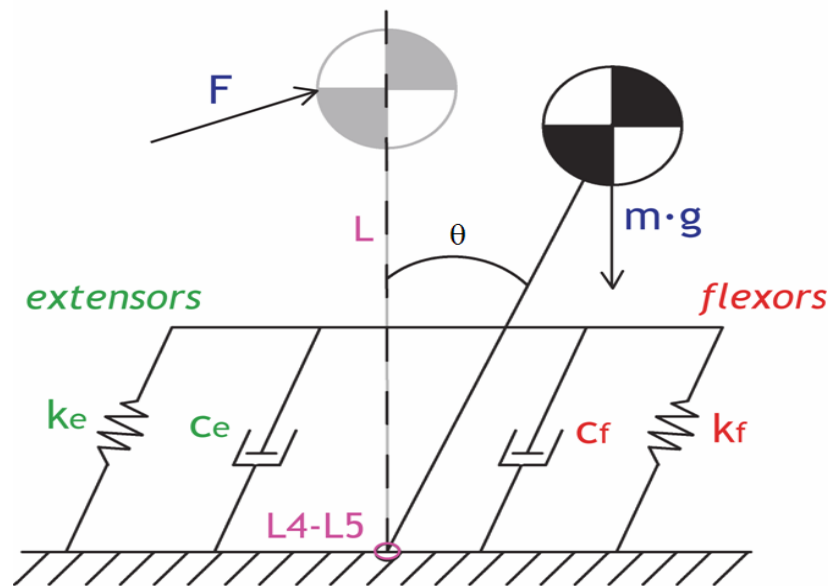


Figure 49: Inverted Pendulum Model

4.3 Mathematical Model of the Spine

The ultimate goal of the research conducted on the spine is to create a stability index. The stability index will indicate what forces one can sustain to maintain equilibrium. The index will be comprised of various numerical values that cannot be exceeded without causing injury to the spine. These values will be crucial in generating a new understanding of what loadings can be applied to the spine. The stability index which will be created is based on the model equation (Equation 1.1):

$$m\ddot{\theta} + C\dot{\theta} + K\theta + G + F(t) + R(t) = 0 \quad [1.1]$$

From the physiological model shown in Figure 49, the equation was derived. The equation was formulated to produce results for the stability index involving the various factors which play significant and minor roles in determining spinal injury.

4.2.1 Forces of the Equation

The first step in creating our mathematical model equation was to look at the forces that would be involved. The equation began by using the fundamental equation known as Newton's second law. (Equation 1.2)

$$\Sigma F := ma \quad [1.2]$$

Initially, the simple equation was used when analyzing free body diagrams of a person sitting in a chair. The forces are summed in the x and y direction, based on the equations, when a force is applied, a person will oscillate back and forth. This oscillation creates the demand to establish an equilibrium point, otherwise also known as a reference point.

For the stability index to be created, an in depth look into the internal forces on the spine was necessary. Since the spine is being observed dynamically, it is much more difficult, versus the static approach. All of the simple formulas for the static spine do not apply when numerous forces are involved. A preliminary equation was formed which included these forces. (Equation 1.3)

$$m\ddot{\theta} + c\dot{\theta} + k\theta = F(t) \quad [1.3]$$

The first of the three typical internal forces is inertia, represented by the first term involving m . This force is proportional to acceleration. With respect to the spine, inertia is the tendency of the muscles to resist acceleration. Therefore, unless an external force is applied to the spine at rest, it will remain at rest or, if the spine is in motion, it will remain in motion in a straight line.

Damping is represented by the second term in Equation 1.3; this is the force proportional to velocity but opposite in direction. Damping is any effect that tends to reduce oscillations and refers to the dissipation of vibrational energy. All physical systems inherent damping, but the level of damping can be different based on the increase energy dissipation in particular vibration modes. With this, the response of a structure driven at a resonant frequency can be greatly decreased. Knowing this, studies have shown that this can significantly reduce overall motion or acceleration of a system.

There are many methods for measuring the damping of a vibration system. To estimate damping ratios from frequency, the half-power bandwidth method can be used. This method provides graphic data which can be used to evaluate the damping of a system. Figure 50 is an example of a graphical analysis created to test motion decay for

viscous damping, the “x” contained in this equation however would be replaced by “θ” in the case of calculating damping for the spine.

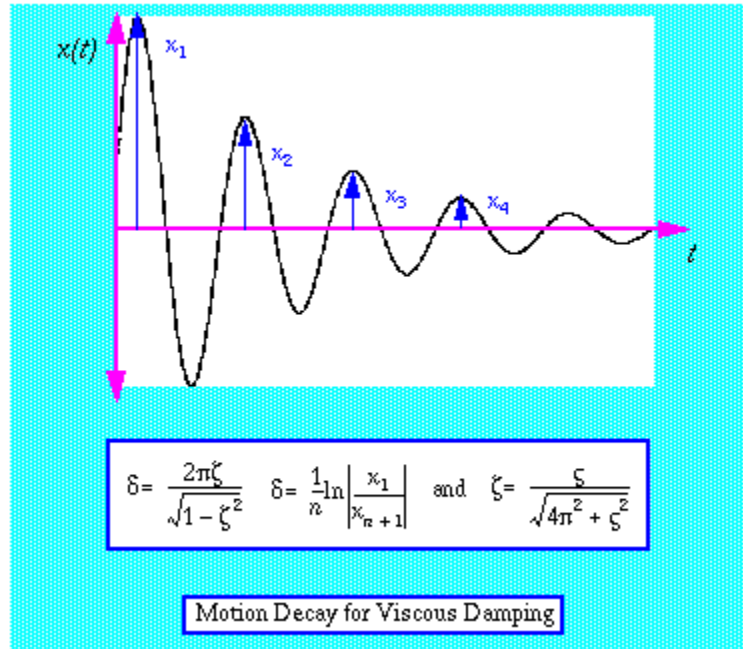


Figure 50: Graph modeling motion decay for damping

There are many methods for measuring the damping of a vibration system. To estimate damping ratios from frequency, the half-power bandwidth method can be used. This method provides graphic data which can be used to evaluate the damping of a system. The figure below is an example of a graphical analysis created to test motion decay for viscous damping.

