THE PENNSYLVANIA STATE UNIVERSITY
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An Analysis of Lumbar Muscle Load Distribution with and without the Presence of the Multifidus Muscle

DANIEL ESPARRAGOZA
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Reviewed and approved* by the following:

Daniel Cortes
Associate Professor of Mechanical Engineering
Thesis Supervisor and Honors Advisor

Anne Martin
Associate Professor of Mechanical Engineering
Faculty Reader

* Electronic approvals are on file.

ABSTRACT

The goal of this research is to analyze spinal stability in relation to the multifidus muscle. Specifically, the study will evaluate if there is a significant effect on load distribution on the spine when the multifidus is deactivated. This is accomplished by analyzing the surrounding lumbar muscle tendon forces for different lumbar movements.

Data was collected for three models and three distinct lumbar movements. The three models included the model developed Raabe and Chaudhari, a modified version of the Raabe and Chaudhari model where the multifidus entry level muscle isometric maximum force was reduced, and another modified model where the multifidus spinous process muscle isometric maximum force was reduced. The three distinct motions analyzed were flexion-extension, axial rotation, and lateral bending.

Results show that the lumbar muscles on the modified models performed at higher tendon forces than the lumbar muscles from the original model. The results would indicate that the deactivation of the multifidus muscle would cause surrounding lumbar muscles to compensate by increasing their tendon force over a range of motion. These results were consistent for all the lumbar muscles and lumbar motions analyzed in this study. Furthermore, it was found that there is a difference to the extent in which the lumbar muscles change performance based on what part of the multifidus muscle was modified. The results show that the deactivation of the multifidus spinous process muscle has a greater impact on the performance of surrounding lumbar muscles than the deactivation of the multifidus entry level muscle.

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I would like to thank my faculty reader Dr. Anne Martin for helping review this thesis and suggest changes that resulted in the final version of this report.

I would also like to thank Jhon Quinones, kinesiology graduate student at Universidad del Valle in Cali, Colombia for the countless hours spent meeting with me to learn how to use the simulation tool OpenSim which was ultimately used in this study to collect data.

Finally, I would like to thank my mother, father, and brother for their endless support throughout my academic career at Penn State as a Mechanical Engineering student. They helped guide me throughout my journey here and provided unconditional love and support throughout my time as an undergraduate student.

I dedicate this thesis to my family and friends who supported me and stood by me during my undergraduate journey.

Chapter 1

Introduction

1.1 Facet Joint Syndrome Overview

Lower back pain is a common issue in adults in the United States. It is estimated that about 65-80% of adults will experience lower back pain in their lifetime [1]. Extensive research has been done on lower back pain because of its high prevalence in society. Studies have found that here are many reasons adults may experience lower back pain in their lives including disease, excessive use of back in daily tasks, degeneration of back muscles and the spine, accidents, and posture. One common source of lower back pain is facet joint syndrome which accounts for 15-45% of cases [2].

Facet joint syndrome has been investigated since it is a common source of back pain. However, facet joint syndrome has been proven to be difficult to understand and commonly misdiagnosed as it has similar symptoms to other back problems [3]. There are some best practices to diagnose facet joint point to avoid falsely diagnosing patients with facet joint syndrome [2]. It is advised that a diverse team of medical experts is required for proper diagnosis and treatment of facet joint syndrome [1].

Facet joint syndrome is a result of degeneration of the spine and natural wearing of the facet joints [1]. This syndrome can be identified using MRI, x-ray, or CT scans which can show joint space narrowing and joint calcification. Although this syndrome can cause extreme pain, there is treatment that exists to relieve discomfort.

1.2 Facet Joint Intervention

Although uncertainties exist surrounding facet joint pain, patients can still be cured if accurately diagnosed. Facet joint interventions exist that can eliminate the lower back pain. The procedure that currently exists involves an image guided injection that eliminates nerve endings that are causing pains near the spine [4]. Severe complications are not common if tools used are of high precision, however, tools available may not always be of high precision.

Using tools of lower precision could result in an error during the intervention. Facet joint pain interventions occur in an area of high sensitivity [4]. The area of high sensitivity involves the medial branch on the dorsal ramus of the spinal nerve which is connected to the multifidus muscle as shown in figure 1.

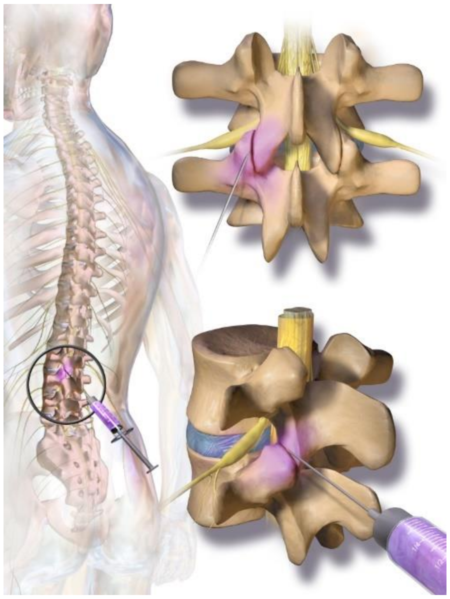

Figure 1. Facet joint intervention in the medial branch on the dorsal ramus. Facet joint is depicted in purple, the nerve is depicted in yellow, discs depicted in blue [5].

The goal of the procedure is to terminate sensory signals from being sent to the nerve effecting the joint. Although the intentions of the procedure are good, the facet joint pain intervention may have a significant effect on spinal stability which leads to back pain in patients in the future [6]. It is believed that during intervention, the multifidus muscle is being deactivated because important signals necessary for activation of the muscle are being eliminated. This will be further discussed in this study.

Our team hypothesizes that the elimination of the signals is reducing the amount of stabilization force the multifidus muscle can provide, affecting the overall stability of the spine. The goal of this research is to analyze spinal stability in relation to the multifidus muscle. Specifically, the study will evaluate if there is a significant effect on load distribution on the spine when the multifidus is deactivated.

1.3 Multifidus and Spinal Stability

The multifidus muscle is located in the back along the spine as can be depicted in figure 2. Despite existing research, uncertainties still exist pertaining to the multifidus muscle and the extent of the muscle's contributions to spinal stability. Our research will address the significance the multifidus muscle has to spinal loading and spinal stability.

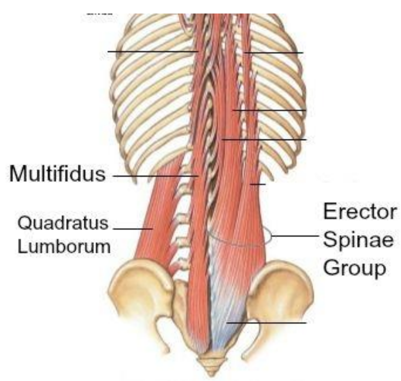

Figure 2. Diagram of the Multifidus Muscle [7].

One of the things researchers have considered is the physical shape and structure of the multifidus muscle [8]. The muscle is structured in such a way that it aligns itself right along the spine leading experts to believe it must have some contribution to spinal support. A study was conducted an architectural analysis on the multifidus muscle using data from different sections of the muscle in separate vertebral regions. The different vertebral regions analyzed can be seen in figure 3. It was found that the mass and structure of the multifidus muscle is such that the muscle can produce large forces to stabilize the spine. Since the multifidus muscle has been found to produce large forces, the team suspects that eliminating the muscle during intervention would have a significant effect on spinal loading that could cause back problems over time.

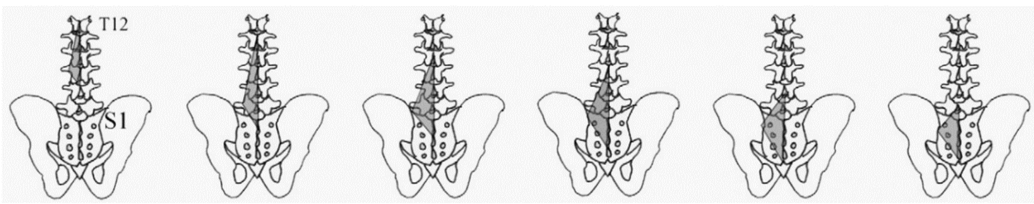

Figure 3. Schematic of Multifidus Muscle Regions [8]

An investigation was also done on the role of different fibers in the muscle [9]. The researchers did this in response to 5 clinical beliefs that existed with regards to the role of fibers. The belief was that deep fibers and superficial fibers played different roles in the stability of the spine, rotational motion of the spine, and activation during motion. While evidence was found that the multifidus does support the spine and is required for intervertebral control, it was concluded that clinical beliefs of fibers had little support. Our study will focus on the overall effect of the multifidus muscle rather than different fibers because fibers have not been found to be a significant determinant in stability and loading. Analyzing the overall multifidus muscle should be sufficient to understand the effect that occurs when it is eliminated.

There is evidence that the multifidus muscle has a role in the stabilization of the spine and that an impaired multifidus muscle can result in back pain [10]. A study was done on athletes to understand why young athletes who train hard experience back pain. The study required participants to take part in a 13-week intense training program that cricket players participate in. During the program, ultrasound, assessments, and interventions were used to determine the root of the lower back pain in young and seemingly healthy people. It was found that excessive training could cause impairments in the multifidus muscle which in turn caused lower back pain. The evidence that impairments cause lower back pain is an indicator to our research team that a non-functioning multifidus muscle could have lower back consequences for patients.

Our research will further explore the contributions the multifidus muscle has on load distribution on the spine. Furthermore, our study will investigate how spinal loading is affecting when the muscle is not functioning due to deactivation.

1.4 Posture and Spinal Load

While muscles are believed to play a big role in spinal stability and spinal loading, research has also been done on how daily posture might have an impact on spinal loading. For several years medical experts have given recommendations on how to move the body to reduce chances of back problems [11]. However, little research was done at the time to find the extent to which posture may play a role in spinal loading. Therefore, a study was done to see the effect of body position changes on spinal loading. Researchers studied the spinal loads that were present when changing body positions. High spinal loading was found to be present when changing body positions and that these loads could be reduced by following recommended instructions on how to change body positions. The team will consider body positioning in the study because that may alter when the multifidus is fully activated and playing a key role in spinal stability.

The effect of posture on spinal loading led to studies on typical day motions people do that may influence the back. A study was done with a focus on trunk bending, a very common motion people do on a regular basis. In this case, the study wanted to see how spinal tissue may prevent back pain with the bending motion. It was determined that there was a shift in loading from active tissue to passive tissue in static trunk bending participants which helps reduce muscle fatigue [12]. Active and passive tissue are not only activated during trunk bending and can be impacted by posture in lifting as well. Another study was done that investigated three different postures and carefully analyzed the load in various tissues and joints. Posture was found to have significant effects on spinal loads and simply changing positions was found to greatly reduce stress on the back [13]. Our study will be conducted on a model in various positions that may be experienced by a typical person to develop a holistic analysis on the multifidus muscle force contributions.

While posture and bending have been found to be a large contributor to spinal loads, posture is not the only contributor to spinal loading. The activities people do also contribute vastly to spinal loads and could be an additional contributor to back pain. A study found that lifting heavy objects causes significant spinal loading [14]. In addition to this, the way the object was lifted or held was also a contributor to the magnitude of the loading. The activities that result in the highest resulting forces are those in which the center of mass of the body is moved toward the front of the body. These are considered activities people should avoid doing to prevent back problems. For the purposes of this study, activities of this nature will not be included for analysis in our model.

1.5 OpenSim

OpenSim is a tool that is used to develop simulations of musculoskeletal to do biomechanical analysis [15]. In OpenSim, researchers can develop their own models to use for various studies. For example, a thoracolumbar model that includes vertebrae, ribs, and sternum that could predict compressible loads was developed by a team of researchers [16]. This was accomplished by using computer tomography scans. The team was able to collect data and perform kinematic and dynamic analysis using built in tools in the software. Getting this data is then used to plot different information. Plotting data is the way this software can allow for analysis of muscle forces. The same team collected inverse-dynamic data in a predictive simulation and compared it to existing data in the public database in vivo [17]. The results were highly in agreement with in vivo data. OpenSim's built in features and highly accurate results are the reasons our team has decided to pursue developing a model using the software.

OpenSim can be used for real time simulations or predictive simulations. A study developed predictive simulations for musculoskeletal movements using MATLAB code [15]. The researchers developed MATLAB code that could interface with OpenSim software to create a simulation of lower limb motion and monitor muscular activation. This could be accomplished by testing different MATLAB functions.

Collecting and importing data can be done in various ways because OpenSim is compatible with various software. It is very common for researchers to collect data on MATLAB, Python, or C++ and interface that information with OpenSim. Inputting data into software can be done using different methods. Using IMU sensors is one of the practical ways to collect kinematic data from the body and our lab has this equipment. Researchers used IMU sensors to collect data on kinematics, generalized forces, muscle forces, joint reaction loads, and predicting ground reaction wrenches during walking and then imported that data to OpenSim to develop a simulation [18]. It was found that small errors could negatively affect other data in the study. However, using tools like IMU sensors could greatly expand studies and help learn more about external environmental effects on data.

OpenSim will be the software the team will be using to develop our model. The software will be further discussed in this study.

Chapter 2

Methods

2.1 Model

This study utilized the software OpenSim to run a simulation on a model to collect data. For this study, a model created by Margert Raabe and Ajit Chaudhari was utilized. The original model was used in a study of full-body movement that investigated the musculature and dynamics of the lumbar spine during jogging [19]. This model consists of 21 segments, 30 degrees-of-freedom, and 324 musculotendon tendon actuators. In the model, the five lumbar vertebrae are modeled as individual bodies, each connected by a 6 degree-of-freedom joint. For this study, lumbar movement is described as flexion-extension, axial rotation, and lateral bending by imposing constraint functions to each individual lumbar vertebra. The model used in this study can be seen in figure 4 and figure 5. The main muscle groups of the lumbar spine are modeled, each consisting of multiple fascicles to allow the large muscles to act in multiple directions. The muscles groups analyzed in this study were the multifidus entry level, multifidus spinous process, iliocostalis lumborum, iliocostalis lumborum thoracis, longissimus thoracis, longissimus thoracis lumborum, and latissimus dorsi.

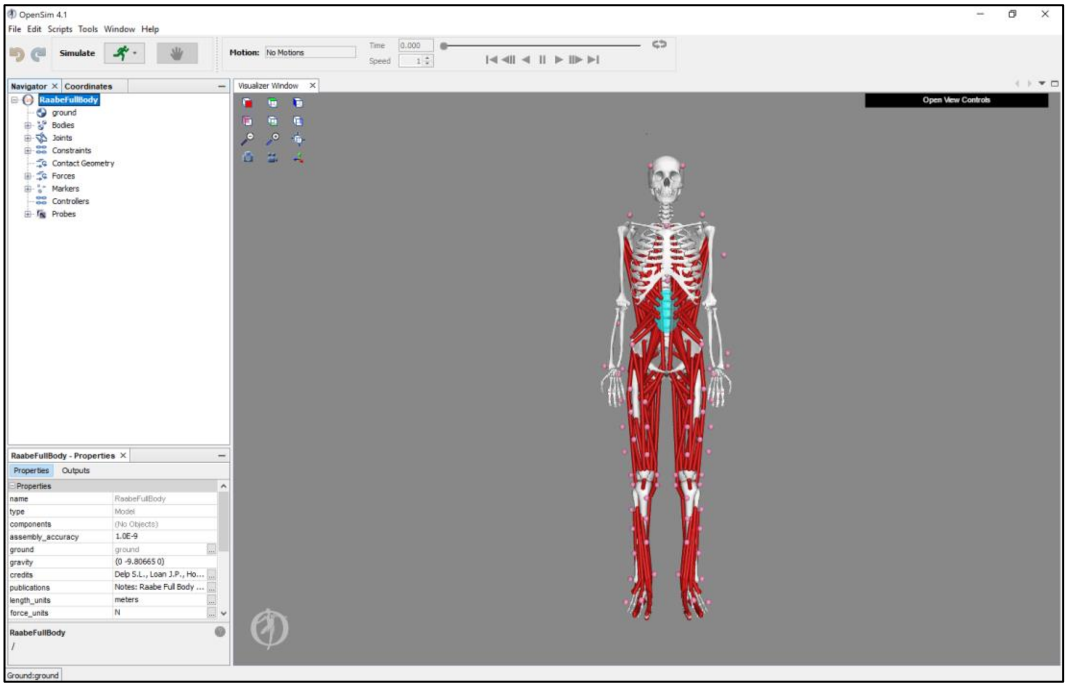

Figure 4. OpenSim full body front view.

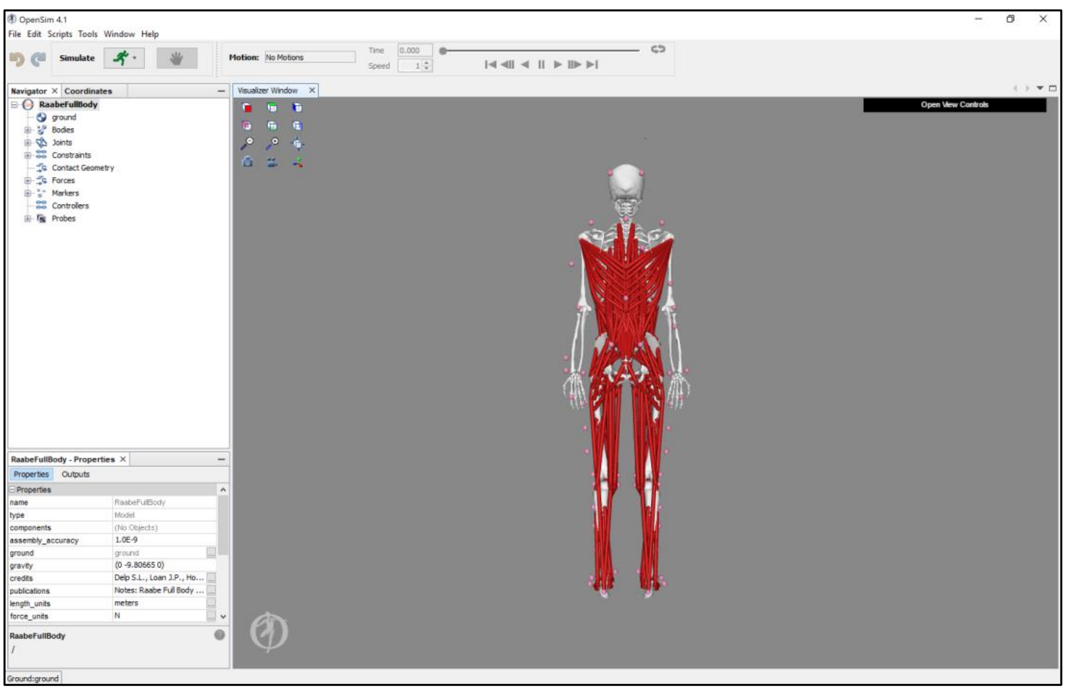

Figure 5. OpenSim full body back view.

2.2 Anatomy

The multifidus muscle is in the back along the spine. In the OpenSim model, the multifidus is split into two muscles: the multifidus entry level muscle and the multifidus spinous process muscle. In the model, the multifidus entry level muscle is depicted as the muscle along the lumbar spine as can be seen in figure 6. The multifidus spinous process muscle is represented as the muscle located in the lumbar spine as can be seen in figure 7.

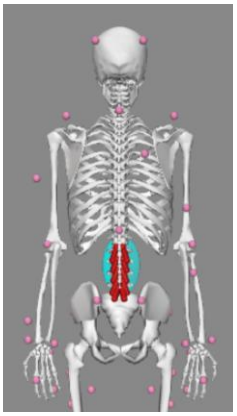

Figure 6. OpenSim representation of the multifidus entry level muscle.

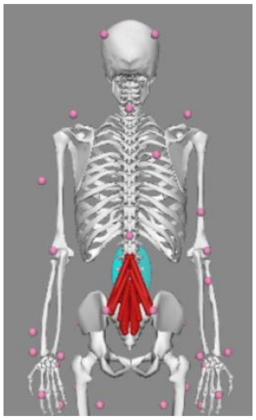

Figure 7. OpenSim representation of the multifidus spinous process muscle.

The multifidus muscle entry level muscle consists of 10 components in the model and the multifidus spinous process muscle consists of 40 components. For the study, iliocostalis lumborum, iliocostalis lumborum thoracis, longissimus thoracis, longissimus thoracis lumborum, and latissimus dorsi muscles were also evaluated. These muscles are all located in the lower back near the spine. The iliocostalis lumborum consists of 8 components, the iliocostalis lumborum thoracis consists of 16 components, the longissimus thoracis consists of 42 components, the longissimus thoracis lumborum consists of 10 components, and the latissimus dorsi consists of 28 components.

2.3 Procedure

The model created by Raabe and Chaudhari was modified for the purposes of this study. The original model was utilized to collect baseline data. Modifying the original model resulted in two new models that were also used to collect data. The first modified model was the result of a reduction to the multifidus entry level muscle maximum isometric force. All models in OpenSim represent muscles as forces and those properties can be modified. For the multifidus entry level muscle, all maximum isometric forces for components of that muscle were reduced to 0.01 N. The second modified model was the result of a reduction to the multifidus spinous process muscle maximum isometric force. For the multifidus spinous process, all maximum isometric forces for components of the muscle were reduced to 0.01 N. These reductions in isometric forces were done to simulate the deactivation of the multifidus muscle. The plotting tool in OpenSim was then utilized to plot the tendon force of the lumbar muscles of each model with relation to the three lumbar movements flexion-extension, axial rotation, and lateral bending.

Chapter 3

Results

Data was collected for three models and three distinct lumbar movements. The three models included the original model, a modified model where the multifidus entry level muscle isometric maximum force was reduced, and another modified model where the multifidus spinous process muscle isometric maximum force was reduced. The three distinct motions analyzed were flexion-extension, axial rotation, and lateral bending. The analysis was performed in two main parts: one considering the effect on surrounding lumbar muscles for the three distinct lumbar movements when the multifidus entry level muscle is modified and one considering the effect on surrounding lumbar muscles for the three distinct lumbar movements when the multifidus spinous process muscle is modified.

3.1 Effect on Lumbar Muscles with Modified Multifidus Entry Level Muscle

3.1.1 Flexion-Extension Movement

Data was collected for the tendon forces of multifidus muscles for the flex-extension movement in OpenSim. Figure 8 shows the multifidus entry level muscle performance for the flex-extension movement before any modifications. Figure 9 shows the multifidus entry level performance for the flexion-extension movement after all maximum isometric forces for components of the multifidus entry level muscle were reduced to 0.01 N. Visually analyzing the graphs, the tendon forces of the modified multifidus entry level muscle components are reduced drastically during the flex extension movement when compared to the baseline data.

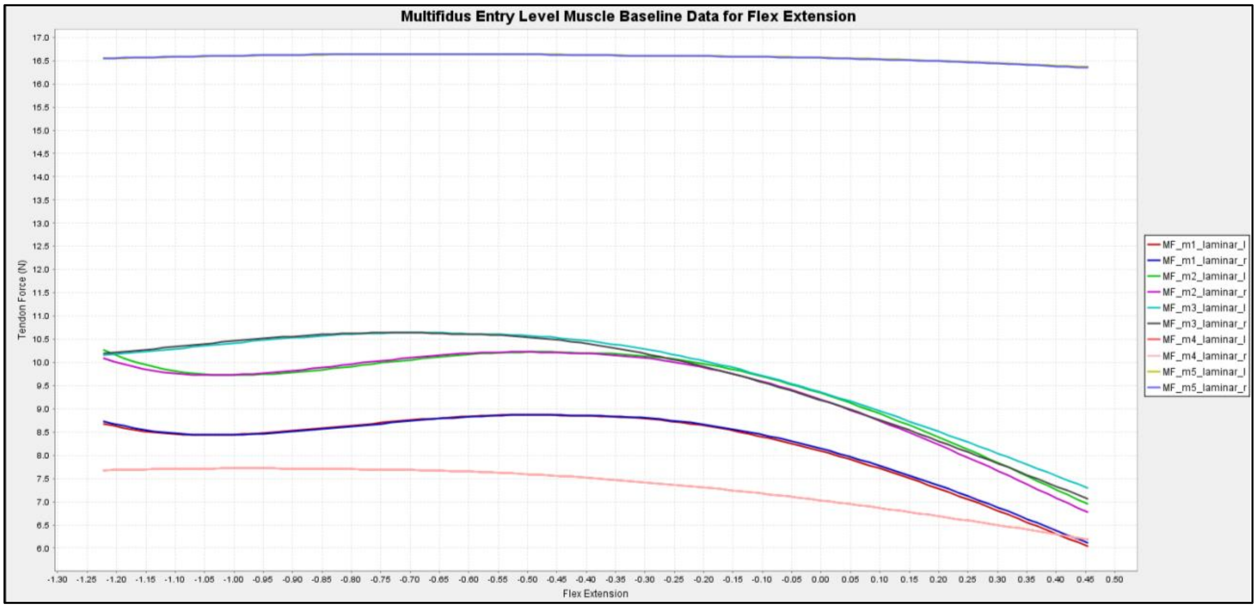

Figure 8. Multifidus Entry Level Muscle Tendon Force Baseline Results for Flex-Extension Movement.

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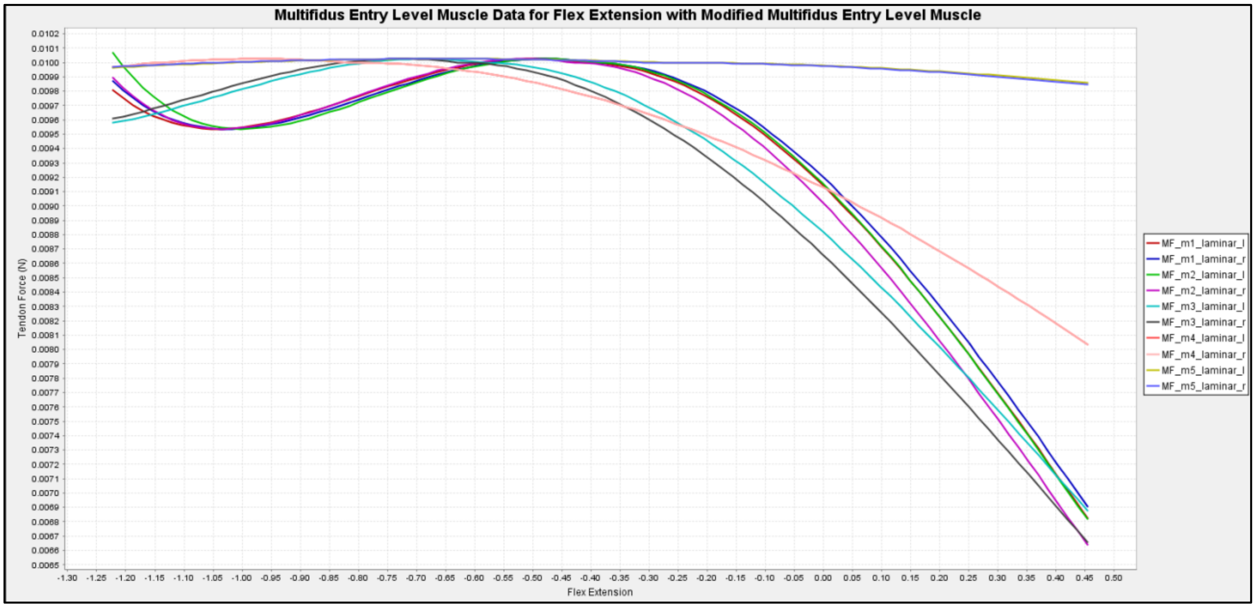

Figure 9. Multifidus Entry Level Muscle Tendon Force Baseline Results for Flex-Extension Movement.

The tendon forces were then analyzed for surrounding lumbar muscles for the flexion-extension movement. Figure 10 shows the iliocostalis lumborum muscle performance for the flexion-extension movement before any modifications to the model. Figure 11 shows the iliocostalis lumborum muscle performance for the flexion-extension movement after the multifidus entry level muscle was modified in the model. As can be seen from the plots, the iliocostalis lumborum muscle performed with the same muscle load distribution over the range of motion. However, the iliocostalis lumborum muscle had a higher tendon force throughout the entirety of the range of motion for the modified model. It can be noted that in the original model, one of the components of the iliocostalis lumborum muscle depicted in red on the plot started off at around 340 N of force. In the modified model, the same component starts at around 350 N of force. This increase in tendon force is consistent for all the components of the iliocostalis lumborum muscle. However, not all the components increase by the same amount. This can be seen by the component depicted in blue that starts at around 278 N in the original model but starts at around 282 N in the modified model. This change is not as drastic as the component that went from around 340 N to around 350 N.

These observations were the same for the other surrounding lumbar muscles examined in this study. The remaining data for lumbar muscle forces for the flexion-extension movement can be found in Appendix A.

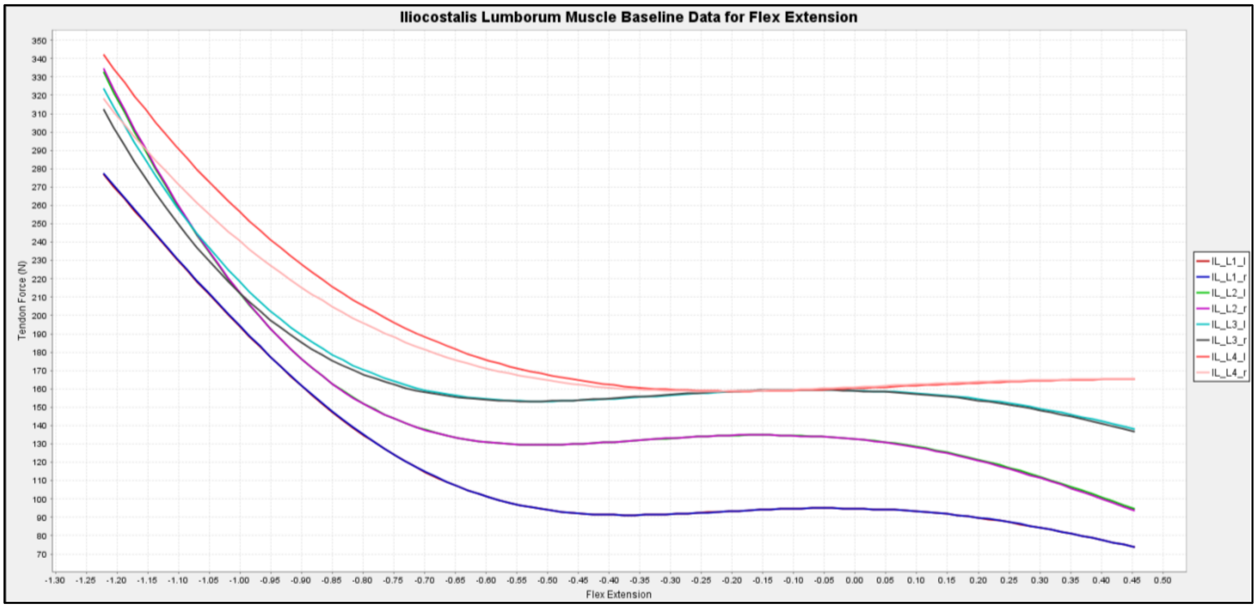

Figure 10. Iliocostalis Lumborum Muscle Tendon Force Baseline Results for Flex-Extension Movement.

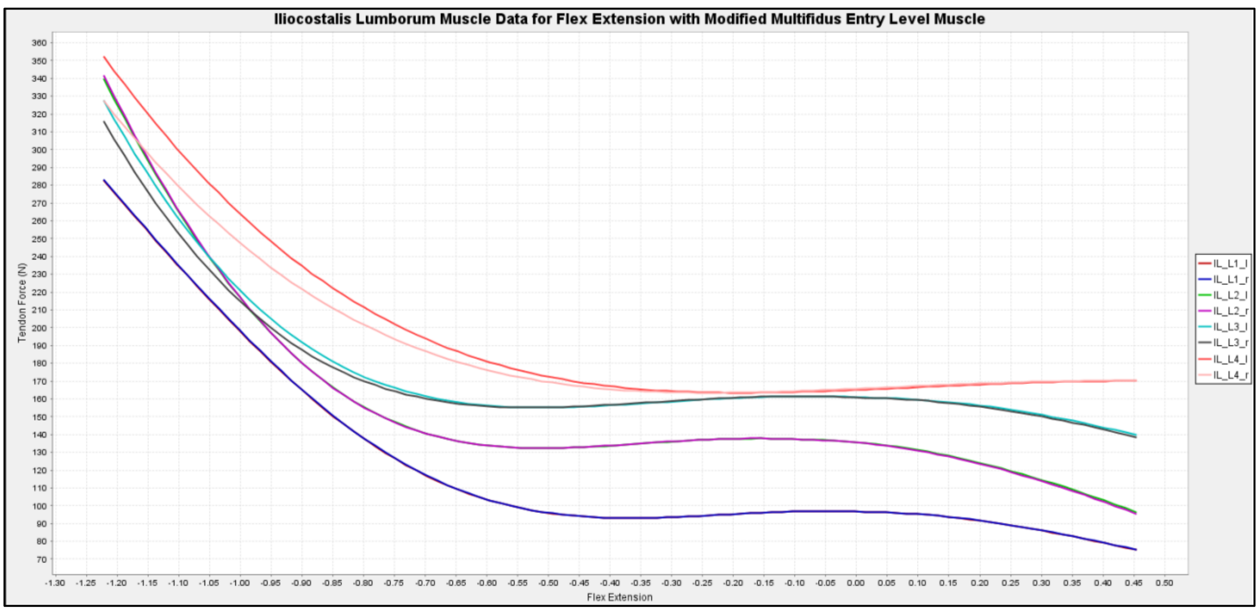

Figure 11. Iliocostalis Lumborum Muscle Tendon Force Results for Flex-Extension Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

3.1.2 Axial Rotation Movement

Data was collected for the tendon forces of the multifidus muscle for the axial rotation movement in OpenSim. Figure 12 shows the multifidus entry level muscle performance for the axial rotation movement before any modifications. Figure 13 shows the multifidus entry level performance for the axial rotation movement with the modified multifidus entry level muscle. From the graphs, the tendon forces of the modified multifidus entry level muscle components are reduced drastically during the axial rotation movement when compared to the baseline data.

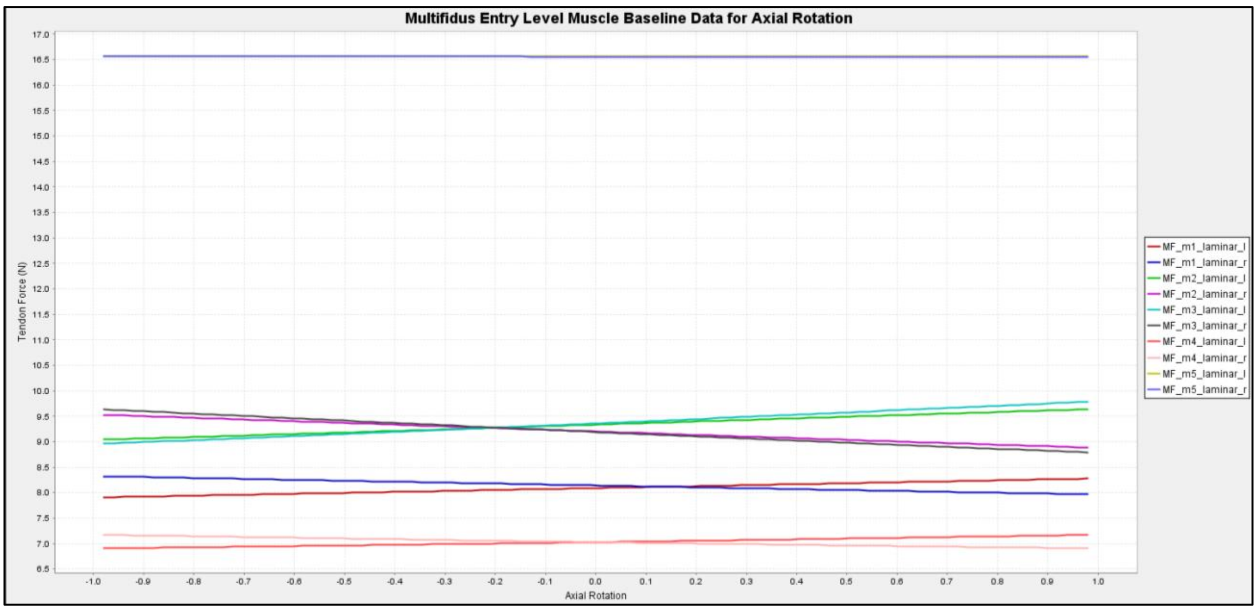

Figure 12. Multifidus Entry Level Muscle Tendon Force Baseline Results for Axial Rotation Movement.

