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ORIGINAL RESEARCH

THE RELATIONSHIP BETWEEN SEGMENTAL ROLLING ABILITY AND LUMBAR MULTIFIDUS ACTIVATION TIME

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ABSTRACT

Background: Segmental rolling has been utilized as an assessment and intervention tool to identify and affect dysfunction of the upper quarter, core, and lower quarter. One theory to explain dysfunctional segmental rolling is a lack of segmental spinal control / stabilization. Faulty muscle firing sequencing has been related to poor spinal stability, however to date, no assessment tool exists to evaluate a patient's motor coordination of local and global musculature.

Purpose: The purpose of this study was to assess the temporal sequence of lumbar multifidus activation associated with anterior deltoid activation, and to determine if faulty sequencing was associated with the inability to segmentally roll in subjects without mobility restrictions. The authors hypothesized that in individuals who could not roll, a multifidus muscle onset latency relative to a prime mover activation would be present. In addition, a subset of the individuals with an inability to roll were utilized for a pilot study examining the ability to address the firing pattern with corrective exercise.

Methods: Twenty healthy subjects (13 females, 7 males), ages 19-25, participated in the study. Each subject underwent an upper and lower quarter screen and assessment of thoracic spine mobility. Subjects were excluded from the study if they had previous spine surgery, or were currently experiencing back pain. In addition, subjects who had any disease, disorders, or pathology that would hinder participation in segmental rolling or who had spinal movement contraindications were excluded. Since shoulder flexion is performed during the study, participants who had shoulder pathology or contraindications to upper extremity movement were excluded as well. Subjects with less than 50 degrees of trunk rotation were excluded from the study due to a possible physical mobility limitation that would prevent proficient segmental rolling. Included subjects were assessed on their ability to segmentally roll. Subjects who could complete the rolling task were placed in cohort A ("can roll"), and subjects who could not roll were placed in cohort B ("can't roll").

Electromyographic (EMG) activity of the multifidus was recorded adjacent to the lamina of the L4 vertebrae using intramuscular fine-wire electrodes. EMG activity of the anterior deltoid was also recorded with a surface electrode during a single arm movement into shoulder flexion. While in a standing position, subjects were instructed to move their right upper arm into flexion as quickly as possible. Subjects flexed their shoulder to 90 degrees for three trials while muscle activity was recorded. Data were high-pass filtered at 30 Hz to remove baseline artifact, and the onset EMG times was selected as the point at which EMG increased two SD above baseline levels. Onset of the multifidus muscle was reported relative to that of the prime mover (anterior deltoid). Muscle onset latency was defined as the time difference between the onset of contraction of the multifidus and the anterior deltoid.

Results: Nine subjects were placed in cohort A, 11 subjects were placed in cohort B. The mean firing time of the lumbar multifidus for the cohort A was 16.67msec before the anterior deltoid, and the mean firing time of the lumbar multifidus for cohort B was 57.36msec after the anterior deltoid. There was a statistically significant difference ($p < 0.00$) in the firing time between cohorts A and B.

Conclusions: In subjects who could segmentally roll, the multifidus muscle activation always preceded that of the prime mover muscle activation. In subjects who could not segmentally roll, the results of this study confirm that there is a multifidus muscle onset latency relative to the activation of the anterior deltoid. The inability to segmentally roll may be related to faulty sequencing of lumbar multifidus firing.