The last term in Equation 1.3 is stiffness which is proportional to displacement. Stiffness is the resistance of the spine to bending. Muscle stiffness is proportional to muscle force. The equation below is used to calculate the stiffness of a muscle. Joint stiffness promotes stability by helping to prevent joints from moving outside their normal

range of motion. The active muscle tissue provides the largest contribution to the overall joint stiffness and is therefore the dominant contributor to functional joint stability.

$$K=(qF)/l \quad [1.4]$$

q, in this equation is a physiological value that ranges between 10 and 80, l represents the length of the muscles and F symbolizes the force of the muscle. Since muscles can only pull to give stiffness the force must be increased. Active muscle stiffness is a primary factor to the control of spinal stability. Stiffness of the trunk is the dynamic relation between a small perturbation force and the succeeding trunk displacement. Trunk stiffness is greater during flexion than extension exertions.³¹

4.2.2 Reflex Delays

After analyzing the internal forces, reflex delays were added to the equation, represented by G in Equation 1.1. Reflex can be described as a body's reaction to a stimulus. Therefore, reflex delays or position delays are a delay in the length of time that it takes to get to the brain to indicate that there is a compromise of the spinal cord. When the body perceives a stimulus, a signal is sent to the brain and then the brain sends a signal in response and the body will react, or in this case, the spine. Studying delay reflex can help predict spinal injury. In order to calculate delays, the following equation will be used:

$$G_e = \mu_e(\theta(t - \tau_e) + \dot{\theta}(t - \tau_e))$$

$$G_f = \mu_f(\theta(t - \tau_f) + \dot{\theta}(t - \tau_f))$$

- is representative of the gain, and this will be a value to determine so that one can maintain stability. The symbol τ is used to compute the torque against joints and muscles of the spine. High levels of torque are capable of damaging the muscles and joints between and around vertebrae. The first part of the equation, $\theta(t - \tau_f)$ is the position delay and the second part, $\dot{\theta}(t - \tau_f)$ is the delay with respect to change in velocity.

There are a number of factors that contribute to reflex delays and this subject is still very much wide open, therefore it is difficult to come to an overall conclusion as to what actually causes the delay in groups of individuals. In order to thoroughly examine an individual's reflex delays, their past history information of spinal pain and injury is important. Joint stability is closely linked to occasion of injury. If an individual has had previous back pain or injury, there is a possibility of ligament damage or nerve damage which could lead to decreased spine stability. Next, are factors like height and weight which may cause a delay and result in injury. The greater the individual's height or weight the greater the torque that the spine must endure. Mechanical instability can also play a part in causing a delay. The ligament structure or the tissue may be damaged. Functional instability, dealing with a disruption of the sensory receptors of the spine, can also cause delays. If an individual is fatigued, they may experience a delay reflex.³¹

4.2.3 Corrective Measures

When reflex delays are inactive, corrective measures must be taken. The letter R in Equation 1.1 symbolizes the corrective measure. A corrective measure can be a variety of different things and can range from something as simple as exercise to something much more complex such as a surgical procedure.

An example of a corrective measure on the spine through surgical solution is spine fusion. This corrective technique is a surgery performed to link together individual segmental vertebrae within the spine. The surgery is necessary when two or more vertebrae need to be linked together. Typically this type of corrective measure will take place when there is not enough disc space; the surgery would eliminate the motion that often occurs within that part of the spine. The spine fusion works by simulating bone growth between the vertebrae. Once new bone is formed, the vertebrae will become linked. Through this linkage, the source of the issue is often eliminated. Figure 51 is an image of what the spine will look like after undergoing spinal fusion surgery.

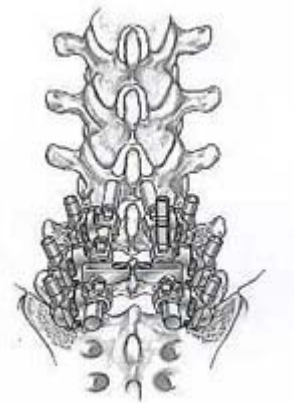


Figure 51: End result of spinal fusion surgery on the spine
"Artificial Disc: an Alternative to Spinal Fusion Surgery." Spine
Universe. 19 Nov. 2005. 10 Dec. 2005 <www.spineuniverse.com/.../aans_charite-NN.jpg>.