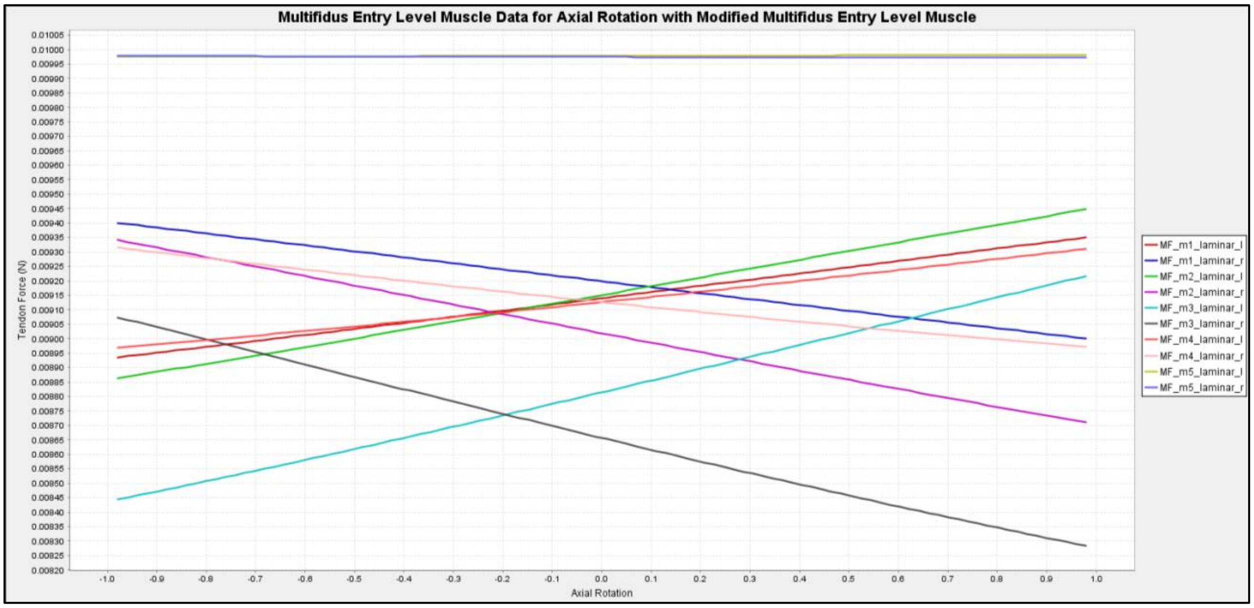

Figure 13. Multifidus Entry Level Muscle Tendon Force Results for Axial Rotation Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

The tendon forces were then analyzed for surrounding lumbar muscles for the axial rotation movement. Figure 14 shows the left side iliocostalis lumborum thoracis muscle performance for the axial rotation movement before any modifications to the model. Figure 15 shows the left side iliocostalis lumborum thoracis muscle performance for the axial rotation movement after the multifidus entry level muscle was modified in the model. As can be seen from the plots, the iliocostalis lumborum thoracis muscle performed with the same force distribution over the range of motion. However, the iliocostalis lumborum thoracis muscle had a higher tendon force throughout the entirety of the range of motion for the modified model. It can be noted that in the original model, one of the components of the iliocostalis lumborum thoracis muscle depicted in green on the plot started off at around 119 N of force. In the modified model, the same component starts at around 125 N of force. This increase in tendon force is consistent for all the components of the iliocostalis lumborum thoracis muscle. However, not all the components increase by the same amount. This can be seen by the component depicted in pink that starts at around 42 N in the original model but starts at around 45 N in the modified model.

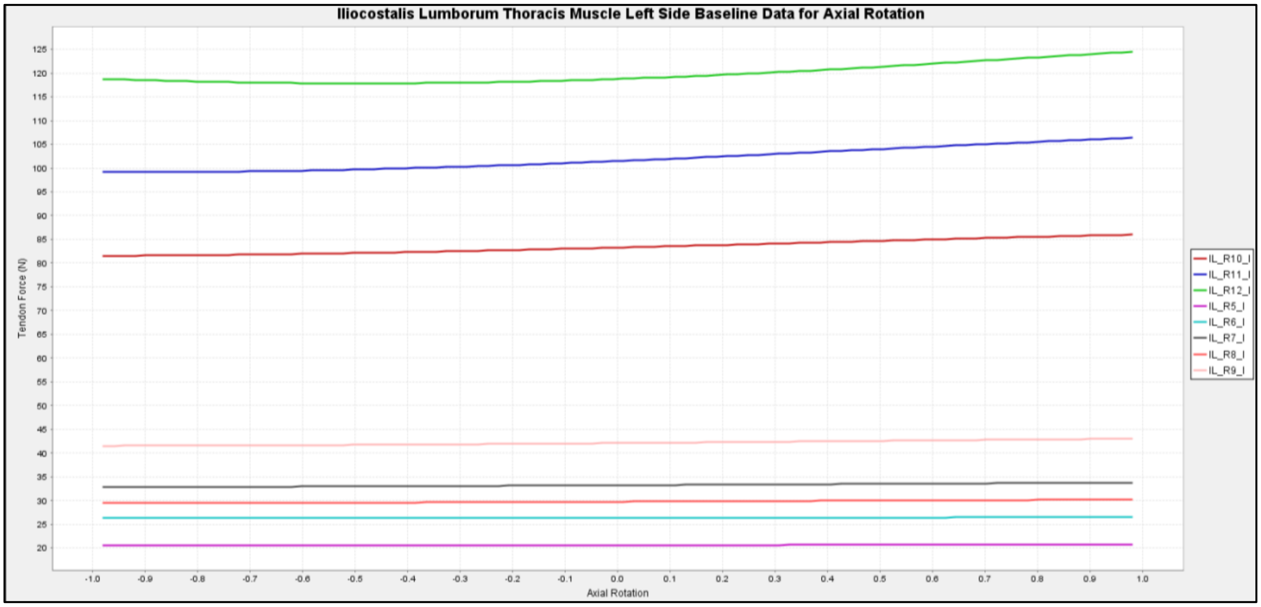

Figure 14. Iliocostalis Lumborum Thoracis Left Side Muscle Tendon Force Baseline Results for Axial Rotation Movement.

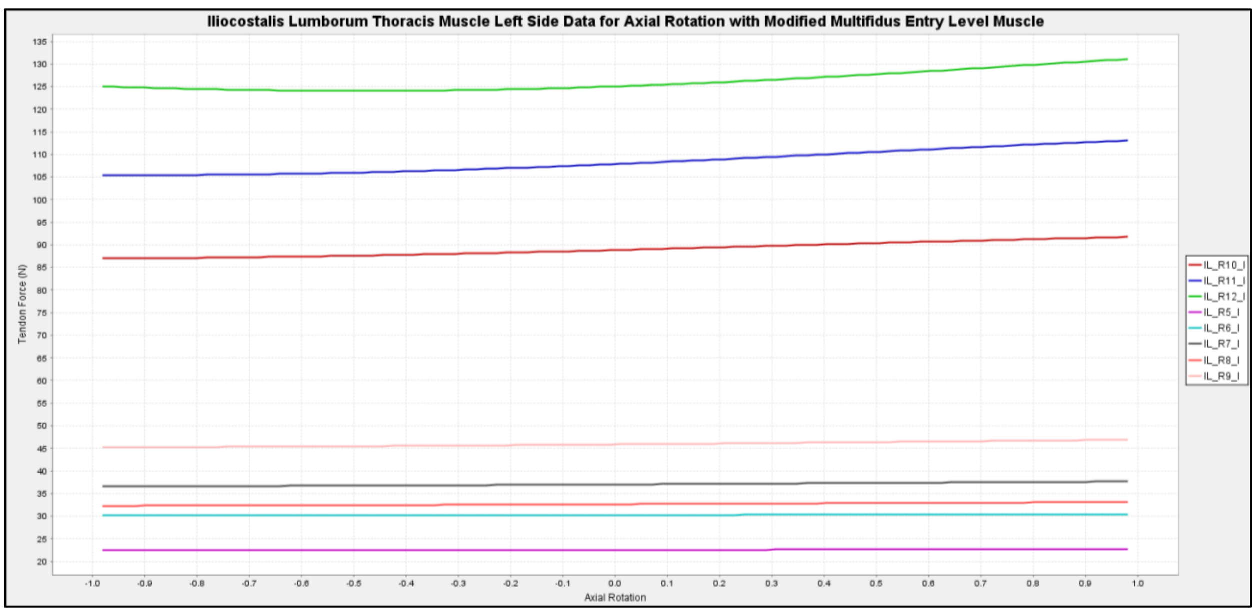

Figure 15. Iliocostalis Lumborum Thoracis Left Side Muscle Tendon Force Results for Axial Rotation Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

These observations were the same for the other surrounding lumbar muscles examined in this study. The remaining data for lumbar muscle forces for the axial rotation movement can be found in Appendix B.

3.1.3 Lateral Bending Movement

Data was collected for the tendon forces of multifidus muscle for the lateral bending movement in OpenSim. Figure 16 shows the multifidus entry level muscle performance for the lateral bending movement before any modifications. Figure 17 shows the multifidus entry level performance for the lateral bending movement with the modified multifidus entry level muscle. From the graphs, the tendon forces of the modified multifidus entry level muscle components are reduced drastically during the lateral bending movement when compared to the baseline data.

The tendon forces were then analyzed for surrounding lumbar muscles for the lateral bending movement. Figure 18 shows the longissimus thoracis lumborum muscle performance for the lateral bending movement before any modifications to the model. Figure 19 shows the longissimus thoracis lumborum muscle performance for the lateral bending movement after the multifidus entry level muscle was modified in the model. As can be seen from the plots, the longissimus thoracis lumborum muscle performed with the same force distribution over the range of motion. However, the longissimus thoracis lumborum muscle had a higher tendon force throughout the entirety of the range of motion for the modified model. It can be noted that in the original model, one of the components of the longissimus thoracis lumborum muscle depicted in pink on the plot started off at around 97.5 N of force. In the modified model, the same component starts at around 102 N of force. This increase in tendon force is consistent for all the components of the longissimus thoracis lumborum muscle. However, not all the components increase by the same amount. This can be seen by the component depicted in blue that starts at around 101 N in the original model but starts at around 103 N in the modified model.

These observations were the same for the other surrounding lumbar muscles examined in this study. The remaining data for lumbar muscle forces for the lateral bending movement can be found in Appendix C.

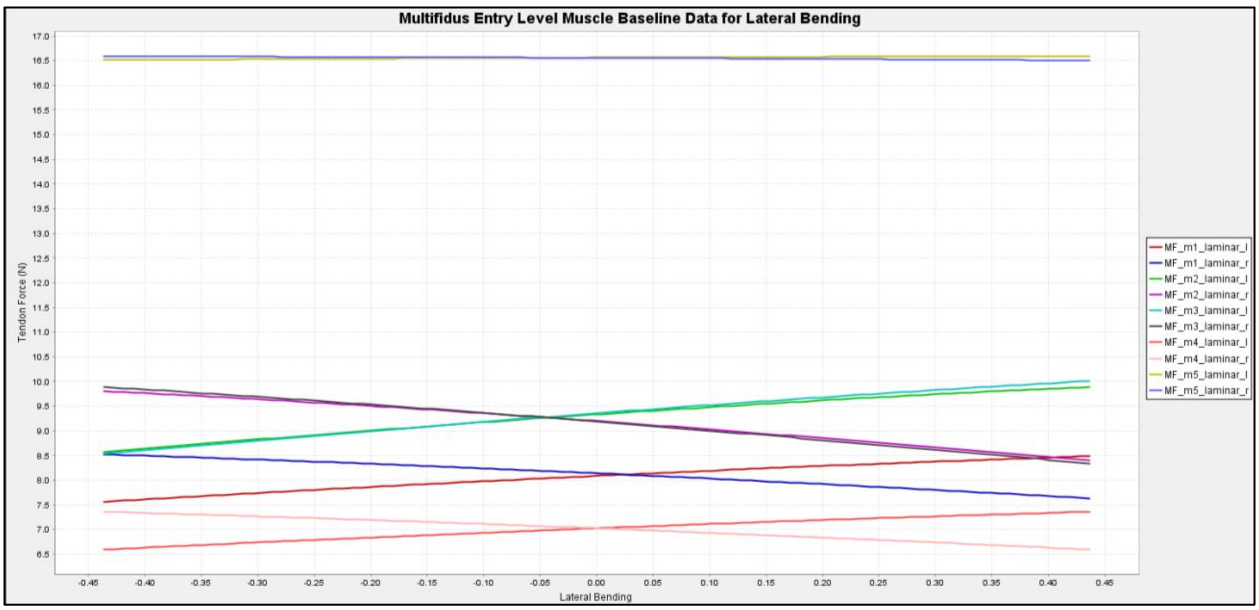

Figure 16. Multifidus Entry Level Muscle Tendon Force Baseline Results for Lateral Bending Movement.

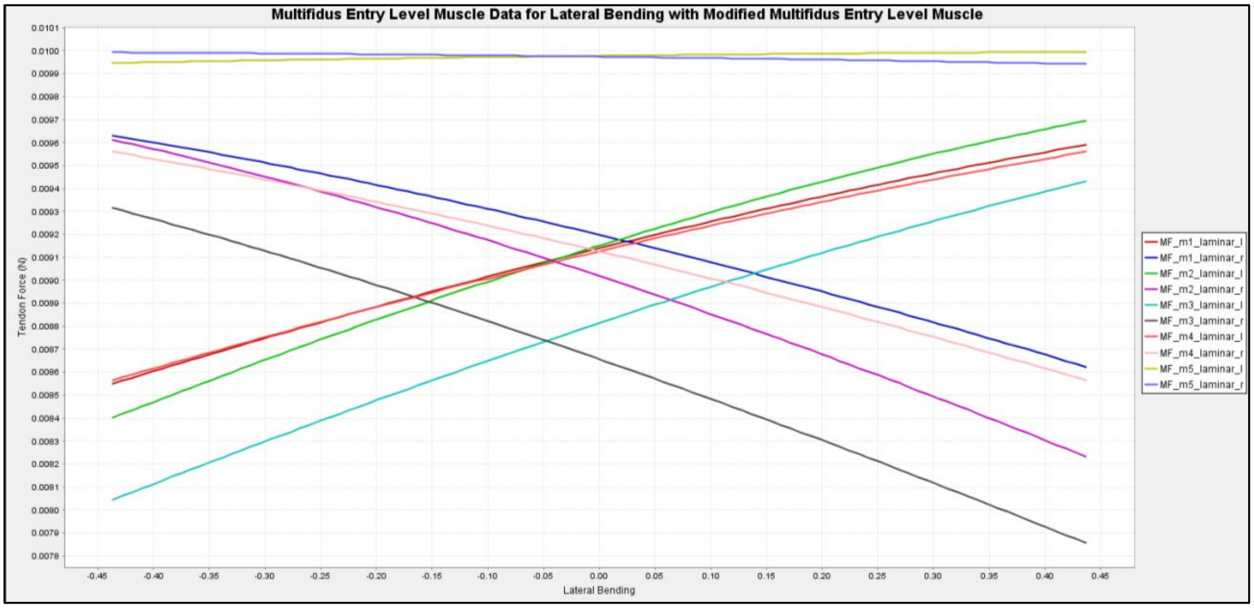

Figure 17 . Multifidus Entry Level Muscle Tendon Force Results for Lateral Bending Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

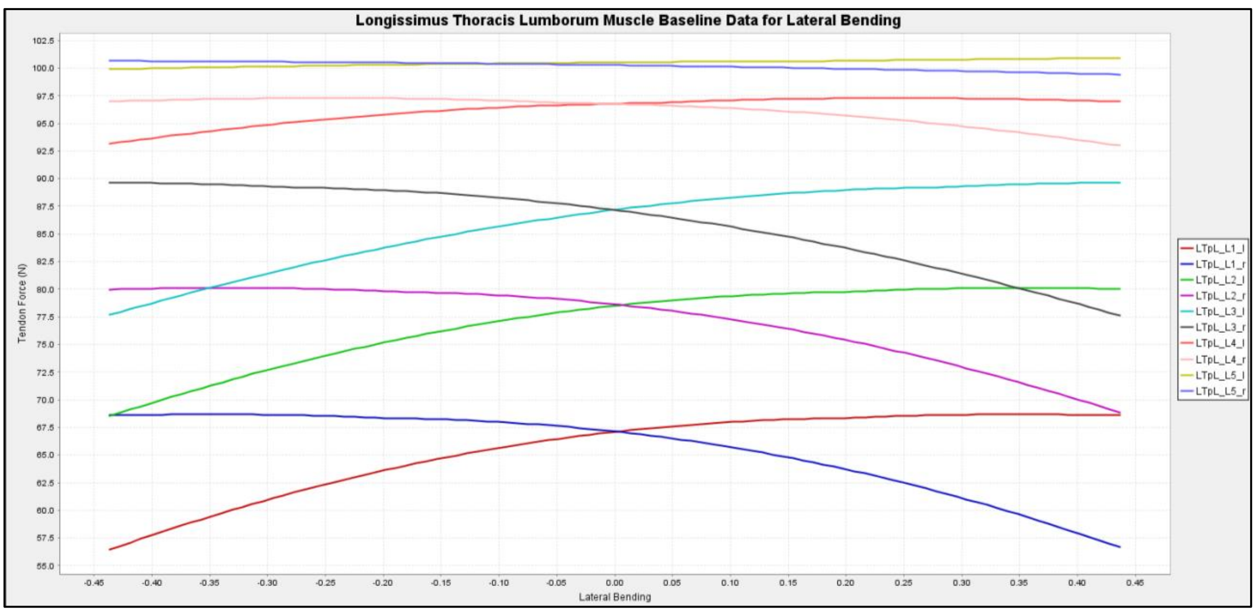

Figure 18. Longissimus Thoracis Lumborum Muscle Tendon Force Baseline Results for Lateral Bending Movement.

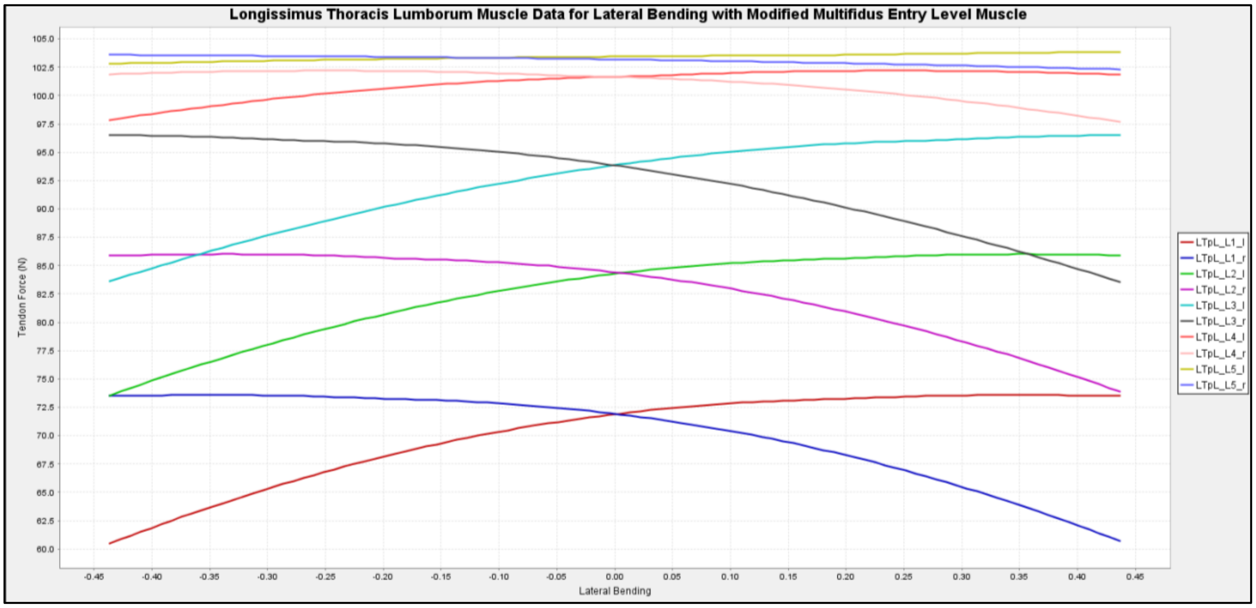

Figure 19. Longissimus Thoracis Lumborum Muscle Tendon Force Results for Lateral Bending Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

3.2 Effect on Lumbar Muscles with Modified Multifidus Spinous Process Muscle

3.2.1 Flexion-Extension Movement

Data was collected for the tendon forces of multifidus muscle for the flexion-extension movement in OpenSim. Figure 20 shows the multifidus spinous process muscle performance for the flexion-extension movement before any modifications. Figure 21 shows the multifidus spinous process performance for the flex extension movement after all maximum isometric forces for components of the multifidus spinous process muscle were reduced to 0.01 N. Visually analyzing the graphs, the tendon forces of the modified multifidus spinous process muscle components are reduced drastically during the flexion-extension movement when compared to the baseline data.

The tendon forces were then analyzed for surrounding lumbar muscles for the flexion-extension movement. Figure 22 shows the iliocostalis lumborum muscle performance for the flexion-extension movement before any modifications to the model. Figure 23 shows the iliocostalis lumborum muscle performance for the flexion-extension movement after the multifidus spinous process muscle was modified in the model. As can be seen from the plots, the iliocostalis lumborum muscle performed with the same force distribution over the range of motion. However, the iliocostalis lumborum muscle had a higher tendon force throughout the entirety of the range of motion for the modified model. It can be noted that in the original model, one of the components of the iliocostalis lumborum muscle depicted in red on the plot started off at around 340 N of force. In the modified model, the same component starts at around 378 N of force. This increase in tendon force is consistent for all the components of the iliocostalis lumborum muscle. However, not all the components increase by the same amount. This can be seen by the component depicted in blue that starts at around 278 N in the original model but starts at around 330 N in the modified model.

These observations were the same for the other surrounding lumbar muscles examined in this study. The remaining data for lumbar muscle forces for the flexion-extension movement can be found in Appendix A.

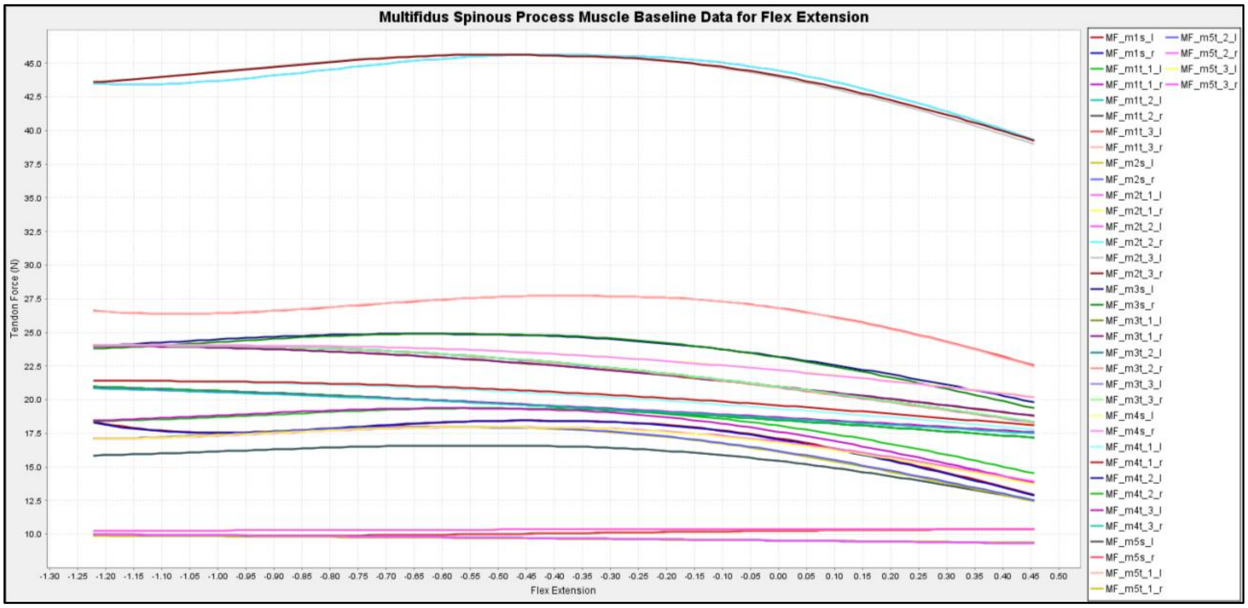

Figure 20. Multifidus Spinous Process Muscle Tendon Force Baseline Results for Flex-Extension Movement.

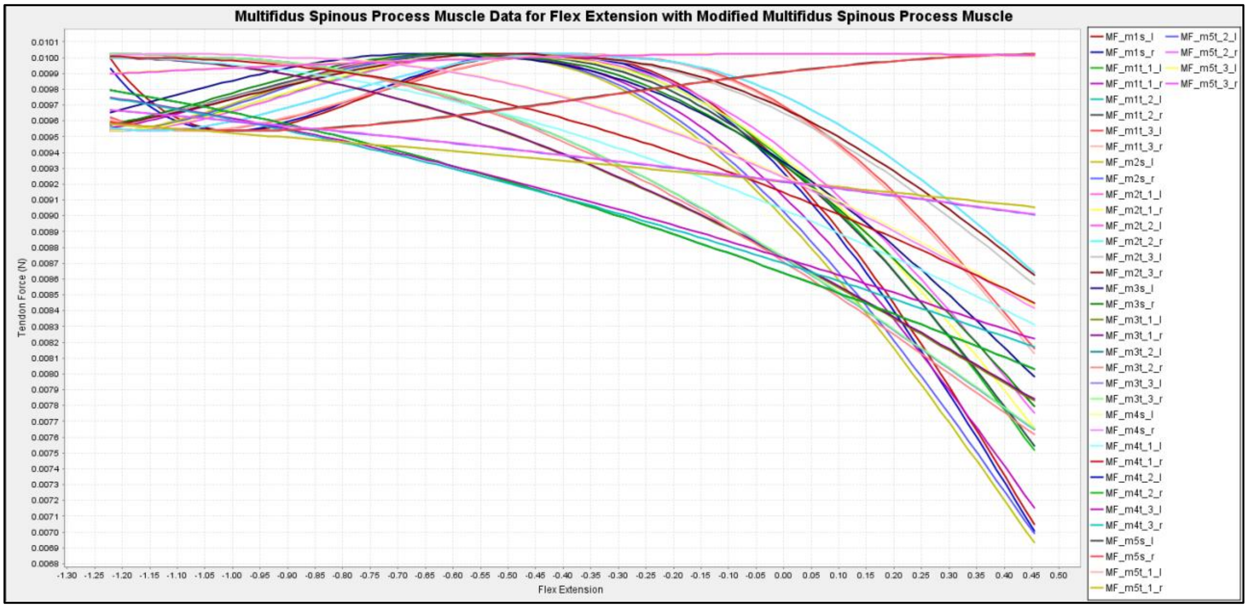

Figure 21. Multifidus Spinous Process Muscle Tendon Force Results for Flex-Extension Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

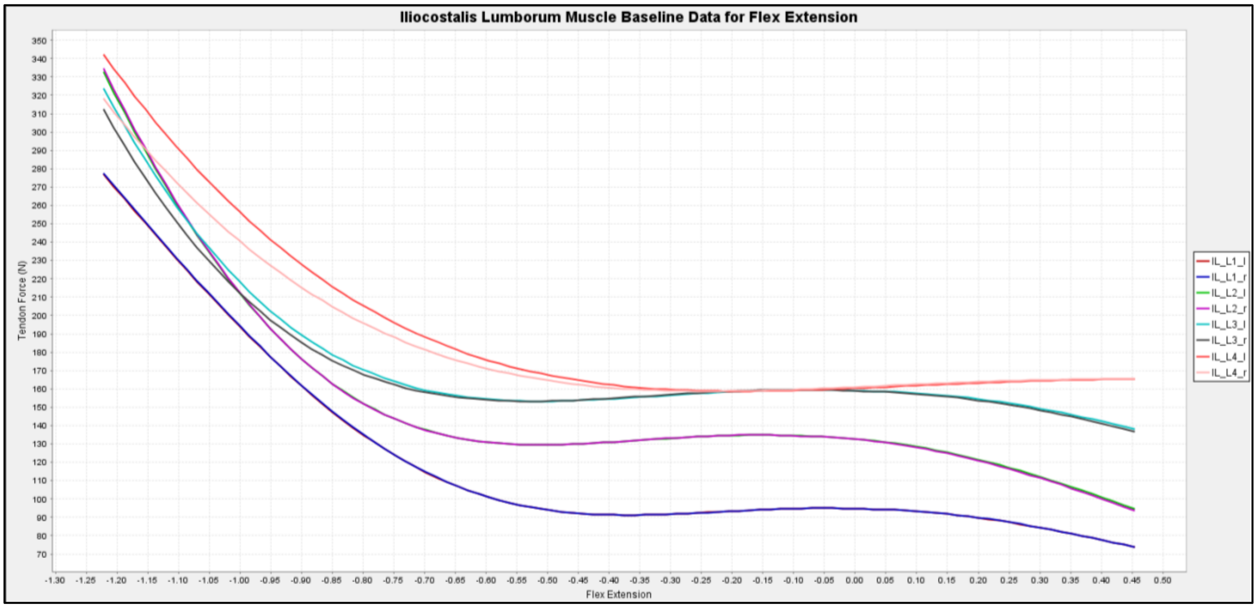

Figure 22. Iliocostalis Lumborum Muscle Tendon Force Baseline Results for Flex-Extension Movement.

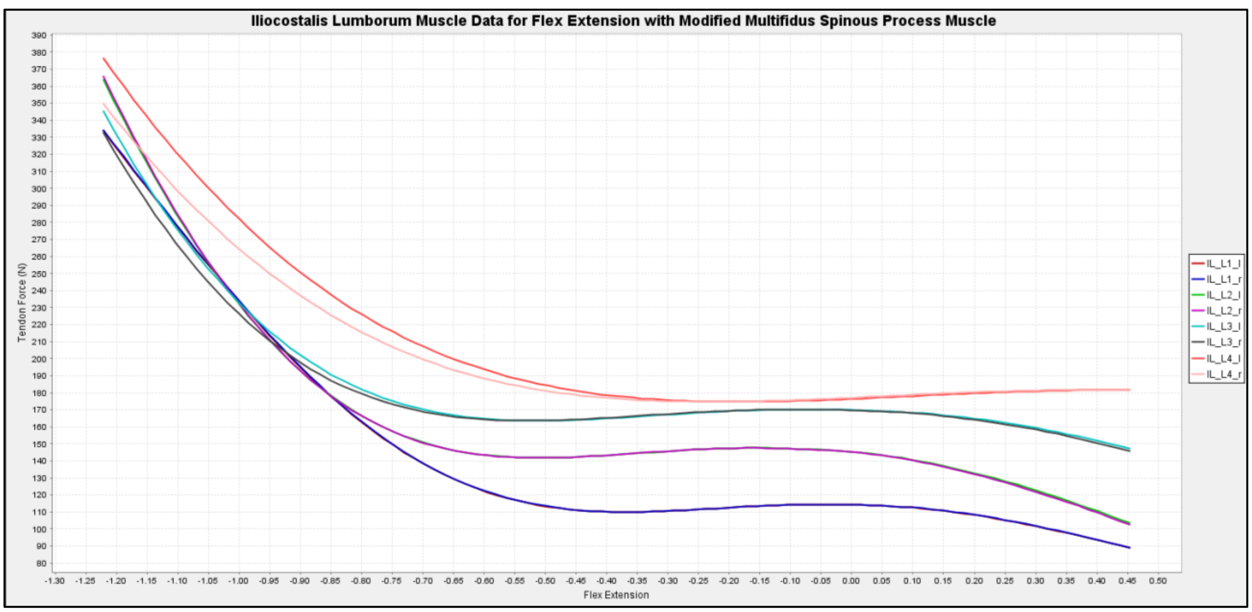

Figure 23. Iliocostalis Lumborum Muscle Tendon Force Results for Flex-Extension Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

3.2.2 Axial Rotation Movement

Data was collected for the tendon forces of multifidus muscle for the axial rotation movement in OpenSim. Figure 24 shows the multifidus spinous process muscle performance for the axial rotation movement before any modifications. Figure 25 shows the multifidus spinous process performance for the axial rotation movement after the modification of the multifidus spinous process muscle. From the graphs, the tendon forces of the modified multifidus spinous process muscle components are reduced drastically during the axial rotation movement when compared to the baseline data.

The tendon forces were then analyzed for surrounding lumbar muscles for the axial rotation movement. Figure 26 shows the left side iliocostalis lumborum thoracis muscle performance for the axial rotation movement before any modifications to the model. Figure 27 shows the left side iliocostalis lumborum thoracis muscle performance for the axial rotation movement after the multifidus spinous process muscle was modified in the model. As can be seen from the plots, the iliocostalis lumborum thoracis muscle performed with the same force distribution over the range of motion. However, the iliocostalis lumborum thoracis muscle had a higher tendon force throughout the entirety of the range of motion for the modified model. It can be noted that in the original model, one of the components of the iliocostalis lumborum thoracis muscle depicted in green on the plot started off at around 119 N of force. In the modified model, the same component starts at around 134 N of force. This increase in tendon force is consistent for all the components of the iliocostalis lumborum thoracis muscle. However, not all the components increase by the same amount. This can be seen by the component depicted in pink that starts at around 42 N in the original model but starts at around 54 N in the modified model.

These observations were the same for the other surrounding lumbar muscles examined in this study. The remaining data for lumbar muscle forces for the axial rotation movement can be found in Appendix B.

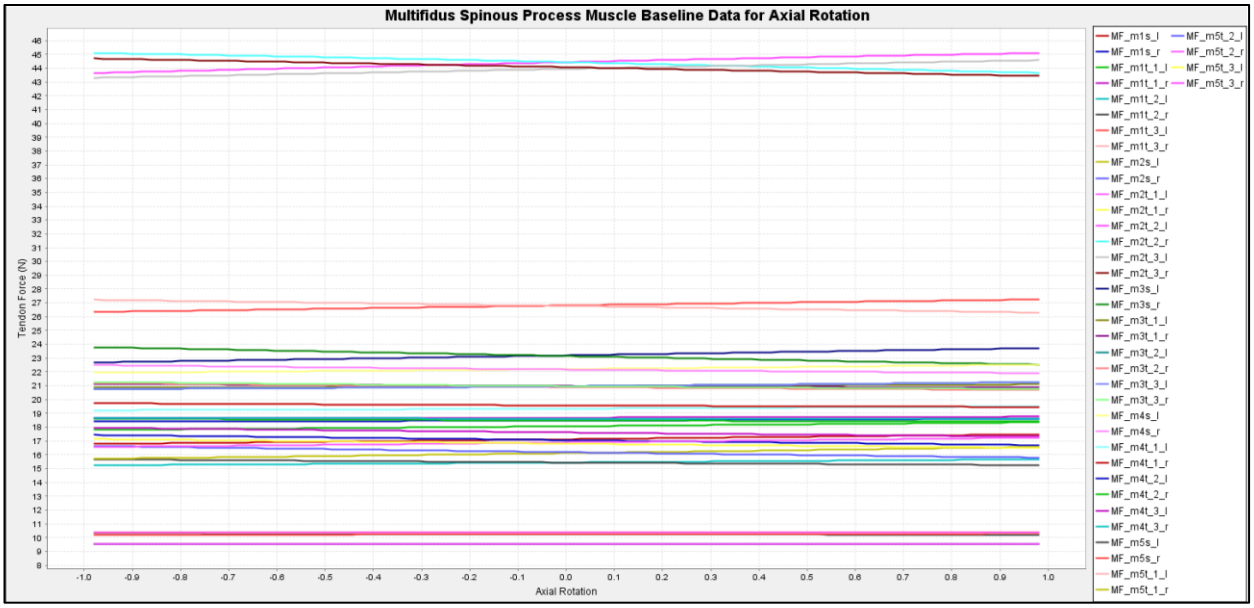

Figure 24. Multifidus Spinous Process Muscle Tendon Force Baseline Results for Axial Rotation Movement.

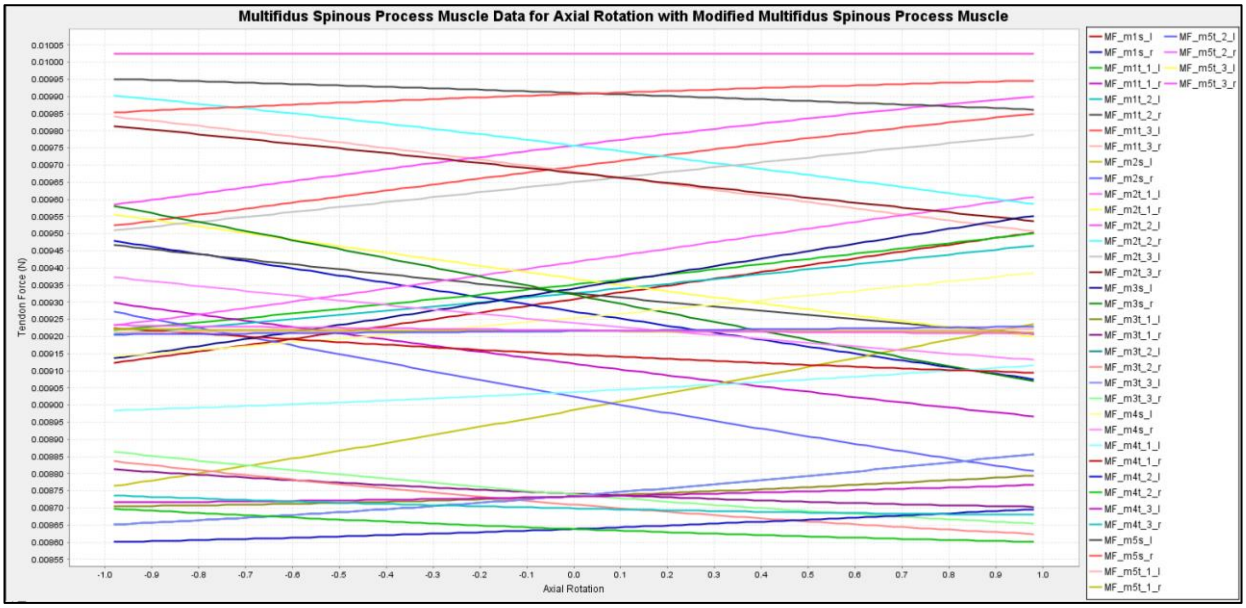

Figure 25. Multifidus Spinous Process Muscle Tendon Force Results for Axial Rotation Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

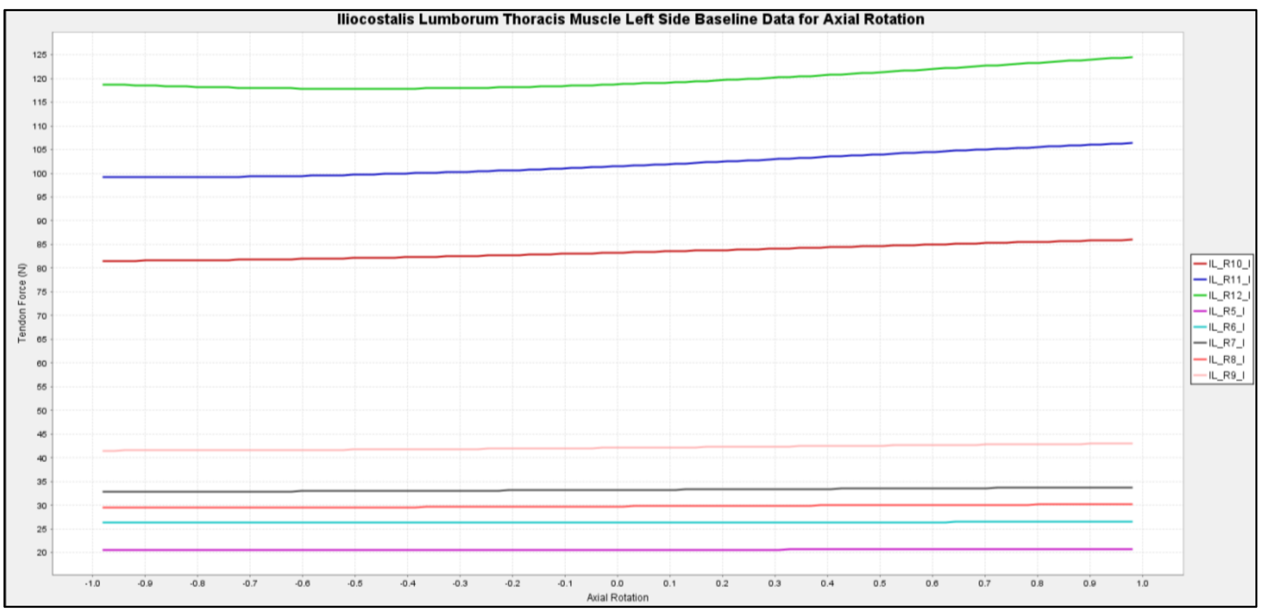

Figure 26. Iliocostalis Lumborum Thoracis Left Side Muscle Tendon Force Baseline Results for Axial Rotation Movement.