Key words: Movement system, multifidus muscle, neuromuscular sequencing, segmental rolling

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INTRODUCTION:

The ability to control movement of the core/trunk contributes to all activities of daily living as well as the ability to perform fundamental movement skills including throwing, catching, jumping, striking, running, kicking, and agility, balance, and coordination tasks.[1,2] Several researchers have established that coordination of the local and global stabilizers of the trunk is changed in those with low back pain, with the activity of the multifidi being delayed and reduced during functional tasks.[1,3] Assessment and intervention related to the activation and sequencing of the trunk muscles can be time consuming and challenging for the clinician, therefore the ability to utilize a simple developmental movement pattern such as segmental rolling to accurately evaluate and treat motor coordination of the trunk may be beneficial, especially in orthopedic and sports rehabilitation settings.[1,4] In development, segmental rolling occurs as a response to the body-righting reaction and results in the body reacting to the rotation of the head to one side, creating a segmental and sequential pattern of the trunk, shoulder girdle, and pelvic girdle that follows the head and neck. Segmental rolling requires rotation around the body axis, the vertebral column and is also known as intra-axial rotation.[5]

The multifidi are widely accepted for their role as spinal stabilizers, and have been examined in many studies for their contribution to stabilization of the spine.[6,7,8,9] As defined by Dutton,[10] the role of the multifidi is to stabilize the spine, bilaterally to extend the vertebrae, and unilaterally to rotate vertebral segments to the opposite side, as well as to eccentrically control lateral flexion to the opposite side. Overall, the multifidi work locally to control motion at each vertebral segmental level. This can be differentiated from the actions of global muscles, which work as prime movers. When global muscles take over the role of local stabilizer muscles, there is generally a latency of onset firing time of the local stabilizing muscles.[11,13] The local stabilizer should govern the contraction to stabilize a joint, by contracting independently of the global musculature.[11,12] When this does not occur, it can result in dysfunction and loss of stability, therefore leading to additional restrictions of normal motion secondary to prime mover guarding, as well as the default to compensatory patterns.[11] As these suboptimal compensatory patterns are used, dysfunction can present in the forms of poor posture, poor movement patterns, and eventually, pain.[13]

Many biomechanical studies have demonstrated the importance of the lumbar multifidi in lumbar segmental stability.[6,7,8,9,14,15] Wilke et. al.[6] conducted a study that examined the effects of five muscles on the stability of L4-L5 vertebral motion and determined that the multifidus contributed to two-thirds of the stability provided by all muscle contractions. Other authors have incriminated the lumbar multifidi for their importance in providing spinal stability to diminish low back pain.[8,15] Hebert et al. found that a decrease in lumbar multifidus activation in subjects with low back pain was associated with an increased presence of factors predictive of clinical success with a stabilization exercise program.[15] This supports the importance of restoring activation of the lumbar multifidi (LM) through stabilization exercises for improved lumbar spine stabilization.[8]

When observing people with low back pain, researchers have used imaging to describe impairments of the multifidus based on cross-sectional area.[14,15,16] Poor activation or disuse of the multifidi could result in excessive segmental motion of the lumbar spine, resulting in back pain and changes to the thickness of the muscle. Multifidus fibers have been described as demonstrating alterations in patients after experiencing only three weeks of low back pain.[14] Using real-time ultrasound imaging, the cross-sectional area of the multifidus has been shown to decrease in size in patients with acute low back pain.[16] Reflex inhibition of the multifidi, or activation of global muscles instead of the multifidi, during movement was found to have a direct correlation with the atrophy and fatty infiltration of the multifidi muscles.[16] The significance of lack of multifidus activation has been observed by many authors who conclude that if the functionality of the multifidus is not restored, the patient is more likely to suffer from low back pain.[8,14,15,17,18]

