The Biomechanical Contribution of Free Floating Ribs to the Thoracic Spine

By

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Abstract

Human cadaveric spine testing is done to provide more knowledge for clinicians in understanding living patients and to validate surgical procedures. There are many limitations to cadaveric testing, whether it be equipment or physiological condition of the specimen. Clinically, floating ribs have been removed for procedures for cosmetic purpose or surgical repair. The understanding of the floating ribs in human cadaveric testing is limited and has never been quantified. The present study aims to examine the mechanical effects of the thoracic spine when the floating ribs are removed.

Eight human cadaveric thoracic spine specimens (T1-T12) with intact rib cage were subjected to 5 Nm pure moments in axial rotation, lateral bending, and flexion/extension with a 400 N follower load before and after floating rib removal. Data was collected and calculated to determine overall range of motion, neutral zone, elastic zone, neutral zone stiffness, elastic zone stiffness, and maximum and minimum dynamic pressure.

Overall range of motion was the only parameter that saw significant differences in axial rotation and lateral bending. No other significant differences were found. The study demonstrated that the floating ribs do biomechanically contribute to the thoracic spine. Therefore, it is necessary to include the floating ribs for future thoracic and thoracolumbar studies.

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Table of Contents

List of Figures:

List of Tables:

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Chapter 1: Introduction

Chapter 2: Background and Significance

2.1 Basic Spinal Anatomy

2.1.1 Spine

The spine serves as a mechanical structure that provides protection for the spinal cord, nerves, and internal organs.[20] There are three sections of the human spine: cervical, thoracic, and lumbar (Figure 1). The first seven vertebrae are cervical vertebrae. The next twelve vertebrae after cervical are thoracic. Finally, the last five vertebrae are called lumbar. The present study looks at only thoracic vertebrae and defines them as T1, T2, etc. to T12. Additional components within the thoracic region include the rib cage, intervertebral disc, and the stabilizing/supporting ligaments and tendons.[1, 20]

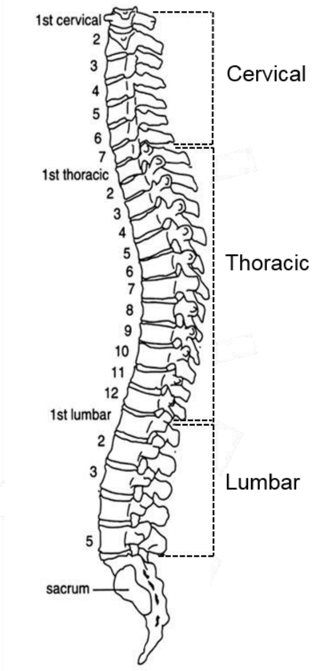

Figure 1. Basic Anatomy of the Spine (Public Domain

2.1.2 Rib Cage

The rib cage is the primary protective barrier from traumatic impact, whether it be anterior or lateral forces composed of twelve sets of ribs (Figure 2).[20] It also stiffens and strengthens the spine providing a resistance to additional displacement.[4, 10, 20] Each rib is joined to the vertebra via the costovertebral joint which plays a crucial role in providing stability to the spine.[9] Ribs along T1 through T10 are all joined to the sternum via the sternocostal joint and provide maximum resistance when loaded in the superior and inferior directions.[19] The last two sets of ribs have no physical connection to the sternum or the costal cartilage at the distal ends. Instead, they are only connected to the vertebral body at the anterior surface of the transverse process via costovertebral ligaments.[20, 22]

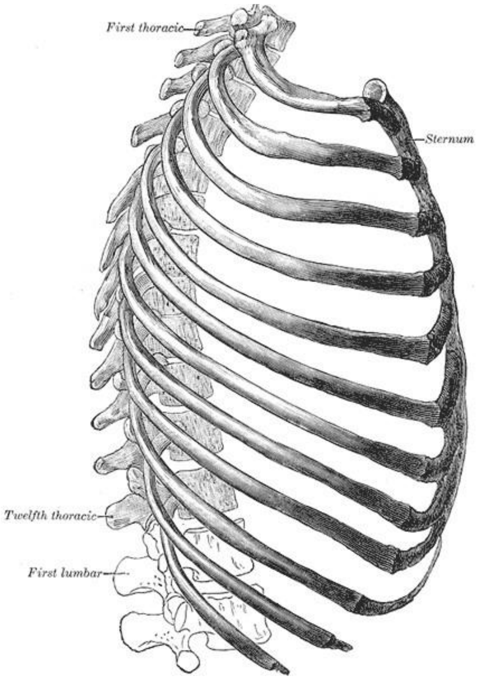

Figure 2. Anatomy of the Rib Cage (Public Domain)

2.1.3 Intervertebral Disc

An intervertebral disc lies between each vertebra and exhibits viscoelastic behavior (Figure 3).[20] Not only does the intervertebral discs help absorb vertebral forces, but also distribute these forces and prevent adjacent vertebra from grinding against one another. The intervertebral disc is composed of three main components: the nucleus pulposus, the annulus fibrosus and the cartilaginous end plates. The nucleus pulposus is the gel-like substance in the center of the intervertebral disc with water content that ranges from 70 to 90%.[20] This high water content allows for intervertebral disc to deform when subjected to a load and return to its normal state when the load is removed. The annulus fibrosus forms the outer boundary of the intervertebral disc and gives it structure. Finally the cartilaginous end plates separate the previous two components from the vertebra.

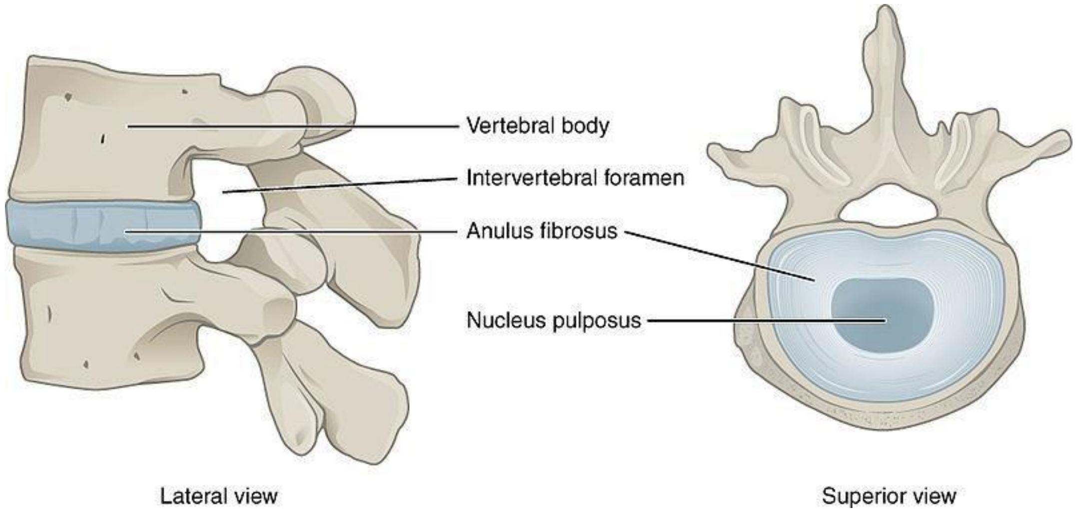

Figure 3. Lateral view of the intervertebral disc in relation to adjacent vertebra. Additionally, sectioned view for Nucleus Pulposus. (Anatomy & Physiology, Connexions Website)

2.1.4 Ligaments and Tendons

Ligaments are similar to rubber bands, in which they resist tensile forces but buckle when compressed. They are the primary connections that connect bone to bone and allow for adequate physiological movement while maintaining defined limits to protect the spinal cord. Tendons are similar but attach bone to muscle.[20]

2.1.5 Functional Spine Unit

The functional spine unit (FSU) consists of a single motion segment in the spine. A single motion segment is defined as two adjacent vertebrae and connecting ligamentous tissues. The behavior of an FSU is dependent upon the condition of the adjacent vertebrae, the intervertebral disc, surrounding musculature including ligaments and tendons, and the articulating surfaces.[20] Most segments in spine cadaveric testing consist of multiple FSUs.

2.2 Biomechanical Spine Testing Terminology

A general summary of all parameters can be identified in Figure 4.

Neutral zone (NZ) is the measurement of the laxity of the spinal specimen.[11, 21] Essentially the neutral zone is the angular displacement when the specimen moves without any load applied to it. This parameter also correlates with stiffness to indicate stability of the spinal system.[10, 11] This is clinically important because an increase in neutral zone may be due to injury or weakness in muscle. Inversely, a decrease may be observed in the presence of physiological limits such as osteophytes, fixation/fusion or muscle strengthening.[10, 11] Neutral zone, elastic zone and overall range of motion are measured in degrees.

Elastic zone (EZ) is defined as how much the specimen deforms from the end of the neutral zone to its maximum load. [6, 21] Outside of NZ, EZ is limited by the surrounding tissue which constrains it. The present study reports EZ as an average of the positive and negative EZ.

Overall range of motion (ROM) is the sum of both neutral zone and elastic zone for one direction of motion. [6, 21] One direction of motion refers to the flexion portion of flexion/extension or lateral bending to the left versus lateral bending to the right.

Neutral zone stiffness (NZS) measures how much mechanical resistance there is within the specimen. [6, 21] This parameter is obtained by calculating the slope of the load-displacement curve within NZ. All stiffness in this study were measured in degrees per Newton meter.

Elastic zone stiffness (EZS) is the measurement of mechanical resistance with the specimen by calculating the slope of the load-displacement curve in the EZ region.[6, 21]

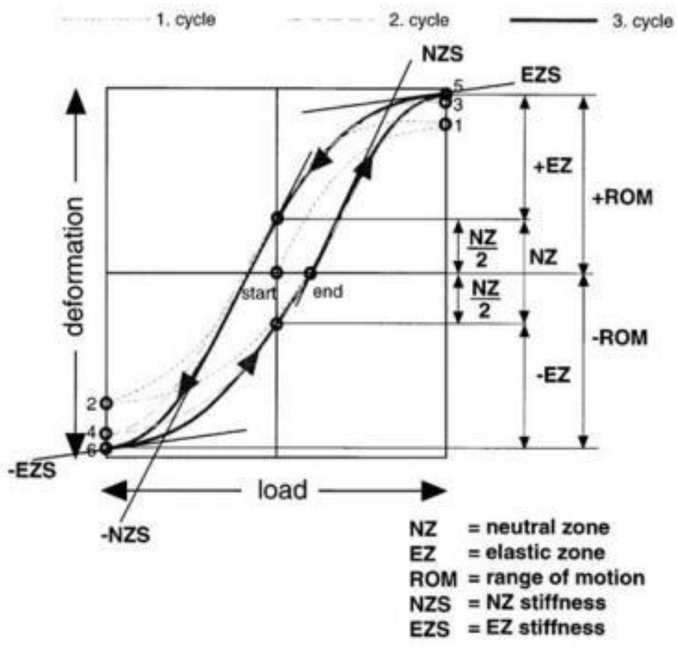

Figure 4. Hysteresis curve showing angular displacement v load with associated parameters in the present study. Image reprinted with permission of Springer©.

The Euler method is used to calculate any change in vertebral orientation, for in plane and out of plane motions.[4,6, 16] The motion in a vertebra relative to its adjacent neighbor can be defined by three angles (α, β, γ) and three translations (x,y, z).[4] Axes were defined in the present study with the x axis representing lateral translation (positive right, negative left), the y axis representing sagittal translation (positive anterior and negative posterior) and the z axis representing vertical translation (positive superior and negative inferior).[6] The purpose of establishing these axes and angles allows for the overall translation to be calculated. Each mode of bending - axial rotation, lateral bending, and flexion/extension can be described by an Euler rotation sequence. For example, calculation of axial rotation would be done by taking the Euler rotation sequence of axial, lateral and sagittal.[6] The differences in angular rotation define the change between motion simulated by an intact rib cage and after removal of floating ribs.

2.3 General Spine Testing Methodology

Spine cadaveric testing in the thoracic region is performed by dissecting away all skin, fat, muscles and organs. The sternum, vertebrae, intervertebral discs and stabilizing ligaments are left intact.[3, 6, 9, 19] Excess vertebra superior to T1 and inferior to T12 were also dissected away for intact rib cage studies.[6, 19] Watkins et al. conducted studies using the entire rib cage including floating ribs. Cadaveric specimens were tested using an MTS 858 Bionix Test System. Results showed that an intact rib cage increased stability of the spine, while a sternal fracture decreased stability. Mannen et al. used a FS20 Biomechanical Spine Test System to test intact cadaveric human spines with intact rib cage but excluded floating ribs. Here, range of motion and stiffness was observed to be higher without the presence of a rib cage.[6] Other studies looked at segments or individual FSU.[3, 9] Brasiliense et al. used a standard servo hydraulic test system (MTS, Minneapolis, MN) to determine the effects of rib cage on spine stability. Conforming to previous literature, the rib cage accounted to thoracic stability, but at a greater percentage than previously estimated.[3] Oda et al. tested functional spine units using an MTS 858 Bionix Test System.[9] Each set of functional spine unit was tested with intact ribs, followed by varying destabilization procedures. Removal of the rib head from the vertebral joint resulted in additional increased range of motion. All studies secured the superior and inferior most portion of their segments to their spine testing machines. These test machines simulated the physiological behaviors of in vivo spines. The test machine used in the present study was a FS20 Biomechanical Spine Test System (Applied Test Machine, Butler, PA, USA). A pure moment was applied to the superior portion of the segment while the inferior portion was rigidly fixed. This machine has two arms in order to simulate the different modes of bending - axial rotation, lateral bending, and flexion/extension. Axial rotation refers to a twisting motion, lateral bending refers to sideways motion, and flexion/extension refers to a forward/back motion.