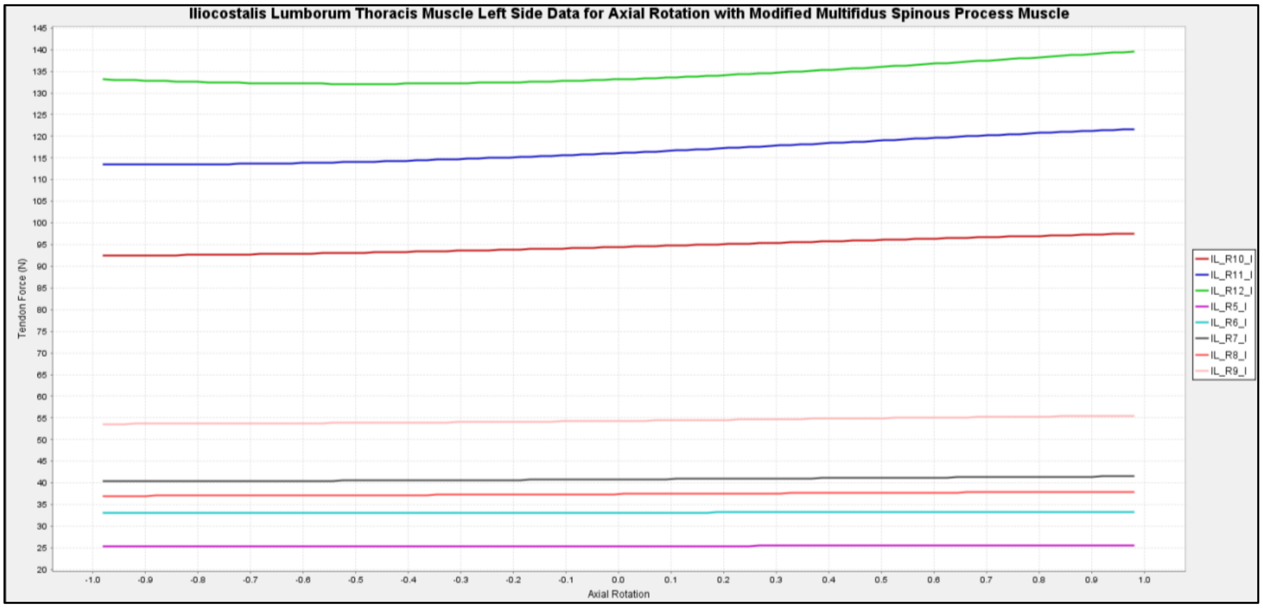

Figure 27. Iliocostalis Lumborum Thoracis Left Side Muscle Tendon Force Results for Axial Rotation Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

3.2.3 Lateral Bending Movement

Data was collected for the tendon forces of multifidus muscle for the lateral bending movement in OpenSim. Figure 28 shows the multifidus spinous process muscle performance for the lateral bending movement before any modifications. Figure 29 shows the multifidus spinous process performance for the lateral bending movement after the modification of the multifidus spinous process muscle. From the graphs, the tendon forces of the modified multifidus spinous process muscle components are reduced drastically during the axial rotation movement when compared to the baseline data.

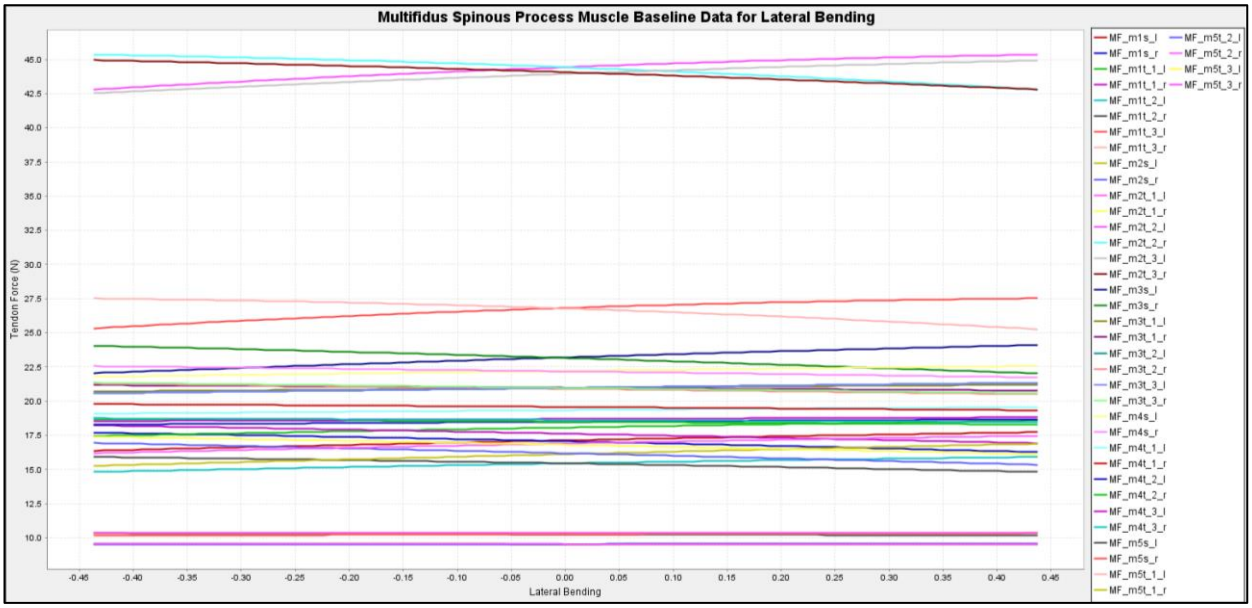

Figure 28. Multifidus Spinous Process Muscle Tendon Force Baseline Results for Lateral Bending Movement.

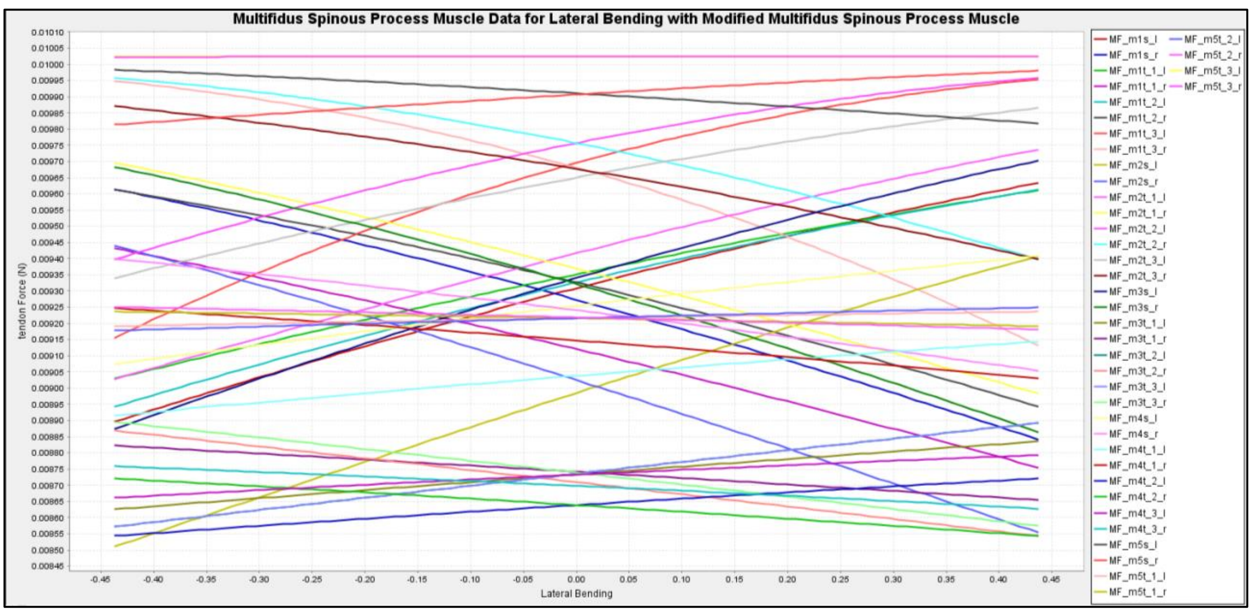

Figure 29. Multifidus Spinous Process Muscle Tendon Force Results for Lateral Bending Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

The tendon forces were then analyzed for surrounding lumbar muscles for the lateral bending movement. Figure 30 shows the longissimus thoracis lumborum muscle performance for the lateral bending movement before any modifications to the model. Figure 31 shows the longissimus thoracis lumborum muscle performance for the lateral bending movement after the multifidus spinous process muscle was modified in the model. As can be seen from the plots, the longissimus thoracis lumborum muscle performed with the same force distribution over the range of motion. However, the longissimus thoracis lumborum muscle had a higher tendon force throughout the entirety of the range of motion for the modified model. It can be noted that in the original model, one of the components of the longissimus thoracis lumborum muscle depicted in pink on the plot started off at around 97.5 N of force. In the modified model, the same component starts at around 113 N of force. This increase in tendon force is consistent for all the components of the longissimus thoracis lumborum muscle. However, not all the components increase by the same amount. This can be seen by the component depicted in blue that starts at around 101 N in the original model but starts at around 118 N in the modified model.

These observations were the same for the other surrounding lumbar muscles examined in this study. The remaining data for lumbar muscle forces for the lateral bending movement can be found in Appendix C.

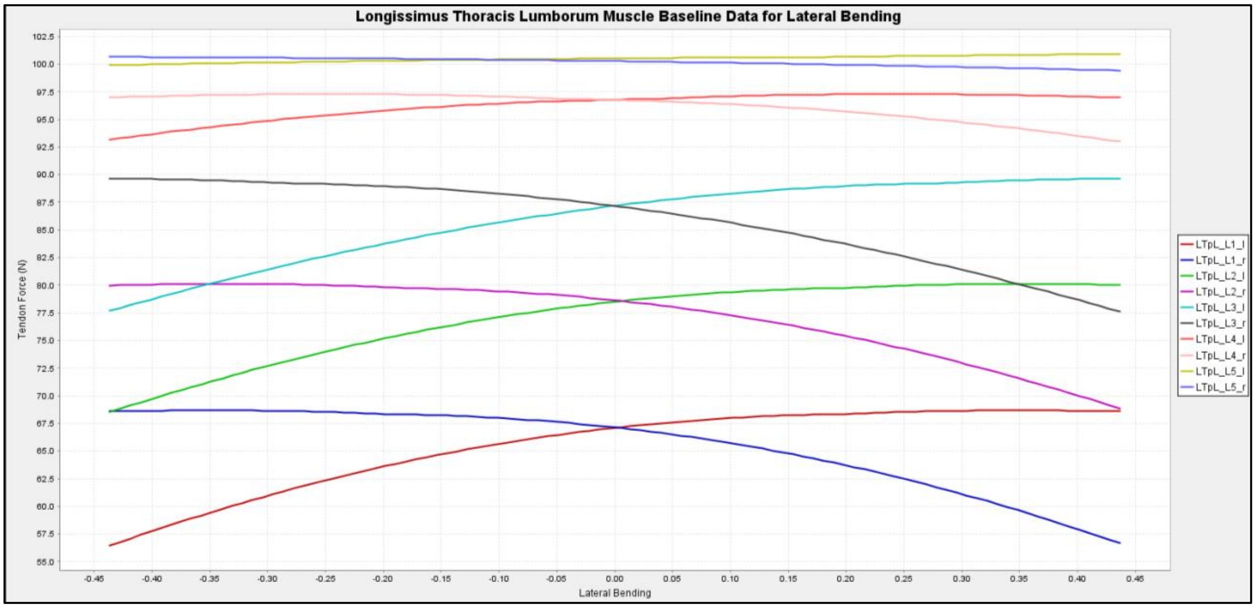

Figure 30. Longissimus Thoracis Lumborum Muscle Tendon Force Baseline Results for Lateral Bending Movement.

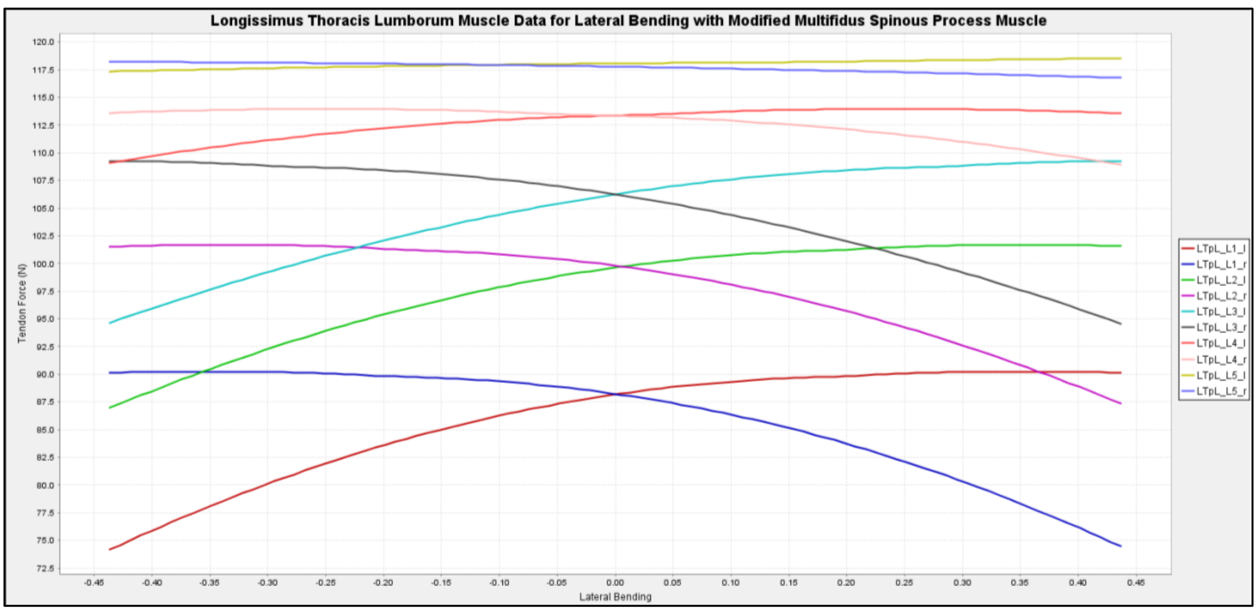

Figure 31. Longissimus Thoracis Lumborum Muscle Tendon Force Results for Lateral Bending Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

Chapter 4

Discussion

Conclusions

A study was done to see what effect the deactivation of the multifidus muscle would have on surround lumbar muscles. A model with a modified multifidus muscle was compared to the original model developed by Raabe and Chaudhari to see how the lumbar muscles performed during three separate lumbar motions. From the results, it was evident that the lumbar muscles on the modified models performed at higher tendon forces than the lumbar muscles from the original model. The model with the modified multifidus entry level muscle showed lumbar muscles performing at a tendon force up to 10 N higher than the original model. For the model with the modified multifidus entry level muscles, it was found that the lumbar muscles performed at a tendon force up to 40 N higher than the original model. These increases in tendon force are significant changes in muscular performance. Furthermore, these increases in tendon force in the modified models occurred in all the components of the lumbar muscles. Therefore, the cumulative change is a significant observation. The increase in tendon forces for lumbar muscles in the simulation could be attributed to the fact that the maximum isometric force for the multifidus muscle components were all reduced. The reduction in maximum isometric force was done to simulate the deactivation of the multifidus muscle. The results would indicate that the deactivation of the multifidus muscle would cause surrounding lumbar muscles to compensate for the underperforming multifidus muscle by increasing the tendon forces in lumbar muscles over a range of motion. The increase in tendon forces in lumbar muscles was consistent for all the lumbar muscles and lumbar movements analyzed in this study. It was found that the changes were different for the components of any given muscle. The changes were found to not be even or consistent for the components of the lumbar muscles. The reason for this is unknown. Furthermore, it can be noted that there is a difference to the extent in which the lumbar muscles change performance based on what part of the multifidus muscle was modified. The results show that the deactivation of the multifidus spinous process muscle has a greater impact on the performance of surrounding lumbar muscles. The reduction in the multifidus spinous process muscle maximum isometric force resulted in the surrounding lumbar muscles having to exert more force during any of the three lumbar motions. The change was more drastic than when only the multifidus entry level muscle was modified. This could be attributed to the fact that the multifidus spinous process muscle has a higher maximum isometric force than the multifidus entry level muscle. Therefore, since the reduction in maximum isometric force is more significant for the multifidus spinous process, the effect on the surrounding lumbar muscles is greater.

Limitations

The model developed by Raabe and Chaudhari was used because it is more physiologically accurate than other existing models because it uses 324 musculotendon actuators [19]. However, the model has some limitations. This model is flawed in the sense that it has not been developed to be used for all the functionalities in OpenSim such as forward dynamics. The reason for this is because the developers of this model modified the maximum force properties of some muscles [19]. Ultimately, this can affect the accuracy of the results and the extent of what data can be collected from the model. For this study, the maximum isometric force of the multifidus entry level muscle and multifidus spinous process were reduced to the value of 0.01 N. This was an arbitrary value selected to simulate the deactivation of the multifidus muscle that could occur after surgery; however, this value is not an accurate depiction of the actual reduction in force that occurs because of the facet joint pain procedure. Therefore, the data may not be an accurate depiction of what is happening with the body. However, the simulation was able to give an idea of what happens to tendon forces in lumbar muscles and shows that the deactivation of the multifidus muscle could change how the lumbar muscles function.

From this study, more was learned about the behavior of the lumbar muscles, however there is still further research that can be done to learn about the effect the deactivation of the multifidus muscle has on spinal loading and spinal stability.

Recommendation for Future Studies

As a recommendation for future study, the impact of the multifidus entry level versus the impact of the multifidus spinous process should be further examined. From this study, it is not clear which exact part of the muscle is deactivated during surgery. Having a better understanding of the surgical impact on the muscle could result in better recommendations of how to modify the procedure. Additionally, joint force data can be evaluated to have a better understanding of the effect the deactivation of the multifidus muscle has on spinal loading. It is unknown in this study why the tendon force changes in the specific components of each muscle were not evenly distributed. Further studies can be done to discover what determines the tendon force distribution change for a given muscle. The exact effect of the increasing tendon forces and how much of an increase in tendon force is significant can also be further explored. Discovering more about the unknowns of this study can result in better recommendations in the long term for the facet joint pain procedure and give us a better understanding of what extent the facet joint procedure might cause back problems.

Appendix A

Flex-Extension Muscle Data

Individual Muscle Baseline Data

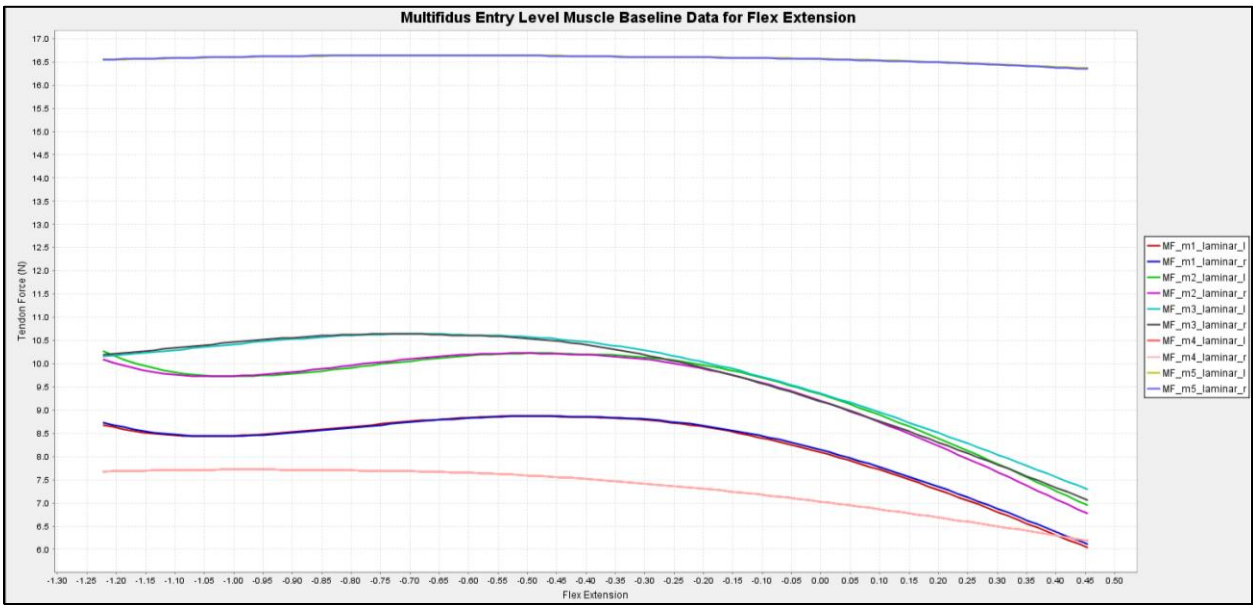

Figure A-1. Multifidus Entry Level Muscle Tendon Force Baseline Results for Flex-Extension Movement.

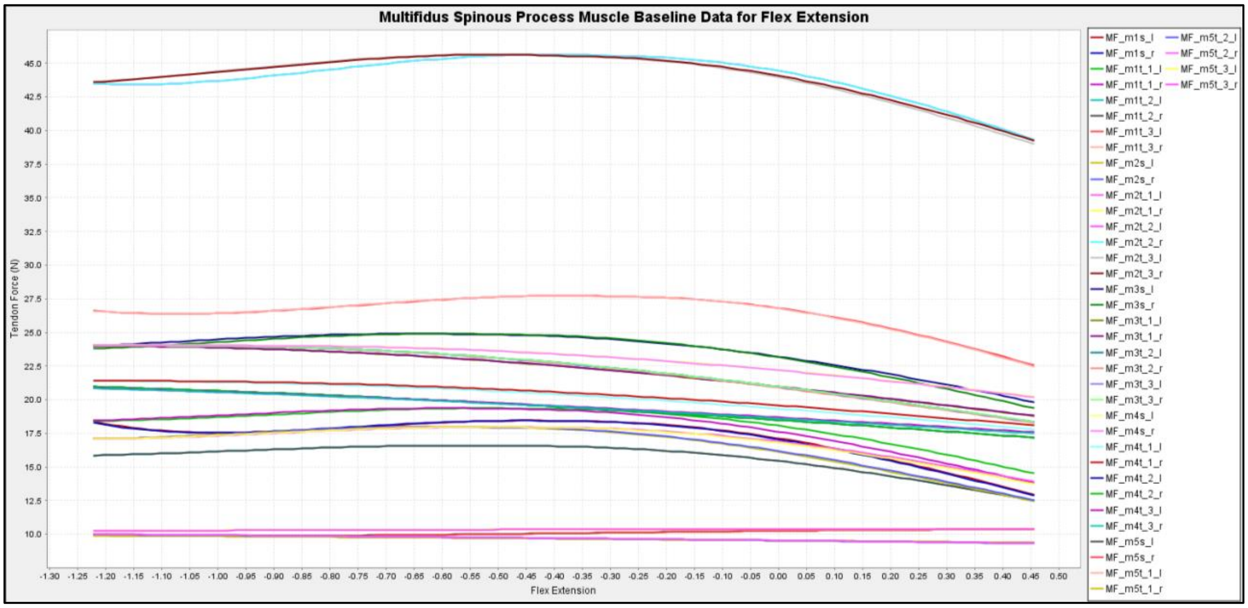

Figure A-2. Multifidus Spinous Process Muscle Tendon Force Baseline Results for Flex-Extension Movement.

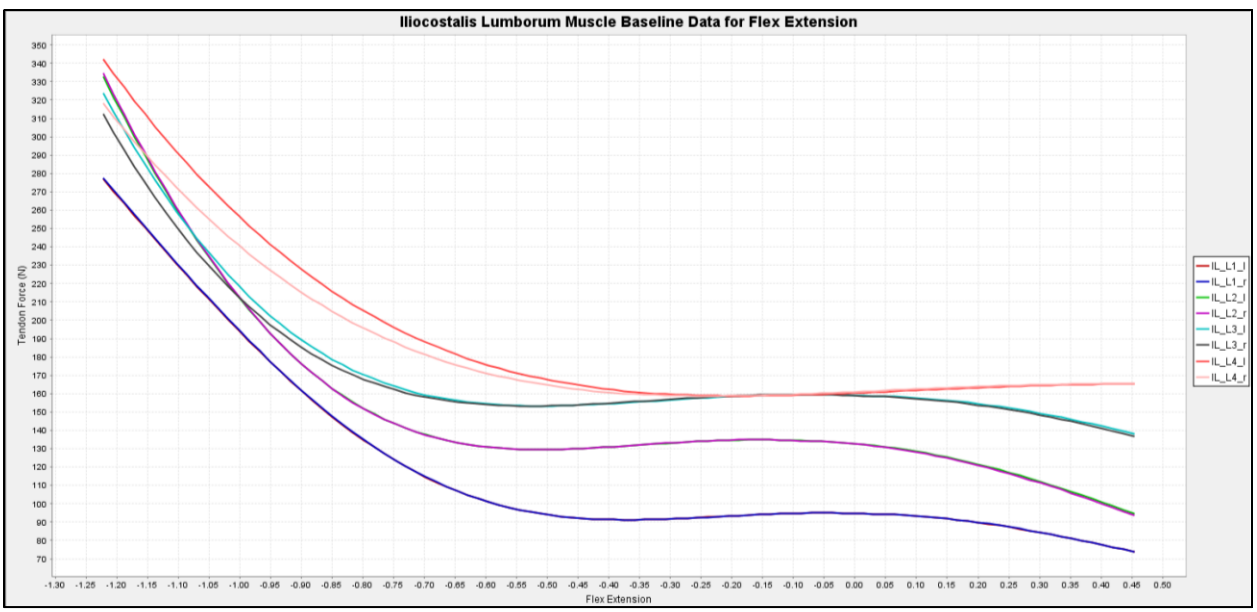

Figure A-3. Iliocostalis Lumborum Muscle Tendon Force Baseline Results for Flex-Extension Movement.

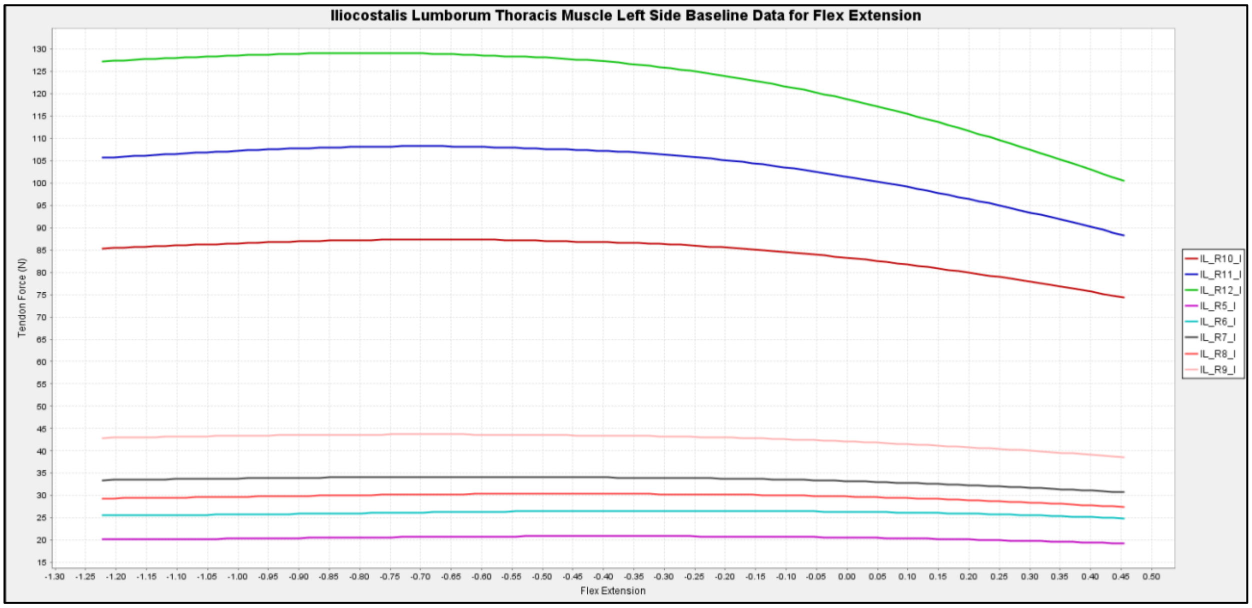

Figure A-4. Iliocostalis Lumborum Thoracis Left Side Muscle Tendon Force Baseline Results for Flex-Extension Movement.

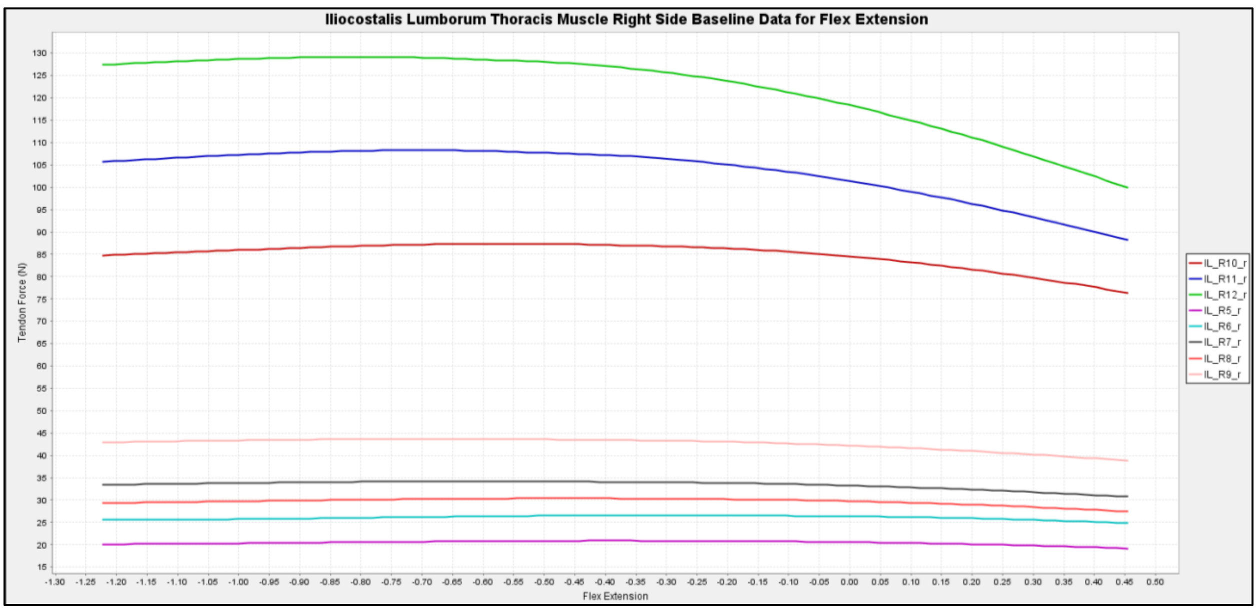

Figure A-5. Iliocostalis Lumborum Thoracis Right Side Muscle Tendon Force Baseline Results for Flex-Extension Movement.

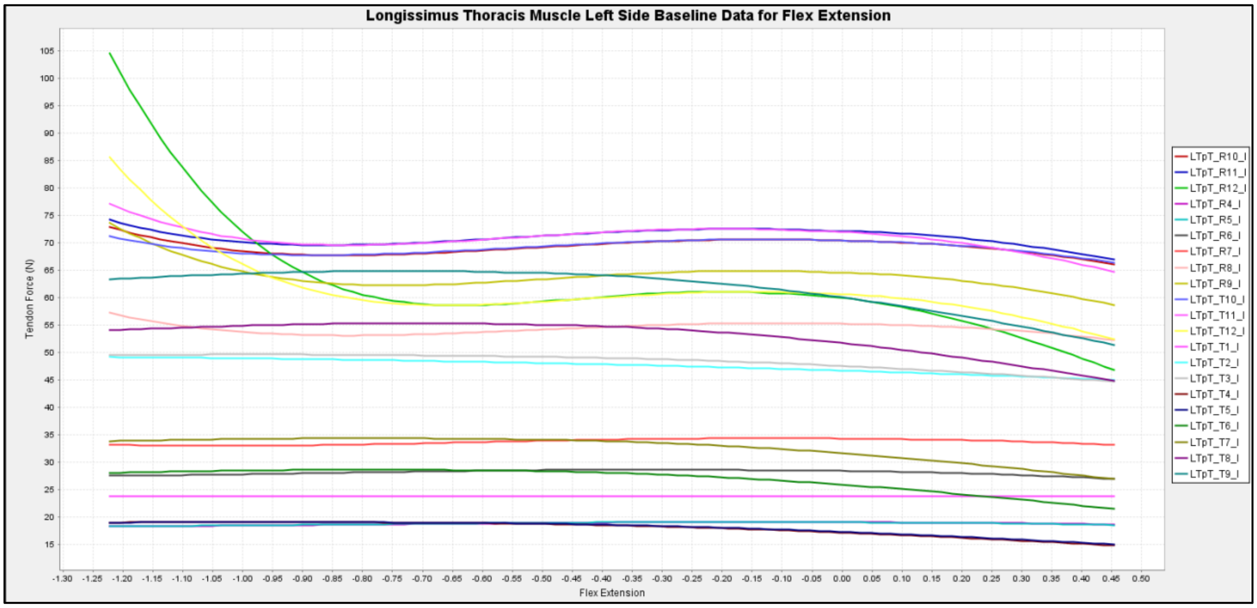

Figure A-6. Longissimus Thoracis Left Side Muscle Tendon Force Baseline Results for Flex-Extension Movement.

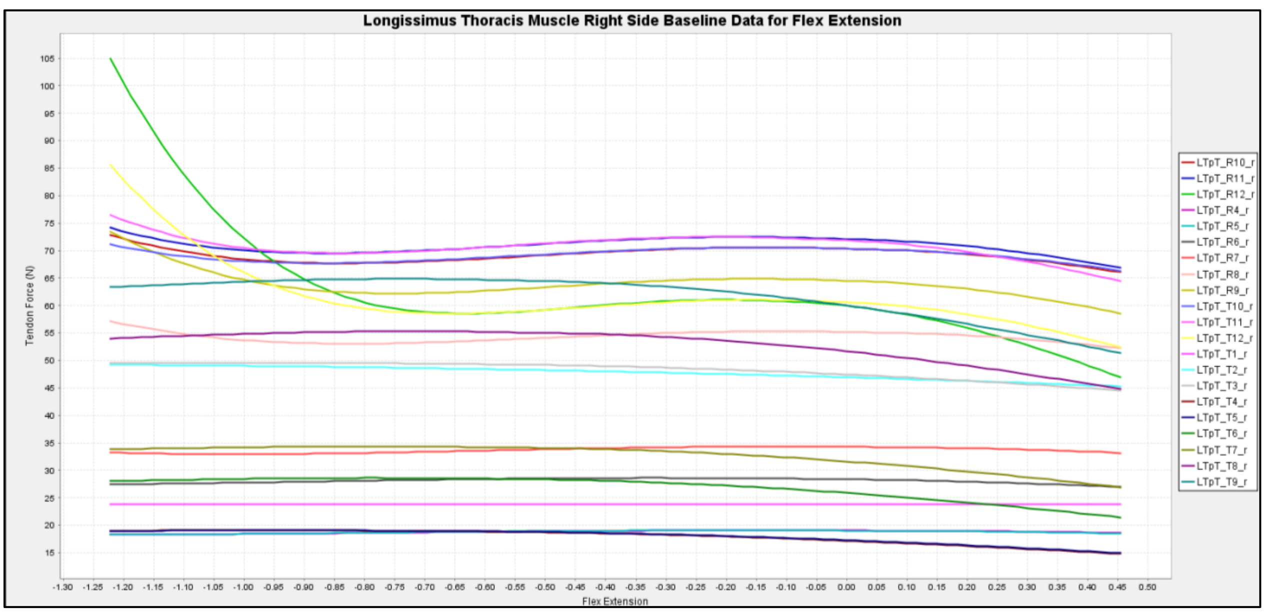

Figure A-7. Longissimus Thoracis Right Side Muscle Tendon Force Baseline Results for Flex-Extension Movement.