Research has also been performed by Hodges et al.[18] that looked specifically at the onset of activation timing of local spinal stabilizer muscles as compared to global prime movers in patients with low back pain. Subjects in the Hodges et al study performed dynamic shoulder flexion, abduction, and extension in standing while EMG of local and global muscles was recorded.[18] The onset of activation time was determined for local stabilizers, the transversus abdominus and the lumbar multifidus, through the utilization of fine wire EMG, which was placed into the respective muscle bellies.[18] The needle was inserted into the left transversus abdominis and into the left lumbar multifidus at L4-L5 interspace, 2 cm lateral to the spinous process.[18] The global muscles, obliquus abdominis internus and obliquus abdominis externus were also recorded using fine wire EMG, while additional global muscles including the rectus abdominis and deltoid (anterior, middle, and posterior) were assessed using surface electrodes.[18] Hodges et al found that patients with low back pain had a latency in the onset of firing time of the transversus abdominis and lumbar multifidus compared to that of the deltoid.[18] This study supports the belief that one of the major contributions to low back pain and dysfunction is a loss of neuromuscular control of the local stabilizer muscles of the lumbar segments, not necessarily ligamentous instability.[19] As this study also assessed the onset of firing time between local stabilizers of the lumbar spine to the onset of firing time of global musculature, this study design was utilized as inspiration for the current study design.

Authors who have discussed the importance of lumbar multifidus activation for spinal stabilization, have suggested implementing an exercise program focused on intersegmental training.[8,15,20,21,22] France et al.[20] examined segmental stabilization of the transversus abdominis and lumbar multifidus against superficial strengthening of the rectus abdominis, internal abdominal oblique, external abdominal oblique, and erector spinae muscles. They concluded that segmental stabilization activities were better at improving muscle activation of local stabilizing muscles as well as improving low back pain when compared to prime mover recruitment exercises.[20] In addition, muscular control of the multifidi can be improved through utilization of therapeutic exercises, specifically ones that focus on movements that challenge trunk control through dissociation of the limbs from the trunk.[12] However, utilization of segmental rolling as a local stabilizer recruitment exercise to challenge control of the trunk has yet to be indicated in the literature.

Rolling is a useful tool which is often overlooked due to its simplistic nature. Despite this, rolling is a fundamental movement pattern developed in infancy that sets the foundation for more complex, coordinated movements.[13,23,24] During early infancy, children lack the ability to move between postures and spend their time in the relatively static positions including prone, supine, and eventually sidelying.[24] The infant develops head control around four months of age, facilitating the onset of developing transitional movements.[13,24] The ability to transition through postures via rolling necessitates that an infant moves their shoulder towards the contralateral hip or vice versa in a diagonal manner.[24] Once this occurs, the infant can begin performing log rolls as a means to transition from prone to supine and then supine to prone.[24] As the infant develops better control of weight transfer during transitions and to the ability to dissociate the limbs from the trunk, an infant can begin rolling segmentally by leading with the upper extremities or the lower extremities.[13,24]

The ability to segmentally roll demonstrates necessary trunk control which is needed for dynamic postural control and coordination of the extremities.[13,24] The spinal control that is developed in infancy continues to develop with age through more complex movements, such as crawling, walking, and running.[23] Unfortunately, these movement patterns have a tendency to become dysfunctional, and at times, even painful, in adults.[24] Dysfunction in general movement tasks such as crossing midline, coordination of the extremities and trunk, as well as weight shifting occur concurrently with a decline in strength and motor control.[13,24] While movement dysfunctions can increase with age, adults also demonstrate an increase in the variability of how the roll is performed.[23] Adults often exhibit a rolling pattern described as "deliberate", instead of the "automatic" pattern first developed during infancy.[24] The compensatory patterns that are revealed during segmental rolling can also be seen in compensatory patterns of normal gait and movement.[13] When moving, adults often do not utilize the contralateral movement of the arms and legs.[13] Global muscles and local muscles fire in reverse temporal order, resulting in inappropriate utilization of the global muscles for the role of the stabilization and primary action.[13,23, B] Inefficient movement is the consequence.

It has been hypothesized that an inability to roll in a segmental fashion indicates a lack of spinal stabilization.[13,23,24,25] Spinal stabilization occurs through the activation of local stabilizers muscles, primarily the multifidi. It has also been suggested that rolling can be used as an intervention to improve spinal stabilization through activation of the spinal stabilizer muscles, i.e. the multifidi.[13,24] Currently, no reported research has identified such a relationship. Therefore, the purpose of this study was to assess the temporal sequence of lumbar multifidus activation associated with anterior deltoid activation, and to determine if faulty sequencing was associated with the inability to segmentally roll in subjects without mobility restrictions. The authors hypothesized that individuals who are not able to perform segmental rolling would exhibit an altered muscle recruitment firing time. Additionally, a small pilot study was conducted with a subset of the experimental group to evaluate whether corrective exercise would change the alterations found in firing time.