Literature has proposed that using a follower load more accurately represents the human spine in vivo. The application of a follower load is done by taking a cable and passing it through guides rigidly fixed into the vertebral bodies. Free hanging weights were suspended at the ends to compress the superior end of the specimen.[12, 15, 16] When a follower load was not applied to the spine, Stanley et al. observed experimental designs where thoracolumbar spines buckled after a vertical load of 20 N was applied.[16] Under a follower load, Patwardhan et al. observed loads of up to 250 N in cervical vertebrae and 1200 N in lumbar vertebrae without any damage.[12] Sis et al. analyzed the use of a follower load in tandem with rib cage attached. Results showed that follower load with rib cage attached impacts motion and stiffness parameters in human cadaveric thoracic testing.[15] Therefore implementation of a follower load would more accurately represent the physiological loadings that are placed on the spine.

After testing and conducting statistical analysis, this allows for conclusions to be drawn. Bonferonni corrections are used to reduce Type I error. This type of error rejects the null hypothesis when the null hypothesis is actually true.[8, 13] The standard procedure modifies the α value of 0.05 with k, where k is the number of tests done. However, Bonferonni methods are only concerned with the null hypothesis which is rarely of interest or use to researchers.[13] The result of Bonferonni corrections also increases the chance for Type II error.[8, 13] The majority of literature in spine cadaveric testing uses an α value of 0.05. The present study disregards correction factors to avoid these errors and remain consistent to literature.

2.4 Clinical Relevance

Rib resection is the surgical removal of part of the rib or the rib entirely.[14] Resections are done to treat fractures that may risk damaging specific organs, such as the lungs or disease such as cancer. The removal of these ribs has seen several situations for clinical application.

Autograft is bone harvested from a patient for use in grafting procedures in their own body. It is commonly used for procedures such as spinal fusion.[18] Typically, bone for this type of procedure is harvested from the pelvic bone. Some circumstances permit the use of bone from a rib. Autografting is considered the gold standard for achieving fusion because there is a greater success for fusion versus cadaveric bone or grafting substitute while also eliminating the risk for disease transmission.[18]

Clinically, a lot of controversy exists with the removal of the floating ribs. Eppley, Amorasak, and MDGuidelines detail the procedure for waistline narrowing where the ribs at T11, T12, and occasionally at T10 are removed. Performed under general anesthesia, surgeons make an incision along the side in order to gain entry to the thoracic cavity.[2, 5, 14] The ribs at T11 and T12 are removed through this entry. Amorasak opposed the procedure due to the manipulation of the rib cage. The loss of the ribs at T11 and T12 would reduce the protection to organs, such as the kidneys.[2] This could also potentially affect structure and support. It is further stated in limited research that floating rib removal for these surgeries can result in scarring, temporary or permanent pain, and pneumothorax.[5] Alternatively, floating ribs have shown potential clinical application for grafting procedures. Moretti et al. and Taggard et al. conducted separate studies where patient's ribs were resected and used for grafts. Moretti et al. reported that the central portion of T5 to T8 is most commonly preferred by surgeons.[7] However, the floating ribs are naturally straighter and require less manipulation before grafting.[7] Taggard et al. described the procedure but does not detail which ribs are commonly harvested for graft use. It is explained that rib grafts for the application of cranioplasty compare favorably to other techniques.[17] This suggested that harvesting ribs for autografts could be done for other surgical procedures as well.

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Chapter 3: The Biomechanical Contribution of Floating Ribs: A Pilot Study

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This study quantifies the biomechanical contribution of floating ribs to the thoracic spine. Benjamin Wong had the responsibilities of data collection, data processing, writing of the manuscript and any recommendations for editing by his fellow co-authors.

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The Biomechanical Contribution of the Floating Ribs to the Thoracic Spine: A Pilot Study

Abstract:

Thoracic spine researchers have used varying test methods with and without floating ribs. Clinically, floating ribs are sometimes removed for cosmetic procedures, but the influence of the floating ribs on thoracic spine biomechanics has yet to be studied. This pilot study measures the influence of floating ribs on motion parameters of human cadaveric thoracic spines in axial rotation, lateral bending, pure flexion, and pure extension. Eight human cadaveric thoracic spine specimens (T1-T12) with rib cage were subjected to 5 Nm pure moments in each mode of bending with a 400 N follower load before and after floating rib removal. Range of motion, elastic and neutral zone, elastic and neutral zone stiffness values, and maximum and minimum dynamic pressures were calculated. Only range of motion in axial rotation and lateral bending were significantly influenced by the removal of the floating ribs. Removal of the floating ribs had no significant influence on stiffness or disc pressure in any region of the thoracic spine. Further research is needed to fully understand the clinical implications of removal of the floating ribs, but this study suggests that they should be implemented in cadaveric studies and cautioned for clinical removal.

Word Count: 194

Key Terms: Range of Motion, Thoracolumbar, Neutral Zone, Disc Pressure, Rib Cage

Introduction

The thoracic spine is prone to deformity, degeneration, and fracture.[4, 10, 25] Each of these pathologies presents a different clinical challenge, but all areas would benefit from a thorough understanding of thoracic spine mechanics. Some research exists that characterizes the thoracic spine kinematics without an attached rib cage, though the clinical relevance of rib removal is not clear.[26] More recent research was conducted to examine the mechanical contribution of the ribs to the thoracic spine. [4, 9, 10, 25] However, some researchers in the field have excluded the floating ribs in cadaveric specimens when testing thoracic sections due to limitations in test equipment or in cadaveric specimens.[4, 9, 10, 25] The purpose of cadaveric testing is informing the effectiveness of a device design or a surgical procedure. However, some surgical procedures involve partial or complete resection of the floating ribs.[6, 12, 24] The influence of the floating ribs (T11-T12) on the biomechanical performance of the thoracic spine and their relevance in evaluation of clinical procedures has not been examined.

The thoracic spine is not as well studied as the lumbar and cervical spine. Standard testing methods and critical biomechanical outputs are still being established, especially for testing that includes the rib cage. There are several studies that employed similar mechanical testing methods, using pure moments to load the specimens, capture the motion of individual vertebrae, and calculate motion and stiffness parameters.[4, 9, 10, 25] However, these studies used a different number of motion segments or did not include the floating ribs. Watkins et al. used full human thoracic cadaveric specimens (T1-T12) that included floating ribs to evaluate the changes in stability with rib cage and compared the stiffness before and after removal of the ribs. Brasiliense et al. used only upper thoracic sections (T1-T10) for their cadaveric specimens. However, Brasiliense et al. employed only functional spine unit levels and varied destabilization by removing the ligaments connecting the rib head to the vertebra or removing the rib head entirely. Mannen et al. incorporated similar techniques to both Brasiliense and Watkins, using full human thoracic cadaveric specimens (T1-T12), but excluded floating ribs. Mannen et al. suggested a future study look into the biomechanical contribution of the floating ribs.[10] These three studies showed that the rib cage had a significant effect on the thoracic biomechanics and provided a better characterization of thoracic kinematics for future clinical use. For the clinical aspect, Hitchon et al. conducted an analysis on thoracolumbar implants using specimens with levels T11 to L3.[9] However, no floating ribs were present in this study. Unlike the previous three studies, Hitchon et al. assessed the biomechanical stability imparted to human cadaveric spines by thoracolumbar implants. Despite having established a more complete understanding of the contribution of the entire rib cage and external devices, the contribution of individual ribs or rib subgroups, such as the floating ribs has yet to be investigated.

Some autograft harvesting procedures and cosmetic surgeries involve removal of the floating ribs.[2, 6, 12, 21, 24] Moretti et al. and Taggard et al. both conducted human subject studies using rib resection for surgical repair. Moretti et al. resected false ribs to obtain cartilage for the use of rhinoplasty but commented that the floating ribs are naturally straighter and require less carving for the procedure.[12] Taggard et al. harvested ribs for cranioplasty, but the specific levels from which the ribs were harvested from was not stated.[24] Both studies demonstrated the clinical use of ribs for autografts. There is also a controversial cosmetic procedure that removes ribs at T10-T12 so that the patient can achieve an hour glass figure.[2, 6, 21] However, no published data could be found on the influence in removal of these ribs on mechanics of the thoracic spine. Research has shown that changes in motion characteristics of the spine can lead to altered clinical outcomes in the patient.[4, 10] There is an obvious need to better understand the influence of the floating ribs on thoracic spine mechanics.

The primary goal of this pilot study is to determine the mechanical contribution of floating ribs to the overall thoracic biomechanics and interpret these results for potential clinical use. Functional spinal unit (FSU) motion, segment motion, stiffness parameters and intervertebral disc pressures were determined for thoracic spine specimens with a 400 N follower load both before and after floating rib removal. The following hypotheses were tested: (i) Range of Motion (ROM), neutral zone ROM, and elastic zone ROM will increase in lower levels of the Thoracic spine, (ii) neutral and elastic zone stiffness will decrease in the lower levels of the Thoracic spine, and (iii) intervertebral disc pressures will increase after removal of the floating ribs. The purpose of this work was to elucidate the influence of the floating ribs to help standardize and validate spine testing and define parameters related to the clinical influence of surgical resection of the floating ribs.

Materials and Methods

Eight fresh-frozen human cadaveric spine specimens (T1-T12) were thawed and dissected to include only the sternum, vertebrae, intervertebral discs and stabilizing ligaments. Specific criteria such as presence of severe scoliosis, patient history of spinal surgery, implantation or extenuating physical trauma were cause for exclusion. All specimens were included in this study (n=8) with an average specimen age of expiration of 66.9 ± 4.4 years.

Specimens were potted post-dissection at T1 and T12 with a two-part filler (Bondo, 3M, USA) to create a rigid surface parallel to the endplates. The inferior end of each specimen (T12) was mounted to a flat plate on an FS20 Biomechanical Spine Test System (Applied Test Machine, Butler, PA, USA) while the superior end of the specimen (T1) was attached the distal end of the test machine.   A pure moment of 5 Nm was continuously applied to the attachment at T1 for five cycles during the simulation of each mode of bending.

Motion capture techniques were used in conjunction with the spine testing system to record position and orientation of selected vertebrae. Optoelectric motion-capture research pins (Optotrak, Northern Digital Inc., Waterloo, ON, Canada) were inserted into the top potting of T1, and the right pedicles of T2, T4, T5, T8, T9, and T11 to track motion before and after floating rib removal. This constructed the FSU levels T1-T2, T4-T5, T8-T9, and T11-T12. Additionally, the motion segments T1-T4 (Upper), T4-T8 (Middle), and T8-T12 (Lower) were established. Anatomical points were probed based on Wilke et al. using adaptations from Mannen et al. and Sis et al. to determine the local coordinate system for all levels and calculate the parameters based on this coordinate system.[11,22,27] Figure 1 shows the general set up for this experiment excluding the follower load applied. The highlighted ribs in Figure 1 define the floating ribs that would be removed after testing with all ribs intact. Each floating rib was resected one inch from the costovertebral joint bilaterally at T11 and T12.

Intact and floating rib removed states were tested in axial rotation (AR), lateral bending (LB), and flexion-extension (FE) with order of the tests randomized. In order to simulate a more accurate representation of spinal loading, a 400 N follower load was implemented for all testing conditions using techniques reported by Sis et al.[22] The 400 N follower load level was chosen to be in the range between levels used in cervical and lumbar regions.[17,23] The follower load was applied bilaterally using cables and dead weights passed through ball joint rod ends attached to the vertebral bodies of T3-T10 and then directed to a pulley system connected to the dead weights under the specimen. The female ball joint rod ends were connected both sides of threaded rods that were inserted laterally through center of rotation of each segment as determined by a lateral radiograph in neutral kyphotic position. The cables were guided through the ball joint rod ends to be tangential to the curvature of the thoracic spine. Use of the ball joint rod ends allowed the cable to continuously follow the curvature of the spine as it was deformed under loading.

Needle pressure transducers (Standard Needle Tip Pressure Transducer, Gaeltec, Isle of Skye, Scotland) were inserted into the intervertebral disc at FSU levels T4-T5 and T8-T9 to determine dynamic disc pressures during each test before and after floating rib removal. Implementation of the pressure transducers was based on Cripton et al., replicated from Anderson et al., and the data was recorded using LabVIEW (National Instruments, Austin, TX, United States).[1,5] Figure 1 shows the locations where the needle pressure transducers were inserted into. The intervertebral disc at T4-T5 and T8-T9 were chosen to represent the motion segment breaks between upper, middle and lower.