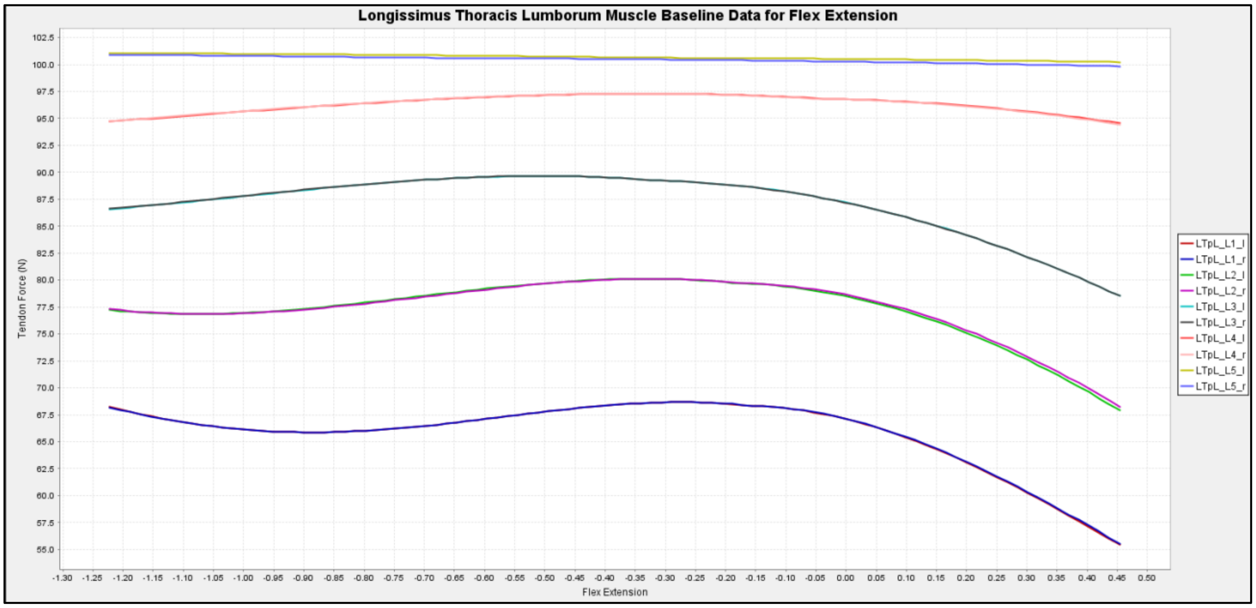

Figure A-8. Longissimus Thoracis Lumborum Muscle Tendon Force Baseline Results for Flex-Extension Movement.

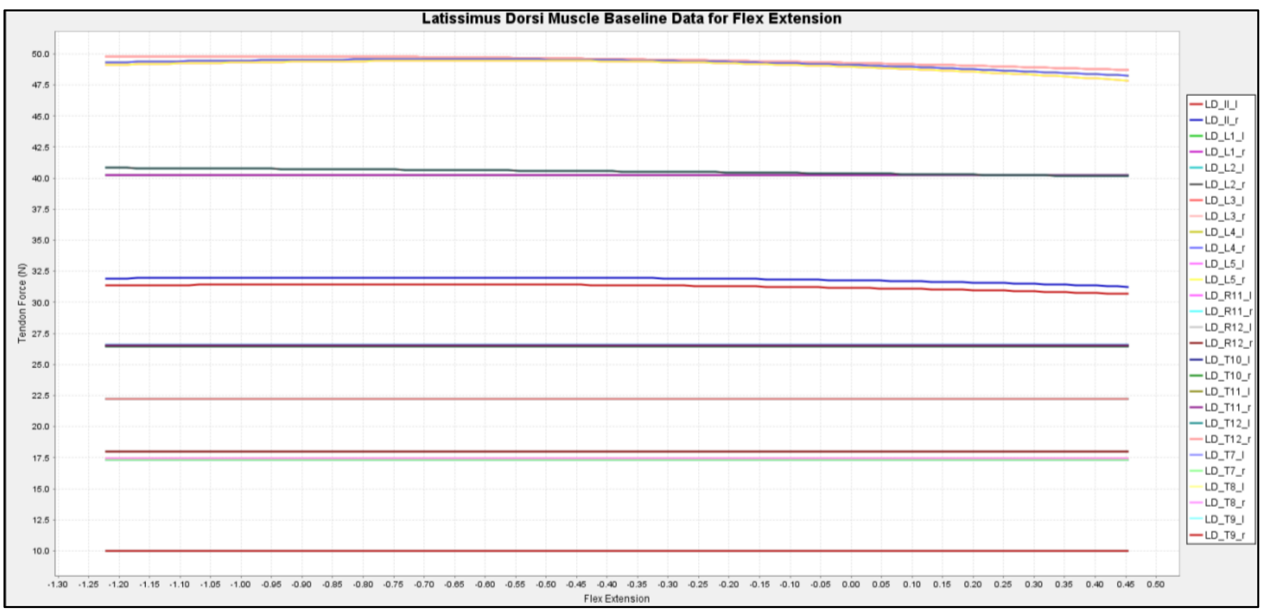

Figure A-9. Latissimus Dorsi Muscle Tendon Force Baseline Results for Flex-Extension Movement.

Individual Muscle Data with Modified Multifidus Entry Level Muscle

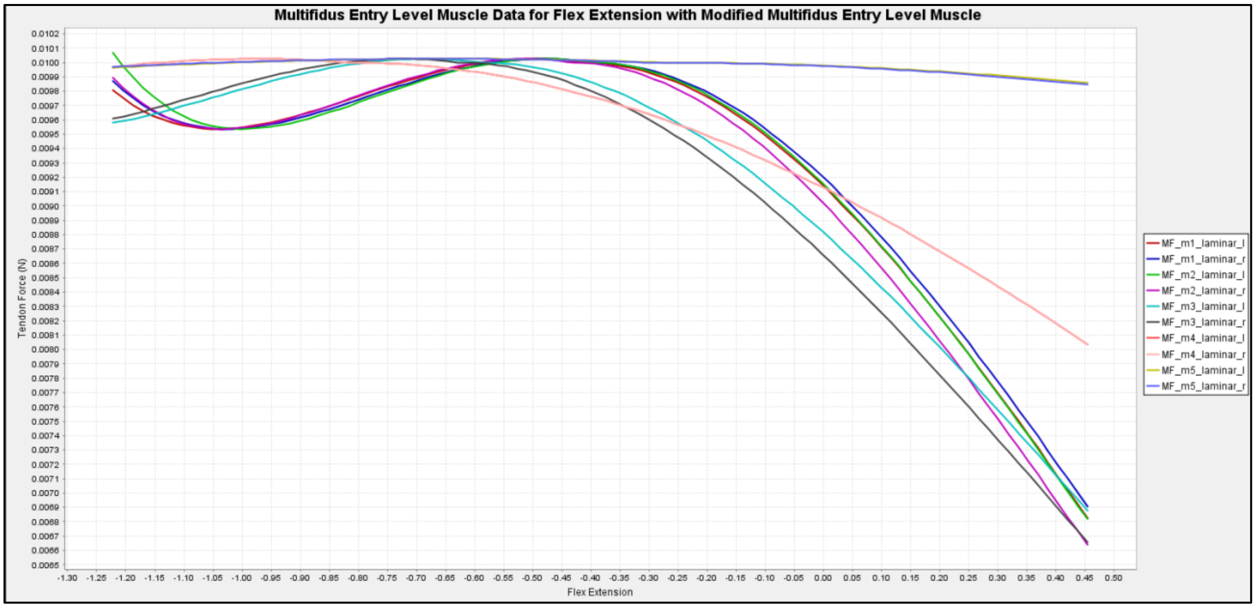

Figure A-10. Multifidus Entry Level Muscle Tendon Force Results for Flex-Extension Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

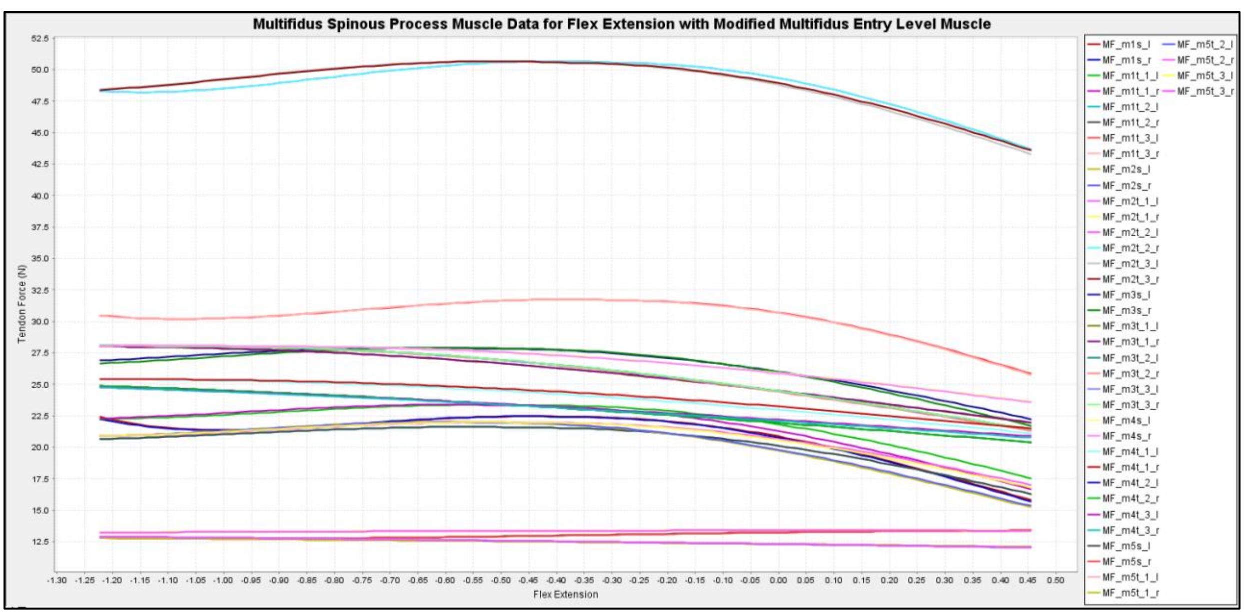

Figure A-11. Multifidus Spinous Process Muscle Tendon Force Results for Flex-Extension Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

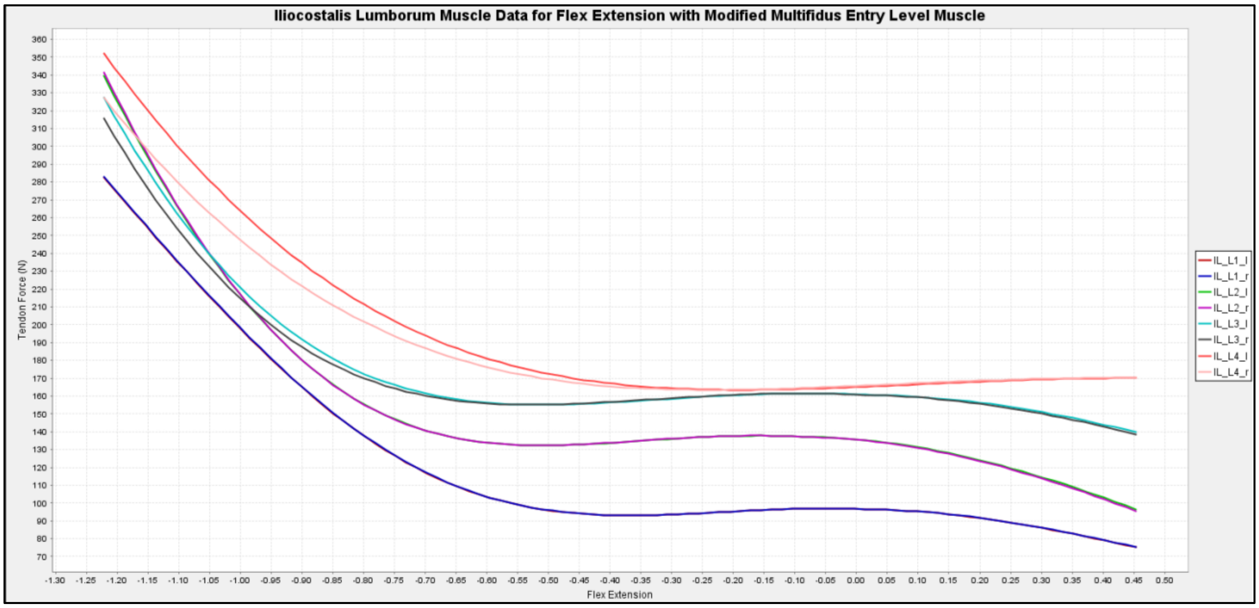

Figure A-12. Iliocostalis Lumborum Muscle Tendon Force Results for Flex-Extension Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

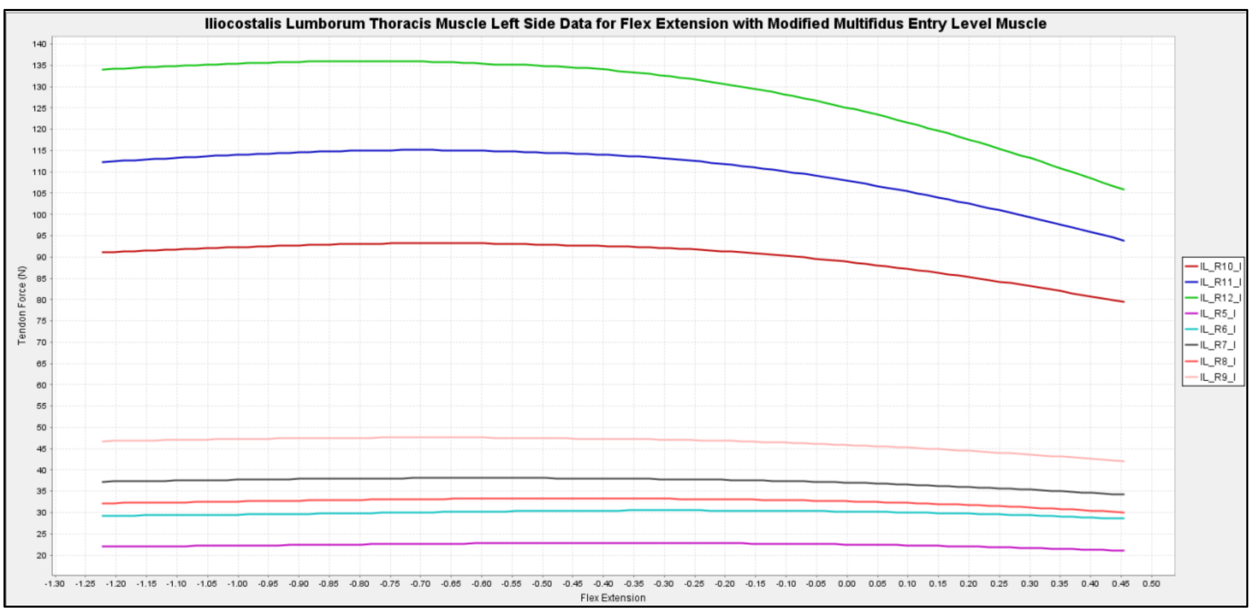

Figure A-13. Iliocostalis Lumborum Thoracis Left Side Muscle Tendon Force Results for Flex-Extension Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

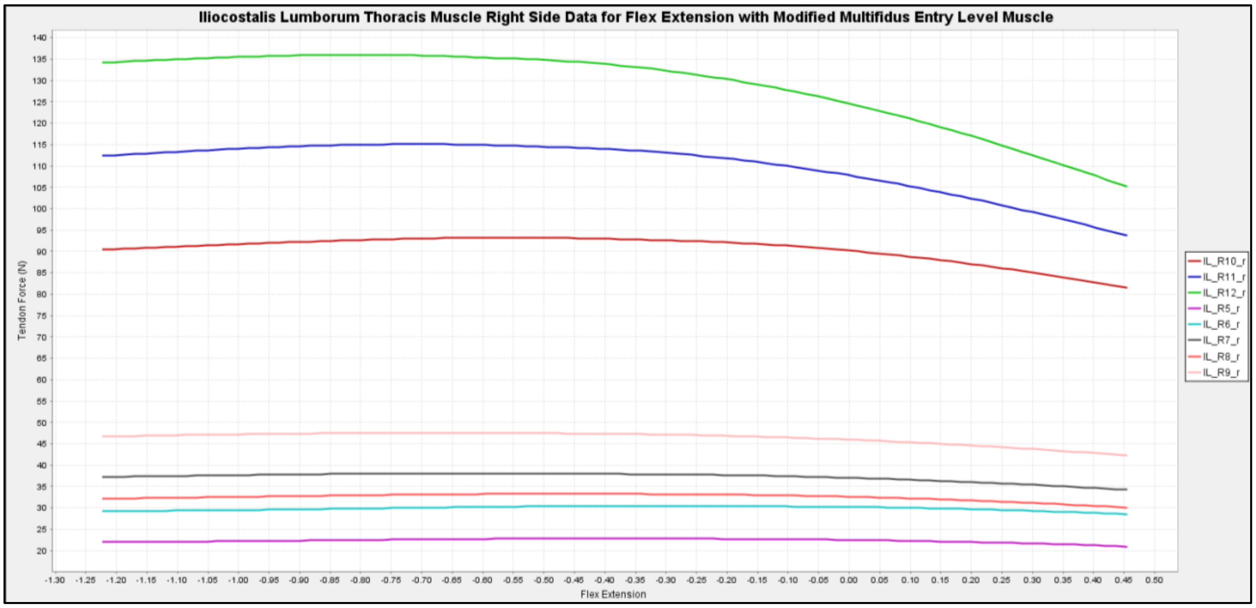

Figure A-14. Iliocostalis Lumborum Thoracis Right Side Muscle Tendon Force Results for Flex-Extension Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

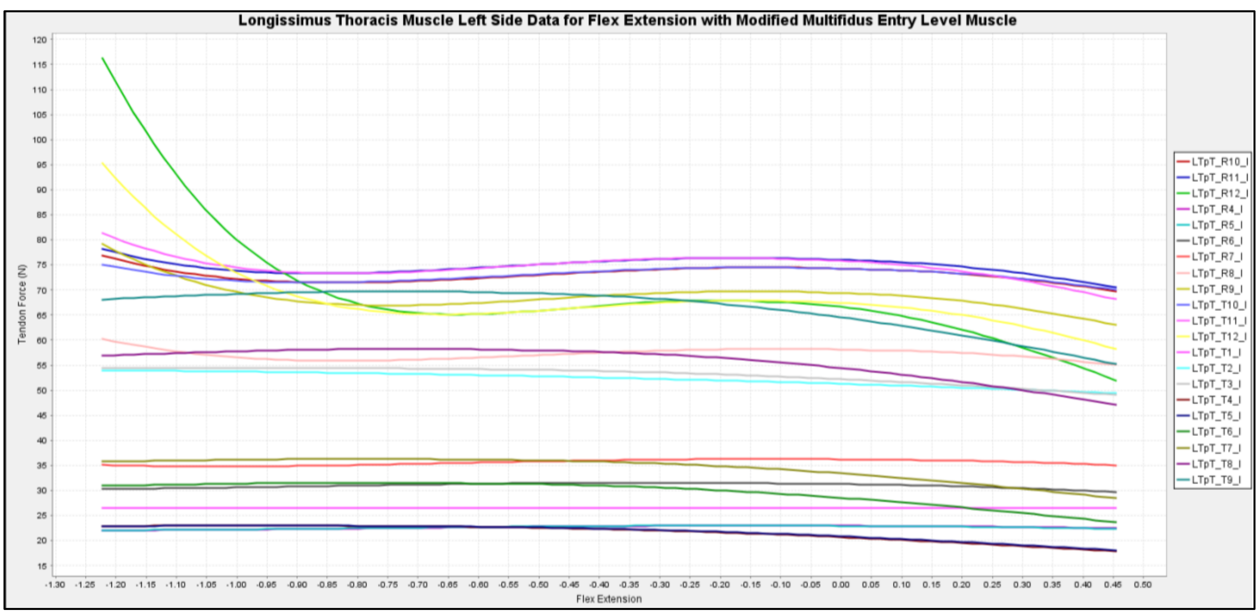

Figure A-15. Longissimus Thoracis Left Side Muscle Tendon Force Results for Flex-Extension Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

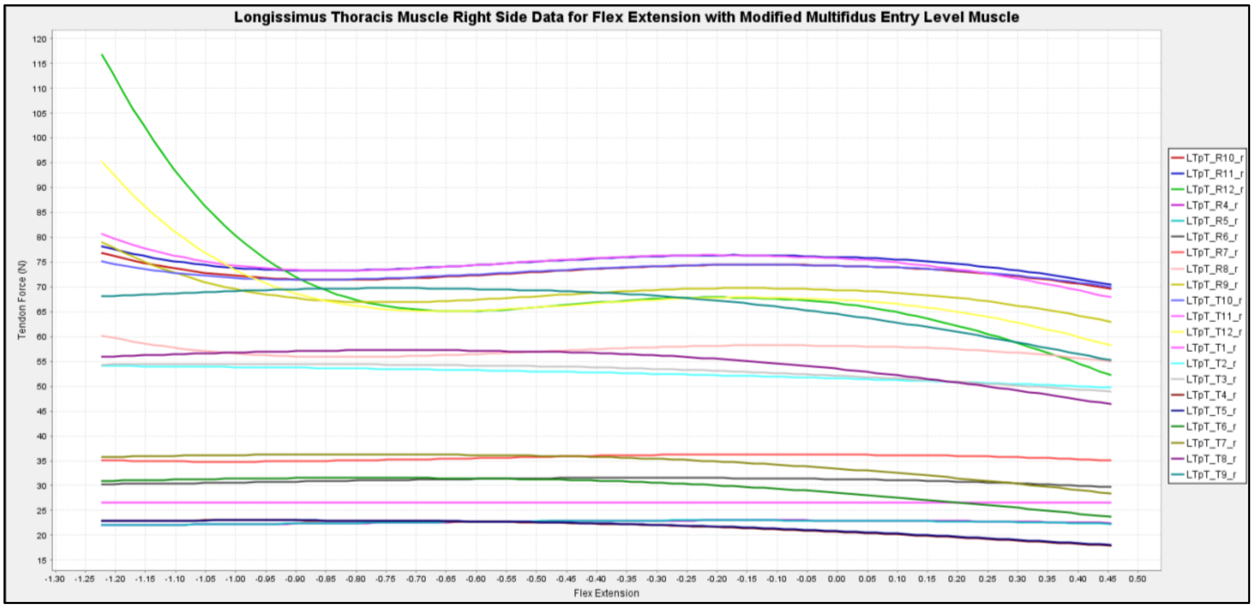

Figure A-16. Longissimus Thoracis Right Side Muscle Tendon Force Results for Flex-Extension Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

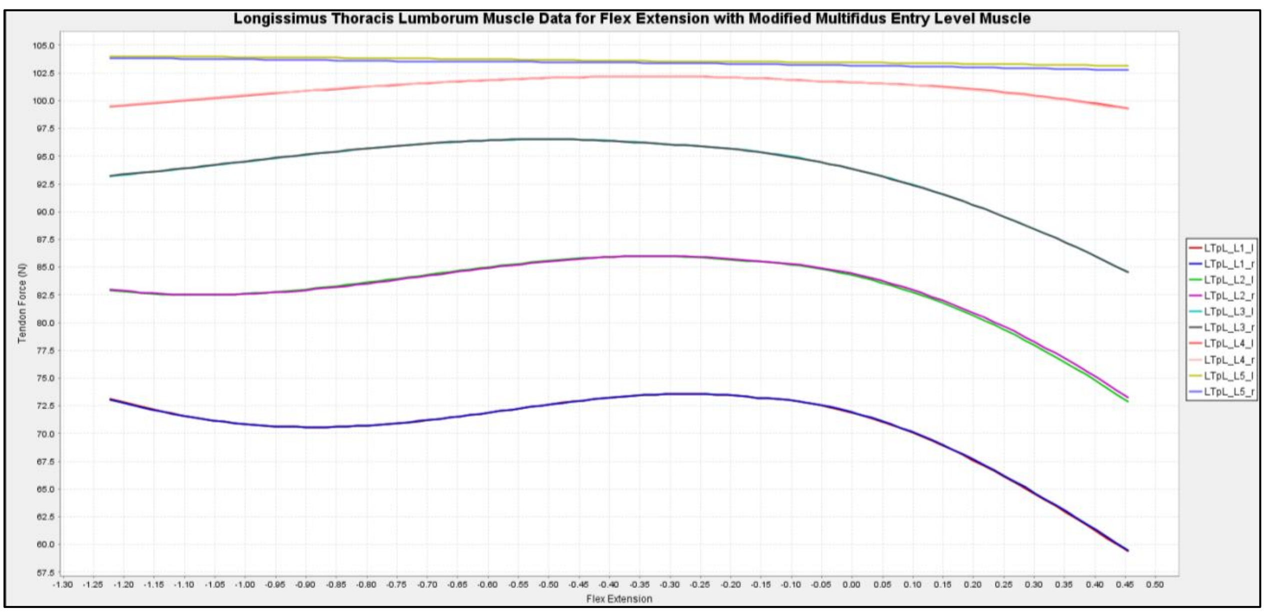

Figure A-17. Longissimus Thoracis Lumborum Muscle Tendon Force Results for Flex-Extension Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

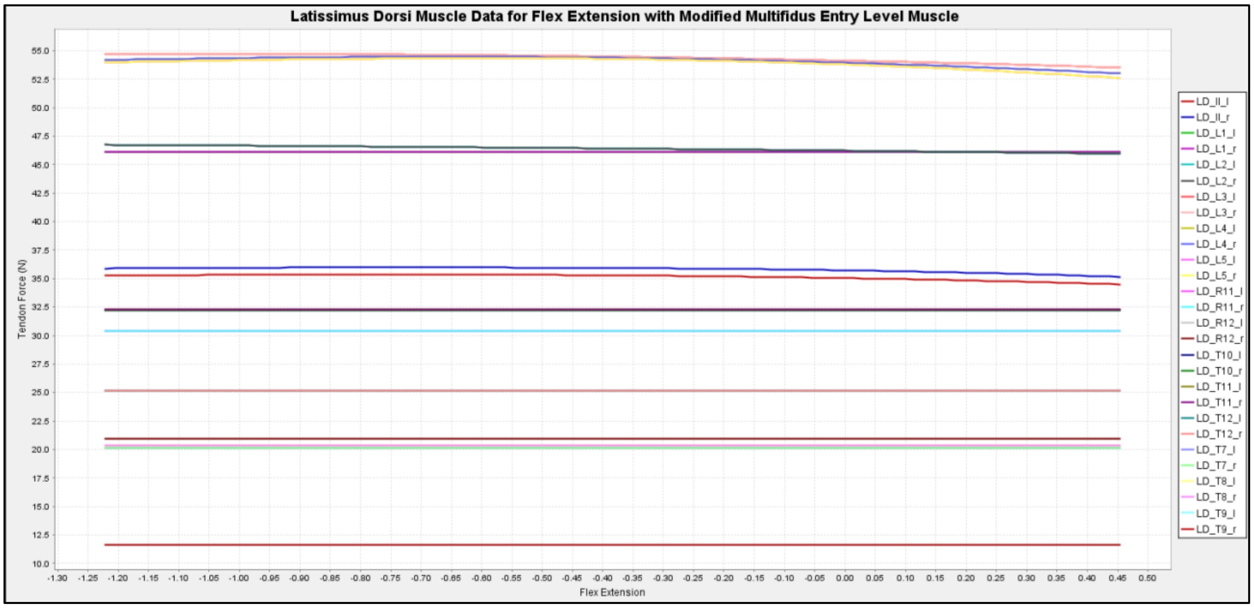

Figure A-18. Latissimus Dorsi Muscle Tendon Force Results for Flex-Extension Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

Individual Muscle Data with Modified Multifidus Spinous Process Muscle

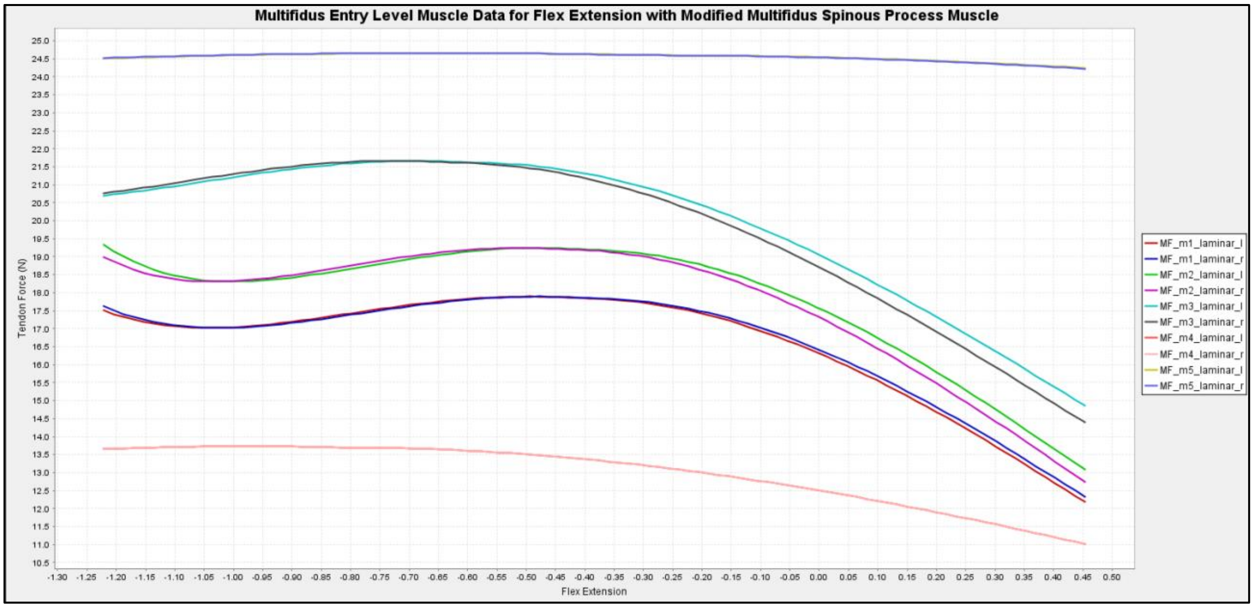

Figure A-19. Multifidus Entry Level Muscle Tendon Force Results for Flex-Extension Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

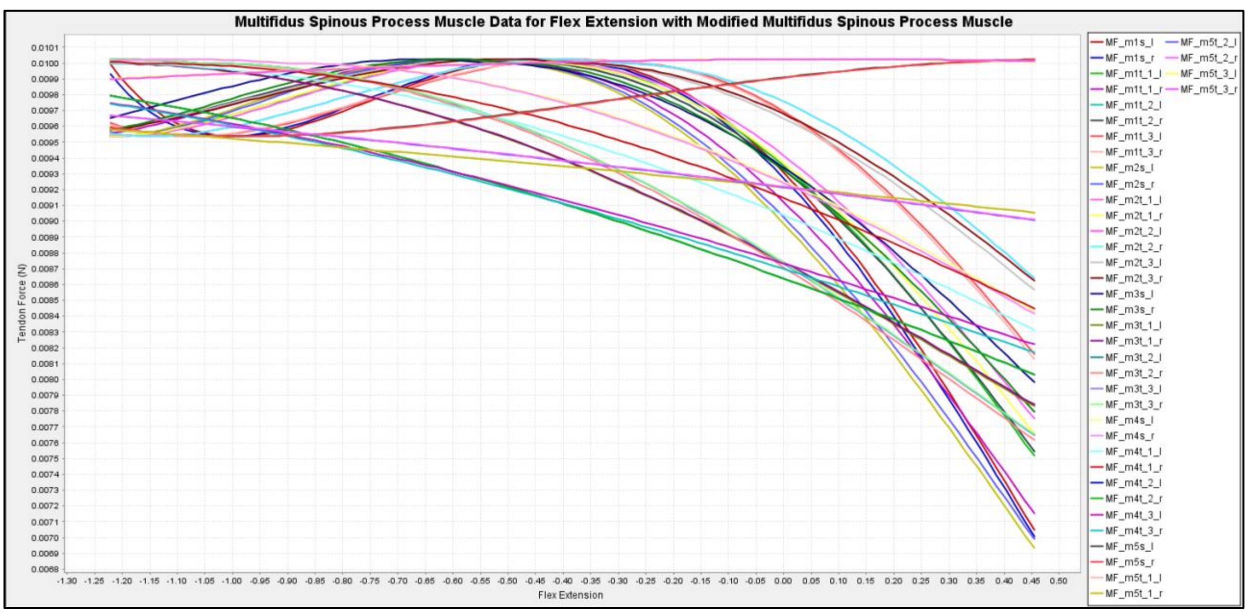

Figure A-20. Multifidus Spinous Process Muscle Tendon Force Results for Flex-Extension Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

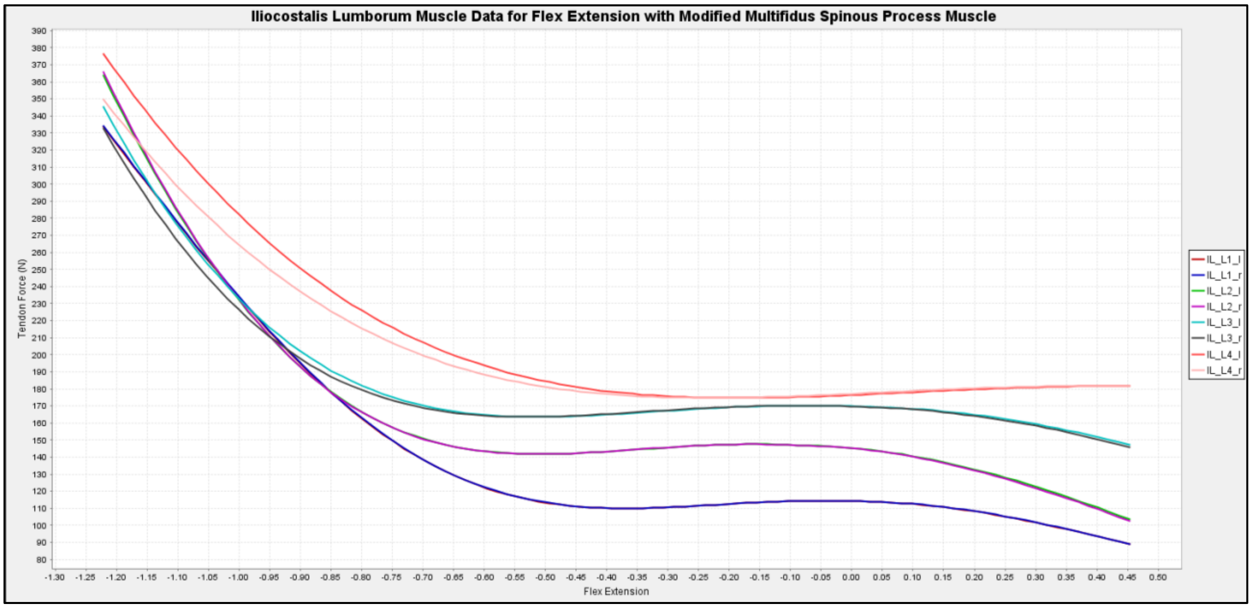

Figure A-21. Iliocostalis Lumborum Muscle Tendon Force Results for Flex-Extension Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

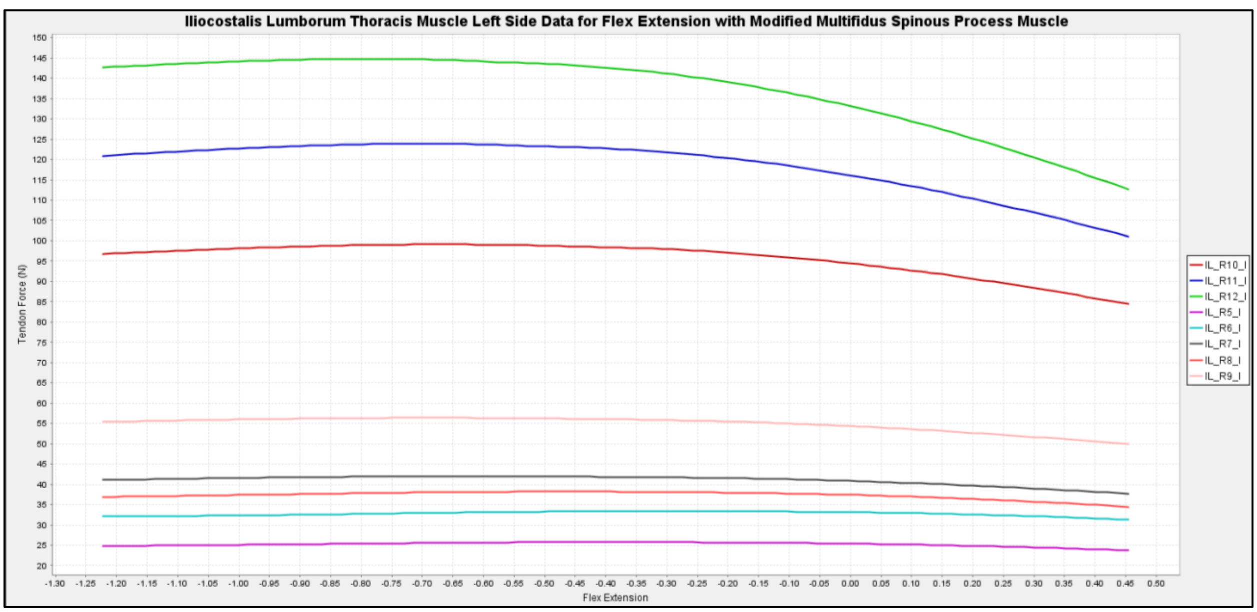

Figure A-22. Iliocostalis Lumborum Thoracis Left Side Muscle Tendon Force Results for Flex-Extension Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