METHODS

Subjects

Following IRB approval by Belmont University, twenty healthy subjects (13 females, 7 males), ages 19-25, were enrolled in the study and informed consent was obtained. Subjects were excluded from the study if they had previous spine surgery, or were currently experiencing back pain. In addition, subjects who had any disease, disorders, or pathology that would hinder participation in segmental rolling or who had spinal movement contraindications were excluded. Since shoulder flexion is performed during experimentation, participants who had shoulder pathology or contraindications to movement were excluded from the study as well. The seated thoracic spine rotation test[26,27] was performed before testing and any participants with a limitation in thoracic rotation (rotation less than 50 degrees bilaterally) were excluded from the study due to a possible physical mobility limitation that would prevent proficient segmental rolling.

Instrumentation

Bi-Polar fine wire electrodes (Motion Lab Systems, Baton Rouge, LA) were utilized to assess activity of the lumbar multifidus adjacent to the left lamina of the L4 vertebrae. The insertion needle had a 50mm, 25-gauge cannula, which held a pair of fine wires. Each wire was 200mm in length, 0.051mm in diameter, and made of 304 series stainless steel with green nylon insulation. The ends of the wires had bare hook sensor ends with 2mm of exposed sensor and a 150mm insulated tail. EMG equipment was attached to the other end of the fine wires, which were clean and free of insulation for 5mm. The subject was placed in the prone position and the needle was inserted at the level of the L4 vertebrae on the left in an inferior and medial direction, aiming for the multifidus adjacent to the left lamina. The cannula was then removed, leaving the hooked sensor fine-wire electrode attached within the muscle. Ambu Blue-Sensor M-00-S ECG surface electrodes were placed on the center of the muscle bellies of the right anterior deltoid. The electrodes were 40.8 x 34 mm in size and were round with an offset snap connector. The backing material was polymer with a conductive wet gel. Utilizing Noraxon MyoResearch XP Master Edition 1.07.64 software, data was collected and band-width filtered at 240 MHz to remove baseline artifact. Data was analyzed utilizing Noraxon software to identity the onset of muscle firing that exceeded mean baseline activity by two standard deviations. The onset firing time of the lumbar multifidus and the anterior deltoid were compared for further analysis. Statistics were performed on SPSS Statistics V18.0.0 software.

Procedures

Prior to participation, all subjects completed an informed consent explaining the study as well as a medical history questionnaire. Subjects were then evaluated utilizing an upper quarter screen, lower quarter screen, and seated thoracic rotation test (Figure 1) to identify any exclusion criteria. Subjects were then instructed via a script on how to segmentally roll based on previously published established criteria (Figure 2 & 3).[24] The rolling ability of the participant was evaluated for proper technique and effort by a single examiner. To be considered able to perform a segmental roll, the subject had to roll from prone to supine and supine to prone without compensation or excessive effort in either direction both by leading with both the upper body and lower body on the left and right sides.[13,24] Compensation

Figure 1. *Seated thoracic rotation test.*

Figure 2. *Supine to prone rolling with upper extremity lead.*

Figure 3. *Prone to supine rolling with upper extremity lead.*

was defined as utilizing the lower extremities or momentum to assist in rolling, not rolling segmentally (i.e.: log rolling), pushing off the ground with the upper extremities, or lack of motor control demonstrated during the rolling task.[13,24] If the subject met the criteria for successfully performing a segmental roll, the subject was placed in cohort A. If the subject could not perform a segmental roll, the subject was placed in cohort B. The testing procedures were identical for cohorts A and B. Subjects stood with feet together, hands at their sides, and head facing forward and were then instructed to flex their right shoulder to 90 degrees as quickly as possible. (Figure 4) This was repeated for three trials while muscle activity was recorded.