Not all corrective measures are solved by a surgical process. Another option is exercise which often replaces the idea of surgery, whenever possible. An example of an exercise used as a corrective measure is the alternate leg raise illustrated in Figure 52. This exercise is designed to release tension and relax the muscles in the middle and lower back. The exercise works by taking a deep breath and exhaling slowly through the

mouth. Lying down, flat on the back one slowly brings one knee up at a time, bringing each closely towards the shoulder. Then one returns the foot to the mat, sliding the leg all the way out. Once returned to the original position, one brings the other knee up towards the shoulder and repeats the same steps. It is extremely important to bring the knee to a comfortable bent position. This exercise has been proven to increase flexibility while relaxing the muscles throughout the back.³²

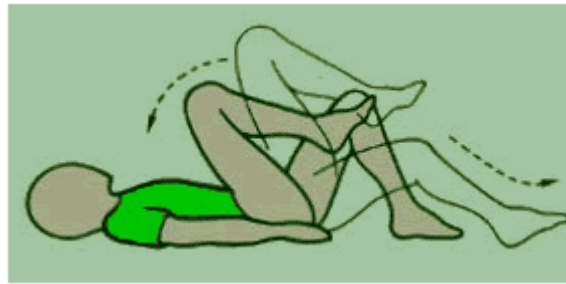


Figure 52: Alternate leg raise exercise

4.2.4 Extensor and Flexor Muscles

The stability of the spine is dependent upon the coactivation of the flexor and extensor muscles of the trunk around a neutral spine posture. This coactivation is increased when a person carries a load and provides the needed mechanical stability. The psoas muscles and the abdominal muscles are agonist and antagonist respectively. Any back movement is combination of flexion, extension and rotation movements. In flexion, when the trunk bends forward and to the side, the rectus abdominus, internal and external obliques and hip flexors are active. When the back straightens from a bent position or extends from an erect position, the erector spinae, quadratus lumborum, in combination with the gluteus maximus and hamstrings, perform this movement. When a subject is turning to the side while sitting down, the rectus abdominus, obliques and erector spinae muscles are involved in this rotation movement.

By taking into account the muscles which surround the spine, the equation takes on a new form seen in Equation 1.5.³¹

$$m\ddot{\theta} + (C_e + C_f)\dot{\theta} + (K_e + K_f)\theta + G_e + G_f + F(t) + R(t) = 0 \quad [1.5]$$

4.4 Linearity and Non-linearity of the Spine

The linearity and non-linearity of the spine is a very controversial and researched topic. Currently, there is no linear way to study the spine with definite mathematical numbers. Although these numbers are often generalized, the great search has remained to produce a linear analysis containing exact values to identify exact points of injury.

The non-linear analysis seen in Figure 53 represents the stable and unstable positioning as one moves themselves alright the peak.

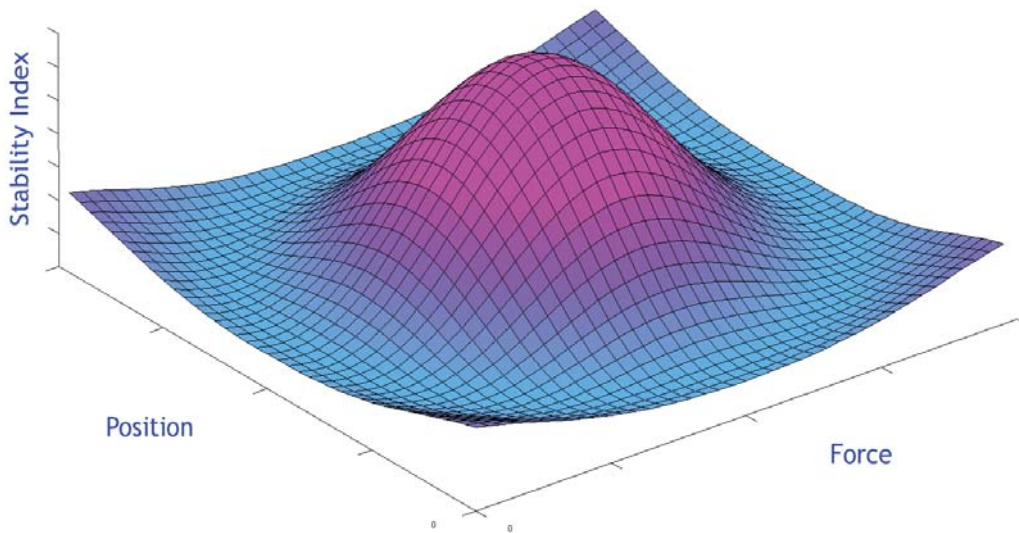


Figure 53: Non-linear analysis
Cholewicki, Jacek. Personal interview. Nov. 2005.

At the very top the individual is the most stable, experience the ideal neutral position. As they extend outwards to the purple region, the stability becomes more unstable approaching complete instability. The blue region represents fully flexed extremities and complete instability. The ideal of the stability indices will determine the exact point where one will experience a certain amount of instability before encountering injury.

Chapter 5. Studies on the Spine Related to the Manufacturing Environment

5.1 Sitting Study

Back injury in the workplace can be related to a variety of different things however the injury due to repetitive sitting is the focus of the case studied. Georgia Tech completed a case study on back injury within the apparel manufacturing work environment. They based their study on three typical plants in the southeastern United States which had identified high occurrences of musculoskeletal discomfort among sewing operators. The study was broken up into five phases. The first phase of the program was to complete a survey of these three plants and decide what the major issues involved were. The next three phases went into detail on how to take corrective measures. The final phase consisted of seeking out a conclusion.

Apparel manufacturing is a labor intensive, assembly line process which calls for substantial amounts of repetitive, skilled operation. Operators must swiftly obtain and position parts, guide them through the machine and then dispose of them. The product that was being made was trousers in all three plants. On a preliminary visit to each plant, management, engineers and floor interviewed and the plant was toured to get an overall feel of the working environment, There were specific jobs that were targeted that resulted in back pain or injury. Preceding the initial visit, confidential interviews were conducted by volunteer operators as well as observation.