MATLAB (Mathworks, Natick, MA, USA) was used to organize, analyze, and statistically compare all data. Preliminary raw data checks were done to determine data validity. After establishing exclusion criteria, these were used for interpolation to adjust raw data when motion sensors were out of bounds of the Optotrak camera. Motion sensor data taken from the orthopaedic research pins outputted displacement of the markers in the x, y and z planes. This was converted into angular displacement data using Euler Rotations, and processed into in-plane range of motion and stiffness parameters. These motion parameters were calculated for the FSU and motion segment levels after truncating to only the third cycle of data in order to obtain the load-deformation curve.

Neutral zone range of motion (NZ) was calculated by locating the deformation points of the cadaveric specimen when the load was at 0 Nm. The minimum value was subtracted from the maximum value in order to establish the neutral zone region. Neutral zone stiffness (NZS) was calculated as the inverse of the slope of the load-displacement data between -1 Nm and +1 Nm. Elastic zone range of motions (EZ) were calculated by locating the deformation point at -5 to -1 Nm and + 5 to +1 Nm. The elastic zone stiffnesses (EZS) were calculated as the inverse of the slope of the displacement-load data between -4.5 to -5.0 Nm and +4.5 to +5.0 Nm. Range of motion (ROM) was the total deformation from +5.0 to -5.0 Nm. Dynamic pressure was analyzed by truncating to only the third cycle and determining the maximum and minimum values for comparison.

Paired t-tests were used to compare the intact and floating rib removal overall range of motion, stiffness, and pressure parameters at a 0.05 significance level for all complete sets of data. Since some data failed to meet quality standards and were excluded, statistical analysis was only conducted on data that maintained at least five specimens. Bonferroni correction factors were not applied in this study as they increase the chance for type II error and may limit insight about cadaveric test results.[13, 18] Because of the large standard deviation in specimen behaviors, and the difficulty and expense of this type of testing, cadaveric research seldom has a large enough sample size to avoid Type II error. For the practical understanding of the biomechanical contribution of the floating ribs, the authors' have chosen a less conservative approach for the statistical analysis.

Results:

While it was expected that the range of motion would increase, stiffness would decrease, and dynamic disc pressure would increase for all modes of bending, significant differences between the intact and floating rib removal were seen only in axial rotation and lateral bending for ROM. Tables 1 and 2 show compiled averaged magnitudes for FSU data and segment data respectively. The table presents intact as pre- and the removal of the floating ribs as post-. Figures 2 and 3 show the range of motion in axial rotation for FSU and segment levels, respectively. Figure 2 shows that there was a significant decrease of 22% in the ROM at T4-T5 (p= 0.038) and a significant increase of 16% in the ROM at T11-T12 (p=0.036). Figure 3 shows that ROM at segment level T8-T12 increased significantly by 17% (p=0.012). In lateral bending, ROM increased significantly by 38% between intact and floating rib removal at T8-T9 (p=0.030), as shown in Figure 4. There were no ROM differences for the segments in lateral bending nor were there differences in segmental and FSU parameters in flexion or extension. No statistical differences were observed in stiffness or in dynamic maximum and minimum disc pressure, regardless of mode of bending.

Discussion:

It was hypothesized that removing the floating ribs would increase overall motion, decrease stiffness, and increase disc pressure in the lower thoracic region. Axial rotation and lateral bending were the only two modes of bending with range of motion parameters that were significantly influenced by the removal of the floating ribs. The floating ribs are lateral protrusions within the coronal and transverse plane. Even in the dissected cadaveric specimens that do not have active muscle support, there is an indirect connection of the floating ribs to the sternum through the soft tissues that attach to the false ribs. Their removal should result in a decrease of rigidity of the rib cage. Logically, it would be expected that lateral bending and axial rotation would be affected by removal of the floating ribs because these two modes of bending occur in these respective planes. To the authors' knowledge, there is no previous research that quantifies the biomechanical significance of the floating ribs on overall thoracic biomechanics. Previous research has been conducted on full and partial removal of the ribcage at other levels, but no study examines these particular levels nor incorporates the appropriate follower load in the test methods.[4,10,22,25] Due to the lack of previous literature, no direct value comparisons can be drawn. However, indirect comparisons can be made to other studies, with an understanding of trends in the data.

While other thoracic spine cadaveric studies utilized only portions of the ribcage, the present study included all ribs to accurately compare intact and floating rib removal conditions.[1] The application of a follower load was important in this study as hypermobility has been observed in other studies when applying loads vertically along a thoracic spine.[17,22,23] Preloads through a follower load application technique minimizes artifact moments and shear forces along the mid plane of the disc.[23] In addition, the follower load pathway ensures that the load transfers between adjacent vertebrae, thus better mimicking behavior typical of *in vivo* phenomena for analyzing differences seen from injury, decompression and stabilization.[23] Patwardhan et al. has shown follower loads of 250 N in cervical vertebrae and 1200 N in lumbar without damage.[17] Stanley et al. used a compressive follower preload up to 800 N on seven thoracolumbar specimens, but that study did not include the ribcage and only tested in flexionextension.[23] The 400 N follower load level used in the present study was chosen to be within the ranges used in cervical and lumbar regions. Sis et al. found that application of a 400 N follower load statistically decreased range of motion in lateral bending.[22] If a follower load was not employed in this study, one would expect that lateral bending values would have been larger, but the magnitude of change due to removal of the floating ribs is unknown. The difference in follower load application should be considered when comparing various studies.

Watkins et al. reported a combination of range of motion and stiffness in order to quantify instability. With the removal of the entire rib cage, Watkins reported an increase of 46%, 55%, and 42% in range of motion in axial rotation, lateral bending, and flexion extension, respectively. In the present study, increases in ROM due to partial rib removal were also found, but only in axial rotation (16%) and lateral bending (38%). Due to the asymmetrical movement in flexion/extension, the present study analyzed pure flexion and pure extension separately.[25] No significance difference were seen in any parameter in flexion or extension for any FSU or segments levels.

In the present study, there was no difference in neutral zone range of motion in any individual FSU or segment. Neutral zone range of motion defines the laxity of the spine and correlates to an increase in pain for *in vivo* studies.[16] Additionally, the neutral zone for *in vitro* studies defines when there is a moment of 0 Nm on the cadaveric specimen. Panjabi et al. uses a ball in a bowl as an analogy for how the spine deforms. The bottom of the bowl defines the neutral zone while the walls of the bowl represent the elastic zone. As the ball moves towards the outer edges of the bowl, the soft tissue engage with the spine, constraining it.[16]

Range of motion is the sum of the elastic zones and the neutral zone. FSU level T8-T9 experienced a 38% increase in overall range of motion in lateral bending after floating rib removal, though the lower segment (T8-T12) did not show a significant change. These results indicate that with the removal of the floating ribs, there was less soft tissue to engage with T8-T9 in lateral bending. This could imply that the lack of engaged tissue from the removal of floating ribs could increase the chance for injury because the spine is less constrained.[8] FSU T4-T5 saw a significant decrease instead of an increase. It should also be noted that vertebrae T11 and T12 serve as attachment points for portions of the erector spinae, external and interal oblique and the lastissimus dorsi muscles. These muscles span the entire thoracic region and because cadaveric studies remove these muscles, there may be a relationship that has not yet been identified. Error in motion tracking diodes have been shown to be ±0.1 mm, which results in an Euler rotation error of ± 0.06 degrees for a single research pin. External factors, inherent cadaveric limitations and set up can also potentially affect noise. However, because of accuracy such as this, this may show statistically significance that may not be clinically relevant. Particularly, FSU T4-T5 in axial rotation and T8-T9 in lateral bending showed statistical significant differences between intact and floating rib removal. A decrease of 0.30 degrees and an increase of 0.13 degrees was observed for each respective mode of bending. However, an error of 0.06 degrees is nearly 50% error in lateral bending. This suggests additional studies need to be done to fully understand the motion of individual levels.

Removal of the floating ribs had no significant influence on stiffness in any region of the thoracic spine. Stability has been a commonly reported factor in spine biomechanics research and in the clinical community. Pope et al. described instability as a loss of stiffness.[21] In the present study, neutral zone stiffness were calculated from the slope of the hysteresis curve in the neutral zone between loads of -1 Nm and 1 Nm.[10] Watkins et al. observed that the rib cage contributed to 31.4%, 35.4%, and 39.8% in neutral zone stiffness in axial rotation, lateral bending and flexion/extension respectively.[25] Likewise, Mannen et al. observed decreases in stiffness as large as 50% for neutral zone stiffness with the removal of rib cage.[10, 11] While there are differences in study design, a comparison of trends can be made to the present study with the removal of the floating ribs. Since no significant differences were observed in any mode of bending, a conclusion can be made that the removal of the floating ribs does not affect the stability of the spine due to neutral or elastic zone stiffness.

Removal of the floating ribs had no significant influence on disc pressure in any region of the thoracic spine. Intervertebral disc pressure measurements have been used to monitor changes in segmental loading and to infer potential for disc degeneration. Other studies have demonstrated intradiscal pressure can vary as much as 40% from changes in position and posture.[7] No previous studies reported examining the influence of rib removal on dynamic disc pressure. In the present study, no statistical significance was seen after removal of the floating ribs in any FSU or segment level for all modes of bending. Similarly, Anderson et al. observed no changes in disc pressure with removal of the ribcage at a given level in static loading.[1] While both studies have limitations of pressure measurement in degenerated discs, it appears that neither static nor dynamic disc pressures change with the removal of floating ribs under a set follower load.

There are many inherent cadaveric limitations in spine testing. Osteophytes are excess bone growths that occur along the anterior portions of the vertebral body and may prevent proper compression against the intervertebral disc. Anderson et al. described a similar effect which may lead to abnormally low readings from pressure transducers.[1] Such effects can obfuscate interpretation of floating rib removal.

The nucleus pulposus is commonly studied in order to determine physiological effects post injury or of disc degeneration. Ferrara et al. conducted a study that assessed the disc pressures in the lumbosacral spine in response to external loading forces. Ferrara et al. showed that cadaveric specimens over the age of 40 have dehydration in lumbar discs caused by age or trauma.[7] The jelly-like substance in the nucleus pulposus becomes more rigid over time from degenerative effects, thus pressure transducers are less likely to obtain distinct changes in readings in older specimens. In the present study, the average specimen age was 66.9 ± 4.4 years. The combination of osteophytes and degenerated intervertebral discs could have masked any changes in disc pressure due to removal of the floating ribs.

One final limitation is the amount of resection that was done to remove the floating ribs. In the present study, each floating rib was resected approximately one inch from the transverse process; the rib head was not removed entirely from the spine. This is a similar technique done in graft harvesting and cosmetic surgery. Oda et al. studied the effects of rib resection on FSUs under constrained loading in order to determine additional anatomical support that contributes to stability. It was concluded that rib head joints serve as stabilizing structures to the human thoracic spine. In the present study, floating ribs were resected only one inch from the transverse process. Partial resections of the rib lead to an increase in range of motion of 111%, 74%, and 193% for axial rotation, lateral bending and flexion/extension, respectively. Subsequent removal of the rib head resulted in a further increase of 72%, 84%, and 81%.[15] However, Oda et al did not analyze levels with floating ribs. In addition, since Oda et al. only tested FSUs, the study did not account for interaction of the individual ribs as a structural unit and therefore has limited comparison to the present study.

Clinical studies have often theorized that the floating ribs provide inconsequential mechanical support to the spine.[3] However, before now, there was no research to validate that statement; research has previously only focused on either complete resection of the ribcage or sternum and rib fractures.[4, 10, 15, 25] Pieracci et al. examined the influence of surgical stabilization of rib fractures in patients to determine the most efficient methods for rib repair. Ultimately, it was noted that the floating ribs at T11 and T12 did not require repair because stabilization of these ribs added little to improved pulmonary mechanics or pain control.[20] However, results of the present study indicate that the floating ribs do contribute to range of motion in the lower thoracic spine in axial rotation and lateral bending. Therefore it may be important to repair these fractures to limit unnatural motion that can lead to early degeneration.[14,19] It is not clear if the changes of motion found in this study will be sufficient to lead to early degeneration, however, caution should be applied to the removal of the floating ribs for cosmetic surgery or in partial resection for autograft use.

The present study demonstrates that floating ribs do have a contribution to the range of motion in the lower thoracic spine. Future cadaveric biomechanical spine studies should consider including the floating ribs as they are seen to significantly influence range of motion in the lower thoracic spine during axial rotation and lateral bending. Inclusion could be particularly important when validating device designs, such as thoracolumbar implants. Overall, the present study shows that inclusion of floating ribs is necessary for all thoracic and thoracolumbar cadaveric studies.