Pilot Study

Following initial data collection, five subjects who could not roll performed an intervention sequence. The purpose was to identify whether changing segmental rolling ability was related to a change in the onset of firing of the lumbar multifidus activation in relation to the anterior deltoid. Four exercises were utilized – manually cued multifidus activation, prone isometrically resisted opposite shoulder flexion and leg extension, quadruped opposite arm and leg (Figure 5) , and assisted segmental rolling.

The manual multifidus activation is performed with the subject lying prone and the experimenter's

Figure 4. *Shoulder flexion to 90 degrees with EMG.*

Figure 5. *Quadruped opposite arm and leg.*

fingers placed just lateral to the L4 spinous process. Subjects are instructed to "swell" the muscles under the fingers, thus trying to activate the multifidus at the segmental level. Subjects held the contraction for five seconds and were then instructed to relax. This was performed for five trials. Subjects were then positioned prone for the prone isometric resisted opposite shoulder flexion and opposite leg extension. Manual resistance was provided to the posterior aspect of the right upper arm and the posterior aspect of the mid-thigh while subjects held isometric shoulder and hip extension for five seconds. This was performed for the right shoulder/left hip and left shoulder/right hip for five trials each. Quadruped opposite arm and leg were then performed with the participants flexing their right shoulder and extending their left hip so the limbs were straight and parallel to the floor, and then returned to the starting position of quadruped. Ten repetitions were performed with the right arm and left leg, then ten repetitions were performed with the left arm and right leg. Assisted segmental rolling was performed to assist in the neuromuscular reeducation of the segmental rolling pattern. Subjects were supine and the left half of their body was elevated on a 45 degree angle to the floor using a wedge. Five segmental rolls were performed from supine to prone with the left arm leading from the elevated position. Subjects then were placed in the prone position and the left half of the body was again elevated. Five segmental rolls were performed from prone to supine with the left arm leading from the elevated position. This sequence was then repeated with the right side of the body elevated/leading with the right arm. Firing sequencing of the lumbar multifidus and the anterior deltoid was then re-assessed as previously described with three trials of right shoulder flexion while muscle activity was recorded.

RESULTS

Nine subjects (4 males and 5 females) were placed in cohort A (can roll) group and eleven subjects (3 males and 8 females) were placed in cohort B (cannot roll) group. Muscle onset timing data for all subjects in both groups can be found in Table 1. In the cohort A, the mean firing time of the lumbar multifidus was -16.67 milliseconds (+/-14.93) indicating a contraction *before* the anterior deltoid. In cohort B, the mean firing time of the lumbar multifidus was 57.36 milliseconds (+/- 15.33), indicating a contraction *after* the anterior deltoid. An independent samples t-test was performed and a statistically significant difference was found in the mean firing times between cohort A and B ($p = 0.000$) with a standard error of difference of 6.812ms.

Table 1. *Results for the "can roll" group/cohort A and "cannot roll" group/cohort B demonstrate the tendencies of lumbar multifidus firing time compared to the anterior deltoid. Positive numbers denote a latency in firing time of the lumbar multifidus muscle, and a negative number indicates that the lumbar multifidus firing occurred prior to that of the anterior deltoid. The mean firing time of the lumbar multifidus in comparison to the anterior deltoid for each group can also be compared.*

Cohort A (Subject Can Roll)		Cohort B (Subject Cannot Roll)	
Subject Number	Lumbar Multifidus Firing Time in Relation to Anterior Deltoid (msec)	Subject Number	Lumbar Multifidus Firing Time in Relation to Anterior Deltoid (msec)
1	-37	1	53
2	-23	2	56
3	-9	3	31
4	3	4	61
5	-17	5	76
6	-31	6	63
7	-29	7	68
8	6	8	42
9	-13	9	77
		10	37
		11	67
Mean	-16.67		57.36
Standard Deviation	14.933		15.331