A major goal of the study was to document musculoskeletal injury or discomfort experienced by the operators and then begin relating this injury to job and workplace elements that might have contributed. Approximately half of the workers reported that they at least sometimes experience pain in their back. It was also that discomfort tended

to increase throughout the work day. Much of this pain was attributed to the operators working posture. Operators typically adopted a hunched working posture. After analyzing videotape records of thirty different operators, it indicated that forty percent stooped forward, flexing the torso at least twenty degrees throughout the cycle of the machine. Sixty percent tilted their heads more than twenty degrees throughout the cycle. The operators stated that this posture described was necessary to obtain maximum production. This posture results in overall muscle fatigue and discomfort which can lead to very serious back injury. They worked in this hunched posture due to the visual demand of the work and the geometry of the workstation. The tendency of operators to work in this hunched posture can be attributed to at least three factors, the visual demands of the work, the geometry of the workstation and inadequate seating.

These three factors were all examined. Sewing is a visually demanding and 36% of the operators stated that because the illumination was insufficient, they were required to lean forward. In relation to the workstation geometry and the operator dimension, it was evaluated that the machine being used was an average of 15 centimeters to close to the edge of the work surface therefore requiring the operator to position their chair away from the work surface once again causing them to lean forward. The chairs being seated in by the operators were straight backed wooden or metal chairs. This style of chair lacked any padding for reducing compression and fatigue.

The spinal related injury that results from these problems can be addressed according to this case study. The badly designed workstation must be designed and adjusted properly for the operators according to specific standards that will reduce the strain on the spine. The hard, unadjustable seating can be replaced with chairs that

promote a lordotic seated posture. Training can be provided to the operators on the most correct way to complete their job.

This case continued on with a study, twelve operators were given proper training on how to avoid spinal injury and then broken up into two groups of six. The first group, after being given the training continued on with their work and they were observed through video surveillance so that a measure of their postural angles could be taken. The second group was not only given training but also chairs that were ergonomically fitting. The first group, with just the training showed improvements, the mean improvement in back angle was 2.3 degrees, with three of the six subject showing improvement. The reported musculoskeletal pain decreased by 53.6%. The second group, given the proper style of chair saw substantial improvement, the mean improvement in back angle was 8.3 degrees with five of six subjects showing improvement and the reported musculoskeletal pain decreased by 90.3%. Also, there was an increase in production in both groups.

This case study emphasized the growing need for a stability indices which can give values one can sustain before injuring themselves based upon that individual's physical makeup as well as their past history. Although there is a lot of ergonomic research done on how to properly sit at your workstation, the subject needs to be looked at more closely since the repetitive motion of the task being performed is the underlying factor for the pain or injury experienced. Being able to have an indices which indicates that after x amount of repetitive motion, you will become unstable and be in danger of injury would be ideal. Of course, the training, correct sitting posture and properly designed work stations can help alleviate the problem as well.³³

5.2 Standing Study

For a better understanding of the injuries the spine encounters when standing, a case study, “Thoracic Spine Pain: Case study Sally’s confused spine” was examined. A young city working woman named Sally was an active participator in exercise although she did not play a specific sport. Sally’s day began with a two hour commute by train, and foot. During her working day, she spent a great deal of time on her feet, especially standing stagnantly in upright positions.

Over a few months time, Sally began experiencing sever pains on the right side of her mid-lower thoracic spine. The pain became more intolerable as days passed, making it nearly impossible to sit for any length of time. After seeking medical attention, the pain was associated with the lower thoracic spine stiffness and was based on over activity of the quadratus lumborum and erector spinae muscles. As the pain progressed, it spread to the T6 to T9 region which intensified as she walked and rotated.

Sally began treatment, consisting of a soft tissue massage, trigger point manipulation and flexibility exercises. An x-ray of her spine showed moderate degenerative changes in the upper/mid- dorsal spine, including deformation. An MRI scan followed, “Small posterior disc bulges are seen at T6/7 and T7/8. At T6/7 the disc is small and right paracentral, abutting the right side of the cord, but with no cord compression or stenosis and at T7/8 a similar small disc is seen, which is in the left paracentral location. Again, it is slightly indenting the left central side of the cord but it is not causing marked cord compression.” As her symptoms began to diminish, it was

constant that she experienced a great deal of pain, especially when walking on her commute.

This study progressed and resulted in the medical attention reporting that they needed to look beyond the structural issues. They felt there was much more issues that underlined Sally's pain and offer her further prevention. The end conclusion for Sally was a direct result of the pressure put on the spine during her daily work and commutes to work. Particularly they related this to standing and sitting in unstable positions for long periods of time.³⁴

5.3 Walking Study

To understand the dynamics of walking better, a study on walking was examined. "Mechanical and metabolic requirements for active lateral stabilization in human walking", by J. Maxwell Donalen, is an investigation into lateral stabilization during walking.³⁵ Walking in itself is a laterally unstable motion. In order to keep itself from collapsing, the central nervous system must provide stability. This is done by foot placement such that it balances out the instability. This balance however does not come free of charge. Stability is traded for metabolic cost due to the active control generated by the central nervous system. Every person's body has a preferred width between each step that it takes for maximum efficiency and stability. The narrower these steps become, the more instability results. By changing the preferred step width to this narrower tread, the metabolic cost was greater due to the greater instability that resulted. With this knowledge, metabolic cost can be used as a measurement of stability versus instability.