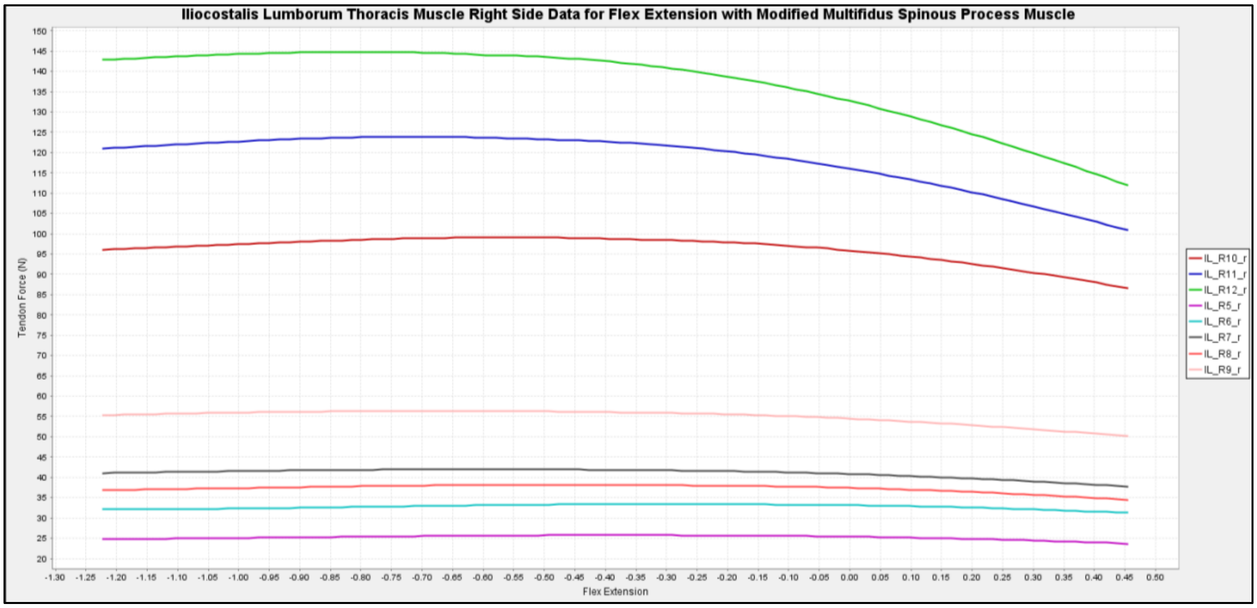

Figure A-23. Iliocostalis Lumborum Thoracis Right Side Muscle Tendon Force Results for Flex-Extension Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

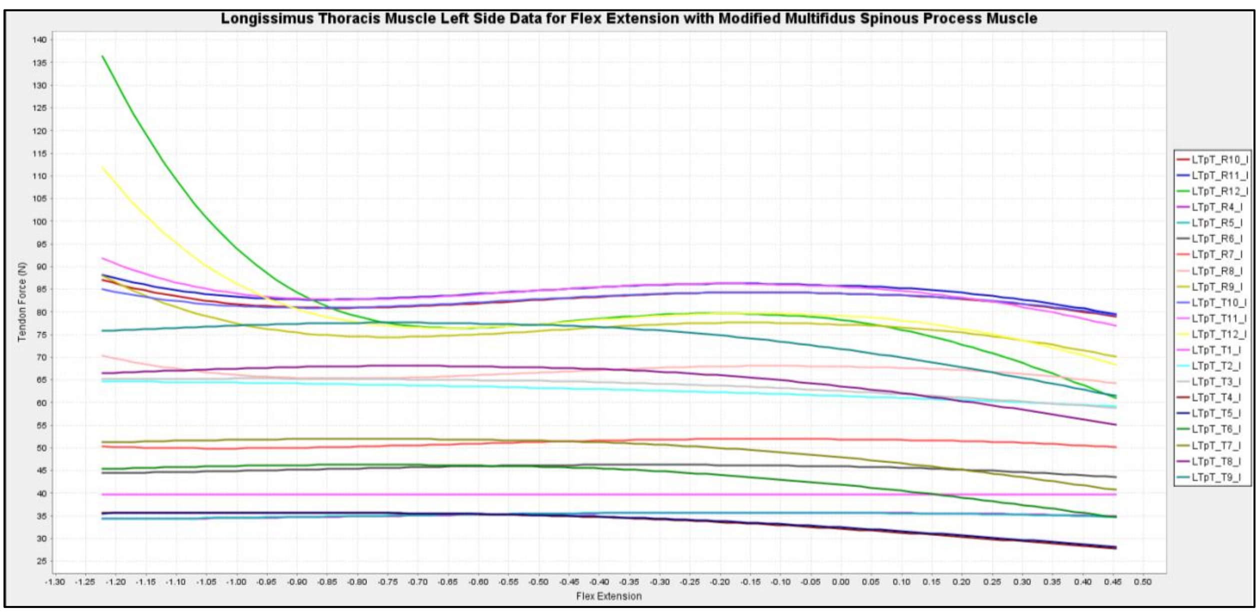

Figure A-24. Longissimus Thoracis Left Side Muscle Tendon Force Results for Flex-Extension Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

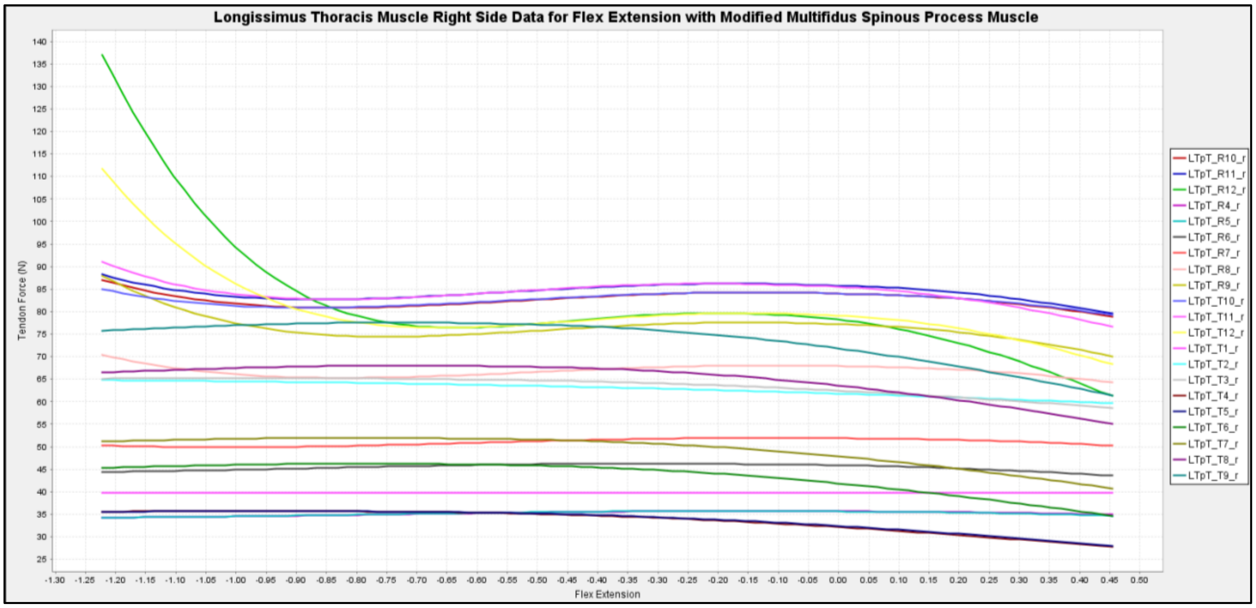

Figure A-25. Longissimus Thoracis Right Side Muscle Tendon Force Results for Flex-Extension Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

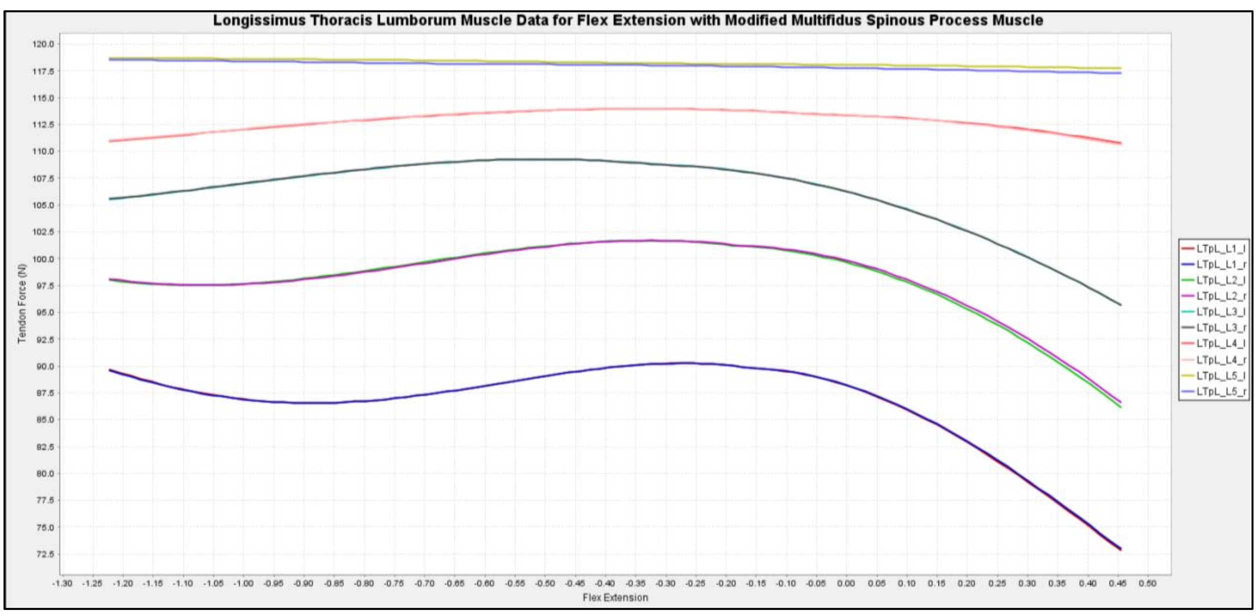

Figure A-26. Longissimus Thoracis Lumborum Muscle Tendon Force Results for Flex-Extension Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

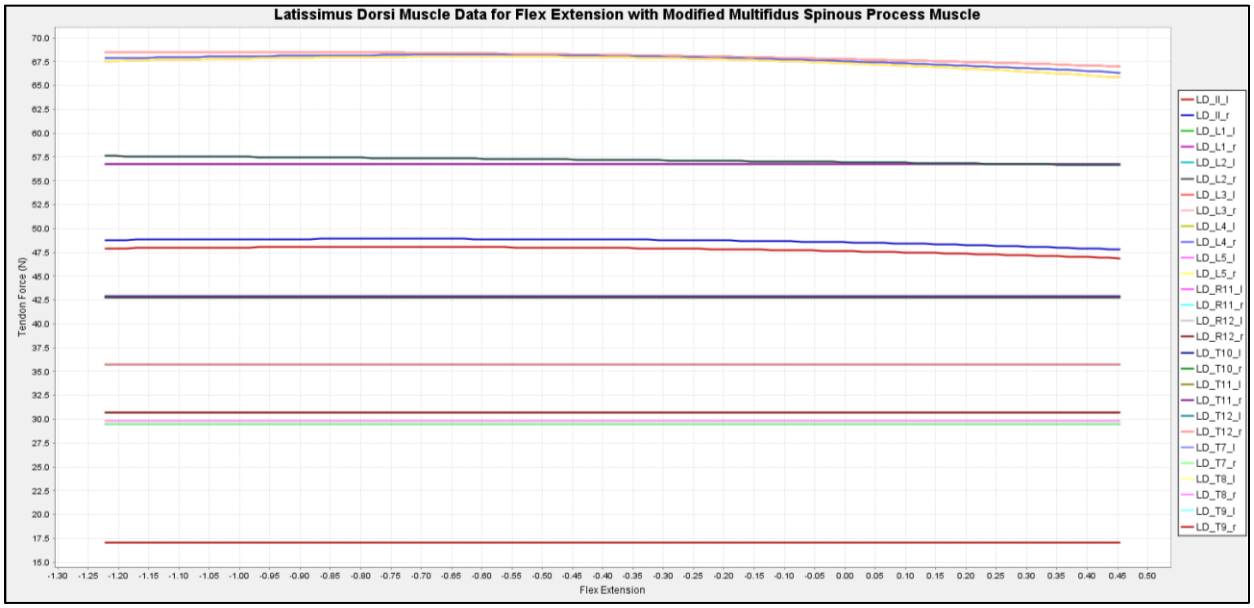

Figure A-27. Latissimus Dorsi Muscle Tendon Force Results for Flex-Extension Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

Appendix B

Axial Rotation Muscle Data

Individual Muscle Baseline Data

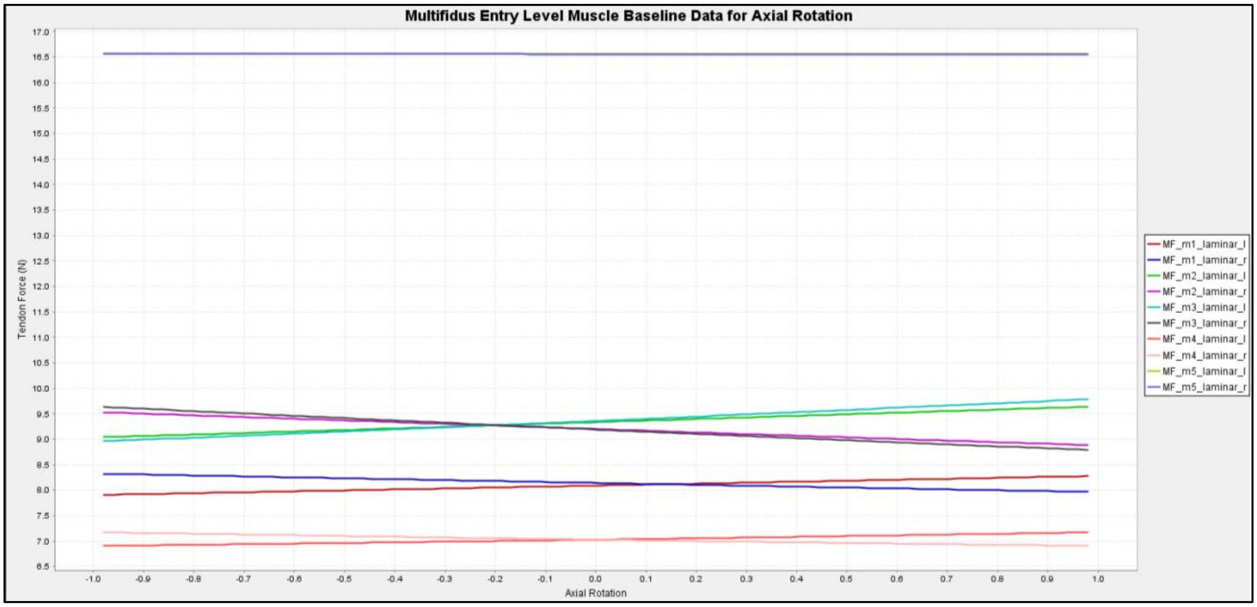

Figure B-1. Multifidus Entry Level Muscle Tendon Force Baseline Results for Axial Rotation Movement.

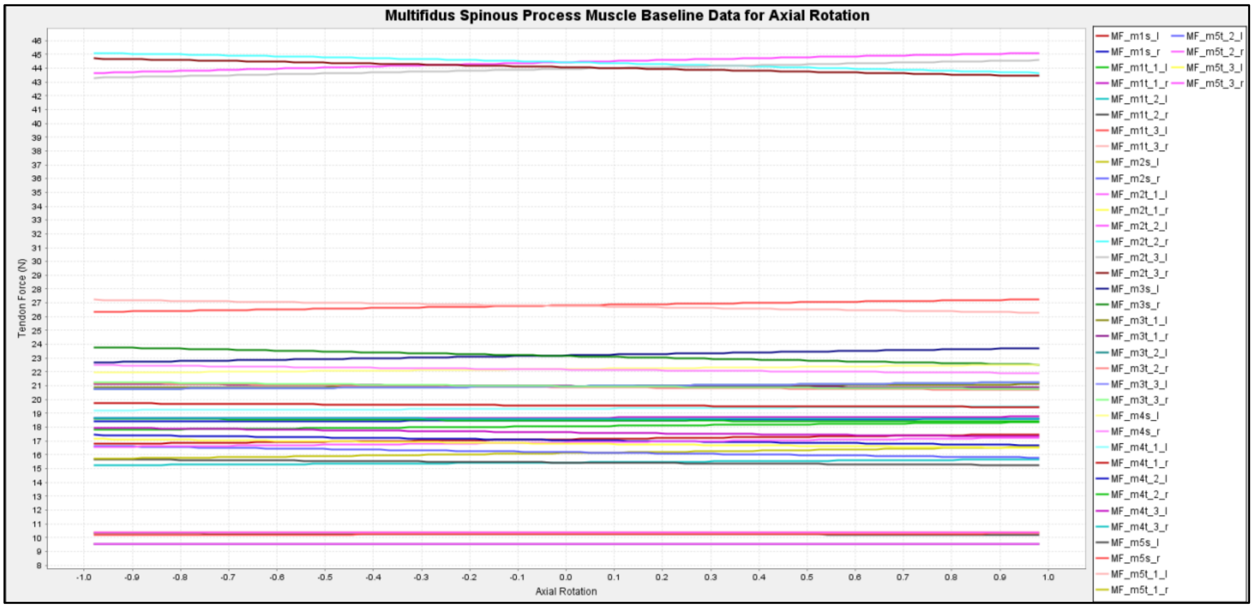

Figure B-2. Multifidus Spinous Process Muscle Tendon Force Baseline Results for Axial Rotation Movement.

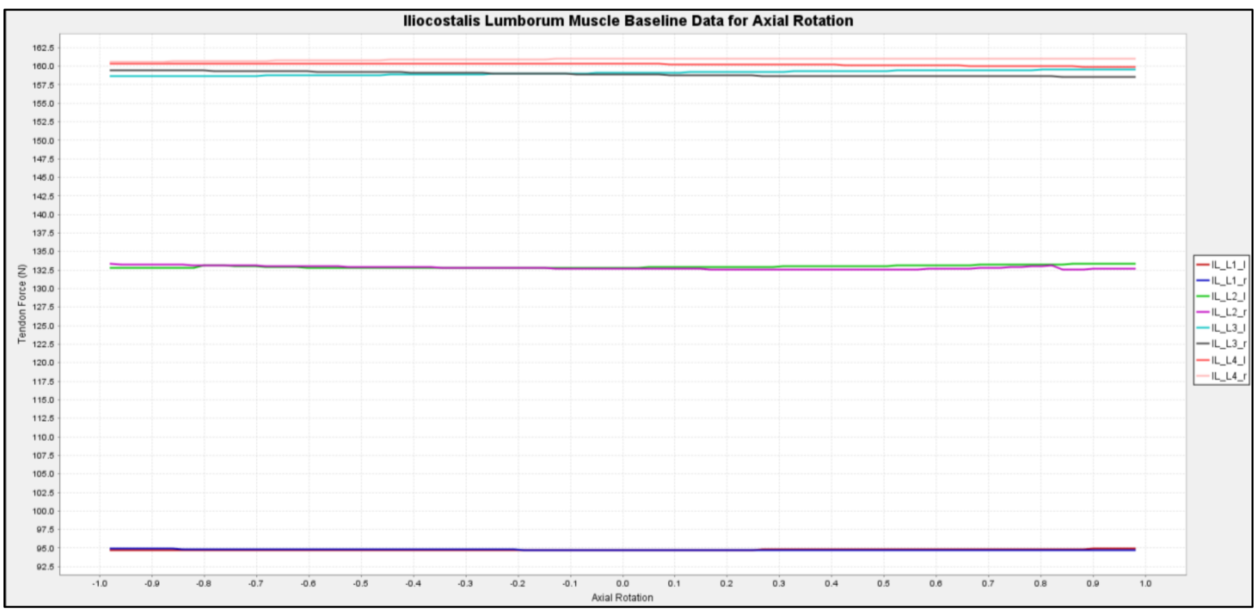

Figure B-3. Iliocostalis Lumborum Muscle Tendon Force Baseline Results for Axial Rotation Movement.

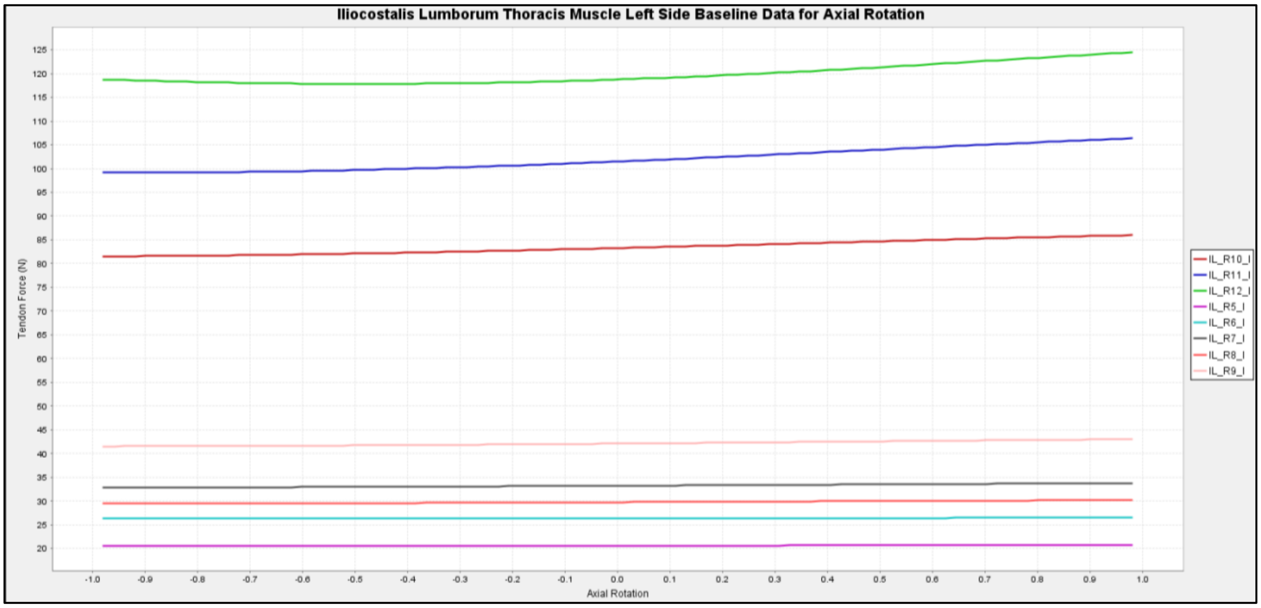

Figure B-4. Iliocostalis Lumborum Thoracis Left Side Muscle Tendon Force Baseline Results for Axial Rotation Movement.

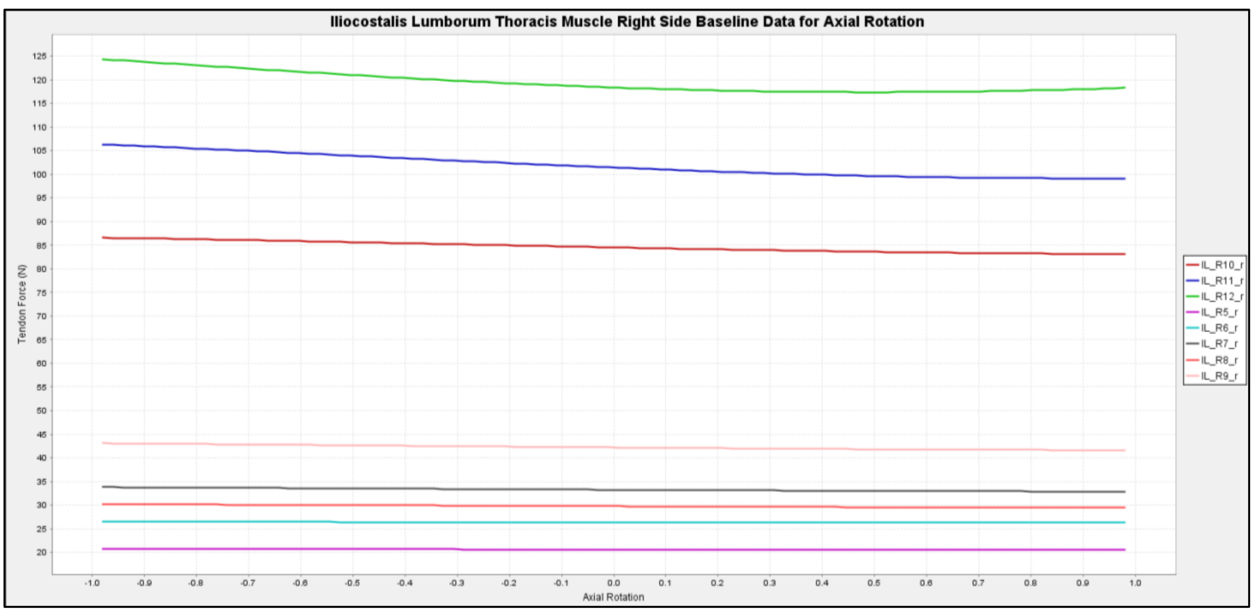

Figure B-5. Iliocostalis Lumborum Thoracis Right Side Muscle Tendon Force Baseline Results for Axial Rotation Movement.

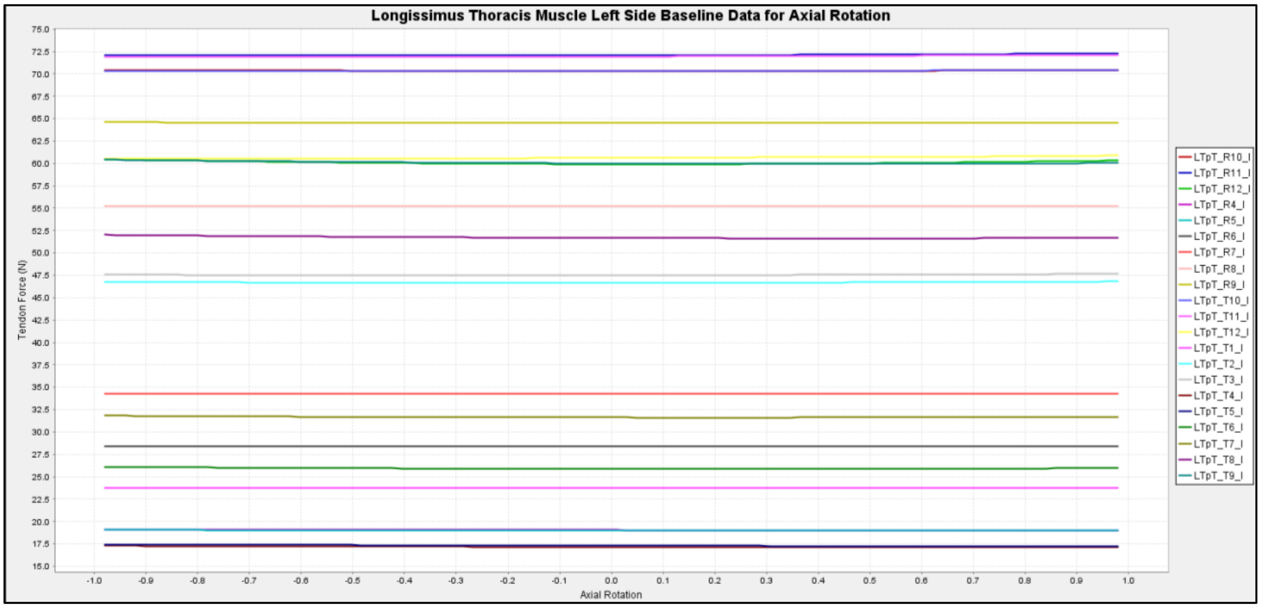

Figure B-6. Longissimus Thoracis Left Side Muscle Tendon Force Baseline Results for Axial Rotation Movement.

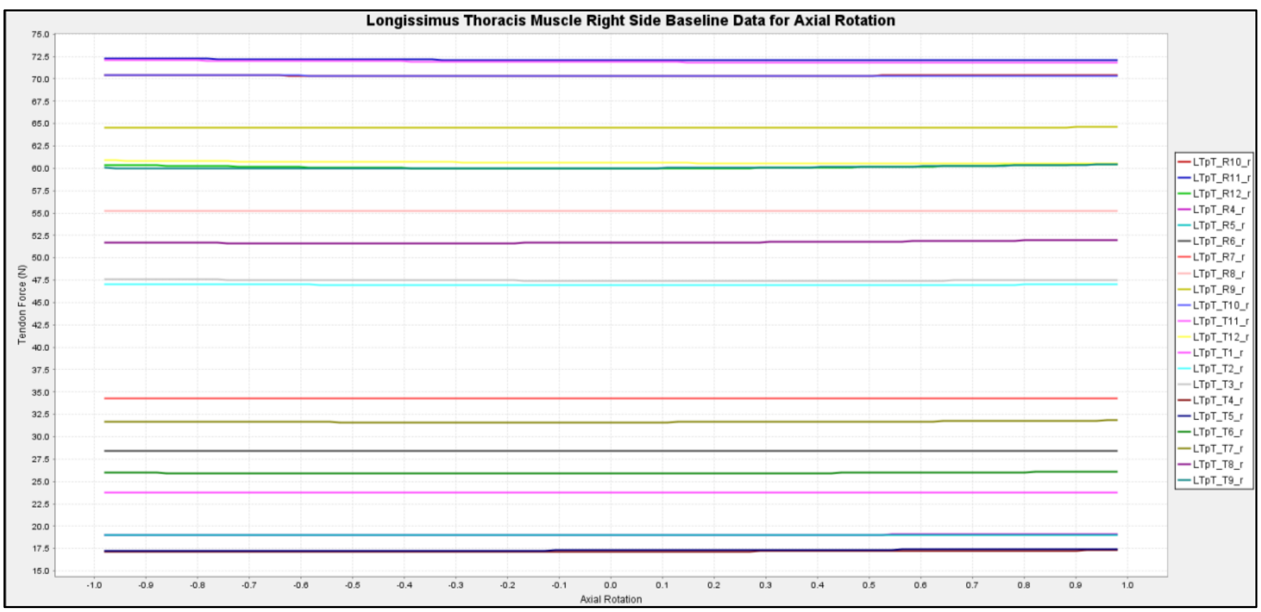

Figure B-7. Longissimus Thoracis Right Side Muscle Tendon Force Baseline Results for Axial Rotation Movement.

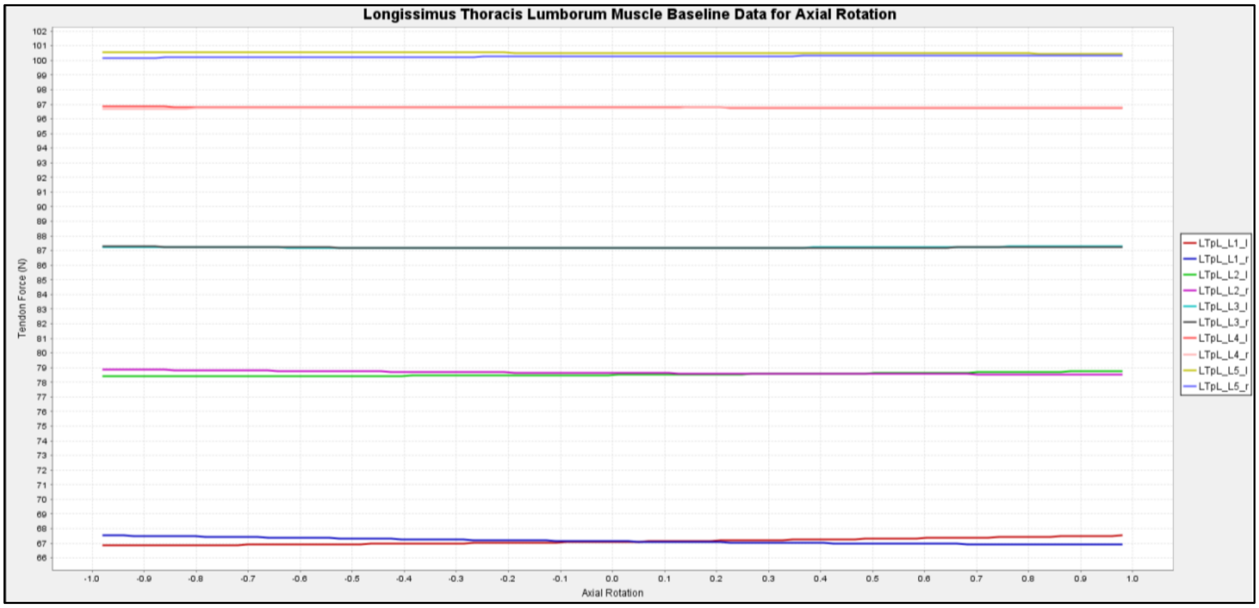

Figure B-8. Longissimus Thoracis Lumborum Muscle Tendon Force Baseline Results for Axial Rotation Movement.

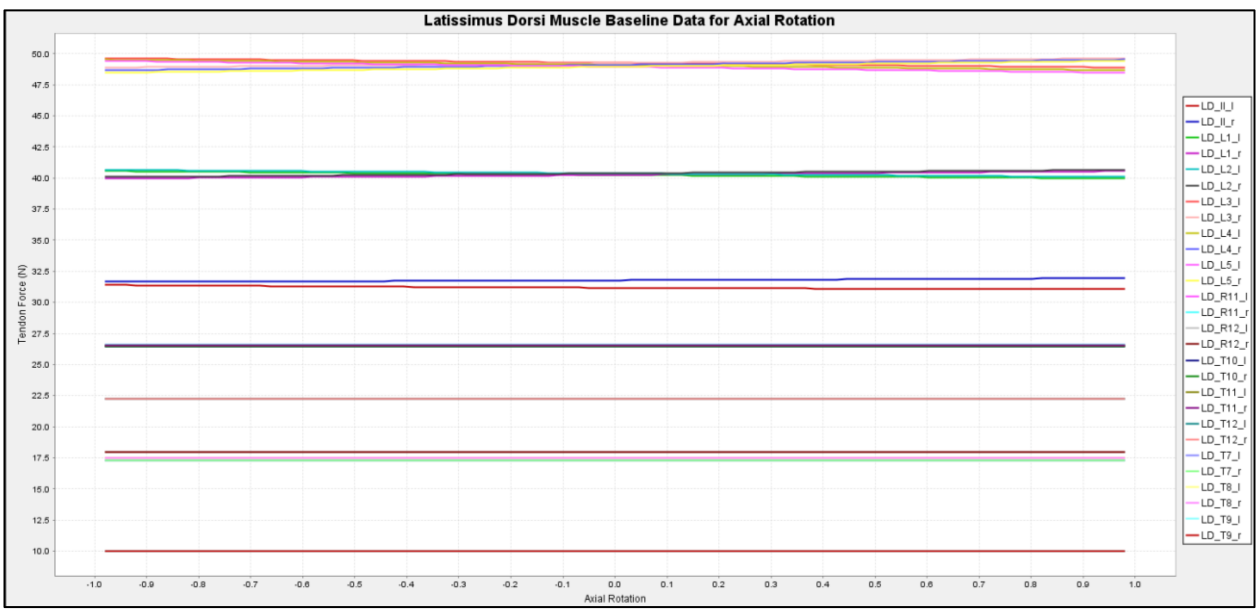

Figure B-9. Latissimus Dorsi Muscle Tendon Force Baseline Results for Axial Rotation Movement.