Acknowledgements:

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Manuscript Figures

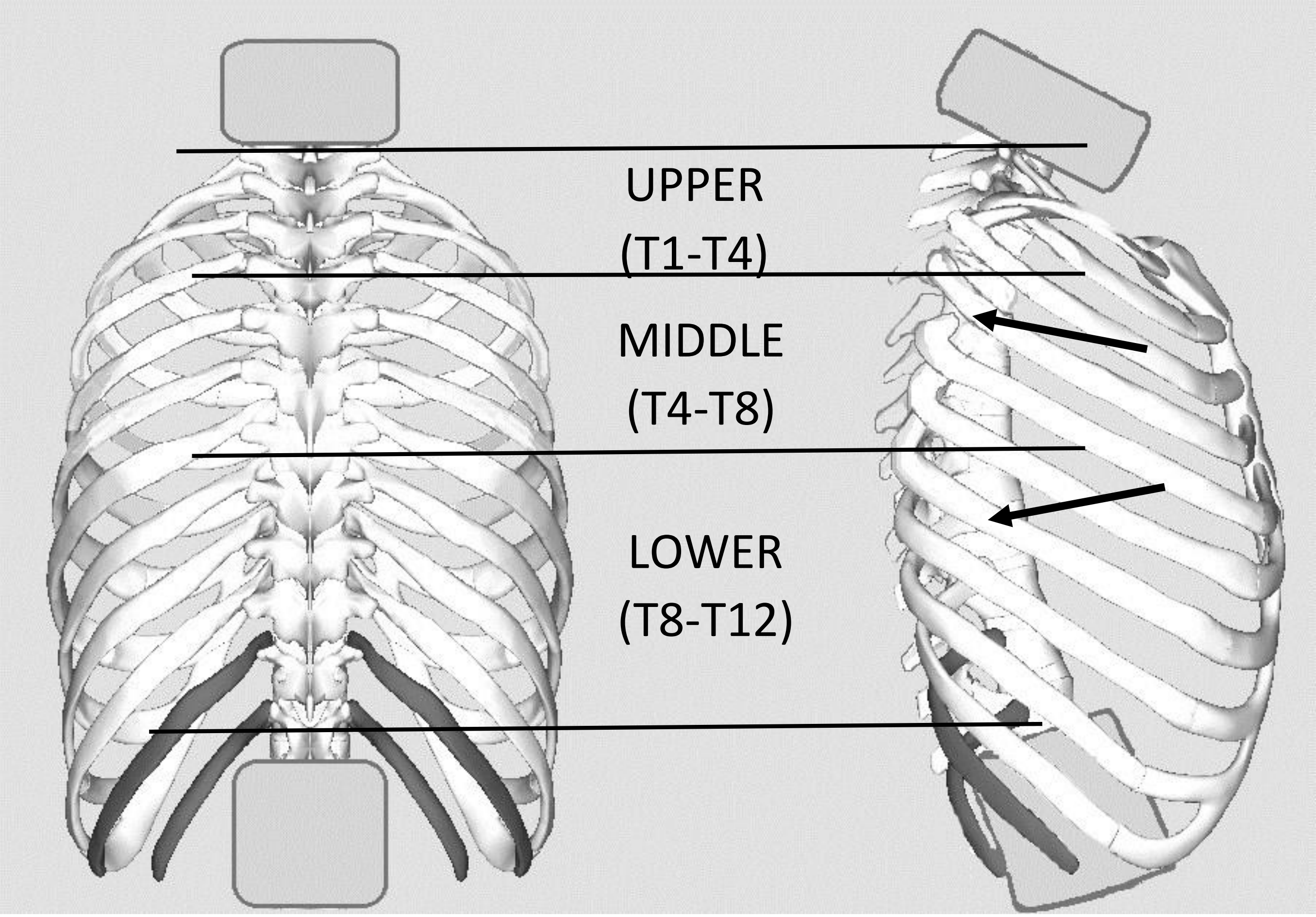


Figure 1. Posterior view of a thoracic spine. Highlighted ribs represent the floating ribs. Arrows point to the locations of the disc pressure measurement. The lower thoracic segment (T9-T12) included the attachment sites of the floating ribs at T11 and T12.

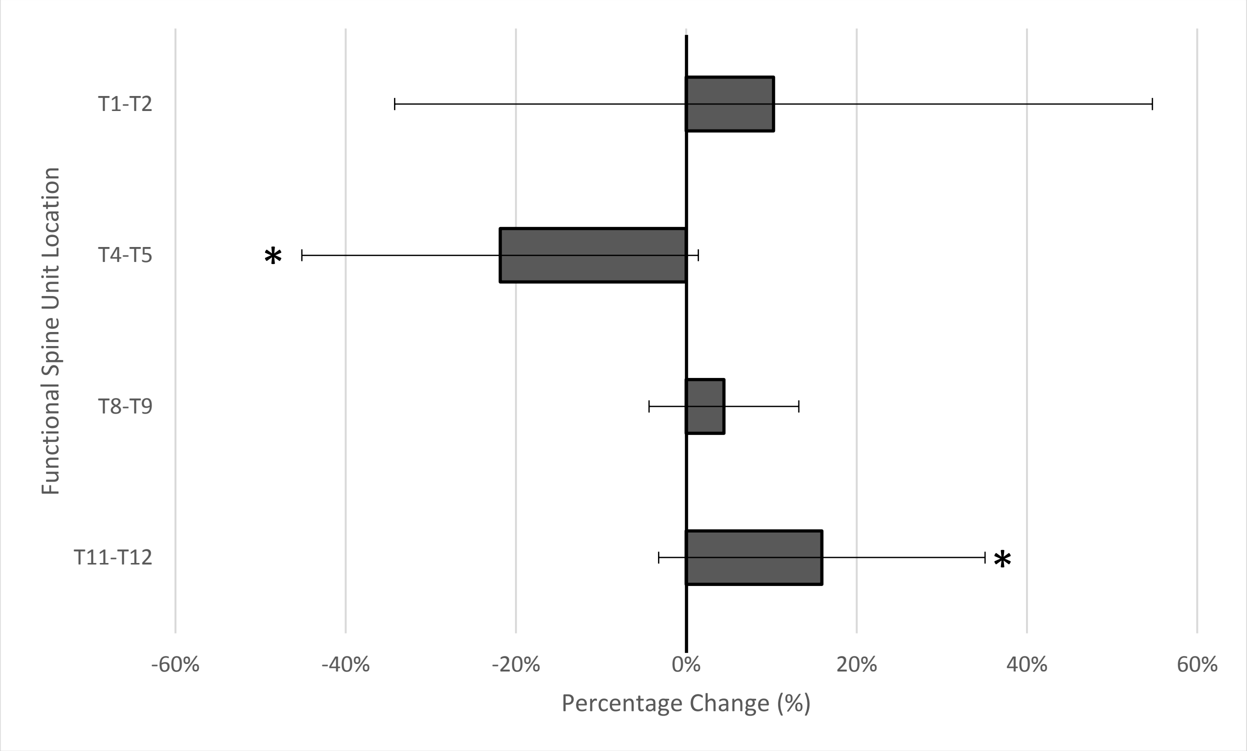


Figure 2. Percent change for range of motion in axial rotation for functional spine units. Asterisks denote significant differences at a level between intact and post floating rib removal using $P < 0.05$.

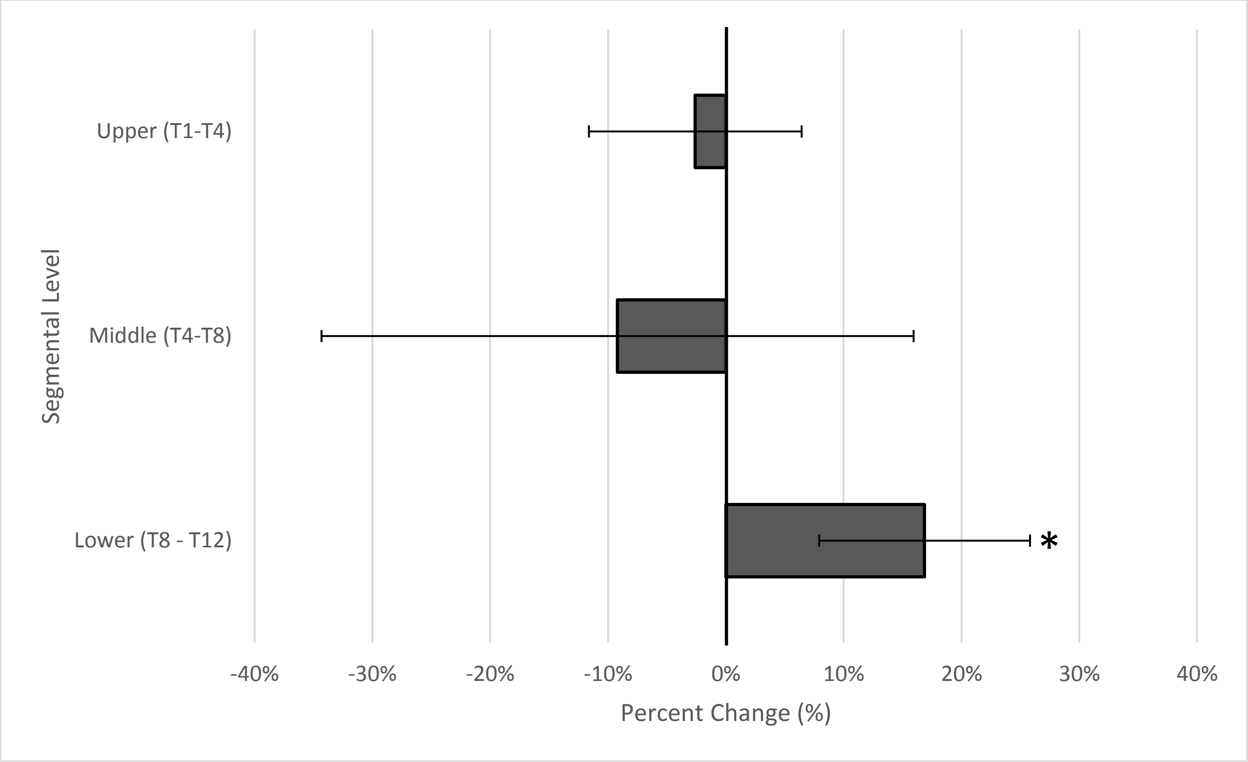


Figure 3. Percent change for range of motion in axial rotation for segmental levels. Asterisks denote significant differences at a level between intact and post floating rib removal using $P < 0.05$

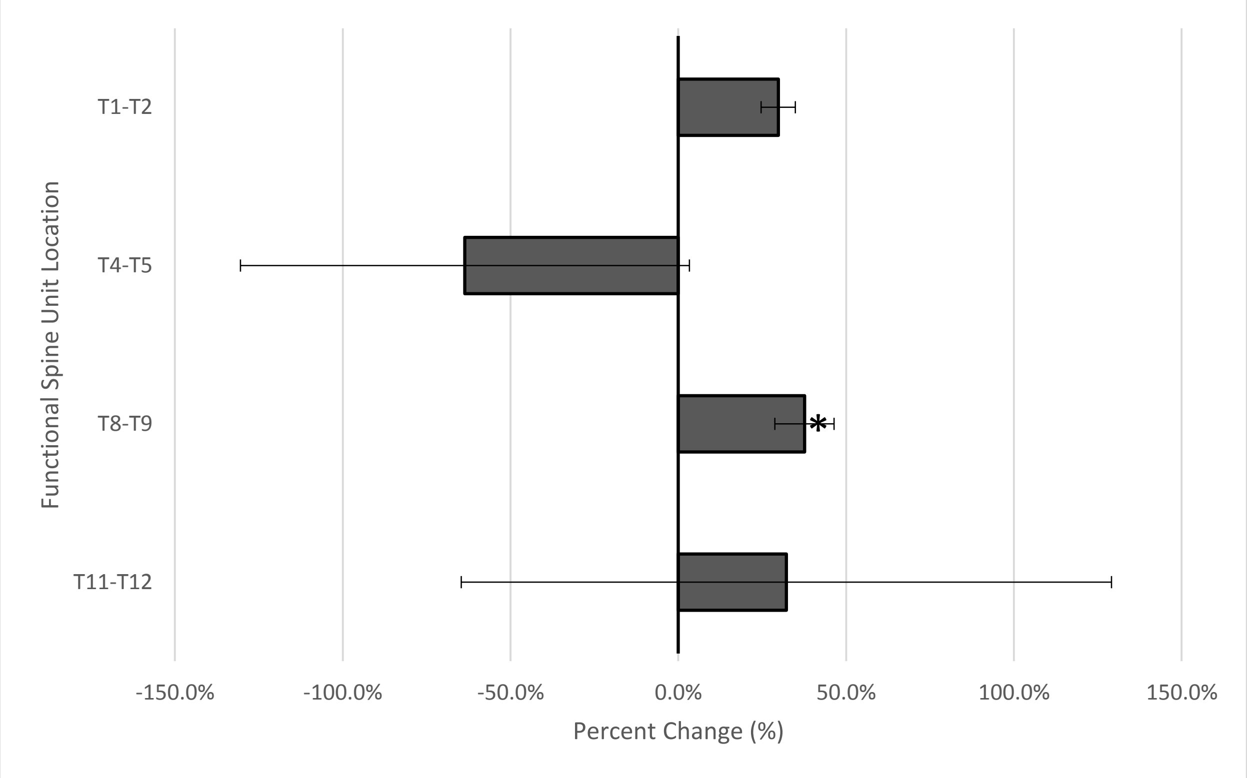
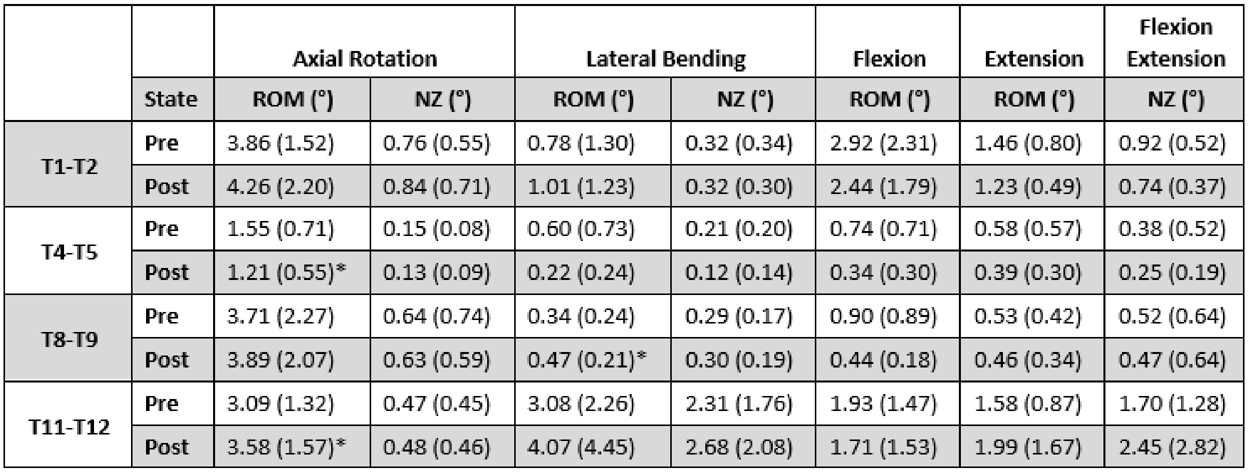