The hypothesis was that by reducing the active control needed, the metabolic cost would be reduced, thus creating a higher level of stability and perhaps narrowing the

preferred step width. To do this, external stabilizers would be used with springs pulling bilaterally from the waist of a human with the other end connected to two nearby walls. The person would then walk on a treadmill at a set pace with the external stabilization and then without. Calorimetry would measure metabolic costs and the pressure sensitive treadmill would calculate the step width.³⁵

Stable walking is created through the interaction and meshing of the central nervous system and the muscular systems. While it can easily look past minor errors in stability certain actions are unavoidable and to counter, the body creates set diagnostics for dealing with and canceling out this noise in the system. This reaction is active control; unfortunately even this has its limitations. Because of this, advantages may result by reducing the need for active control, therefore avoiding these limitations. Walking constitutes a passively stable action in the sagittal plane lateral motion and can sustain its motion with no active control until the factors of mass and bipedal lateral motion is included. Figure 54 displays that much more control needs to be exerted when one is not externally stable.

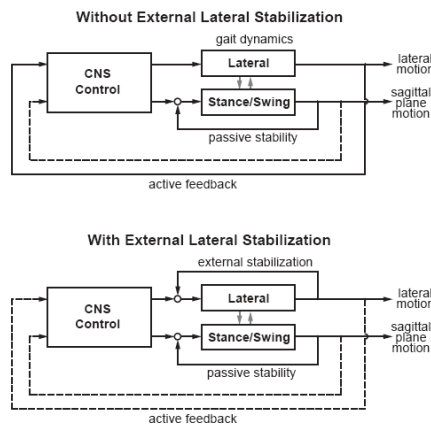


Figure 54: Dynamic Stability Chart
Donelan, J M. Dynamic Stability. 2003. University of Alberta, Edmonton. Mechanical and metabolic requirements for active lateral stabilization in human walking.

Dynamic stability overall exists when passive stability and active control / stability work together. During standard walking, passive stability is used to control motion in the sagittal plane. Lateral motion due to its instability requires active control from the nervous system. In a system containing external stabilization, active control is not required for either sagittal or lateral motion. In the former, the instability of the lateral motion determines the width of the steps one uses to balance themselves. This width is that which requires the least metabolic cost. In an attempt to remove all active control, an externally stabilizing mechanism was built to provide stability and measure how it affects the metabolic costs of walking. Narrower steps requiring less mechanical work but more metabolic cost to provide balance can now be measured seeing as how the need for active control has been totally eliminated.

Walking consists of two separate repeating phases. The first is the single support phase. This is when one structure supports the weight and the legs act as freely swinging coupled pendula. The second is the double support phase when both feet are making contact with the ground and are seen as instantaneous burst between single support phases. Figure 55 is a model of the single support phase.³⁵

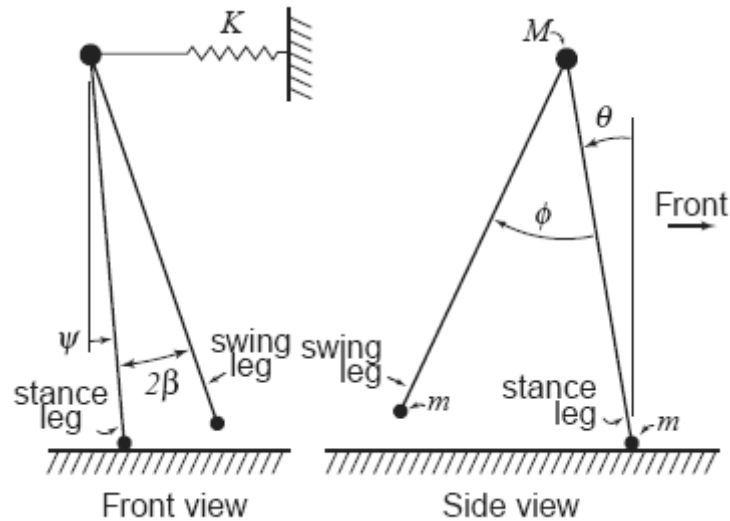


Figure 55: 3-D Walking Model
 Donelan, J M. 3-D Walking Model. 2003. University of Alberta, Edmonton. Mechanical and metabolic requirements for active lateral stabilization in human walking.

In this study a device was used to show walking with external stabilization. Using springs, a lateral elastic force is applied to the pelvis. With this, all stability is done passively. This allows for much more narrow steps, which is when the action of the springs can actually best be seen. At no lateral width, there is no lateral motion whatsoever and so the spring serves as proportional control about the pelvis, which only served to provide force when disturbances were encountered.

The procedure for the experiment was modeled across ten subjects. These subjects were human adults and the platform for measurement was a treadmill. Total equipment included the previously mentioned pressure sensitive treadmill, an external lateral stabilizer and a calorimeter. Each person did two treks types on the treadmill. The first type was at zero lateral width steps and the other was their normal walk. These were done with and without the external support, four in all. After the trials were completed the data was averages and the results analyzed and can be seen in Figure 56.