Individual Muscle Data with Modified Multifidus Entry Level Muscle

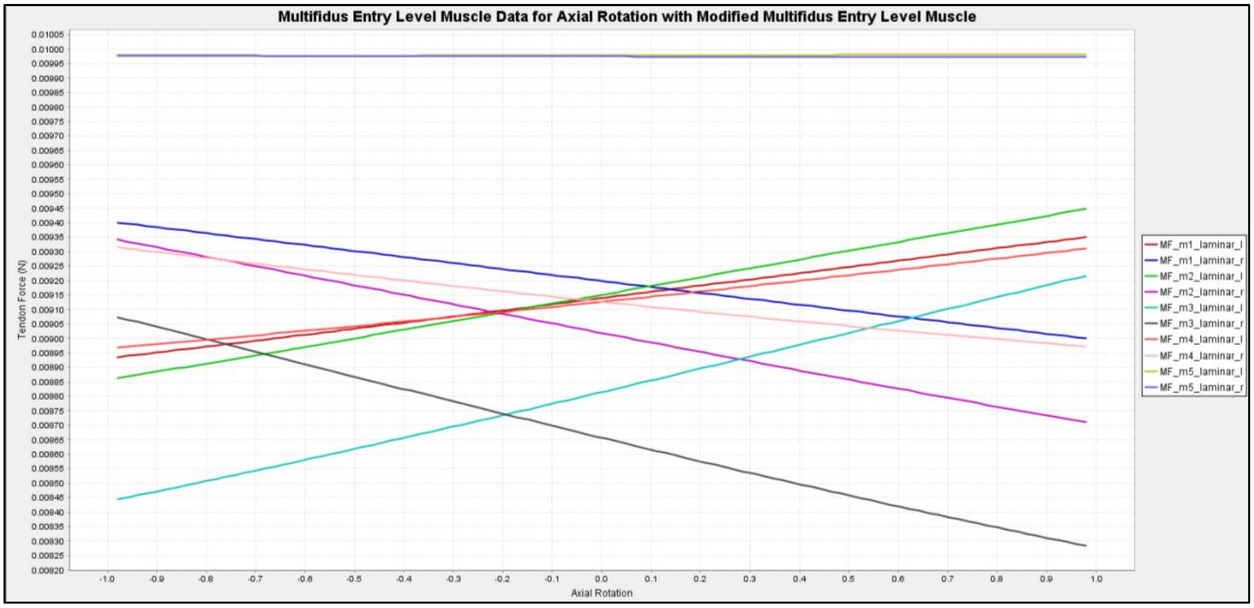

Figure B-10. Multifidus Entry Level Muscle Tendon Force Results for Axial Rotation Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

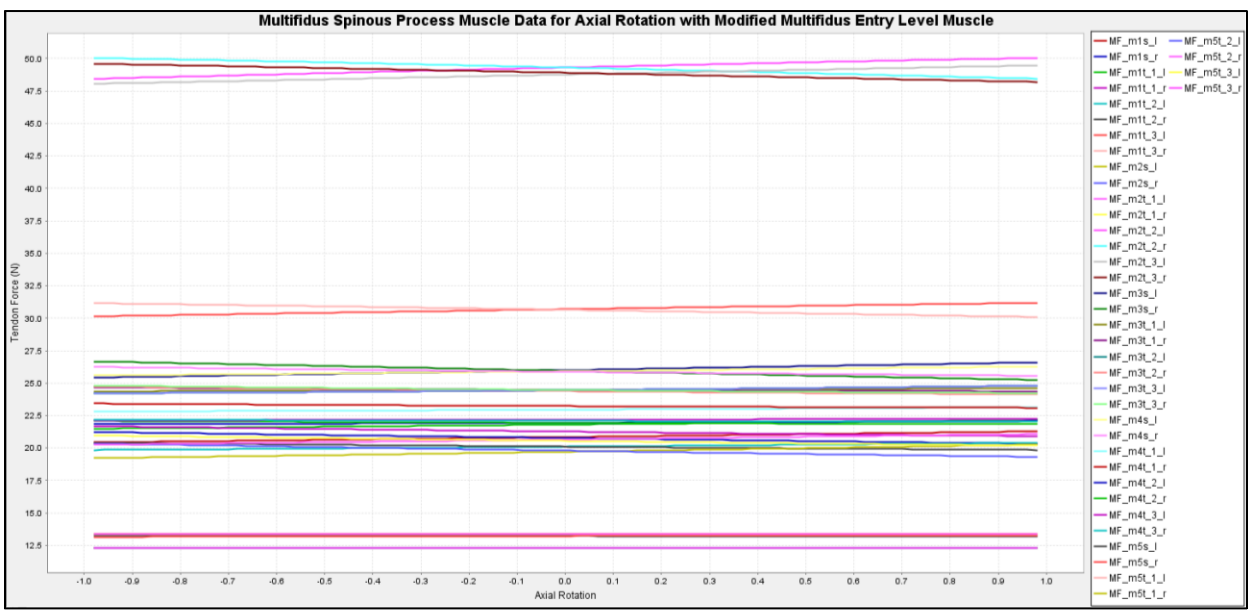

Figure B-11. Multifidus Spinous Process Muscle Tendon Force Results for Axial Rotation Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

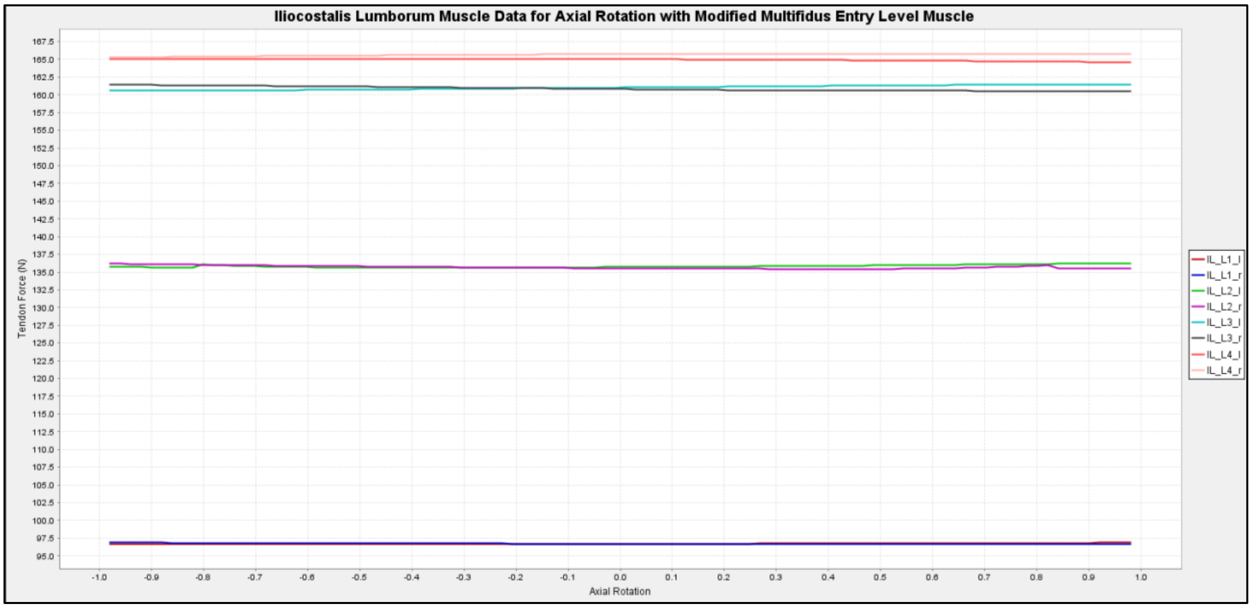

Figure B-12. Iliocostalis Lumborum Muscle Tendon Force Results for Axial Rotation Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

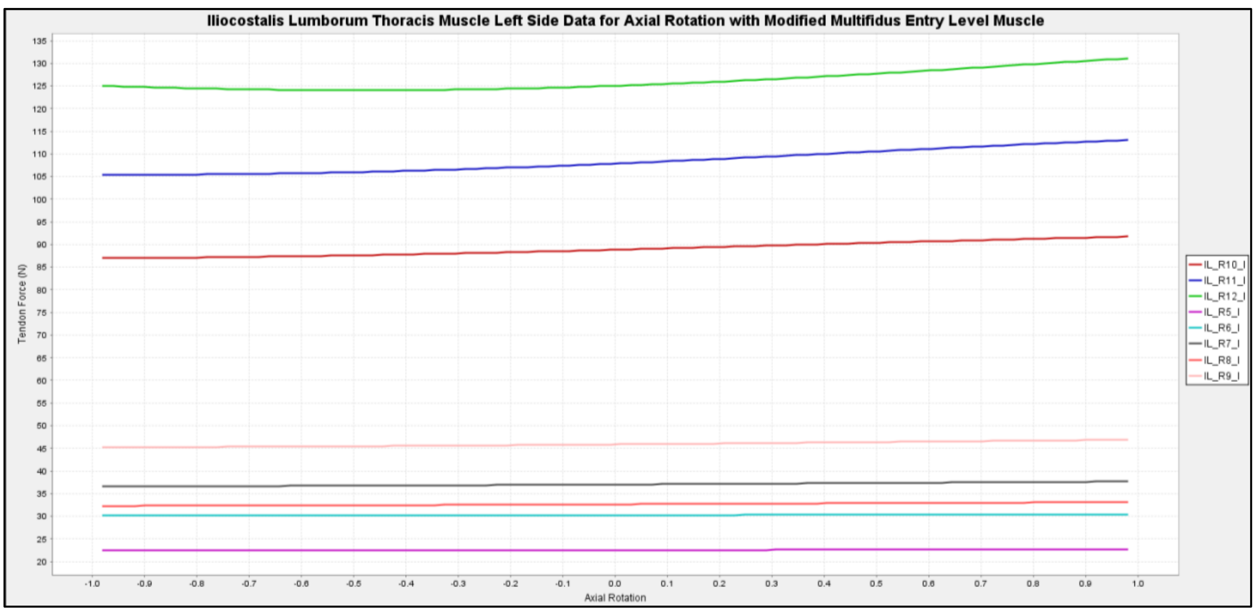

Figure B-13. Iliocostalis Lumborum Thoracis Left Side Muscle Tendon Force Results for Axial Rotation Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

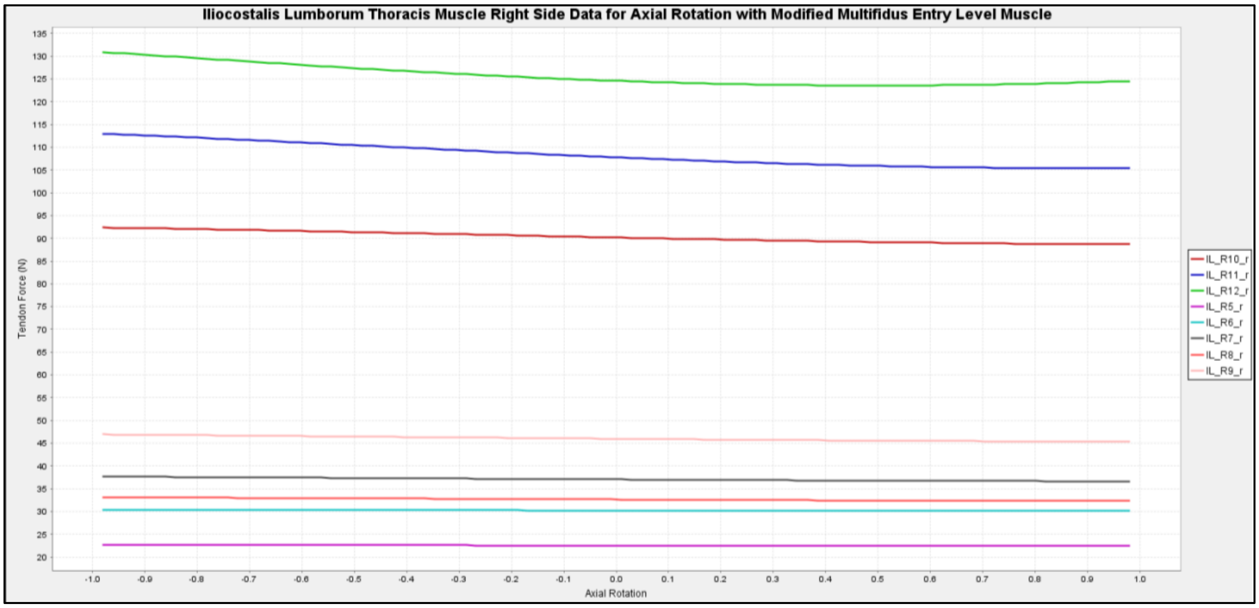

Figure B-14. Iliocostalis Lumborum Thoracis Right Side Muscle Tendon Force Results for Axial Rotation Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

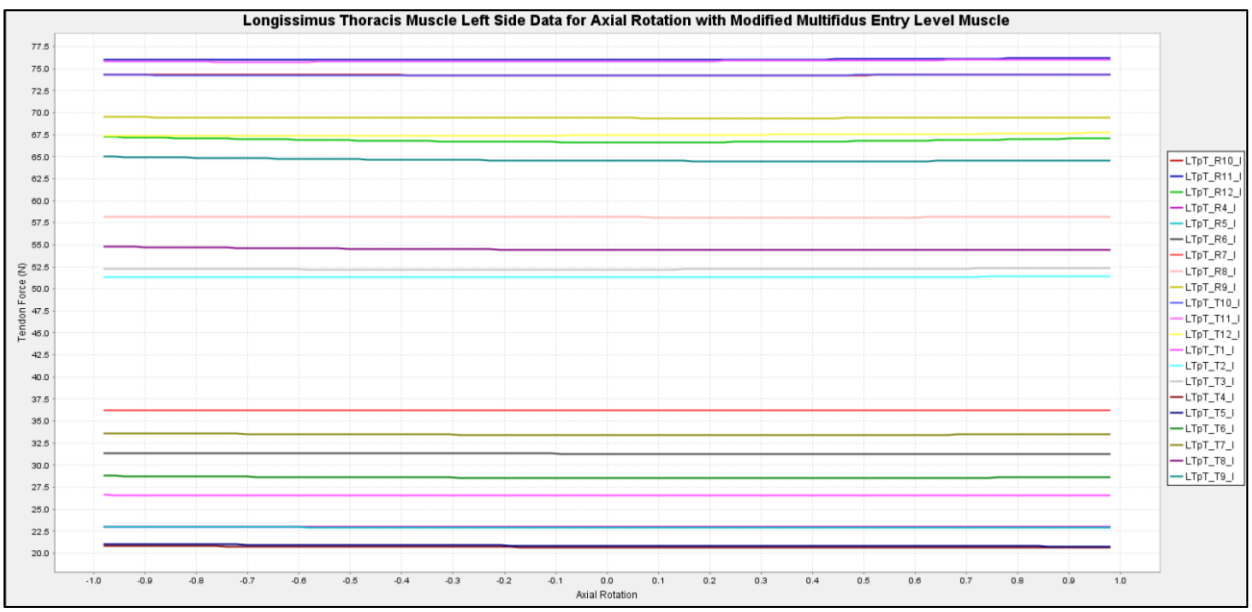

Figure B-15. Longissimus Thoracis Left Side Muscle Tendon Force Results for Axial Rotation Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

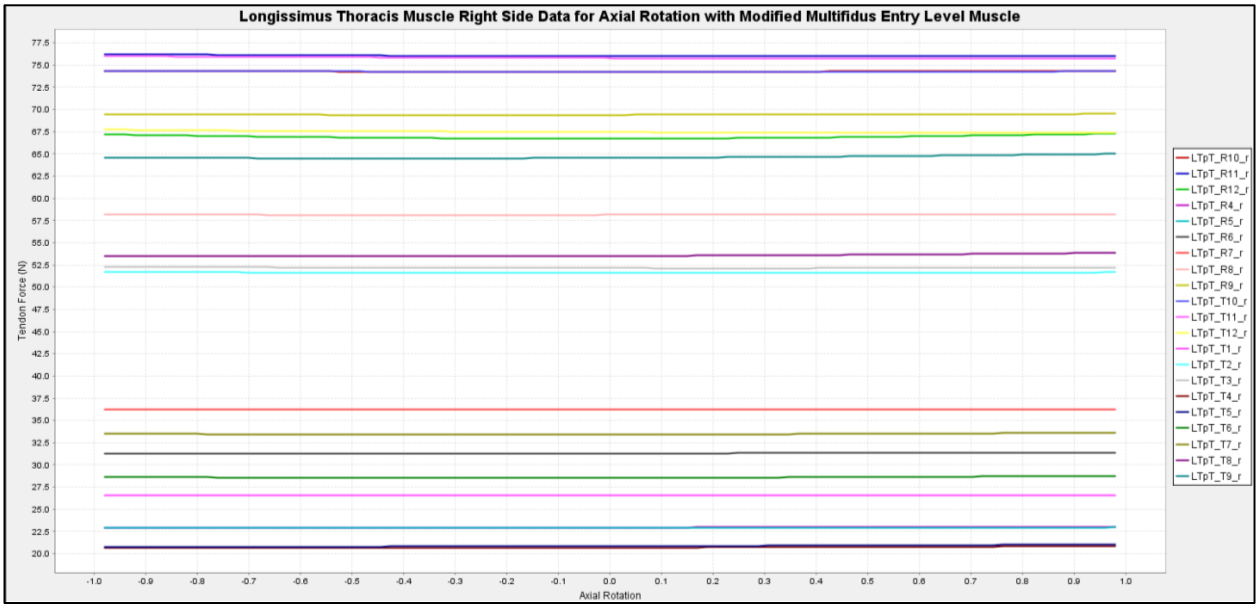

Figure B-16. Longissimus Thoracis Right Side Muscle Tendon Force Results for Axial Rotation Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

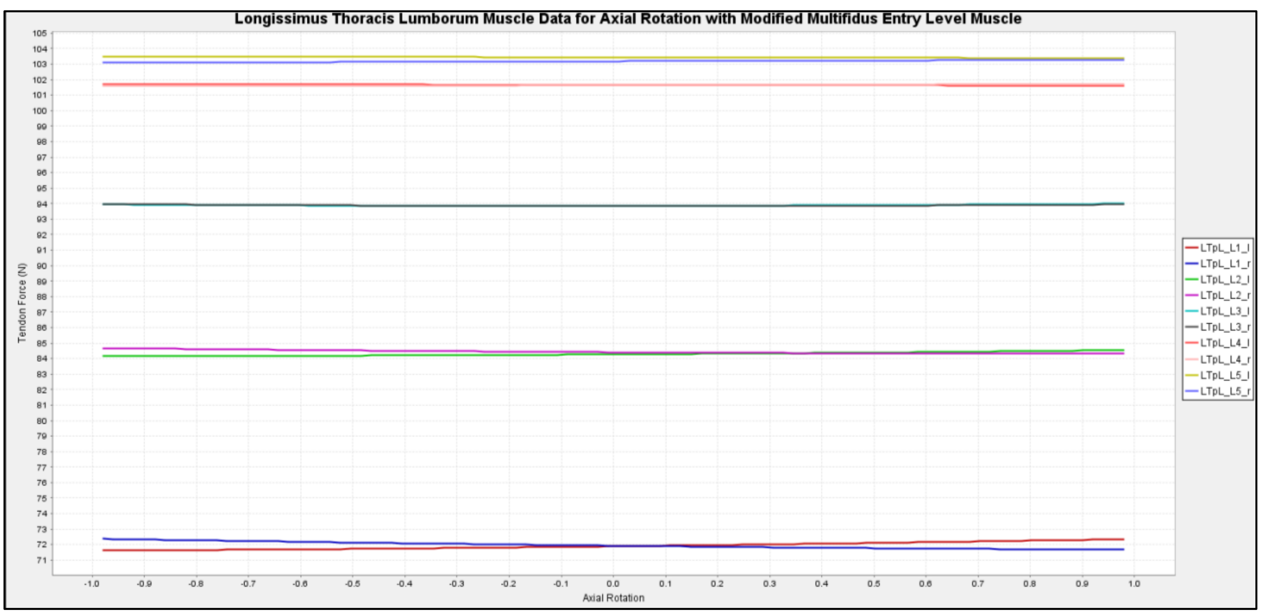

Figure B-17. Longissimus Thoracis Lumborum Muscle Tendon Force Results for Axial Rotation Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

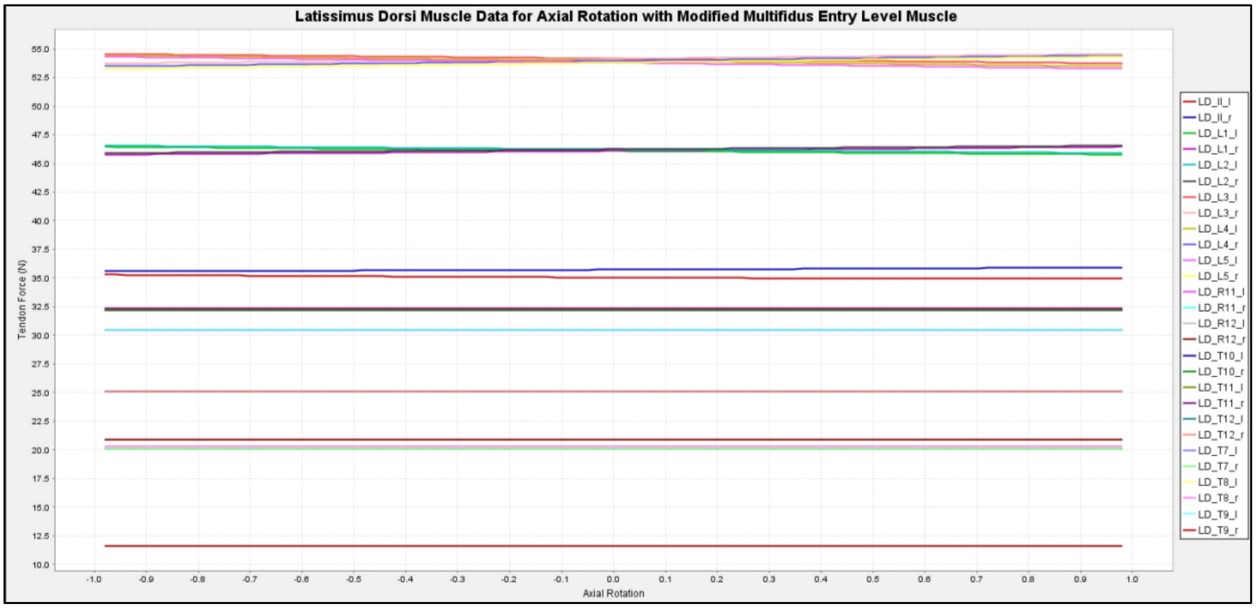

Figure B-18. Latissimus Dorsi Muscle Tendon Force Results for Axial Rotation Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

Individual Muscle Data with Modified Multifidus Spinous Process Muscle

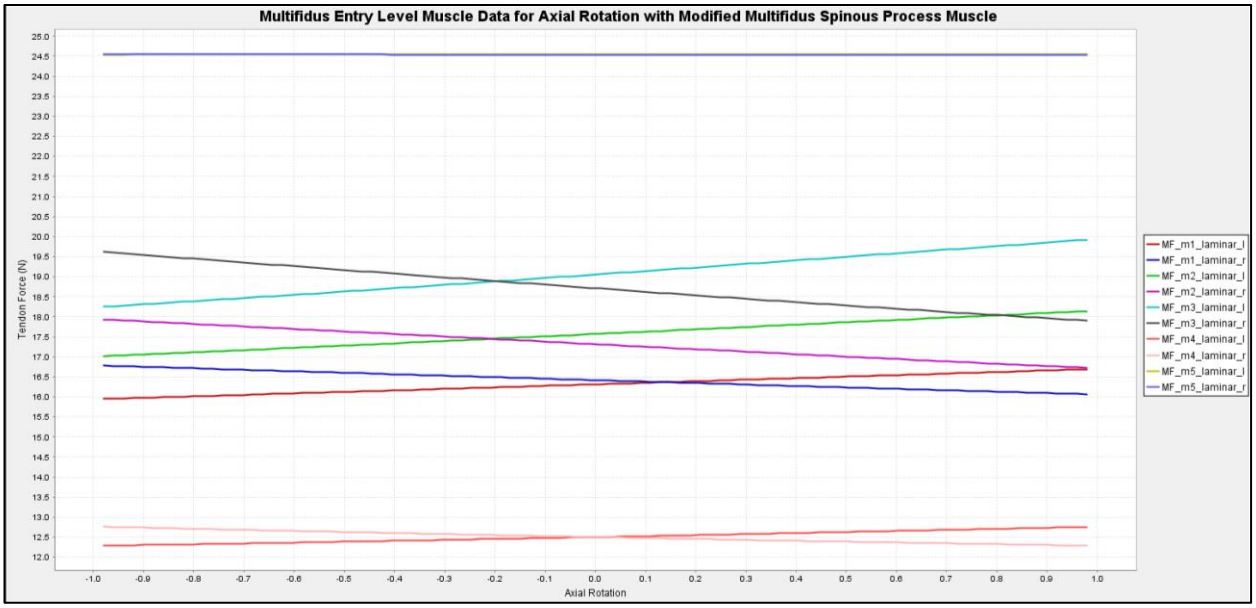

Figure B-19. Multifidus Entry Level Muscle Tendon Force Results for Axial Rotation Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

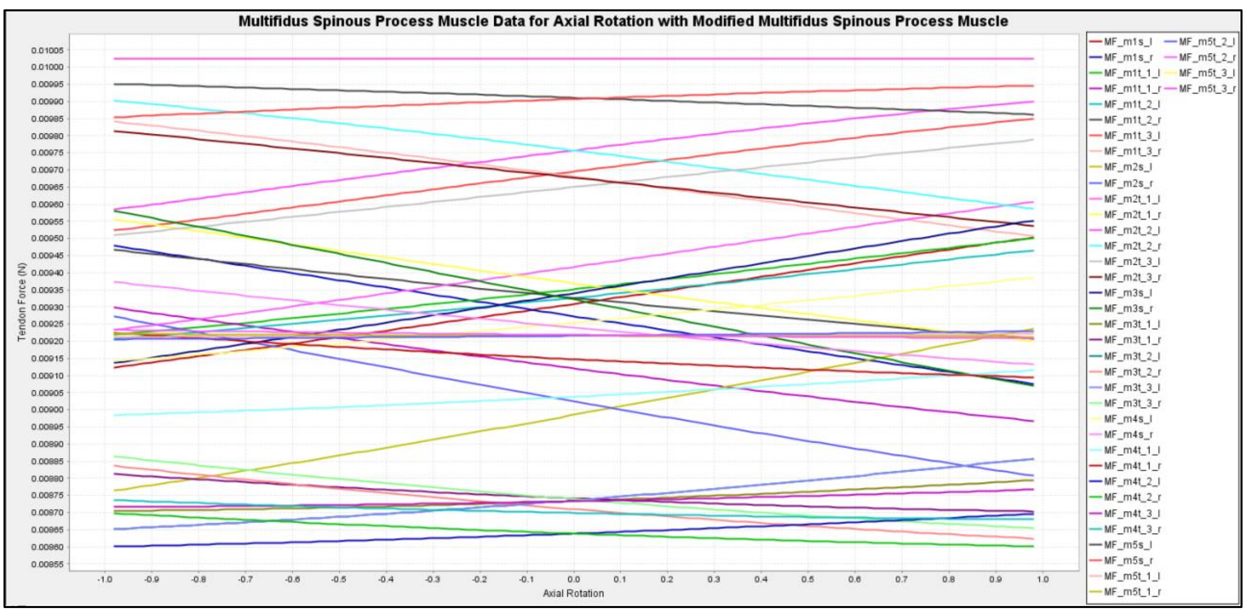

Figure B-20. Multifidus Spinous Process Muscle Tendon Force Results for Axial Rotation Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

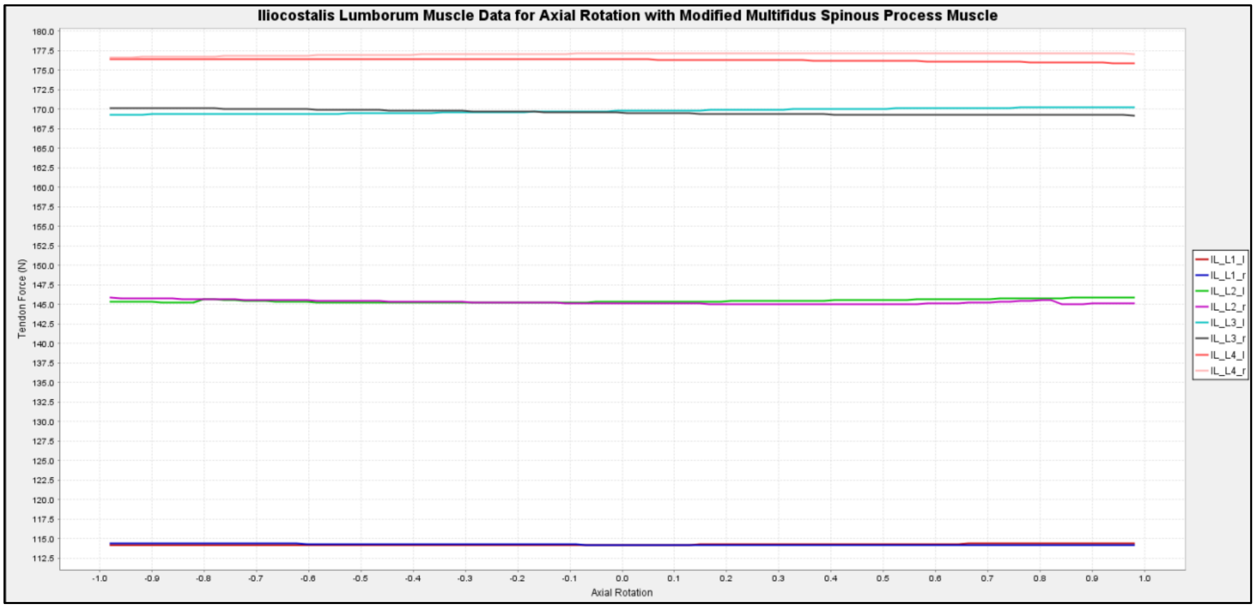

Figure B-21. Iliocostalis Lumborum Muscle Tendon Force Results for Axial Rotation Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

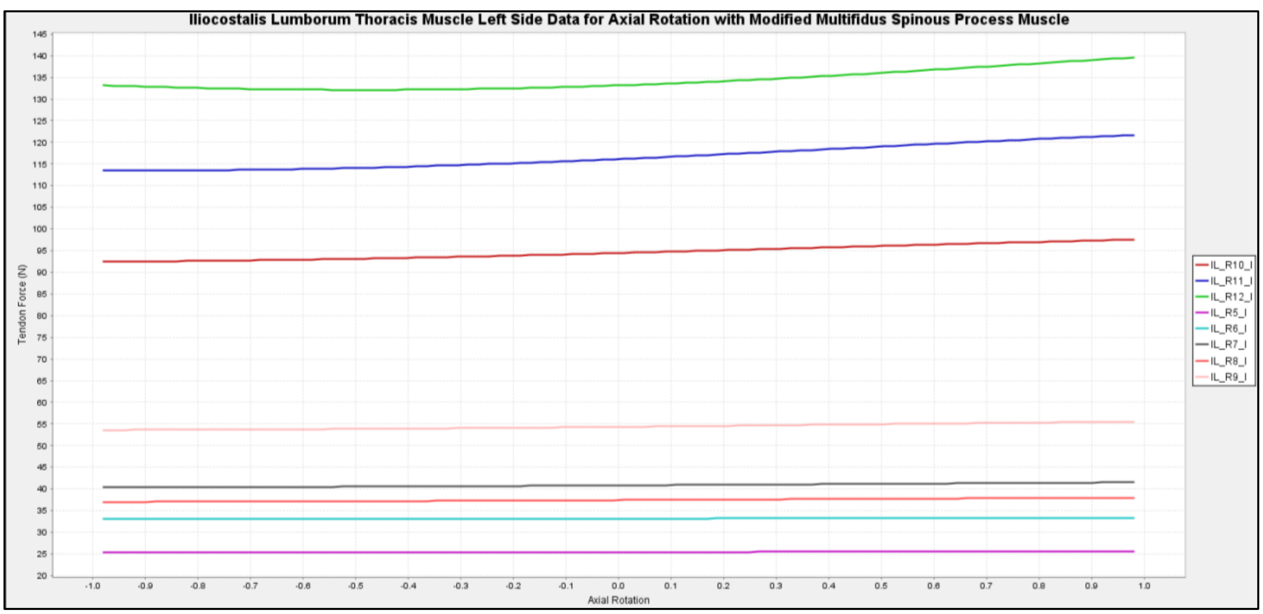

Figure B-22. Iliocostalis Lumborum Thoracis Left Side Muscle Tendon Force Results for Axial Rotation Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

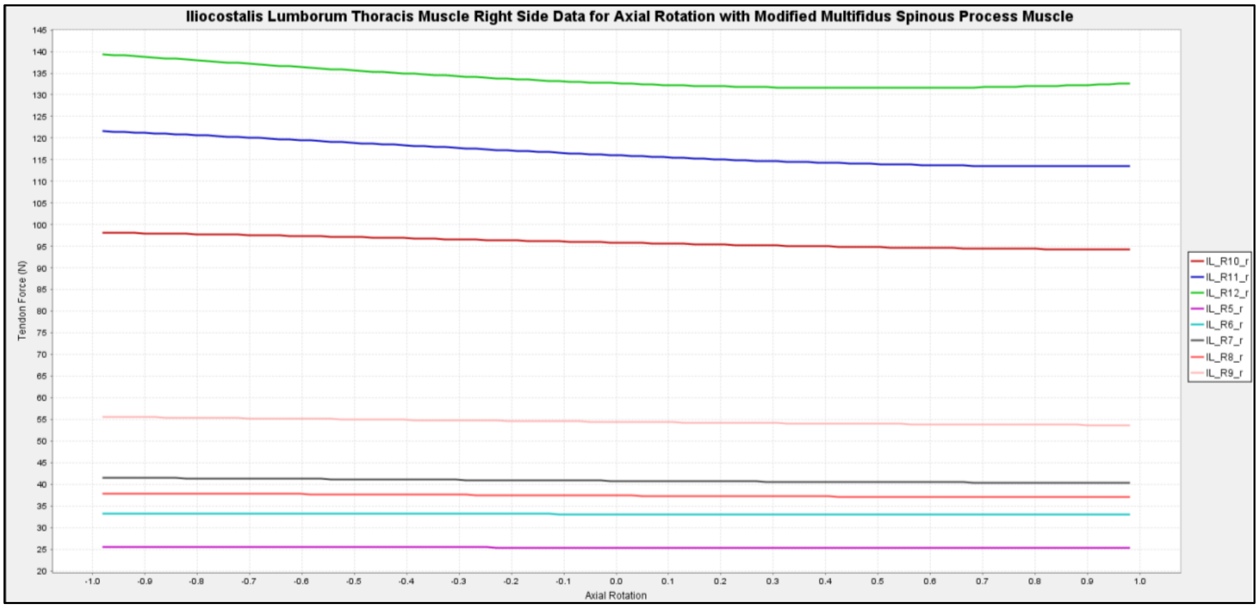

Figure B-23. Iliocostalis Lumborum Thoracis Right Side Muscle Tendon Force Results for Axial Rotation Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

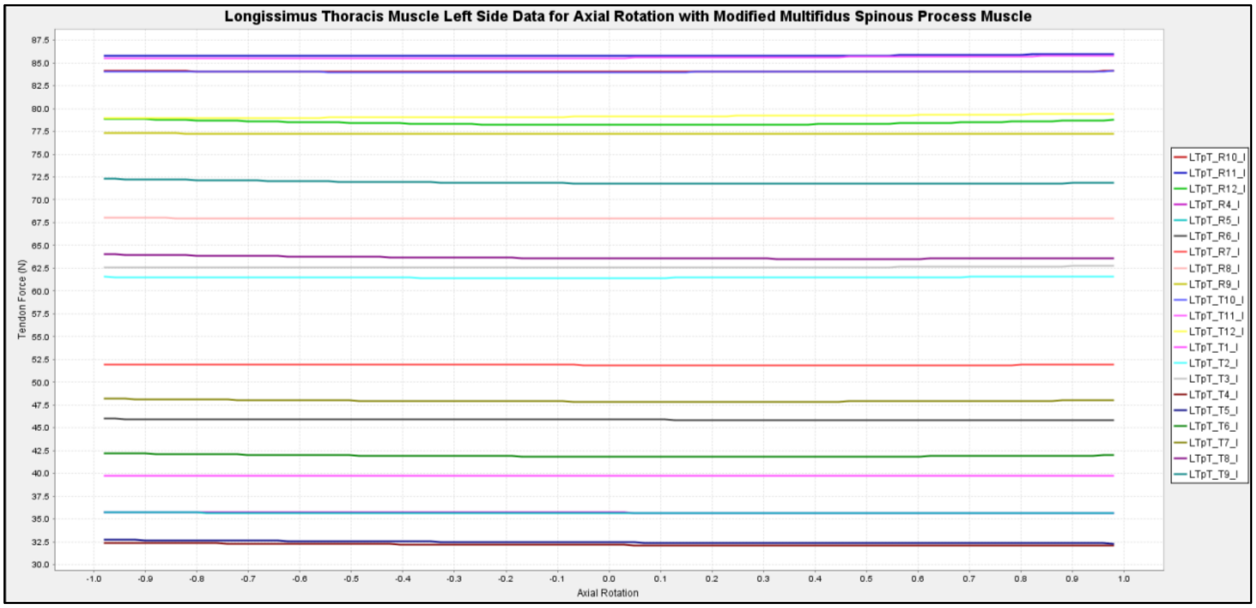

Figure B-24. Longissimus Thoracis Left Side Muscle Tendon Force Results for Axial Rotation Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

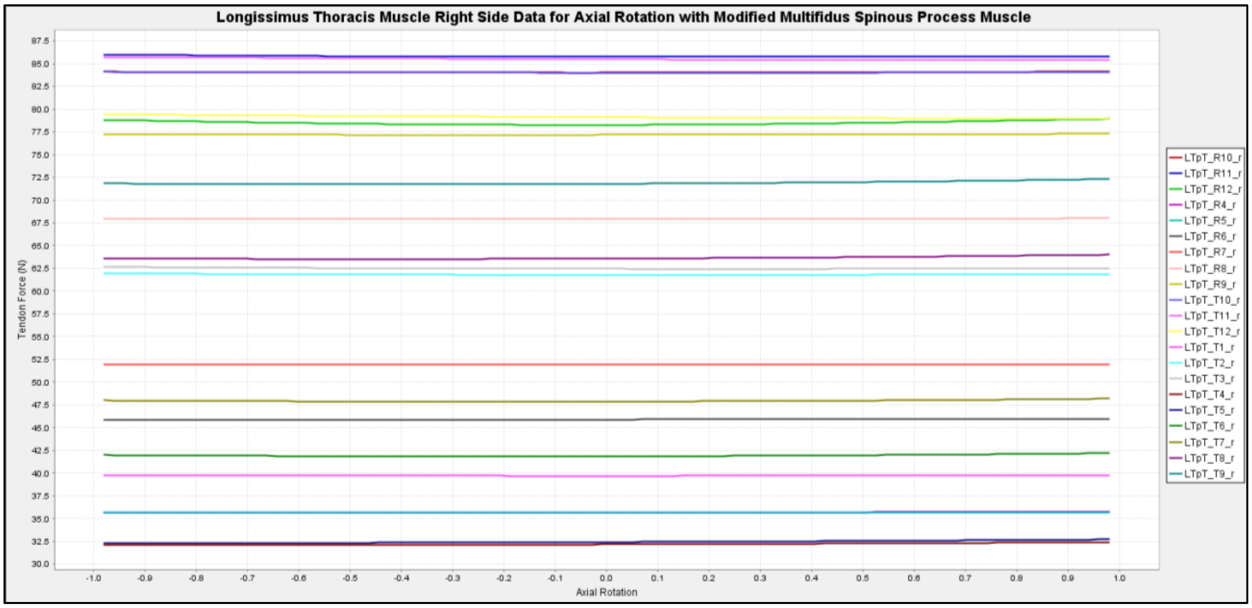

Figure B-25. Longissimus Thoracis Right Side Muscle Tendon Force Results for Axial Rotation Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