Figure 4. Percent change for range of motion in lateral bending for functional spine units. Asterisks denote significant differences for a level between intact and post floating rib removal using $P < 0.05$.

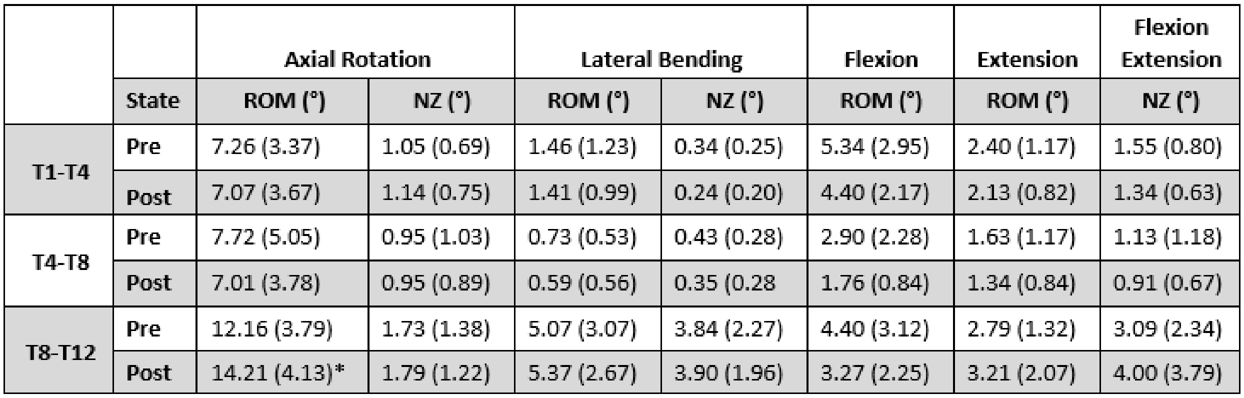
Manuscript Tables

Table 1. Overall range of motion parameters representing FSU levels between intact (pre-) and floating rib removal (post-). Asterisks denote where a significant difference between intact and floating rib removal was present (P < 0.05).



		Axial Rotation		Lateral Bending		Flexion	Extension	Flexion Extension
	State	**ROM (°)**	**NZ (°)**	**ROM (°)**	**NZ (°)**	**ROM (°)**	**ROM (°)**	**NZ (°)**
T1-T2	**Pre**	3.86 (1.52)	0.76 (0.55)	0.78 (1.30)	0.32 (0.34)	2.92 (2.31)	1.46 (0.80)	0.92 (0.52)
	Post	4.26 (2.20)	0.84 (0.71)	1.01 (1.23)	0.32 (0.30)	2.44 (1.79)	1.23 (0.49)	0.74 (0.37)
T4-T5	**Pre**	1.55 (0.71)	0.15 (0.08)	0.60 (0.73)	0.21 (0.20)	0.74 (0.71)	0.58 (0.57)	0.38 (0.52)
	Post	1.21 (0.55)*	0.13 (0.09)	0.22 (0.24)	0.12 (0.14)	0.34 (0.30)	0.39 (0.30)	0.25 (0.19)
T8-T9	**Pre**	3.71 (2.27)	0.64 (0.74)	0.34 (0.24)	0.29 (0.17)	0.90 (0.89)	0.53 (0.42)	0.52 (0.64)
	Post	3.89 (2.07)	0.63 (0.59)	0.47 (0.21)*	0.30 (0.19)	0.44 (0.18)	0.46 (0.34)	0.47 (0.64)
T11-T12	**Pre**	3.09 (1.32)	0.47 (0.45)	3.08 (2.26)	2.31 (1.76)	1.93 (1.47)	1.58 (0.87)	1.70 (1.28)
	Post	3.58 (1.57)*	0.48 (0.46)	4.07 (4.45)	2.68 (2.08)	1.71 (1.53)	1.99 (1.67)	2.45 (2.82)

Table 2. Overall range of motion representing segmental levels between intact (pre-) and floating rib removal (post-). Asterisks denote where a significant difference between intact and floating rib removal was present (P < 0.05).



		Axial Rotation		Lateral Bending		Flexion	Extension	Flexion Extension
	State	**ROM (°)**	**NZ (°)**	**ROM (°)**	**NZ (°)**	**ROM (°)**	**ROM (°)**	**NZ (°)**
T1-T4	**Pre**	7.26 (3.37)	1.05 (0.69)	1.46 (1.23)	0.34 (0.25)	5.34 (2.95)	2.40 (1.17)	1.55 (0.80)
	Post	7.07 (3.67)	1.14 (0.75)	1.41 (0.99)	0.24 (0.20)	4.40 (2.17)	2.13 (0.82)	1.34 (0.63)
T4-T8	**Pre**	7.72 (5.05)	0.95 (1.03)	0.73 (0.53)	0.43 (0.28)	2.90 (2.28)	1.63 (1.17)	1.13 (1.18)
	Post	7.01 (3.78)	0.95 (0.89)	0.59 (0.56)	0.35 (0.28	1.76 (0.84)	1.34 (0.84)	0.91 (0.67)
T8-T12	**Pre**	12.16 (3.79)	1.73 (1.38)	5.07 (3.07)	3.84 (2.27)	4.40 (3.12)	2.79 (1.32)	3.09 (2.34)
	Post	14.21 (4.13)*	1.79 (1.22)	5.37 (2.67)	3.90 (1.96)	3.27 (2.25)	3.21 (2.07)	4.00 (3.79)

Chapter 4: Conclusion and Future Work

The study results indicate that removal of floating ribs significantly affect the overall range of motion for lateral bending and axial rotation. Although there is no direct connection to the sternum, floating ribs do impart some biomechanical support. There were changes seen in overall range of motion, but no significant differences were present in stiffness or dynamic pressure. This suggests a number of improvements that could be made in the present study.

While cadaveric specimens showed no presence of scoliosis, five specimens were observed to have the presence of osteophytes. Although osteophytes were superficial, it is uncertain of the interior of the cadaveric specimens without compromising them. Additionally, age was one of the major limitations of the present study because older specimens may have degenerated bone and/or intervertebral disc. Future studies should implement additional screening to avoid these limitations as much as possible.

Outside of inherent cadaveric limitations, improvements could also be made in terms of statistical power. To rectify this, statistical power can be improved by decreasing alpha, or increasing sample size. From literature, an alpha of 0.05 indicates a probability that there is a 5% chance that the null hypothesis of the floating ribs not significantly contributing to the spine is falsely rejected. However, this may increase the chance of committing a type II error. A larger sample size is suggested. Finally, suggestions for futures studies should consider mitigating the effects of floating ribs by analyzing the effects of fracture and resection in stages. Similar to Brasiliense et al. this would provide a better understanding of quantifying how much each portion of the floating rib contributes. Fracturing would resemble more in vivo situations in which the floating ribs are not typically repaired. Another future study would be to look at the mechanical contributions of each level individually. By removing the ribs starting at T12 and working superiorly to T1, this provides more insight on how much stability a true rib offers versus a false rib. Above all, eliminating these effects could provide clinical application in partial resection of the floating ribs as a resource for autograft harvesting.