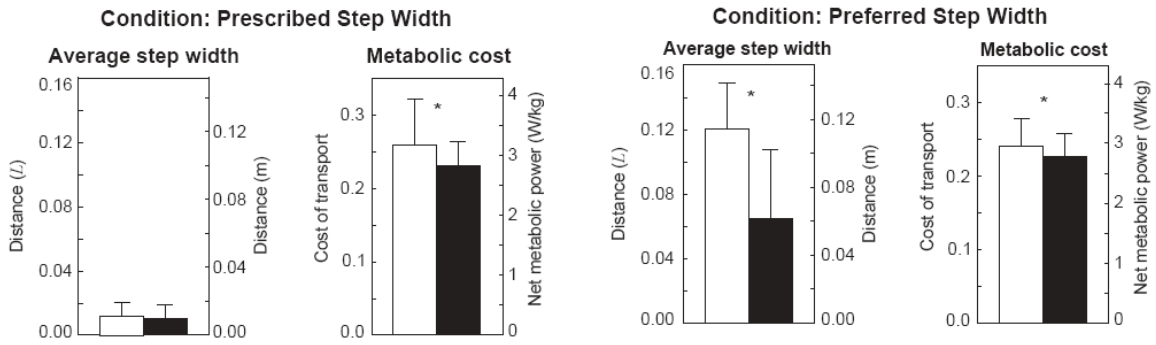


Figure 56: Step Width versus Metabolic Cost
Donelan, J M. 3-D Walking Model. 2003. University of Alberta, Edmonton. Mechanical and metabolic requirements for active lateral stabilization in human walking.

This data provides a lot of insight into stabilization during walking, mainly answering four important issues about the act of walking. The first was whether walking was passively stable in the lateral direction. Next was the idea of what the body uses to provide active stabilization. Thirdly, unanswered was the issue of whether or not instability resulted in a cost and finally whether or not all of these issues influence the lateral step width, people prefer. And this study shows that it in fact is passively stable, while using active control to provide balance through foot position. The cost paid for this stability is metabolic and yes, stability directly affects chosen preferred step width. Also from the analysis, it can be seen that in concurrence with the fourth issue, that with external stability, preferred width decreased as well as metabolic costs.³⁵

Chapter 6. Results and Discussion

The two major equations which evolved from our research were the foundation for the results obtained in this section. These two equations are the characteristic for $f(t)=0$ and governing equations respectively:

$$\Delta(\lambda, \mu) = \lambda^2 + 2\delta\omega\lambda + \mu_1 e^{-\lambda} + \mu_2 e^{-\lambda}$$

$$f(t) = \ddot{\theta} + 2\omega \cdot \delta \cdot \dot{\theta} + \omega^2 \cdot \theta + \mu_1 \theta(t - \tau_1) + \mu_2 \theta(t - \tau_2)$$

The characteristic equation was developed using the equation $\Theta = Ae^{\lambda t}$. The velocity and acceleration were found using this equation. This equation then formed the model in Figure 57, which is representative of linear stability.

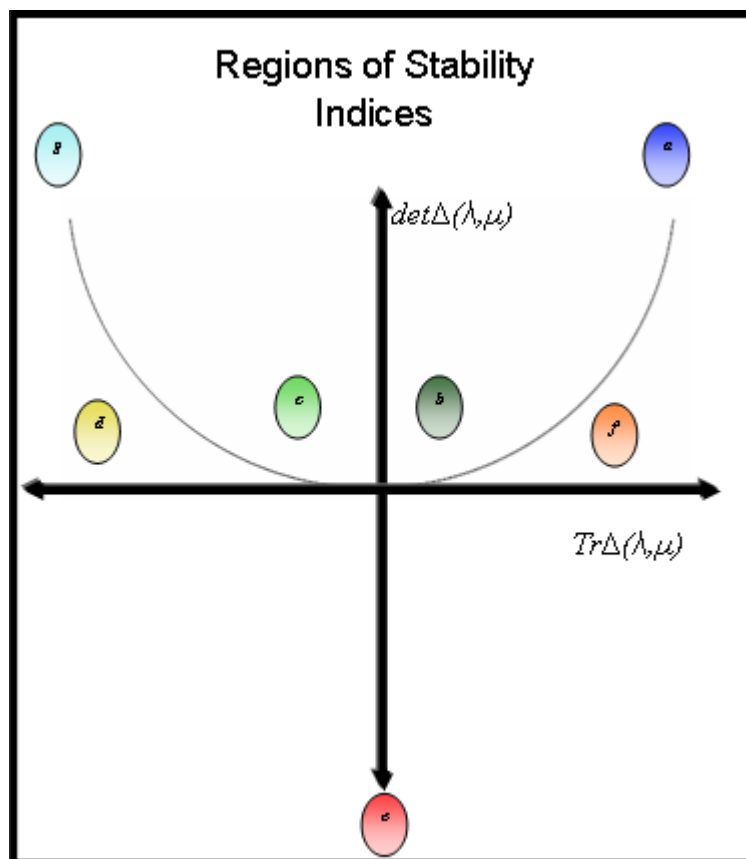


Figure 57: Regions of Stability Indices

The model itself was formed through an extremely complex matrix requiring an immense amount of calculation. This is a very generic and general model which is representative of any scenario. On the x-axis lies the trace, the sum of the diagonal elements of the matrix. On the y-axis lies the determinant of the matrix. The determinant of the matrix minus the trace of the matrix, set equal to zero gave the model its parabolic shape.

The variables “a-g” symbolize the state in which one can be stable or unstable. For example, if you are at state “b”, and are stable, this would cause you to be unstable at state “a”. Any variable can be stable or unstable depending on μ_1 or μ_2 which are found in the characteristic equation. μ_1 should be positive for stability to occur. However, if μ_1 is greater than μ_2 then the individual is unstable or delay is not sufficient enough.

The next model formed was representative of the eigenvalues (λ) from the equation, which determine the stability index. These values correlate to the roots of the characteristic equation and can be real or imaginary. Eigenvalues are known for always traveling in pairs. The components are found in the complex plane where linear analysis allows for the calculation of the eigenvalues. As gain is varied, the eigenvalues move from left to right as seen in figures a-f below. The representation of these values can be seen in Figure 58.