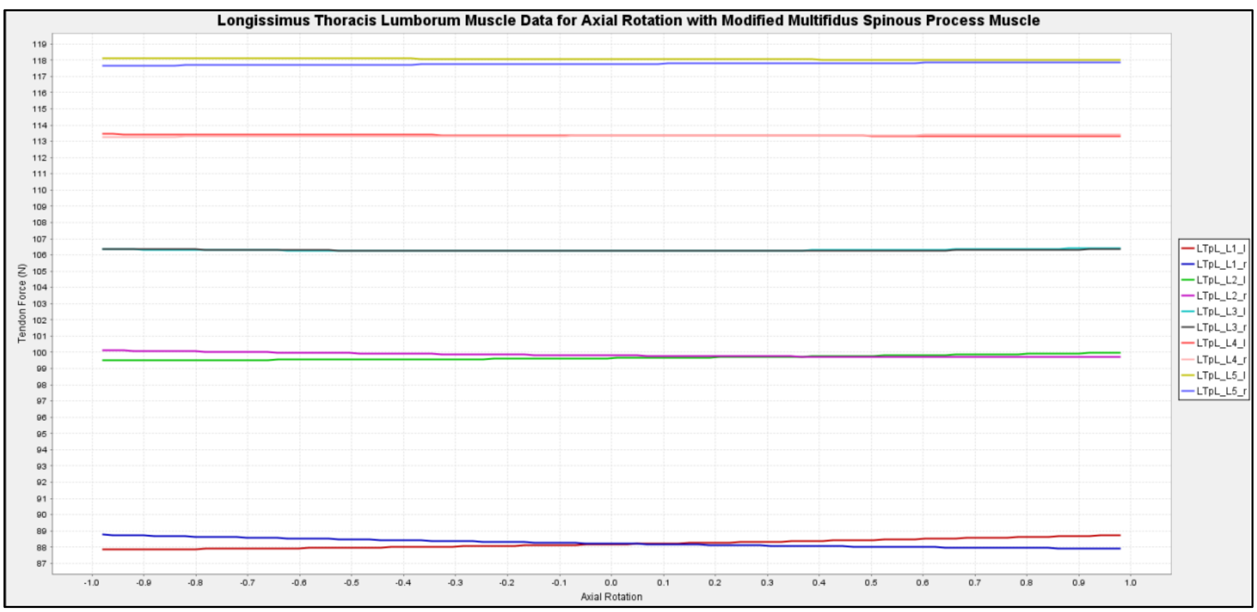

Figure B-26. Longissimus Thoracis Lumborum Muscle Tendon Force Results for Axial Rotation Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

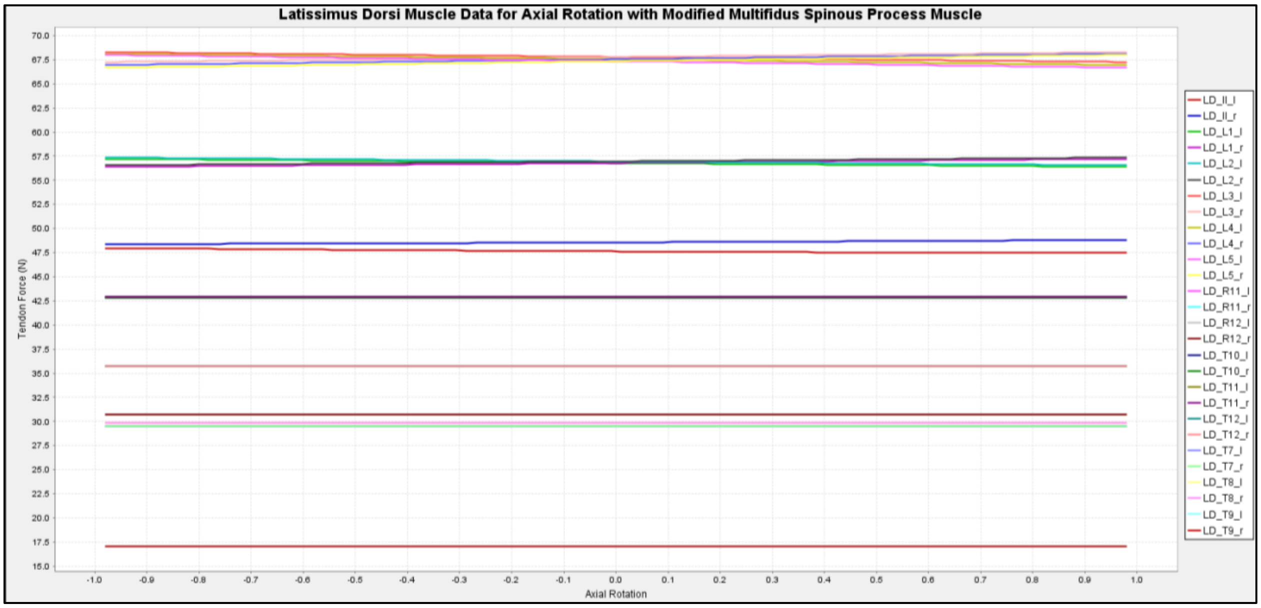

Figure B-27. Latissimus Dorsi Muscle Tendon Force Results for Axial Rotation Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

Appendix C

Lateral Bending Muscle Data

Individual Muscle Baseline Data

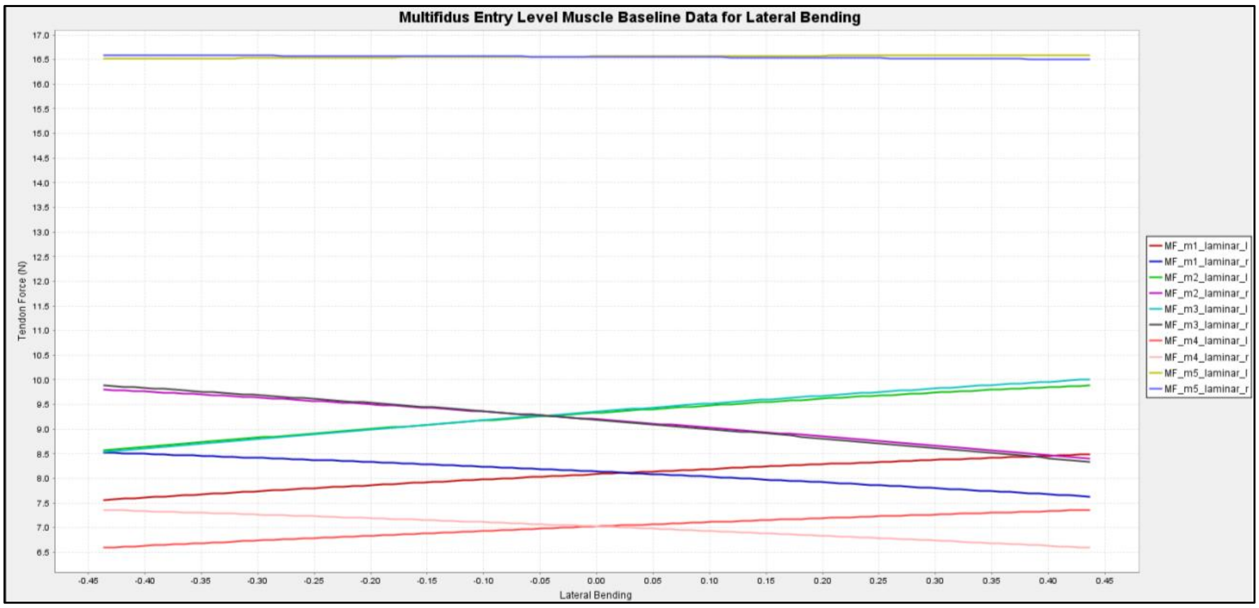

Figure C-1. Multifidus Entry Level Muscle Tendon Force Baseline Results for Lateral Bending Movement.

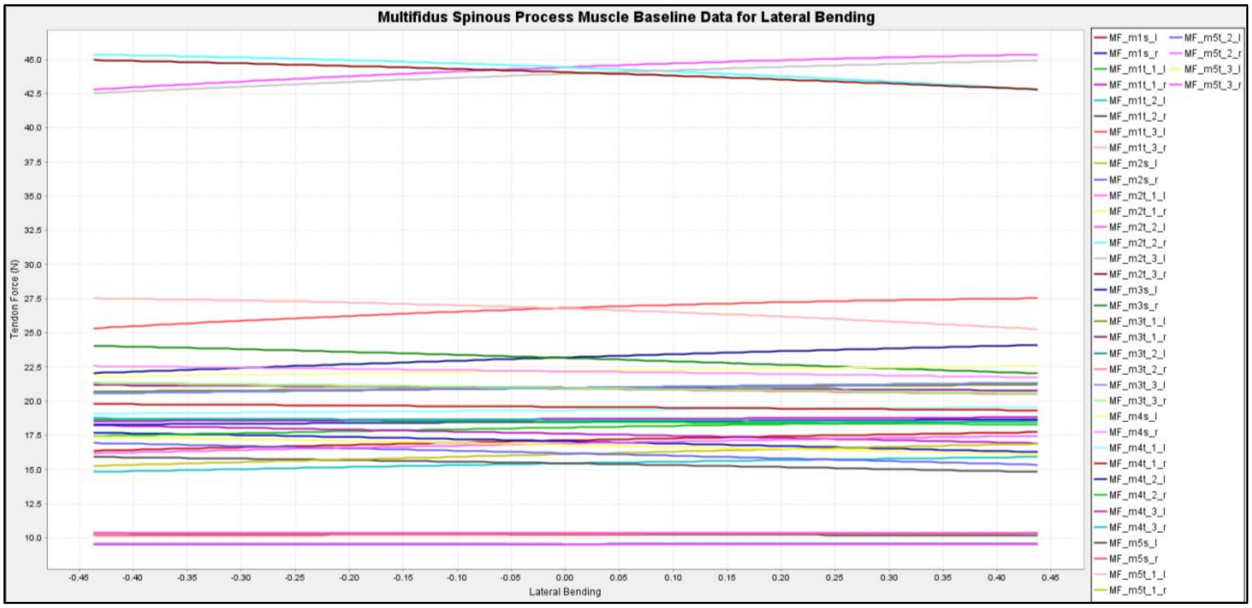

Figure C-2. Multifidus Spinous Process Muscle Tendon Force Baseline Results for Lateral Bending Movement.

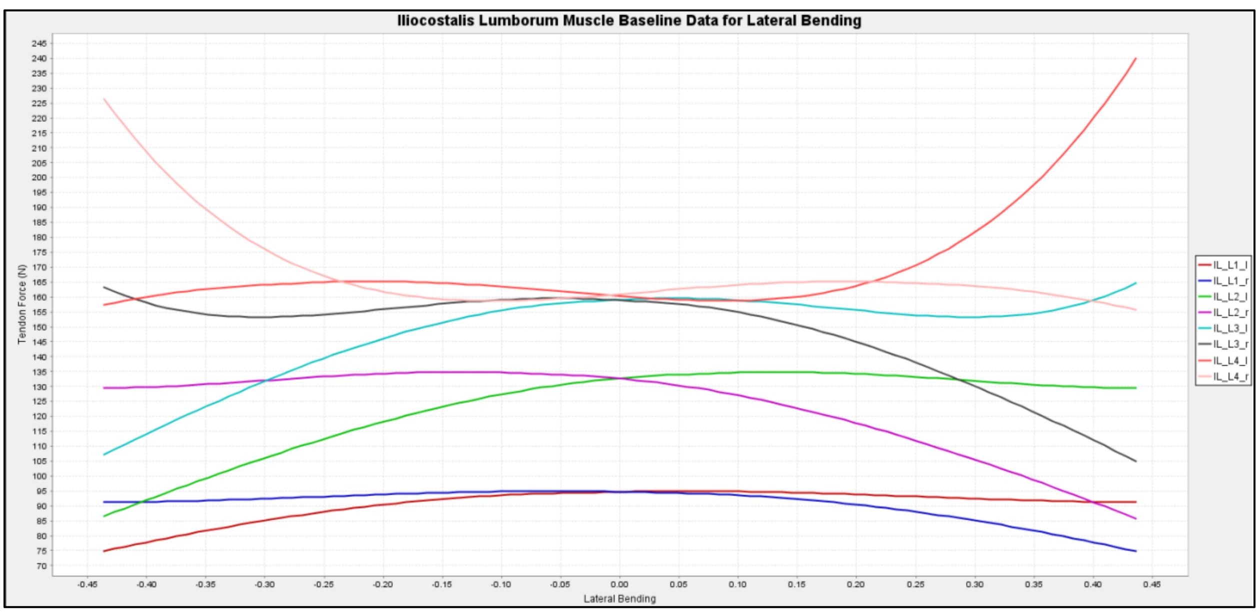

Figure C-3. Iliocostalis Lumborum Muscle Tendon Force Baseline Results for Lateral Bending Movement.

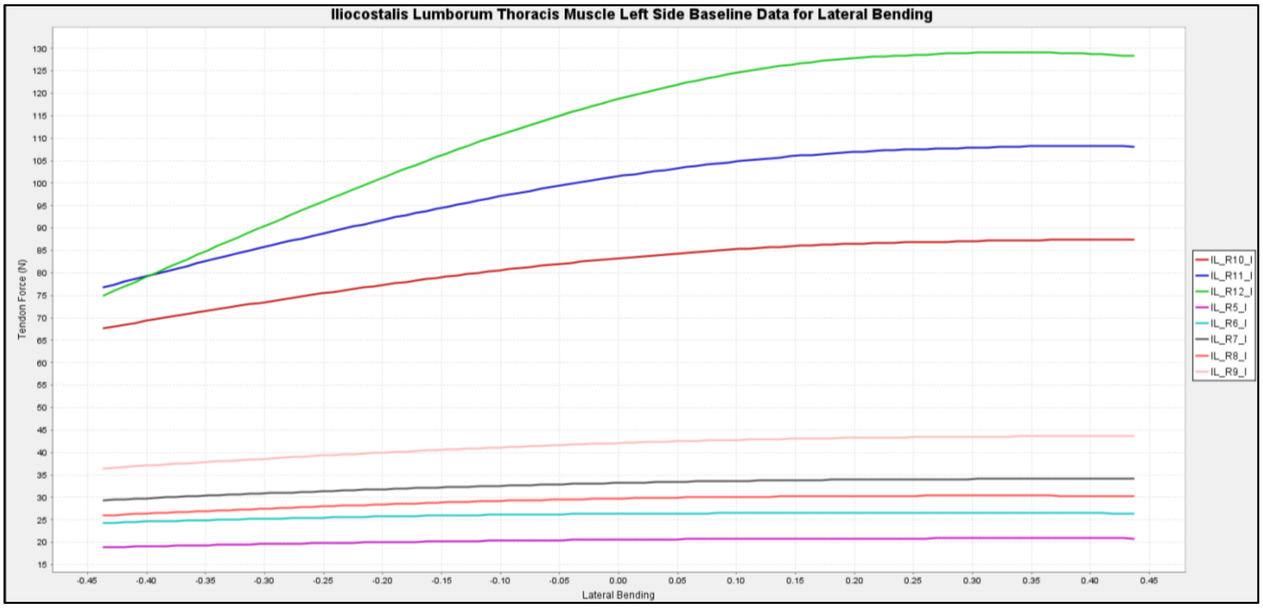

Figure C-4. Iliocostalis Lumborum Thoracis Left Side Muscle Tendon Force Baseline Results for Lateral Bending Movement.

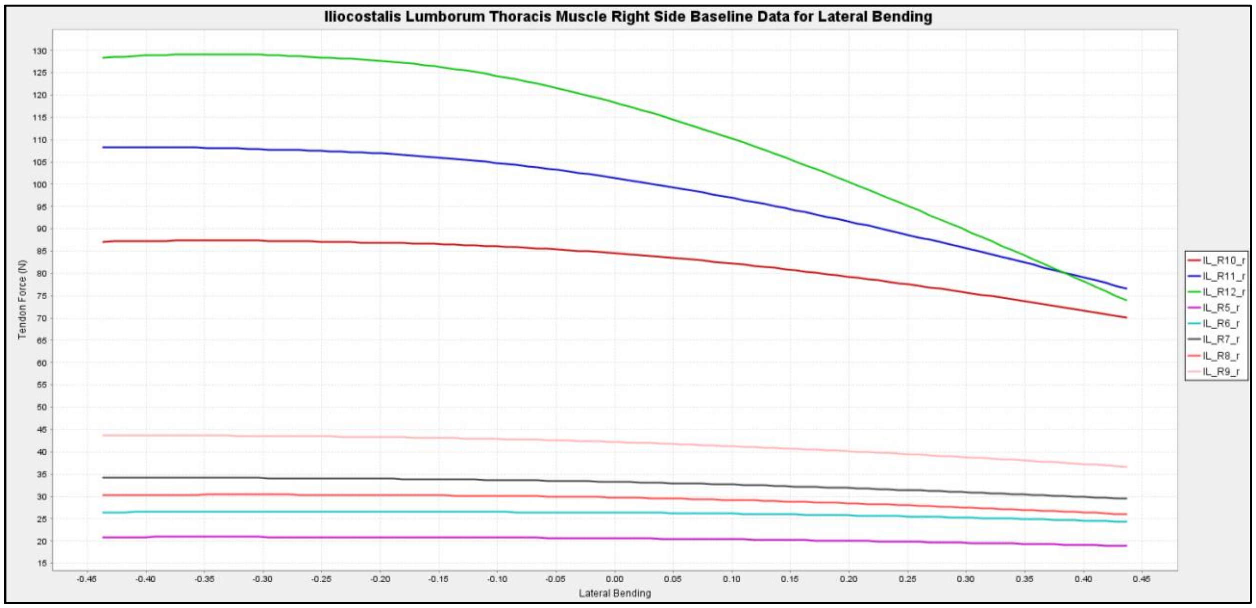

Figure C-5. Iliocostalis Lumborum Thoracis Right Side Muscle Tendon Force Baseline Results for Lateral Bending Movement.

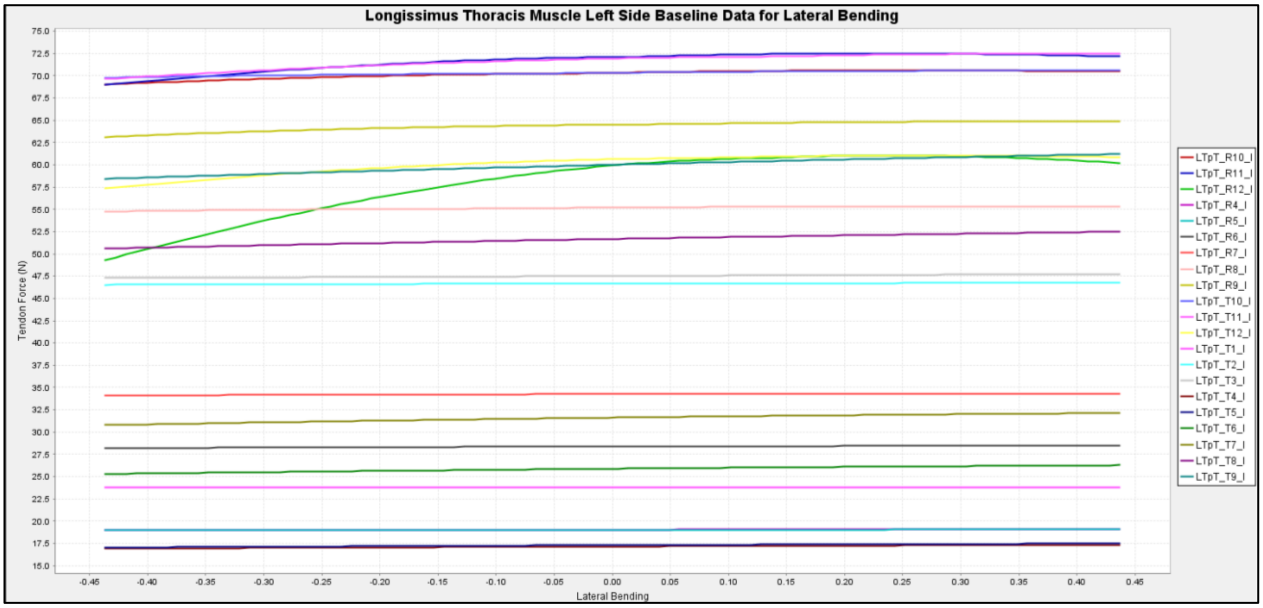

Figure C-6. Longissimus Thoracis Left Side Muscle Tendon Force Baseline Results for Lateral Bending Movement.

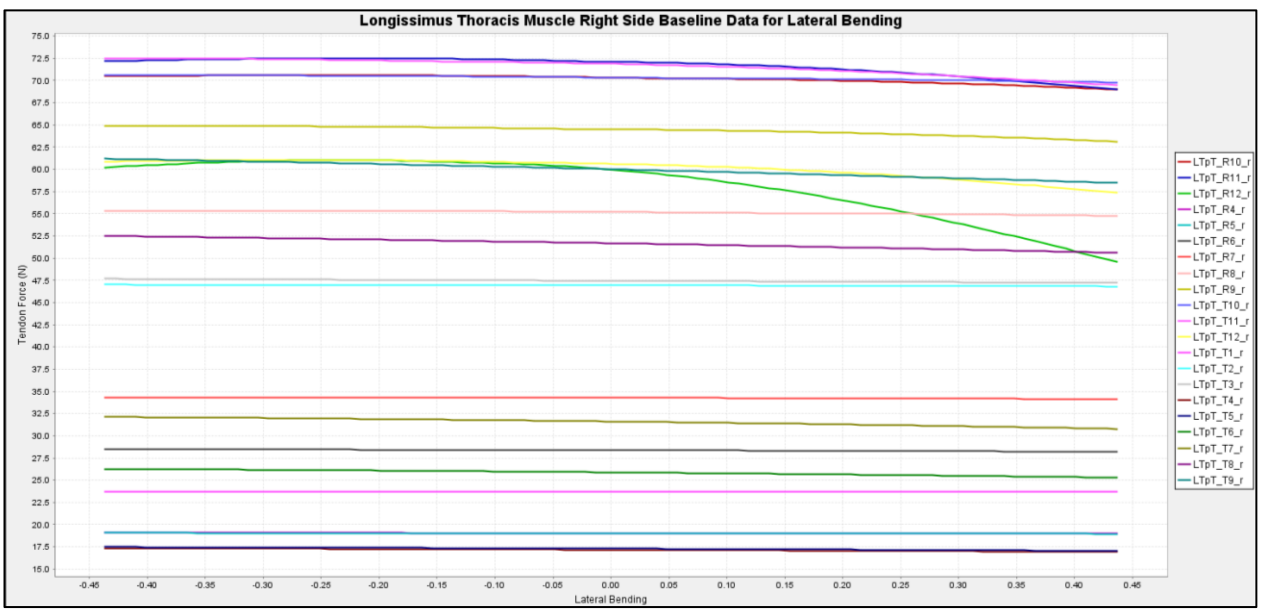

Figure C-7. Longissimus Thoracis Right Side Muscle Tendon Force Baseline Results for Lateral Bending Movement.

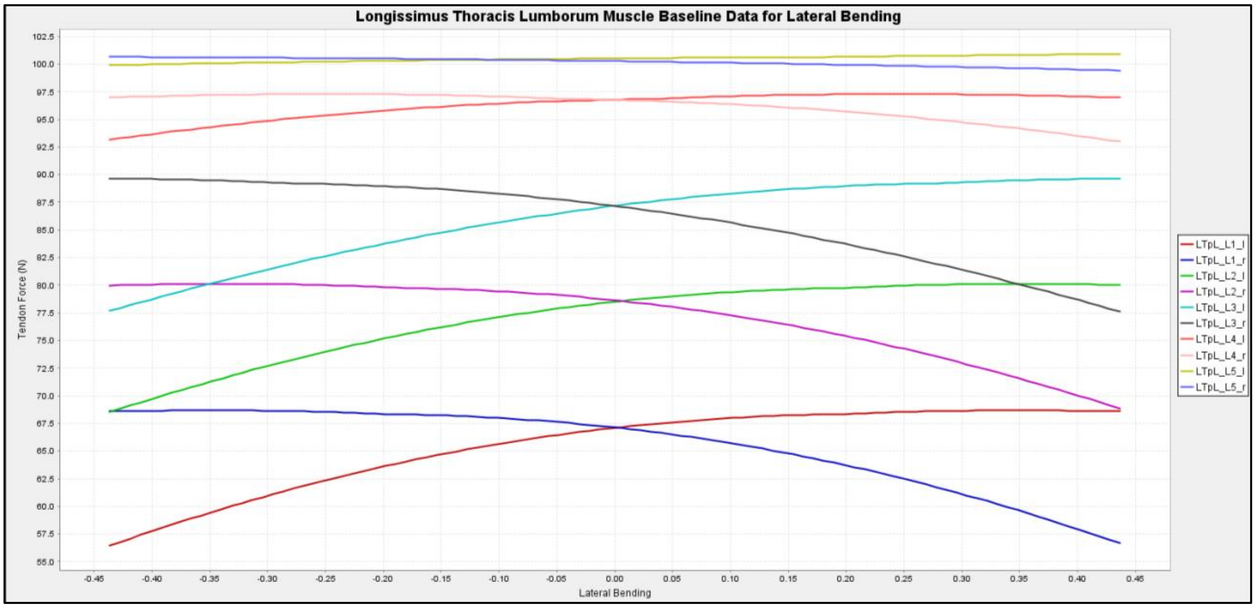

Figure C-8. Longissimus Thoracis Lumborum Muscle Tendon Force Baseline Results for Lateral Bending Movement.

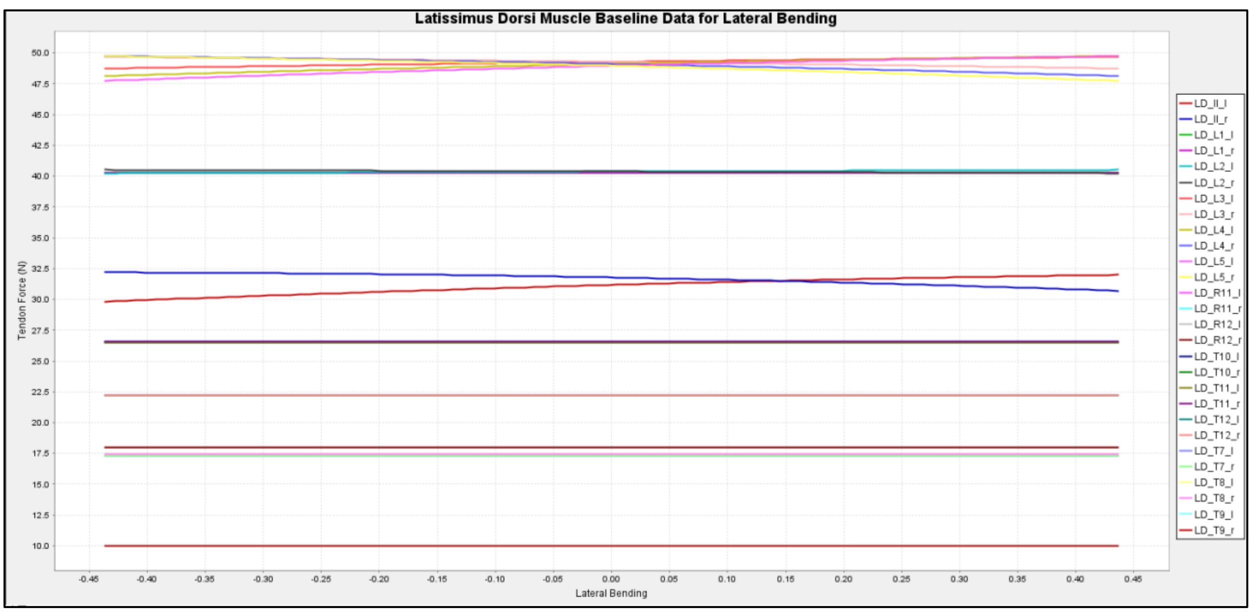

Figure C-9. Latissimus Dorsi Muscle Tendon Force Baseline Results for Lateral Bending Movement.

Individual Muscle Data with Modified Multifidus Entry Level Muscle

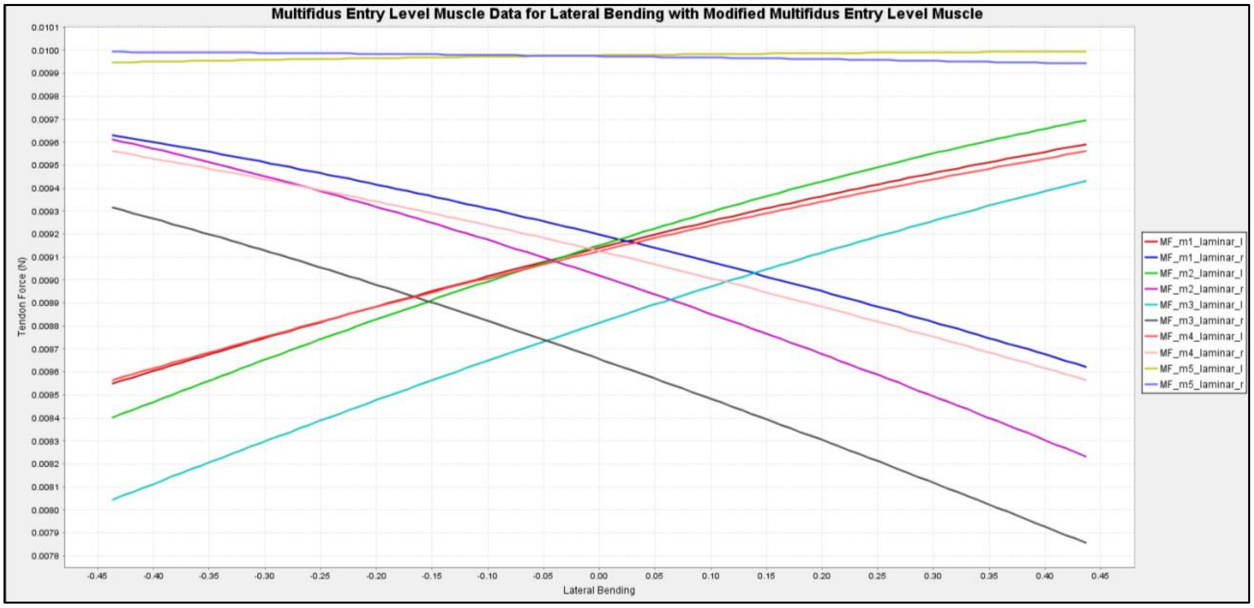

Figure C-10. Multifidus Entry Level Muscle Tendon Force Results for Lateral Bending Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

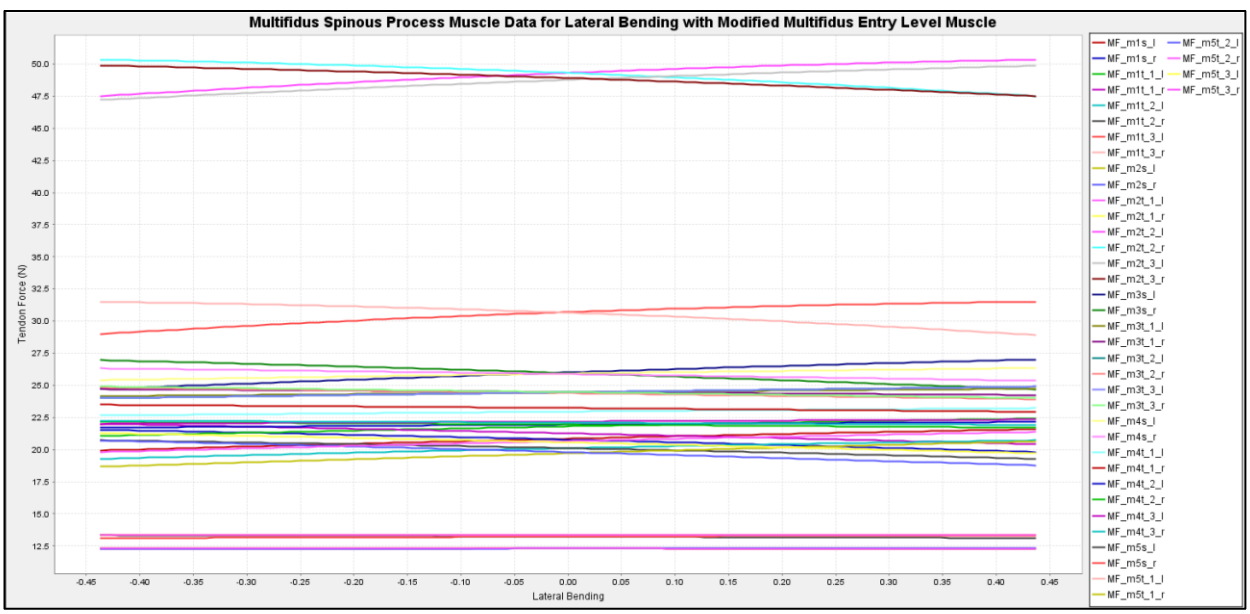

Figure C-11. Multifidus Spinous Process Muscle Tendon Force Results for Lateral Bending Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

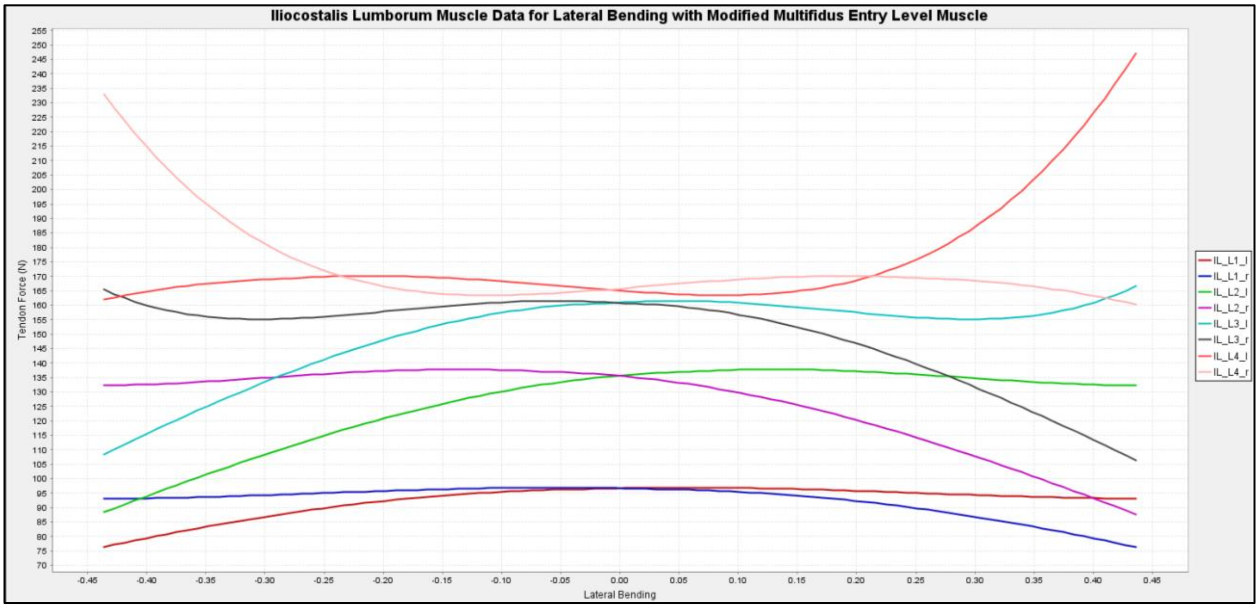

Figure C-12. Iliocostalis Lumborum Muscle Tendon Force Results for Lateral Bending Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

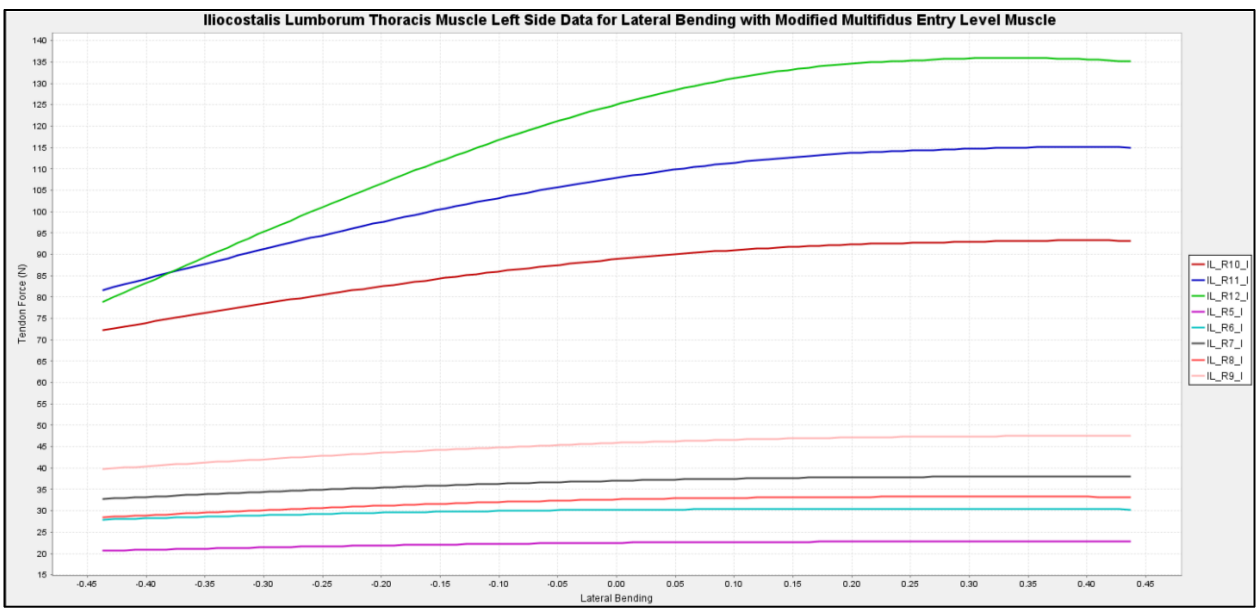

Figure C-13. Iliocostalis Lumborum Thoracis Left Side Muscle Tendon Force Results for Lateral Bending Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