Appendix A: Parameter Output Code

```
%% The purpose of this code is to analyze the crunched angle & displacement %
data to find meangingful parameters:
% Step 1: Separate into one cycle
% Step 2: Smooth data
% Step 3: Find Overall ROM, NZS, NZ, EZS, and EZ
% Step 4: Write data to file clear;
clc; close all
  %%
Data
% Determine file names: test = {'FlRibs', 'Intact'}; specimen =
{'FL12111534', 'FL15013190', 'IL13012749', 'IN12102967',
'MD12053191', 'MD12101843', 'MD15022062', 'PA14121034'}; for n =
1:length(specimen);      for test_num = 1:length(test)         bend = {'LB',
'FE', 'AR', 'AP', 'RL', 'SI'};          for bend_num = 1:3 % Cooresponds to
test conducted             if n == 5                    sheetname =
{'2','4','5','8','9','11'};             else                sheetname =
{'1','2','4','5','8','9','11'};             end              filename =
['\\people.soecs.ku.edu\a\b281w225\Home\Desktop\Thesis
Work\Rotations and Translation Data\' specimen{n} '\NewData_'
char(test(test_num)) '_' char(bend(bend_num)) '_4.xls'];


            %% Main Program
            for kk = 1:length(sheetname) %each T level
                % Read-in data
                data = xlsread(filename,char(sheetname(kk)));

                % Separate into one cycle
                [cycle_range_up,cycle_range_dn] = Separate(data(:,7),2,5,1);
for jj = [1:6];%:9 % Each rotation angle (FE, RL, TO) & displ
(AP, RL, SI)
                    disp = data(:,jj);
                    %% ROM Calculations
% Smooth data at ends:

[min_range_up,disp_min_smoothed_up,coeff_min_up,max_range_up,disp_max_smoothe
d_up,coeff_max_up] = Smooth(data(:,7), disp, cycle_range_up, 10, 2);

[min_range_dn,disp_min_smoothed_dn,coeff_min_dn,max_range_dn,disp_max_smoothe
d_dn,coeff_max_dn] = Smooth(data(:,7), disp, cycle_range_dn, 10, 2);

                    % Values of displacement data at -5Nm, 5Nm for up and dn
cycles
                    neg5_up_min = coeff_min_up(1)*(-5)^3 + coeff_min_up(2)*(-
```

```
5)^2 + coeff_min_up(3)*(-5) + coeff_min_up(4);
pos5_up_max = coeff_max_up(1)*(5)^3 + coeff_max_up(2)*(5)^2 +
coeff_max_up(3)*(5) + coeff_max_up(4);

                    pos5_dn_min = coeff_min_dn(1)*(5)^3 +
coeff_min_dn(2)*(5)^2 + coeff_min_dn(3)*(5) + coeff_min_dn(4);
                    neg5_dn_max = coeff_max_dn(1)*(-5)^3 + coeff_max_dn(2)*(-
5)^2 + coeff_max_dn(3)*(-5) + coeff_max_dn(4);

                    ROM_up = pos5_up_max - neg5_up_min;
                    ROM_dn = neg5_dn_max - pos5_dn_min;
                    ROM_mean = (abs(ROM_up)+abs(ROM_dn))/2;

if jj == bend_num
                        %% Neutral Zone
                        % Find index values of ~-1Nm and ~1 Nm within
selected cycle
                        NZ_up_logicals = data(cycle_range_up,7)>=-1 &
data(cycle_range_up,7)<=1;
                        NZ_up_range = (find(NZ_up_logicals == 1,1,'first') +
min(cycle_range_up) - 1):(find(NZ_up_logicals == 1,1,'last')+
min(cycle_range_up) - 1);

                        NZ_dn_logicals = data(cycle_range_dn,7)>=-1 &
data(cycle_range_dn,7)<=1;
                        NZ_dn_range = (find(NZ_dn_logicals == 1,1,'first') +
min(cycle_range_dn) - 1):(find(NZ_dn_logicals == 1,1,'last')+
min(cycle_range_dn) - 1);

                        % Plot to check
                        %                  figure(100)
                        %                  hold on
%
plot(data(cycle_range_up,3),disp(cycle_range_up),'b-')
                        %
plot(data(cycle_range_dn,3),disp(cycle_range_dn),'b-')
                        %
plot(data(NZ_up_range,3),disp(NZ_up_range),'r-')
%
plot(data(NZ_dn_range,3),disp(NZ_dn_range),'r-')
                        % Smooth data from -1 to 1
NZ_coeff_up =
polyfit(data(NZ_up_range,7),disp(NZ_up_range),1);
NZ_coeff_dn =
polyfit(data(NZ_dn_range,7),disp(NZ_dn_range),1);

                        % NZS - Deriv of line at 0 Nm = 3rd coeffecient
                        NZS_up = 1/NZ_coeff_up(1);
```

```
                        NZS_dn = 1/NZ_coeff_dn(1);
                        NZS_mean = (abs(NZS_up)+abs(NZS_dn))/2;

                        % NZ
                        NZ = NZ_coeff_up(2) - NZ_coeff_dn(2);

                        % Neutral position
                        NP = (NZ_coeff_up(2)+NZ_coeff_dn(2))/2;

                        %NZS and NZ check
                        if abs(1/NZS_up) < .05 && abs(1/NZS_dn) < .05
                            NZS_mean = 0;
                            NZS_up = 0;
                            NZS_dn = 0;
NZ = 0;
                        elseif abs(1/NZS_up) < 0.05
                            NZS_mean = NZS_dn;
NZS_up = 0;
                        elseif abs(1/NZS_dn) < 0.05
                            NZS_mean = NZS_up;
NZS_dn = 0;                         else
end
                        %% For FE Only - redo ROM Calculations to separate
into F/E                          if jj==2 %FE only
                            ROM_up = pos5_up_max - NP;
ROM_dn = neg5_dn_max - NP;                          end

                        %% Elastic Zone
                        %EZ                           if jj==2;
if ROM_up>0 %Takes care of sign (+/-) issues
                                EZ_up = ROM_up - abs(NZ/2);
EZ_dn = ROM_dn + abs(NZ/2);                              else
                                EZ_up = ROM_up + abs(NZ/2);
EZ_dn = ROM_dn - abs(NZ/2);                              end
                                                      else
if ROM_up>0 %Takes care of sign (+/-) issues
                                EZ_up = ROM_up/2 - abs(NZ/2);
EZ_dn = ROM_dn/2 + abs(NZ/2);                              else
                                EZ_up = ROM_up/2 + abs(NZ/2);
EZ_dn = ROM_dn/2 - abs(NZ/2);
end                         end
                        %
                        EZ_mean = (abs(EZ_up)+abs(EZ_dn))/2;

                        %EZS - Deriv of coeff equation, at load = +/-5Nm
EZS_up = 3*coeff_max_up(1)*(5)^2 +
2*coeff_max_up(2)*(5) + coeff_max_up(3);
                        EZS_dn = 3*coeff_max_dn(1)*(-5)^2 +
```

```
2*coeff_max_dn(2)*(-5) + coeff_max_dn(3);

                        EZS_dn = 1/EZS_dn;
                        EZS_up = 1/EZS_up;
                        EZS_mean = (abs(EZS_up)+abs(EZS_dn))/2;

else

NZ=0;NZS_up=0;NZS_dn=0;NZS_mean=0;EZ_up=0;EZ_dn=0;EZ_mean=0;EZS_up=0;EZS_dn=0
;EZS_mean=0;
                    end
                    %Code Check
%First, we check ROM
if abs(ROM_mean) < .5
                        EZS_up = 0;
                        EZS_dn = 0;
                        EZS_mean = 0;
                        NZS_up = 0;
                        NZS_dn = 0;
NZS_mean = 0;
else                     end
                    %Second we check the ends of the EZS
                    if abs(1/EZS_up) < .05 && abs(1/EZS_dn) < .05 %Both ends
bad, we eliminate it entirely                            ROM_up = 0;
                        ROM_dn = 0;
                        ROM_mean = 0;
                        EZS_up = 0;
                        EZS_dn = 0;
                        EZS_mean = 0;
                        NZS_mean = 0;
                        EZ_up = 0;
                        EZ_dn = 0;
EZ = 0;
                    elseif abs(1/EZS_up) < .05
                        %Note if one end is bad we must find the displacement
                        %at a load of zero so that we can simulate the good
                        %side and mirror it. UP refers to the line on top and
                        %DN refers to the line on bottom.
                        %Locate where the data is greater than zero (or less
                        %than)
if jj == 2
EZS_up = 0;
EZS_mean = 0;
else
                            loc_zero_dn = find(data(NZ_dn_range,7) < 0,1);
loc_zero_up = find(data(NZ_up_range,7) > 0,1);
%Now find the actual zero (the index)
zero_cross_dn_loc = NZ_dn_range(loc_zero_dn);
```

```
zero_cross_up_loc = NZ_up_range(loc_zero_up);
zero_dn_displacement = data(zero_cross_dn_loc,jj);
                            zero_up_displacement =
data(zero_cross_up_loc,jj);
                            %zero_mean is the "center" point of the plot
zero_mean = (zero_dn_displacement + zero_up_displacement)/2;
                            ROM_half_dn = disp_max_smoothed_dn(end,1);
                            ROM_up = 0;
                            ROM_mean = abs(abs(ROM_half_dn)abs(zero_mean))*2;
                            EZS_mean = EZS_dn;
                            NZ = zero_up_displacement - zero_dn_displacement;
                            EZ_up = ROM_mean/2 - abs(NZ/2);
                            EZ_dn = ROM_mean/2 + abs(NZ/2);
EZ_mean = (abs(EZ_up)+abs(EZ_dn))/2;
end

                    elseif abs(1/EZS_dn) < .05 %Repeat similarly for dn if dn
is the bad data                         if jj == 2
EZS_dn = 0;                             EZS_mean = 0;
else                             loc_zero_dn = find(data(NZ_dn_range,7) <
0,1);                             loc_zero_up = find(data(NZ_up_range,7) >
0,1);                             %Now find the actual zero (the index)
zero_cross_dn_loc = NZ_dn_range(loc_zero_dn);
zero_cross_up_loc = NZ_up_range(loc_zero_up);
zero_dn_displacement = data(zero_cross_dn_loc,jj);
                            zero_up_displacement =
data(zero_cross_up_loc,jj);
                            %zero_mean is the "center" point of the plot
zero_mean = (zero_dn_displacement + zero_up_displacement)/2;
                            ROM_half_up = disp_max_smoothed_up(end,1);
                            ROM_dn = 0;
                            ROM_mean = abs(abs(ROM_half_up)abs(zero_mean))*2;
                            EZS_mean = EZS_up;
                            NZ = zero_up_displacement - zero_dn_displacement;
                            EZ_up = ROM_mean/2 - abs(NZ/2);
                            EZ_dn = ROM_mean/2 + abs(NZ/2);
EZ_mean = (abs(EZ_up)+abs(EZ_dn))/2;
end                      else                      end

                    %% Write Data
                    header2save = {'Rotation','ROM up','ROM
dn','ROM','NZ','NZS up','NZS dn','NZS','EZ_up','EZ_dn','EZ','EZS up','EZS
dn','EZS'};
                    data2save = [bend(jj),ROM_up,
ROM_dn,ROM_mean,NZ,NZS_up,NZS_dn,NZS_mean,EZ_up,EZ_dn,EZ_mean,EZS_up,EZS_dn,E
ZS_mean];                    filename2write = [specimen{n} '_'
char(test(test_num))
'_' char(bend(bend_num)) '_Parameters.xls'];
```

```
                    xlswrite(filename2write,header2save,char(sheetname(kk)));
line2write = ['A' num2str(jj+1)];

xlswrite(filename2write,data2save,char(sheetname(kk)),line2write);
end              end          end      end  end
```

Appendix B: Compile Parameter Code

```
%Organization of all the data from Arrange_Parameter_13
%Sheets_Code_Eliminating_All_Bad_Data.m and Arrange_Parameter_13
%Sheets_Code_Eliminating_All_Bad_Data_Seg.m
  clc; clear all; close
all;

%Establish all variables and naming conventions mode =
{'FlRibs','Intact'}; folder = {'FSU', 'Segment'}; datapath =
['\\people.soecs.ku.edu\a\b281w225\Home\Desktop\Thesis
Work\Rotations and Translation Data\Parameter Analysis\'];
sheet = {'ROM_up', 'ROM_dn', 'ROM', 'NZ', 'NZS_up', 'NZS_dn', 'NZS', 'EZ_up',
'EZ_dn', 'EZ', 'EZS_up', 'EZS_dn', 'EZS'};
header1 = {'T1', 'T2', 'T4', 'T5', 'T8', 'T9', 'T11',
'Upper','Middle','Lower','Bonus'};
header2 = {'Specimen', 'T1wrtT2', 'T2wrtT4', 'T4wrtT5', 'T5wrtT8', 'T8wrtT9',
'T9wrtT11', 'T11wrtT12','T1wrtT4','T4wrtT8','T8wrtT12','T9wrtT12'}; column1
= {'FL12111534', 'FL15013190', 'IL13012749', 'IN12102967', 'MD12053191',
'MD12101843', 'MD15022062', 'PA14121034'}; output =
['Final_Data_Eliminated_Ready_for_Plotting_&_Tables.xls']; title1 =
{'LB_FlRibs'}; title2 = {'FE_FlRibs'}; title3 = {'AR_FlRibs'}; title4 =
{'LB_Intact'}; title5 = {'FE_Intact'}; title6 = {'AR_Intact'};
%Load all the data in for each mode of bending whether it is FSU or Segment
for count = 1:2     for sheet_count = 1:13
    filename_1 = [datapath 'FSU Parameter
Analysis\Modified_New_Parameters_Data_Eliminate_Final_' mode{count} '.xls'];
data_FSU_LB{sheet_count,count} =
xlsread(filename_1,sheet{sheet_count},'B3:H10');
data_FSU_FE{sheet_count,count} =
xlsread(filename_1,sheet{sheet_count},'B14:H21');
data_FSU_AR{sheet_count,count} =
xlsread(filename_1,sheet{sheet_count},'B25:H32');
         filename_2 = [datapath 'Segment
Parameter
Analysis\Modified_New_Parameters_Data_Eliminate_Seg_' mode{count} '.xls'];
data_Seg_LB{sheet_count,count} =
xlsread(filename_2,sheet{sheet_count},'B3:E10');
data_Seg_FE{sheet_count,count} =
xlsread(filename_2,sheet{sheet_count},'B14:E21');
data_Seg_AR{sheet_count,count} =
xlsread(filename_2,sheet{sheet_count},'B25:E32');     end end
%Correct all the spreadsheets to correlate with what was run in t-tests
for sheet_count = 1:13     for row = 1:8          for column_fsu = 1:7
if data_FSU_LB{sheet_count,1}(row,column_fsu)== 0
data_FSU_LB{sheet_count,2}(row,column_fsu) = 0;            elseif
data_FSU_LB{sheet_count,2}(row,column_fsu) == 0
data_FSU_LB{sheet_count,1}(row,column_fsu) = 0;            end
if data_FSU_FE{sheet_count,1}(row,column_fsu)== 0
```

```
data_FSU_FE{sheet_count,2}(row,column_fsu) = 0;                elseif
data_FSU_FE{sheet_count,2}(row,column_fsu) == 0
data_FSU_FE{sheet_count,1}(row,column_fsu) = 0;                end
            if data_FSU_AR{sheet_count,1}(row,column_fsu)== 0
data_FSU_AR{sheet_count,2}(row,column_fsu) = 0;
elseif data_FSU_AR{sheet_count,2}(row,column_fsu) == 0
data_FSU_AR{sheet_count,1}(row,column_fsu) = 0;                end
end
        for column_seg = 1:4             if
data_Seg_LB{sheet_count,1}(row,column_seg) == 0
data_Seg_LB{sheet_count,2}(row,column_seg) = 0;
elseif data_Seg_LB{sheet_count,2}(row,column_seg) == 0
data_Seg_LB{sheet_count,1}(row,column_seg) = 0;                end
if data_Seg_FE{sheet_count,1}(row,column_seg) == 0
data_Seg_FE{sheet_count,2}(row,column_seg) = 0;
elseif data_Seg_FE{sheet_count,2}(row,column_seg) == 0
data_Seg_FE{sheet_count,1}(row,column_seg) = 0;                end
if data_Seg_AR{sheet_count,1}(row,column_seg) == 0
data_Seg_AR{sheet_count,2}(row,column_seg) = 0;
elseif data_Seg_AR{sheet_count,2}(row,column_seg) == 0
data_Seg_AR{sheet_count,1}(row,column_seg) = 0;                end
end     end end
%Writing all the data together and appropriately placing the data in the
%correct places.  for sheet_count = 1:13
    %Writing the Lateral Bending Data
    xlswrite(output,title1,sheet{sheet_count},'G1');
xlswrite(output,title4,sheet{sheet_count},'U1');
xlswrite(output,header1,sheet{sheet_count},'B2');
xlswrite(output,header2,sheet{sheet_count},'A3');
xlswrite(output,column1',sheet{sheet_count},'A4');
xlswrite(output,header1,sheet{sheet_count},'P2');
xlswrite(output,header2,sheet{sheet_count},'O3');
xlswrite(output,column1',sheet{sheet_count},'O4');
    %FlRibs
    xlswrite(output,data_FSU_LB{sheet_count,1},sheet{sheet_count},'B4');
xlswrite(output,data_Seg_LB{sheet_count,1},sheet{sheet_count},'I4');
    %Intact
    xlswrite(output,data_FSU_LB{sheet_count,2},sheet{sheet_count},'P4');
xlswrite(output,data_Seg_LB{sheet_count,2},sheet{sheet_count},'W4');
    %Writing the Flexion Extension Data
xlswrite(output,title2,sheet{sheet_count},'G13');
xlswrite(output,title5,sheet{sheet_count},'U13');
xlswrite(output,header1,sheet{sheet_count},'B14');
xlswrite(output,header2,sheet{sheet_count},'A15');
xlswrite(output,column1',sheet{sheet_count},'A16');
xlswrite(output,header1,sheet{sheet_count},'P14');
xlswrite(output,header2,sheet{sheet_count},'O15');
xlswrite(output,column1',sheet{sheet_count},'O16');
    %FlRibs
      xlswrite(output,data_FSU_FE{sheet_count,1},sheet{sheet_count},'B16');
     xlswrite(output,data_Seg_FE{sheet_count,1},sheet{sheet_count},'I16');
```

```
    %Intact
xlswrite(output,data_FSU_FE{sheet_count,2},sheet{sheet_count},'P16');
xlswrite(output,data_Seg_FE{sheet_count,2},sheet{sheet_count},'W16');
    %Writing the Axial Rotation Data
    xlswrite(output,title3,sheet{sheet_count},'G25');
xlswrite(output,title6,sheet{sheet_count},'U25');
xlswrite(output,header1,sheet{sheet_count},'B26');
xlswrite(output,header2,sheet{sheet_count},'A27');
xlswrite(output,column1',sheet{sheet_count},'A28');
xlswrite(output,header1,sheet{sheet_count},'P26');
xlswrite(output,header2,sheet{sheet_count},'O27');
xlswrite(output,column1',sheet{sheet_count},'O28');
    %FlRibs
xlswrite(output,data_FSU_AR{sheet_count,1},sheet{sheet_count},'B28');
xlswrite(output,data_Seg_AR{sheet_count,1},sheet{sheet_count},'I28');
    %Intact
xlswrite(output,data_FSU_AR{sheet_count,2},sheet{sheet_count},'P28');
xlswrite(output,data_Seg_AR{sheet_count,2},sheet{sheet_count},'W28'); end
```