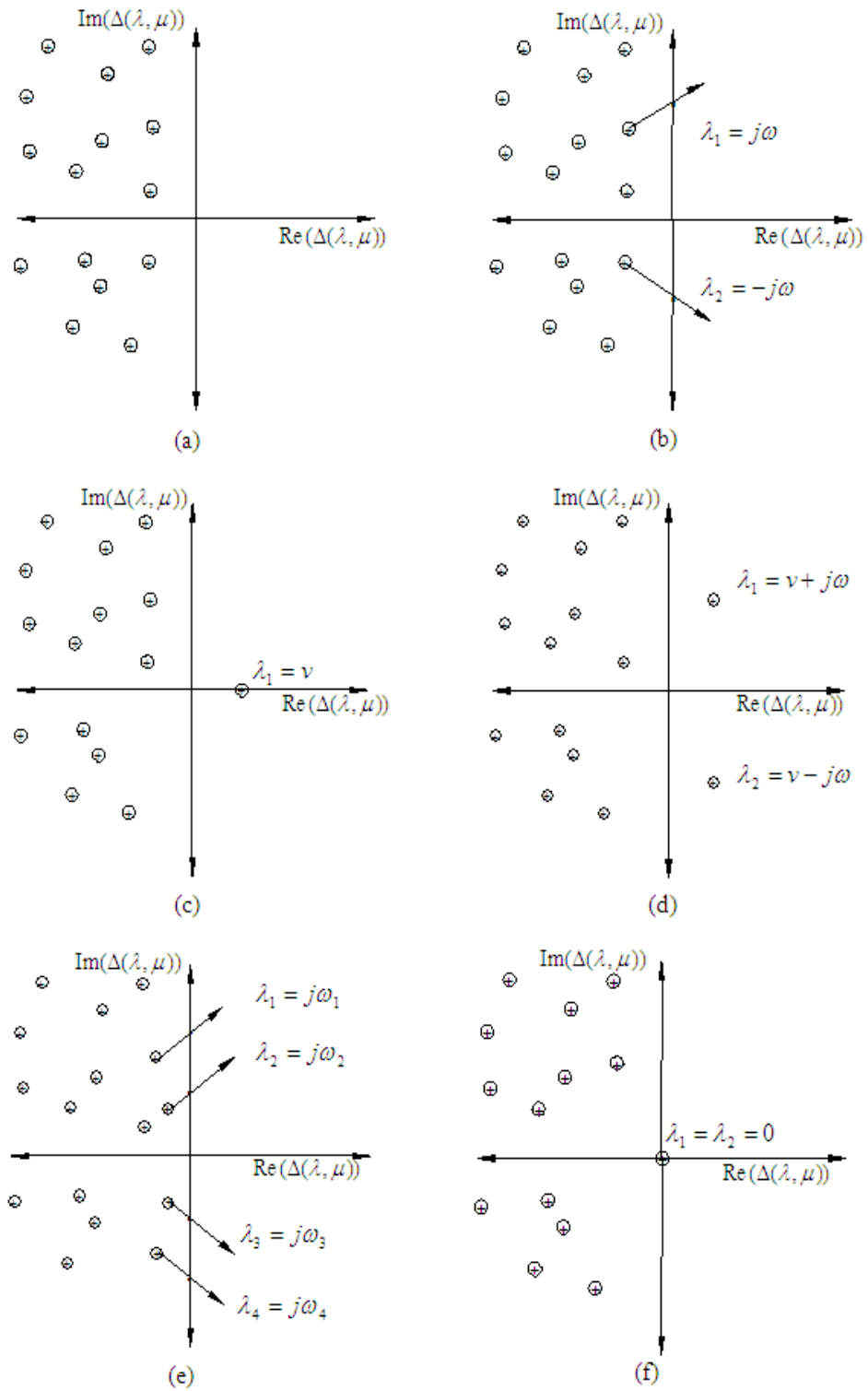


Figure 58: Location of Eigenvalues in Complex Plane

Chapter 7. Conclusion

The purpose of the project was to provide a manufacturing company an opportunity to study forces and obtain a new form of safety guidelines. The research and results found through this MQP has set the groundwork for a follow up project to continue and enhance the stability indices. The work preceding this project would allow one to acquire numerical values which would set ideal standards for the manufacturing working environment. With these statistics individuals would be able to determine injury in places before it actually occurred. Ideally, this would reduce the alarming facts related to back injury in the workplace.

References

- ¹ Unknown. “Your Spine – Facet Joints” (Professional Planets, 1999) <http://www.dcdotor.com> (Accessed November 21, 2005).
- ² Encyclopedia Britannica. 2006. “Vertebral Column” Encyclopedia Britannica Premium.
- ³ Stewart G. Eidelson, M.D. “Thoracic Spine” (SpineUniverse, 2002), <http://www.spineuniverse.com/> (Accessed November 20, 2005).
- ⁴ Unknown “Anatomy - Sacral Spine (Sacrum)” (Medtronic Sofamor Danek, 2001), www.back.com (Accessed November 25, 2005).
- ⁵ Unknown. “Your Spine – Intervertebral Discs” (Professional Planets, 1999) <http://www.dcdotor.com> (Accessed November 21, 2005).
- ⁶ Stewart G. Eidelson, M.D. “Spine Ligaments and Tendons” (SpineUniverse, 2002), <http://www.spineuniverse.com/> (Accessed November 20, 2005).
- ⁷ Stewart G. Eidelson, M.D. “Spinal Muscles” (SpineUniverse, 2002), <http://www.spineuniverse.com/> (Accessed November 23, 2005).
- ⁸ Keither Bridwell, M.D. “Spine Facet Joints of the Spine Anatomy” (SpineUniverse, 2001), <http://www.spineuniverse.com/> (Accessed November 23, 2005).
- ⁹ Unknown. “Spinal Cord Anatomy” (Apparelyzed, 2003). www.apparelyzed.com/ (Accessed February 24, 2006).
- ¹⁰ Back.com. “Lumbar Spine” (Medtronic Sofamor Danek, 2001), www.back.com (Accessed February 24, 2006).
- ¹¹ Gray’s Anatomy. “The Cervical Vertebrae” (Bartleby.com 2000) <http://education.yahoo.com/reference/gray/subjects> (Accessed September, 2005)
- ¹² http://www.dr-carlevans.com/Spine_Cervical_03.htm
- ¹³ Stewart G. Eidelson, M.D. “Cervical Spine Anatomy” (SpineUniverse, 2004), <http://www.spineuniverse.com/> (Accessed November 20, 2005).
- ¹⁴ Gray’s Anatomy. “The Anterior Divisions” (Bartleby.com 2000) <http://education.yahoo.com/reference/gray/subjects> (Accessed September, 2005)