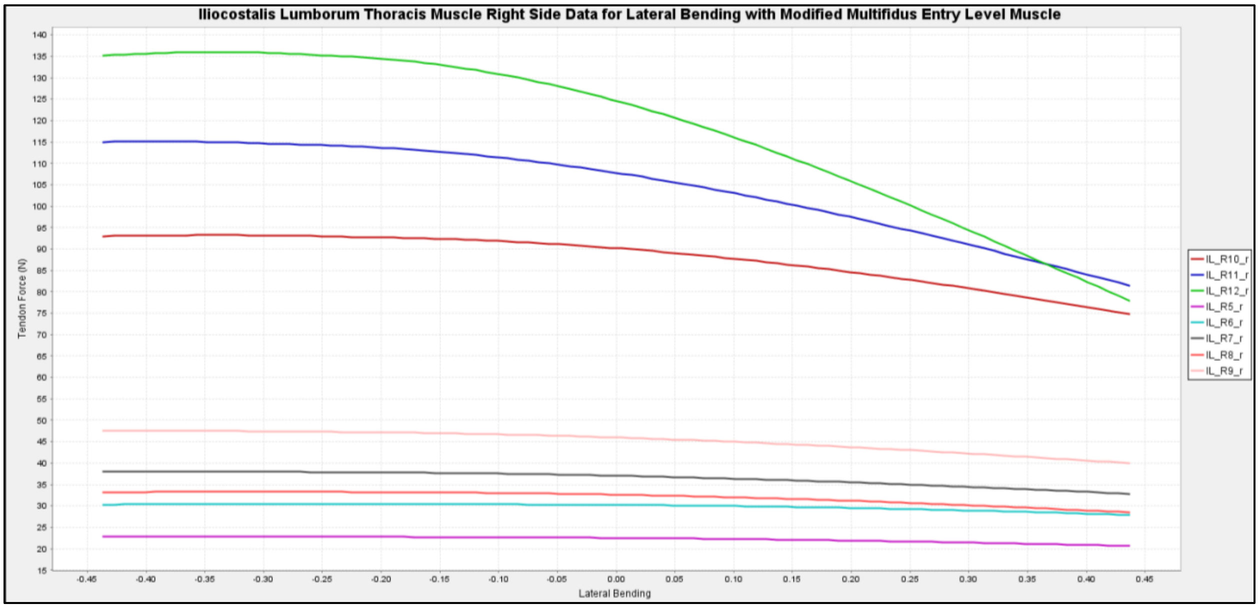

Figure C-14. Iliocostalis Lumborum Thoracis Right Side Muscle Tendon Force Results for Lateral Bending Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

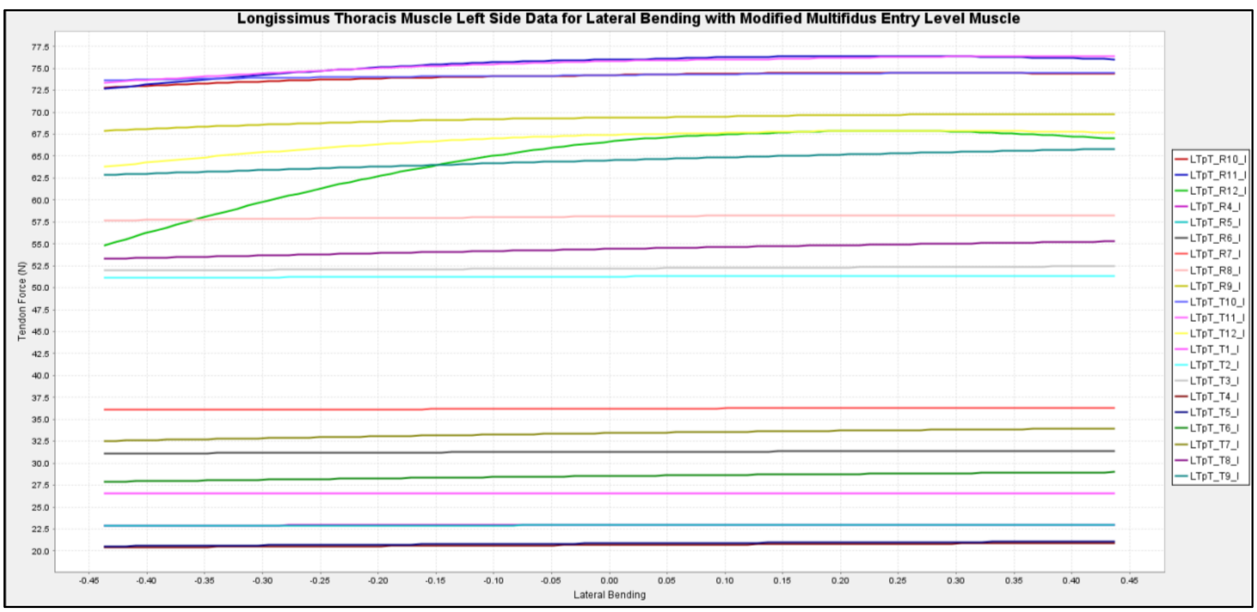

Figure C-15. Longissimus Thoracis Left Side Muscle Tendon Force Results for Lateral Bending Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

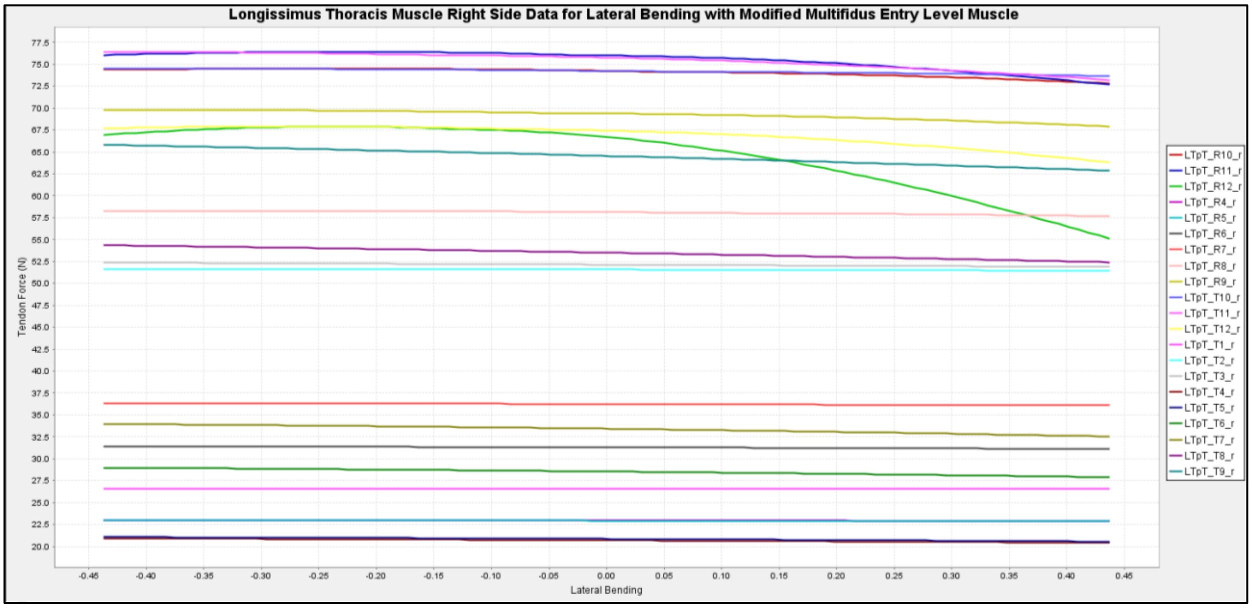

Figure C-16. Longissimus Thoracis Right Side Muscle Tendon Force Results for Lateral Bending Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

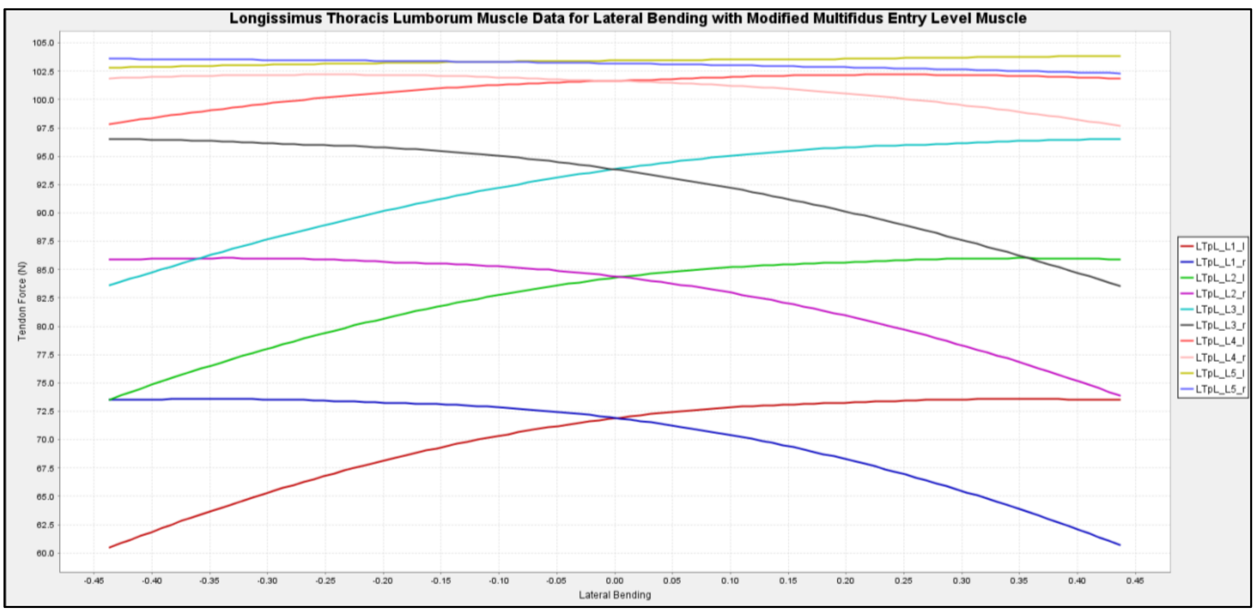

Figure C-17. Longissimus Thoracis Lumborum Muscle Tendon Force Results for Lateral Bending Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

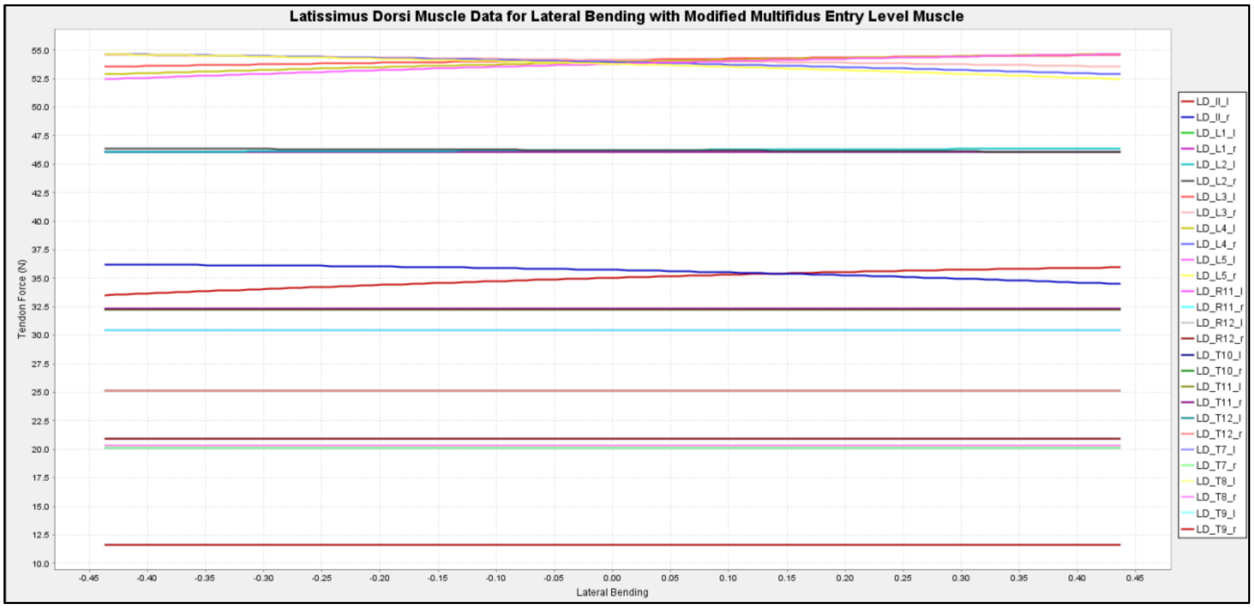

Figure C-18. Latissimus Dorsi Muscle Tendon Force Results for Lateral Bending Movement when Multifidus Entry Level Muscle Isometric Maximum Force is Reduced.

Individual Muscle Data with Modified Multifidus Spinous Process Muscle

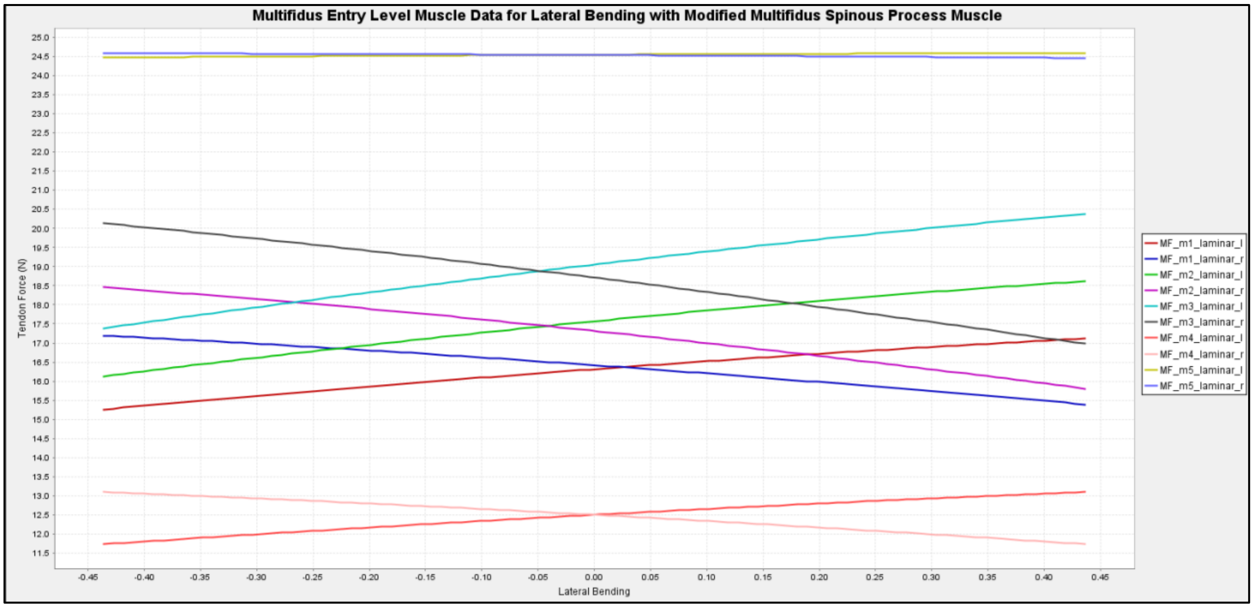

Figure C-19. Multifidus Entry Level Muscle Tendon Force Results for Lateral Bending Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

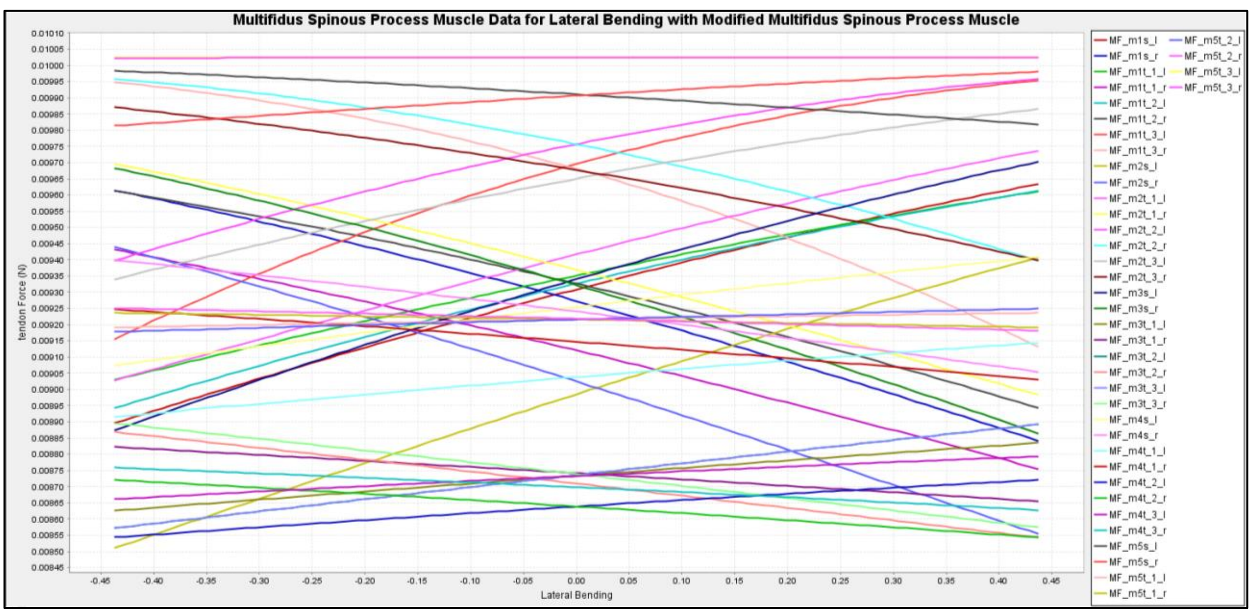

Figure C-20. Multifidus Spinous Process Muscle Tendon Force Results for Lateral Bending Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

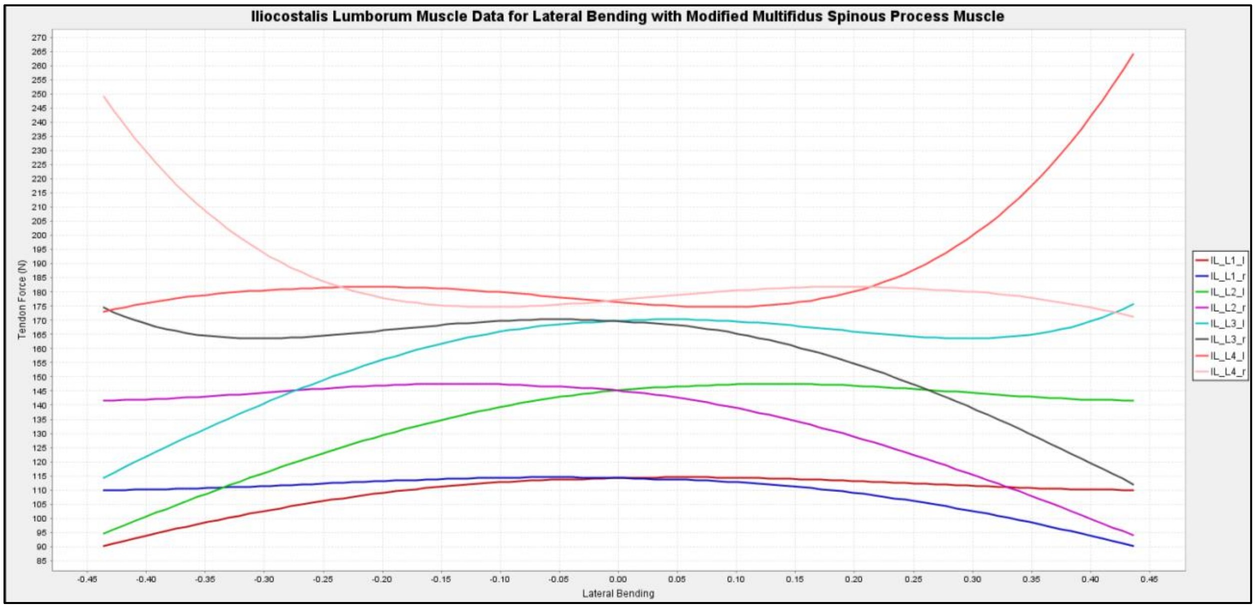

Figure C-21. Iliocostalis Lumborum Muscle Tendon Force Results for Lateral Bending Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

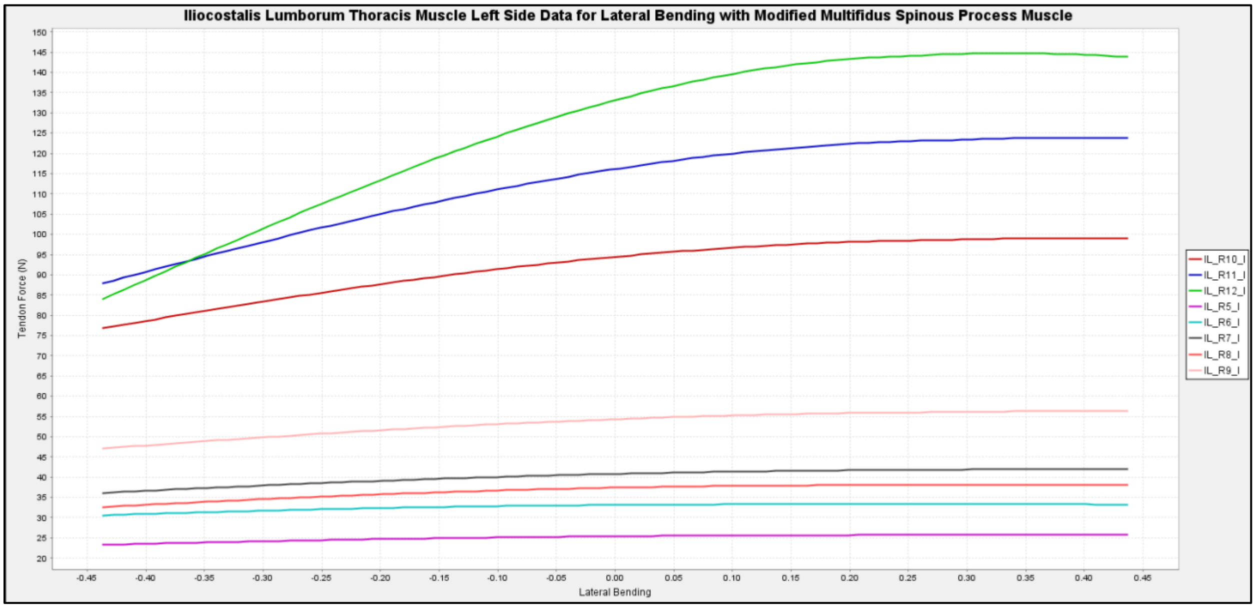

Figure C-22. Iliocostalis Lumborum Thoracis Left Side Muscle Tendon Force Results for Lateral Bending Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

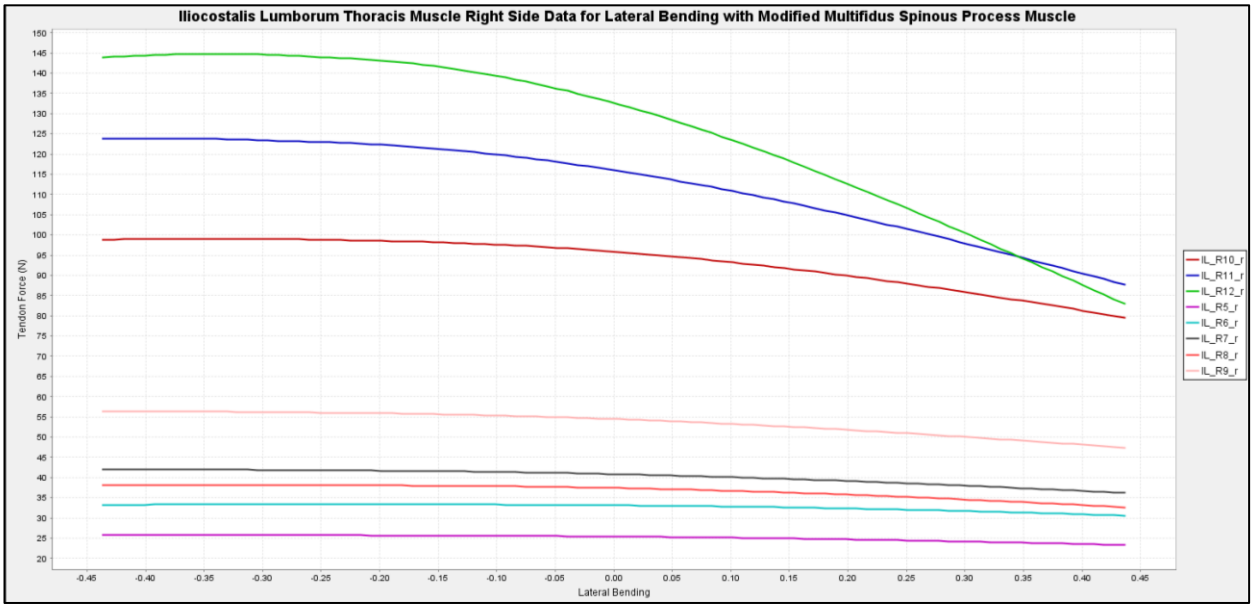

Figure C-23. Iliocostalis Lumborum Thoracis Right Side Muscle Tendon Force Results for Lateral Bending Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

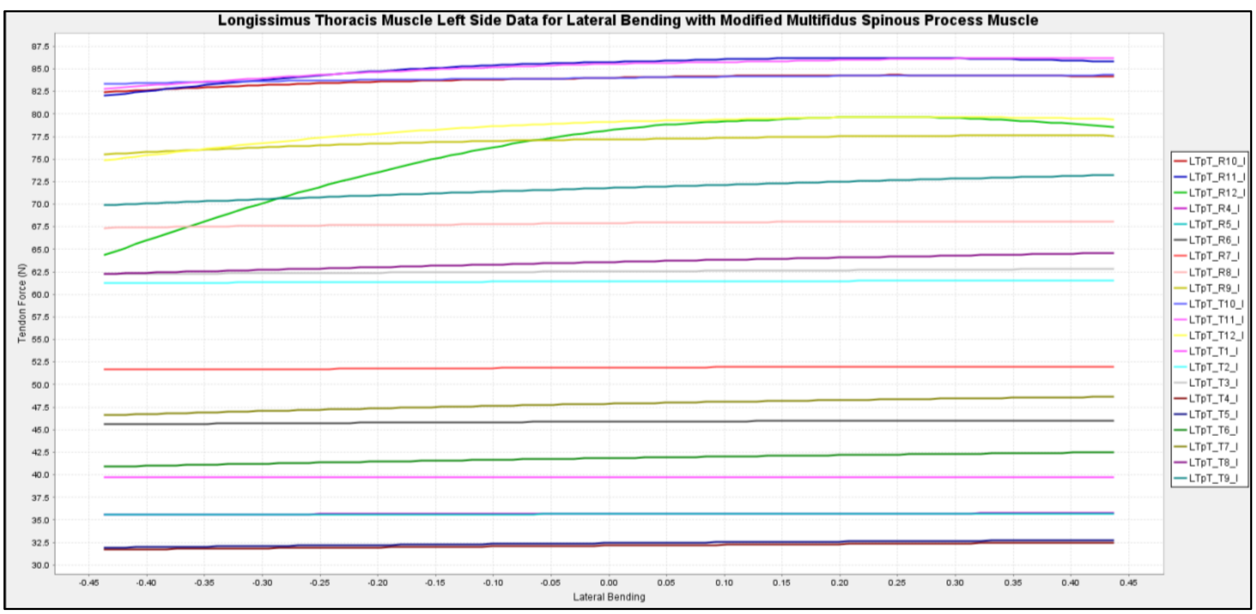

Figure C-24. Longissimus Thoracis Left Side Muscle Tendon Force Results for Lateral Bending Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

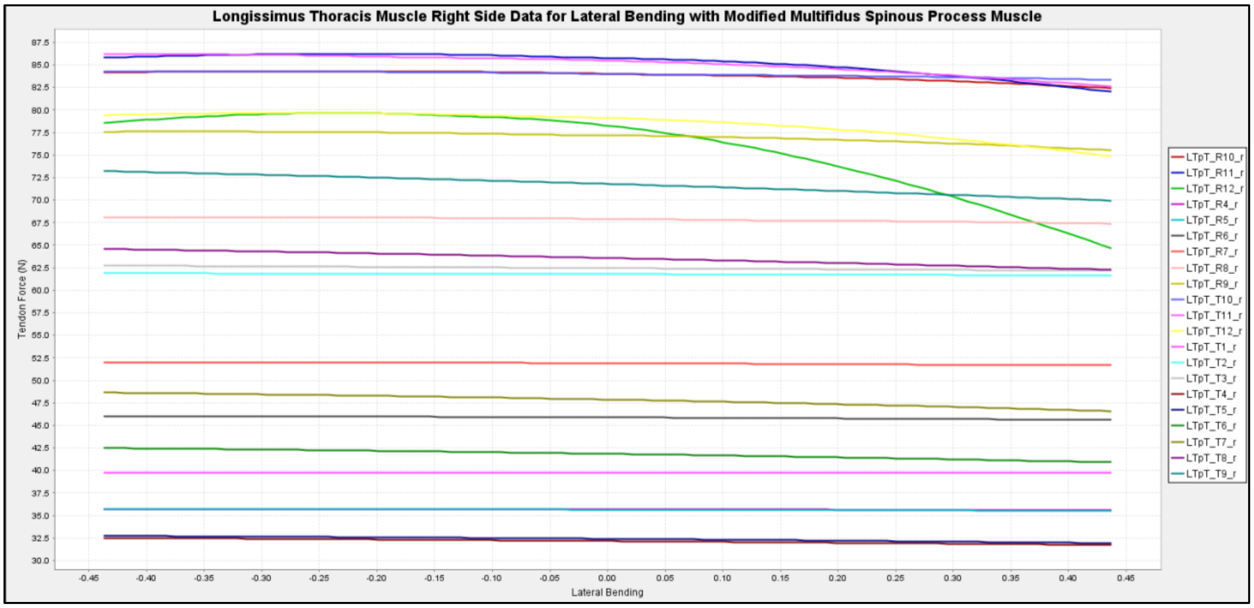

Figure C-25. Longissimus Thoracis Right Side Muscle Tendon Force Results for Lateral Bending Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

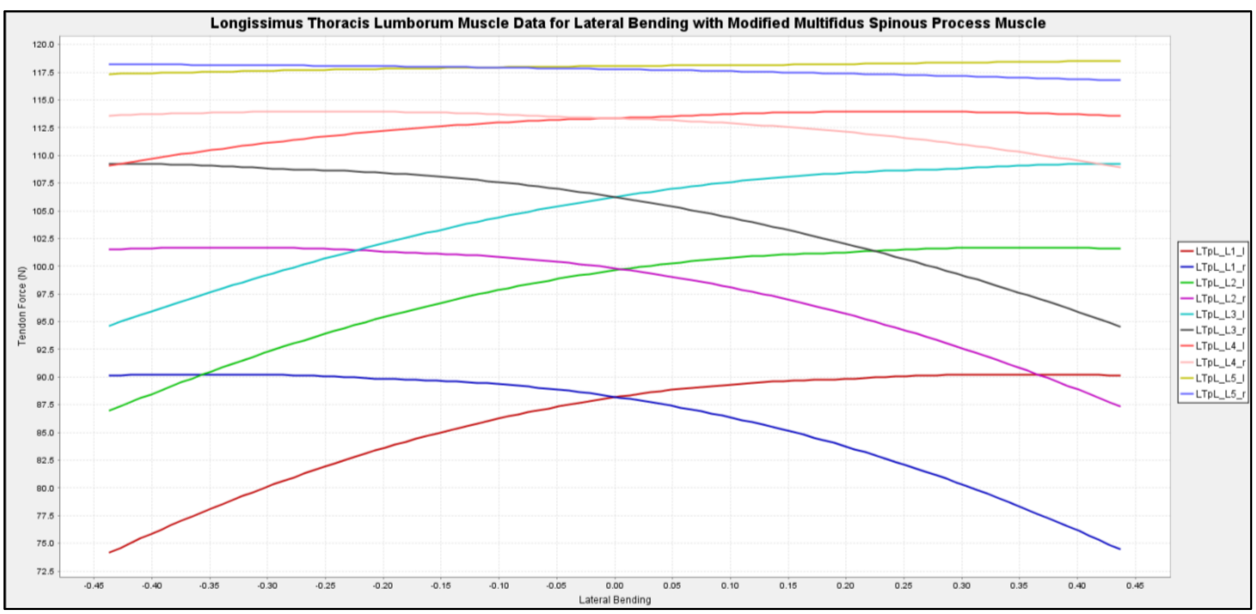

Figure C-26. Longissimus Thoracis Lumborum Muscle Tendon Force Results for Lateral Bending Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

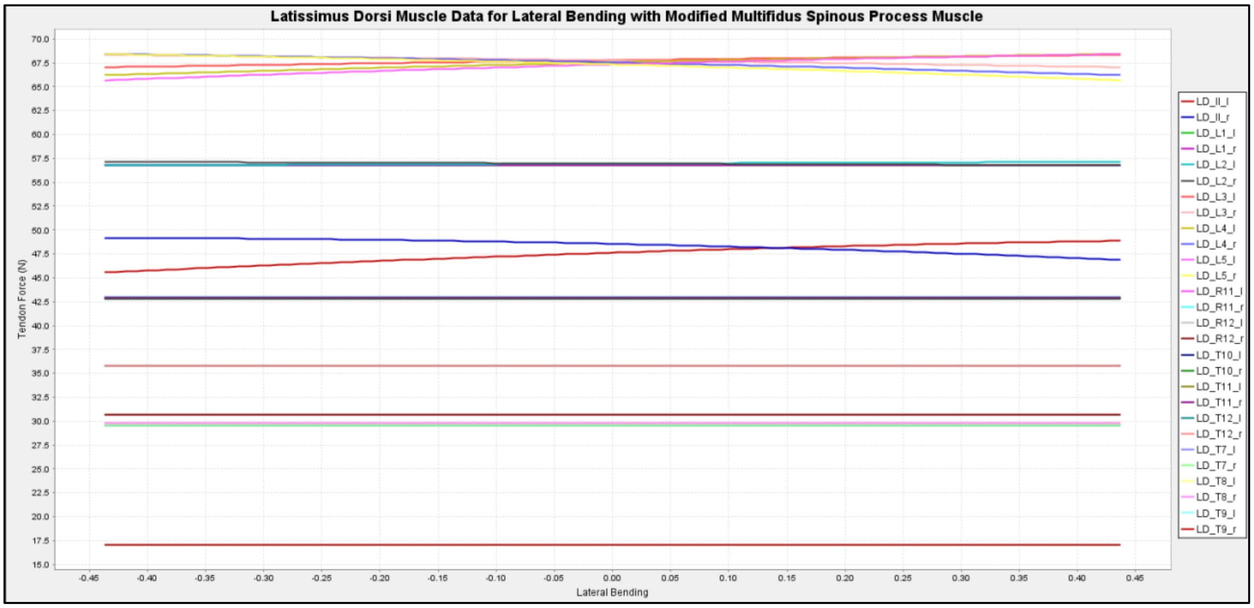

Figure C-27. Latissimus Dorsi Muscle Tendon Force Results for Lateral Bending Movement when Multifidus Spinous Process Muscle Isometric Maximum Force is Reduced.

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ACADEMIC VITA

DANIEL ENRIQUE ESPARRAGOZA
dee5101@psu.edu

EDUCATION

The Pennsylvania State University: Schreyer Honors College — University Park, PA
B.S. in Mechanical Engineering — December 2022

WORK EXPERIENCE

Lockheed Martin: Mount Laurel, NJ (May 2022-August 2022)
Systems Engineering Intern
- Perform testing and integration of the display system on the Aegis Combat System
- Report problems, write requirement changes, and test software changes for Aegis
- Develop an automated deployment system for software updates

Delta Air Lines: Atlanta, GA (September 2020-May 2022)
Component Engineering Co-op
- Reviewed maintenance requests, developed solutions, drafted engineering documents
- Ensured service bulletins and repairs are in compliance with Delta and FAA regulations
- Provided technical support to maintenance by interpreting and clarifying manuals

Community Volunteers in Medicine: West Chester, PA (July 2020-August 2020)
Staff Assistant
- Screened and escorted patients into clinic as a result of COVID-19
- Disinfected surfaces in patient rooms, restrooms, and waiting room
- Assisted staff with COVID-19 reports and mammogram visits

VOLUNTEER EXPERIENCE

Engineering Ambassadors: University Park, PA (March 2020-Present)
General Member
- Promote diversity, equity, and inclusion in the field of engineering
- Participate in outreach to inspire K-12 students to pursue a career in engineering

Lion Ambassadors: University Park, PA (January 2020-Present)
General Member
- Communicate Penn State history, promote traditions, and instill pride through campus events
- Provide students with tours of campus and participate in student panels

PROJECTS

Pennsylvania State University: University Park, PA (January 2020-Present)
Biomechanics Research
- Developed a report for the hardware and software required to run a facet-joint injection simulation
- Analyzed compressible loads on the spine in the absence of the multifidus muscle

Pennsylvania State University: Brandywine, PA(May 2019-August 2019)
Drone Project
- Researched how drones function and designed, tested, and manufactured drones
- Utilized Solidworks, 3D printing, electronics, microcontrollers, and programming

Pennsylvania State University: Puerto Rico (Spring Break 2019)
Puerto Rico Service Project
- Restored mangroves in a local reserve in response to hurricane and human interferences
- Learned about community service, sustainability, and Puerto Rican culture

COMPUTER SKILLS

CAD Software-SolidWorks | MATLAB | Microsoft Office | Google Drive | Linux

PERSONAL SKILLS

Communication | Public Speaking | Technical Writing | Creative | Organization | Detail-Oriented

LANGUAGE SKILLS

Native English | Native Spanish | Limiting Working French