Appendix C: Sort Parameter Code

```
%Create Sectional Analysis and Total Analysis Files clc clear all
close all   specimen = {'FL12111534', 'FL15013190', 'IL13012749',
'IN12102967',
'MD12053191', 'MD12101843', 'MD15022062', 'PA14121034'};
test = {'FlRibs'}; %Must run twice. Once with FlRibs and once with Intact
bend_test = {'LB', 'FE', 'AR'}; parameter = {'Rotation', 'ROM up', 'ROM dn',
'ROM', 'NZ', 'NZS up', 'NZS dn',
'NZS', 'EZ up', 'EZ dn', 'EZ', 'EZS up', 'EZS dn', 'EZS'};
sheetname = {'T1wrtT4','T4wrtT8','T8wrtT12','T9wrtT12'}; name
= {'Upper', 'Middle', 'Lower', 'Total'};

%Write the data into a 3D structure. 7 x 8 cell array that holds the 3x16
%data for each subject. In other words, the structure contains all the data
%for each vertebrae(7) by specimen (8) which contains each of the data for
test_num = 1: length(test)     for specimen_num = 1:length(specimen)
for num_test = 1:length(test)             for bend_test_num = 1:3
filename =
['\\people.soecs.ku.edu\a\b281w225\Home\Desktop\Thesis Work\Rotations and
Translation Data\' specimen{specimen_num} '_' char(test(num_test)) '_'
char(bend_test(bend_test_num)) '_Parameters_Seg.xls'];
%Import all the data for each bend test                 if specimen_num
== 5
                    for level = 2:length(sheetname)
data{level,specimen_num,bend_test_num} =
xlsread(filename,char(sheetname(level)));
end                 else
                    for level = 1:length(sheetname)
data{level,specimen_num,bend_test_num} =
xlsread(filename,char(sheetname(level)));
end                 end                                end
end     end
        Parameters_LB = data(:,:,1);
        Parameters_FE = data(:,:,2);
        Parameters_AR = data(:,:,3);

    for specimen_num = 1:length(specimen)
if specimen_num == 5
            for vert_count = 2:length(sheetname)
ROM_up_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,1);
                ROM_dn_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,2);
                ROM_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,3);

%                 if abs(ROM_LB(specimen_num,vert_count)) < .5
```

```
%                      NZ_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,4);
%                      NZS_up_LB(specimen_num,vert_count) = 0;
%                      NZS_dn_LB(specimen_num,vert_count) = 0; %
NZS_LB(specimen_num,vert_count) = 0;
%                      EZ_up_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,8);
%                      EZ_dn_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,9);
%                      EZ_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,10);
%                      EZS_up_LB(specimen_num,vert_count) = 0;
%                      EZS_dn_LB(specimen_num,vert_count) = 0;
%                      EZS_LB(specimen_num,vert_count) = 0;
%                  else
                    NZ_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,4);
                    NZS_up_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,5);
                    NZS_dn_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,6);
                    NZS_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,7);
                    EZ_up_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,8);
                    EZ_dn_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,9);
                    EZ_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,10);
                    EZS_up_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,11);
                    EZS_dn_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,12);
                    EZS_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,13);
%                      if abs(1/EZS_up_LB(specimen_num,vert_count))<.05 &&
abs(1/EZS_dn_LB(specimen_num,vert_count)) < .05
%                          EZS_LB(specimen_num,vert_count) = 0;
%                          EZS_dn_LB(specimen_num,vert_count) = 0;
%                          EZS_up_LB(specimen_num,vert_count) = 0;
%                          ROM_up_LB(specimen_num,vert_count) = 0;
%                          ROM_dn_LB(specimen_num,vert_count) = 0;
%                          ROM_LB(specimen_num,vert_count) = 0;
%                      elseif abs(1/EZS_dn_LB(specimen_num,vert_count))<.05 %
EZS_LB(specimen_num,vert_count) =
EZS_up_LB(specimen_num,vert_count);
%                          EZS_dn_LB(specimen_num,vert_count) = 0;
%                          ROM_dn_LB(specimen_num,vert_count) = 0;
%                          ROM_LB(specimen_num,vert_count) =
```

```
ROM_up_LB(specimen_num,vert_count);
%                      elseif abs(1/EZS_up_LB(specimen_num,vert_count)) < .05
%                          EZS_LB(specimen_num,vert_count) =
EZS_dn_LB(specimen_num,vert_count);
%                          EZS_up_LB(specimen_num,vert_count) = 0;
%                          ROM_up_LB(specimen_num,vert_count) = 0;
%                          ROM_LB(specimen_num,vert_count) =
ROM_dn_LB(specimen_num,vert_count);
%                      else
%                      end
%                  end

                ROM_up_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,1);
                ROM_dn_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,2);
                ROM_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,3);

%                  if abs(ROM_FE(specimen_num,vert_count)) < 0.5
%                      NZ_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,4);
%                      NZS_up_FE(specimen_num,vert_count) = 0;
%                      NZS_dn_FE(specimen_num,vert_count) = 0; %
NZS_FE(specimen_num,vert_count) = 0;
%                      EZ_up_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,8);
%                      EZ_dn_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,9);
%                      EZ_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,10);
%                      EZS_up_FE(specimen_num,vert_count) = 0;
%                      EZS_dn_FE(specimen_num,vert_count) = 0;
%                      EZS_FE(specimen_num,vert_count) = 0;
%                  else
                    NZ_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,4);
                    NZS_up_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,5);
                    NZS_dn_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,6);
                    NZS_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,7);
                    EZ_up_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,8);
                    EZ_dn_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,9);
                    EZ_FE(specimen_num,vert_count) =
```

```
Parameters_FE{vert_count,specimen_num}(2,10);
                    EZS_up_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,11);
                    EZS_dn_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,12);
                    EZS_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,13);
%                     if abs(1/(EZS_up_FE(specimen_num,vert_count))) < .05 &&
abs(1/(EZS_dn_FE(specimen_num,vert_count))) < .05
%                         ROM_up_FE(specimen_num,vert_count) = 0;
%                         ROM_dn_FE(specimen_num,vert_count) = 0; %
ROM_FE(specimen_num,vert_count) = 0;
%                         EZS_FE(specimen_num,vert_count) = 0;
%                         EZS_up_FE(specimen_num,vert_count) = 0;
%                         EZS_dn_FE(specimen_num,vert_count) = 0;
%                     elseif abs(1/(EZS_up_FE(specimen_num,vert_count)))<.05
%                         ROM_up_FE(specimen_num,vert_count) = 0; %
ROM_FE(specimen_num,vert_count) = 0;
%                         EZS_up_FE(specimen_num,vert_count) = 0;
%                         EZS_FE(specimen_num,vert_count) = 0;
%                     elseif abs(1/(EZS_dn_FE(specimen_num,vert_count)))<.05
%                         ROM_dn_FE(specimen_num,vert_count) = 0;
%                         ROM_FE(specimen_num,vert_count) = 0;
%                         EZS_dn_FE(specimen_num,vert_count) = 0;
%                         EZS_FE(specimen_num,vert_count) = 0;
%                     else
%                     end

%                     if abs(1/(NZS_up_FE(specimen_num,vert_count))) < .05 &&
abs(1/(NZS_dn_FE(specimen_num,vert_count))) <.05
%                         NZS_up_FE(specimen_num,vert_count) = 0;
%                         NZS_dn_FE(specimen_num,vert_count) = 0;
%                         NZS_FE(specimen_num,vert_count) = 0;
%                     elseif abs(1/(NZS_up_FE(specimen_num,vert_count))) <
.05
%                         NZS_up_FE(specimen_num,vert_count) = 0;
%                     elseif abs(1/(NZS_dn_FE(specimen_num,vert_count))) <
.05
%                         NZS_dn_FE(specimen_num,vert_count) = 0;
%                     else
%                     end
%                 end

                ROM_up_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,1);
                ROM_dn_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,2);
                ROM_AR(specimen_num,vert_count) =
```

```
Parameters_AR{vert_count,specimen_num}(3,3);

%                  if abs(ROM_AR(specimen_num,vert_count)) < 0.5
%                      NZ_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,4);
%                      NZS_up_AR(specimen_num,vert_count) = 0;
%                      NZS_dn_AR(specimen_num,vert_count) = 0; %
NZS_AR(specimen_num,vert_count) = 0;
%                      EZ_up_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,8);
%                      EZ_dn_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,9);
%                      EZ_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,10);
%                      EZS_up_AR(specimen_num,vert_count) = 0;
%                      EZS_dn_AR(specimen_num,vert_count) = 0;
%                      EZS_AR(specimen_num,vert_count) = 0;
%                  else
                     NZ_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,4);
                     NZS_up_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,5);
                     NZS_dn_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,6);
                     NZS_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,7);
                     EZ_up_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,8);
                     EZ_dn_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,9);
                     EZ_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,10);
                     EZS_up_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,11);
                     EZS_dn_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,12);
                     EZS_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,13);
%                      if abs(1/EZS_up_AR(specimen_num,vert_count)) < .05 &&
abs(1/EZS_dn_AR(specimen_num,vert_count)) < .05
%                          EZS_AR(specimen_num,vert_count) = 0;
%                          EZS_up_AR(specimen_num,vert_count) = 0;
%                          EZS_dn_AR(specimen_num,vert_count) = 0;
%                          ROM_up_AR(specimen_num,vert_count) = 0;
%                          ROM_dn_AR(specimen_num,vert_count) = 0;
%                          ROM_AR(specimen_num,vert_count) = 0;
%                      elseif abs(1/EZS_dn_AR(specimen_num,vert_count)) < .05
%                          EZS_dn_AR(specimen_num,vert_count) = 0;
```

```
%                         EZS_AR(specimen_num,vert_count) =
EZS_up_AR(specimen_num,vert_count);
%                         ROM_dn_AR(specimen_num,vert_count) = 0;
%                         ROM_AR(specimen_num,vert_count) =
ROM_up_AR(specimen_num,vert_count);
%                     elseif abs(1/EZS_up_AR(specimen_num,vert_count))<0.05 %
EZS_up_AR(specimen_num,vert_count) = 0;
%                         EZS_AR(specimen_num,vert_count) =
EZS_dn_AR(specimen_num,vert_count);
%                         ROM_up_AR(specimen_num,vert_count) = 0;
%                         ROM_AR(specimen_num,vert_count) =
ROM_up_AR(specimen_num,vert_count);
%                     else
%                     end %                end
end         else              for vert_count =
1:length(sheetname)
                ROM_up_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,1);
                ROM_dn_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,2);
                ROM_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,3);

%                 if abs(ROM_LB(specimen_num,vert_count)) < .5
%                     NZ_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,4);
%                     NZS_up_LB(specimen_num,vert_count) = 0;
%                     NZS_dn_LB(specimen_num,vert_count) = 0;
%                     NZS_LB(specimen_num,vert_count) = 0;
%                     EZ_up_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,8);
%                     EZ_dn_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,9);