-
- ¹⁵ Gray's Anatomy. "The Posterior Divisions" (Bartleby.com 2000)
<http://education.yahoo.com/reference/gray/subjects> (Accessed September, 2005)
- ¹⁶ "Thoracic Spine." Spine Universe. 30 Dec. 2002. Save your back and neck. 9 Sept. 2005 <<http://www.spineuniverse.com/displayarticle.php/article1397.html>>.
- ¹⁷ "Vertebrae of the Thoracic Spine." Vertebrae in the cervical, thoracic and lumbar spine. 18 June 1999. Spine Health. 11 Sept. 2005 <<http://www.spine-health.com/topics/anat/a02.html>>.
- ¹⁸ Gray, Henry. Gray's Anatomy. Barnes and Noble Books, 2000.
- ¹⁹ Kostopoulos, Dimitrios. Cervical Spine: Comprehensive Manual Therapy For The Cervical And Thoracic Spine (Hardcover). Slack, 2004. 15 Sept. 2005
<http://www.amazon.com/exec/obidos/tg/detail/-/1556427107/qid=1127105139/sr=8-1/ref=pd_bbs_1/102-8177547-3781726?v=glance&s=books&n=507846>.
- ²⁰ Kostopoulos, Dimitrios. Cervical Spine: Comprehensive Manual Therapy For The Cervical And Thoracic Spine (Hardcover). Slack, 2004. 15 Sept. 2005
<http://www.amazon.com/exec/obidos/tg/detail/-/1556427107/qid=1127105139/sr=8-1/ref=pd_bbs_1/102-8177547-3781726?v=glance&s=books&n=507846>.
- ²¹ All about the back and neck. 19 Aug. 2005. De Puy, Inc. 10 Sept. 2005
<<http://www.allaboutbackandneckpain.com/>>.
- ²² Mitchell, Fredric L. The Muscle energy manual, volume two: Evaluation and treatment of the thoracic spine, lumbar spine, and rib cage. 2nd ed. MET P, 2002.
- ²³ "Muscles of the Spine." A patients guide to the function and anatomy of the spine. Colorado Springs Orathpedic Group. 14 Sept. 2005
<<http://www.spineuniversity.com/public/spinesub.asp?id=71>>.
- ²⁴ Ozkaya, Nihat, and Margareta Nordin. Fundamentals of Biomechanics. 2nd ed. New York: Springer Science and Business Media, Inc, 1999. 95-99.
- ²⁵ "Anatomy of the Spine." Spine Universe. 1999. Nuvasive. 12 Sept. 2005
<<http://www.spineuniverse.com/index.html>>.
- ²⁶ Callaghan, JP. 1999. Low back three-dimensional joint forces, kinematics, and kinetics during walking. *Clin Biomech* Mar 14(3):203-16.
- ²⁷ Goh, JH. 1998. Low back three-dimensional joint forces, kinematics, and kinetics during walking. *Clin Biomech* 13(1 Suppl 1):S26-S31.

-
- ²⁸ Dave Thompson. "Effects of chronic lengthening or shortening of muscle: "stretch weakness" and "adaptive shortening" (Dave Thompson PT, 2001), <http://moon.ouhsc.edu/> (accessed February 23, 2006).
- ²⁹ Craig Liebenson. "The Neurodevelopmental Basis for Spine Stability" (2006) www.chiroweb.com (accessed March 1, 2006).
- ³⁰ Teri Holwerda. "Fractures and Spine Stability" (2004) www.spineuniverse.com (accessed March 1, 2006).
- ³¹ Fofana, Mustapha S. Personal interview. 1 Dec. 2005.
- ³² "Treatment Options." Back.Com. 18 Nov. 2003. Michelson Technology at Work. 12 Feb. 2006 <<http://www.back.com/treatment-surgical-minimally.html?mastbox=yep>>.
- ³³ Folds, Dennis J., Nancy Davis, and Jeffery M. Gerth, comps. Ergonomic Challenges in Conventional and Advanced Apparel Manufacturing. 20 July 2004. Georgia Tech. 22 Mar. 2006.
- ³⁴ Fyfe, Sean. "Thoracic Spine Pain." Sports Injury Bulletin. 03 Mar. 2006 <<http://www.sportsinjurybulletin.com/archive/thoracic-spine-pain.htm>>.
- ³⁵ Donelan, J. Maxwell. 2003. Mechanical and metabolic requirements for active lateral stabilization in human walking. *Journal of Biomechanics* 37: 827-835.