%                     EZ_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,10);
%                     EZS_up_LB(specimen_num,vert_count) = 0;
%                     EZS_dn_LB(specimen_num,vert_count) = 0;
%                     EZS_LB(specimen_num,vert_count) = 0;
%                 else
                    NZ_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,4);
                    NZS_up_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,5);
                    NZS_dn_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,6);
                    NZS_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,7);
                    EZ_up_LB(specimen_num,vert_count) =
```

```
Parameters_LB{vert_count,specimen_num}(1,8);
                    EZ_dn_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,9);
                    EZ_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,10);
                    EZS_up_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,11);
                    EZS_dn_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,12);
EZS_LB(specimen_num,vert_count) =
Parameters_LB{vert_count,specimen_num}(1,13);
%                     if abs(1/EZS_up_LB(specimen_num,vert_count))<.05 &&
abs(1/EZS_dn_LB(specimen_num,vert_count)) < .05
%                         EZS_LB(specimen_num,vert_count) = 0;
%                         EZS_dn_LB(specimen_num,vert_count) = 0;
%                         EZS_up_LB(specimen_num,vert_count) = 0;
%                         ROM_up_LB(specimen_num,vert_count) = 0;
%                         ROM_dn_LB(specimen_num,vert_count) = 0;
%                         ROM_LB(specimen_num,vert_count) = 0;
%                     elseif abs(1/EZS_dn_LB(specimen_num,vert_count))<.05
%                         EZS_LB(specimen_num,vert_count) =
EZS_up_LB(specimen_num,vert_count);
%                         EZS_dn_LB(specimen_num,vert_count) = 0;
%                         ROM_dn_LB(specimen_num,vert_count) = 0;
%                         ROM_LB(specimen_num,vert_count) =
ROM_up_LB(specimen_num,vert_count);
%                     elseif abs(1/EZS_up_LB(specimen_num,vert_count)) < .05
%                         EZS_LB(specimen_num,vert_count) =
EZS_dn_LB(specimen_num,vert_count);
%                         EZS_up_LB(specimen_num,vert_count) = 0;
%                         ROM_up_LB(specimen_num,vert_count) = 0;
%                         ROM_LB(specimen_num,vert_count) =
ROM_dn_LB(specimen_num,vert_count);
%                     else
%                     end
%                 end

                ROM_up_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,1);
                ROM_dn_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,2);
                ROM_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,3);

%                 if abs(ROM_FE(specimen_num,vert_count)) < 0.5
%                     NZ_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,4);
%                     NZS_up_FE(specimen_num,vert_count) = 0;
```

```
%                     NZS_dn_FE(specimen_num,vert_count) = 0;
%                     NZS_FE(specimen_num,vert_count) = 0;
%                     EZ_up_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,8);
%                     EZ_dn_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,9);
%                     EZ_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,10);
%                     EZS_up_FE(specimen_num,vert_count) = 0;
%                     EZS_dn_FE(specimen_num,vert_count) = 0;
%                     EZS_FE(specimen_num,vert_count) = 0;
%                 else
                    NZ_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,4);
NZS_up_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,5);
                    NZS_dn_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,6);
                    NZS_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,7);
                    EZ_up_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,8);
                    EZ_dn_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,9);
                    EZ_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,10);
                    EZS_up_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,11);
                    EZS_dn_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,12);
                    EZS_FE(specimen_num,vert_count) =
Parameters_FE{vert_count,specimen_num}(2,13);
%                     if abs(1/(EZS_up_FE(specimen_num,vert_count))) < .05 &&
abs(1/(EZS_dn_FE(specimen_num,vert_count))) < .05
%                         ROM_up_FE(specimen_num,vert_count) = 0;
%                         ROM_dn_FE(specimen_num,vert_count) = 0;
%                         ROM_FE(specimen_num,vert_count) = 0;
%                         EZS_FE(specimen_num,vert_count) = 0;
%                         EZS_up_FE(specimen_num,vert_count) = 0;
%                         EZS_dn_FE(specimen_num,vert_count) = 0;
%                     elseif abs(1/(EZS_up_FE(specimen_num,vert_count)))<.05
%                         ROM_up_FE(specimen_num,vert_count) = 0;
%                         ROM_FE(specimen_num,vert_count) = 0;
%                         EZS_up_FE(specimen_num,vert_count) = 0;
%                         EZS_FE(specimen_num,vert_count) = 0;
%                     elseif abs(1/(EZS_dn_FE(specimen_num,vert_count)))<.05
%                         ROM_dn_FE(specimen_num,vert_count) = 0;
%                         ROM_FE(specimen_num,vert_count) = 0;
%                         EZS_dn_FE(specimen_num,vert_count) = 0;
```

```
%                         EZS_FE(specimen_num,vert_count) = 0;
%                     else
%                     end

%                     if abs(1/(NZS_up_FE(specimen_num,vert_count))) < .05 &&
abs(1/(NZS_dn_FE(specimen_num,vert_count))) <.05
%                         NZS_up_FE(specimen_num,vert_count) = 0;
%                         NZS_dn_FE(specimen_num,vert_count) = 0;
%                         NZS_FE(specimen_num,vert_count) = 0;
%                     elseif abs(1/(NZS_up_FE(specimen_num,vert_count))) <
.05
%                         NZS_up_FE(specimen_num,vert_count) = 0;
%                     elseif abs(1/(NZS_dn_FE(specimen_num,vert_count))) <
.05
%                         NZS_dn_FE(specimen_num,vert_count) = 0;
%                     else
%                     end
%                 end

                ROM_up_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,1);
                ROM_dn_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,2);
                ROM_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,3);

%                 if abs(ROM_AR(specimen_num,vert_count)) < 0.5
%                     NZ_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,4);
%                     NZS_up_AR(specimen_num,vert_count) = 0;
%                     NZS_dn_AR(specimen_num,vert_count) = 0;
%                     NZS_AR(specimen_num,vert_count) = 0;
%                     EZ_up_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,8);
%                     EZ_dn_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,9);
%                     EZ_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,10);
%                     EZS_up_AR(specimen_num,vert_count) = 0;
%                     EZS_dn_AR(specimen_num,vert_count) = 0;
%                     EZS_AR(specimen_num,vert_count) = 0;
%                 else
                    NZ_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,4);
                    NZS_up_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,5);
                    NZS_dn_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,6);
```

```
                    NZS_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,7);
                    EZ_up_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,8);
                    EZ_dn_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,9);
                    EZ_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,10);
                    EZS_up_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,11);
                    EZS_dn_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,12);
                    EZS_AR(specimen_num,vert_count) =
Parameters_AR{vert_count,specimen_num}(3,13);
%                     if abs(1/EZS_up_AR(specimen_num,vert_count)) < .05 &&
abs(1/EZS_dn_AR(specimen_num,vert_count)) < .05
%                         EZS_AR(specimen_num,vert_count) = 0;
%                         EZS_up_AR(specimen_num,vert_count) = 0;
%                         EZS_dn_AR(specimen_num,vert_count) = 0;
%                         ROM_up_AR(specimen_num,vert_count) = 0;
%                         ROM_dn_AR(specimen_num,vert_count) = 0;
%                         ROM_AR(specimen_num,vert_count) = 0;
%                     elseif abs(1/EZS_dn_AR(specimen_num,vert_count)) < .05
%                         EZS_dn_AR(specimen_num,vert_count) = 0;
%                         EZS_AR(specimen_num,vert_count) =
EZS_up_AR(specimen_num,vert_count);
%                         ROM_dn_AR(specimen_num,vert_count) = 0;
%                         ROM_AR(specimen_num,vert_count) =
ROM_up_AR(specimen_num,vert_count);
%                     elseif abs(1/EZS_up_AR(specimen_num,vert_count))<0.05
%                         EZS_up_AR(specimen_num,vert_count) = 0;
%                         EZS_AR(specimen_num,vert_count) =
EZS_dn_AR(specimen_num,vert_count);
%                         ROM_up_AR(specimen_num,vert_count) = 0;
%                         ROM_AR(specimen_num,vert_count) =
ROM_up_AR(specimen_num,vert_count);
%                     else
%                     end
%                 end
%             end
end         end
        %XLS write
        Filename = ['\\people.soecs.ku.edu\a\b281w225\Home\Desktop\Thesis
Work\Rotations and Translation
Data\Modified_New_Parameters_Data_Eliminate_Seg_' test{test_num}];
headsub1 = ['LB' test{test_num}];         headsub2 = ['FE'
test{test_num}];         headsub3 = ['AR' test{test_num}];
header1 = [{headsub1},{headsub2},{headsub3}];         header2 =
{'Specimen', 'Upper','Middle','Lower','Bonus'};
```

```
        sheet = {'ROM_up', 'ROM_dn', 'ROM', 'NZ', 'NZS_up', 'NZS_dn', 'NZS',
'EZ_up', 'EZ_dn', 'EZ', 'EZS_up', 'EZS_dn', 'EZS'};
for a = 1:13                 xlswrite(Filename,
header1{1},sheet{a}, 'A1')              xlswrite(Filename,
header1{2},sheet{a}, 'A12')
xlswrite(Filename, header1{3},sheet{a}, 'A23')
xlswrite(Filename, header2, sheet{a}, 'A2')
xlswrite(Filename, header2, sheet{a}, 'A13')
xlswrite(Filename, header2, sheet{a}, 'A24')
xlswrite(Filename, specimen', sheet{a}, 'A3')
xlswrite(Filename, specimen', sheet{a}, 'A14')
xlswrite(Filename, specimen', sheet{a}, 'A25')
end
        %ROM_up Writing         xlswrite(Filename,
ROM_up_LB, sheet{1}, 'B3')          xlswrite(Filename,
ROM_up_FE, sheet{1}, 'B14')
xlswrite(Filename, ROM_up_AR, sheet{1}, 'B25')
        %ROM_dn Writing         xlswrite(Filename,
ROM_dn_LB, sheet{2}, 'B3')          xlswrite(Filename,
ROM_dn_FE, sheet{2}, 'B14')
xlswrite(Filename, ROM_dn_AR, sheet{2}, 'B25')
        %ROM Writing         xlswrite(Filename,
ROM_LB, sheet{3}, 'B3')          xlswrite(Filename,
ROM_FE, sheet{3}, 'B14')
xlswrite(Filename, ROM_AR, sheet{3}, 'B25')
%NZ Writing         xlswrite(Filename, NZ_LB,
sheet{4}, 'B3')         xlswrite(Filename, NZ_FE,
sheet{4}, 'B14')         xlswrite(Filename, NZ_AR,
sheet{4}, 'B25')
        %NZS_up Writing         xlswrite(Filename,
NZS_up_LB, sheet{5}, 'B3')          xlswrite(Filename,
NZS_up_FE, sheet{5}, 'B14')
xlswrite(Filename, NZS_up_AR, sheet{5}, 'B25')
        %NZS_dn Writing         xlswrite(Filename,
NZS_dn_LB, sheet{6}, 'B3')          xlswrite(Filename,
NZS_dn_FE, sheet{6}, 'B14')
xlswrite(Filename, NZS_dn_AR, sheet{6}, 'B25')
        %NZS Writing         xlswrite(Filename,
NZS_LB, sheet{7}, 'B3')          xlswrite(Filename,
NZS_FE, sheet{7}, 'B14')
xlswrite(Filename, NZS_AR, sheet{7}, 'B25')
        %EZ_up Writing         xlswrite(Filename,
EZ_up_LB, sheet{8}, 'B3')          xlswrite(Filename,
EZ_up_FE, sheet{8}, 'B14')
xlswrite(Filename, EZ_up_AR, sheet{8}, 'B25')
        %EZ_dn Writing         xlswrite(Filename,
EZ_dn_LB, sheet{9}, 'B3')          xlswrite(Filename,
EZ_dn_FE, sheet{9}, 'B14')
xlswrite(Filename, EZ_dn_AR, sheet{9}, 'B25')
        %EZ Writing         xlswrite(Filename,
EZ_LB, sheet{10}, 'B3')          xlswrite(Filename,
```

```
EZ_FE, sheet{10}, 'B14')
xlswrite(Filename, EZ_AR, sheet{10}, 'B25')
        %EZS_up Writing         xlswrite(Filename,
EZS_up_LB, sheet{11}, 'B3')          xlswrite(Filename,
EZS_up_FE, sheet{11}, 'B14')
xlswrite(Filename, EZS_up_AR, sheet{11}, 'B25')
        %EZS_dn Writing         xlswrite(Filename,
EZS_dn_LB, sheet{12}, 'B3')          xlswrite(Filename,
EZS_dn_FE, sheet{12}, 'B14')
xlswrite(Filename, EZS_dn_AR, sheet{12}, 'B25')
        %EZS Writing         xlswrite(Filename,
EZS_LB, sheet{13}, 'B3')          xlswrite(Filename,
EZS_FE, sheet{13}, 'B14')
xlswrite(Filename, EZS_AR, sheet{13}, 'B25')
end end
```