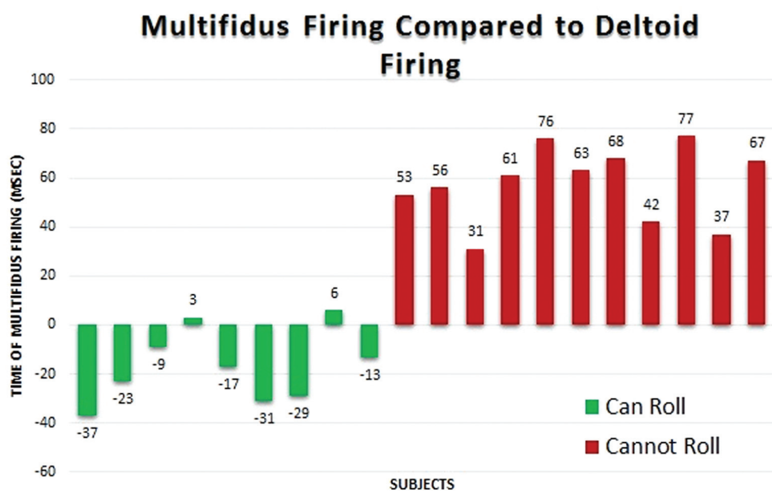

Figure 6. *Data for the "can roll" group/cohort A is in green and for the "cannot roll" group/cohort B is in red, with the subjects identified on the X-axis. The Y-axis depicts the onset of firing time of the lumbar multifidus compared to the anterior deltoid, with a time of zero indicating the onset of firing time of the anterior deltoid. All positive values represent a latency in firing time of the lumbar multifidus and all negative values represent the lumbar multifidus firing prior to the anterior deltoid.*

Pilot Study Results

Five subjects, who could not segmentally roll and had faulty muscle firing sequences, participated in the intervention. Table 2 shows the firing time of the lumbar multifidus compared to the anterior deltoid. Negative and positive values indicate the same sequencing pattern as previously described. Pre-intervention, the average firing time of the lumbar multifidus was 58.20 milliseconds (+/- 17.60) after the anterior deltoid. Post-intervention, the average firing time of the lumbar multifidus was 16.60 milliseconds (+/- 14.33) before the anterior deltoid. A paired sample t-test of the pre- and post-intervention values determined that there was a statistically significant difference between latency values before and after the intervention (p-0.003).

DISCUSSION

This is the first study to examine segmental rolling and how it relates to motor coordination between spine and the extremity musculature. In this study, the authors found that the ability to segmentally roll without compensation or excessive effort is associated with an earlier onset of multifidus firing as compared to the prime mover activation. In subjects who could segmentally roll, the onset of firing of the lumbar multifidus preceded that of the anterior deltoid by an average of 16.67 milliseconds. The "cannot roll" group demonstrated a faulty firing sequence, in which the onset of firing of the lumbar multifidus always occurred after that of the anterior deltoid by an average of 57.36 milliseconds. Based on the findings of this study, the ability to activate

Table 2. *Pre-intervention data and post-intervention data demonstrate the tendencies of lumbar multifidus firing time compared to the anterior deltoid. Positive numbers denote a latency in firing time of the lumbar multifidus muscle, and a negative number indicates the lumbar multifidus firing occurred prior to that of the anterior deltoid. The mean firing time of the lumbar multifidus in comparison to the anterior deltoid for the group before and after intervention can also be compared.*

Subject	Pre-Intervention Firing Time (msec)	Post-Intervention Firing Time (msec)
1	68	-17
2	42	6
3	77	-27
4	37	-31
5	67	-14
Mean	58.20	-16.60
Standard Deviation	17.598	14.433

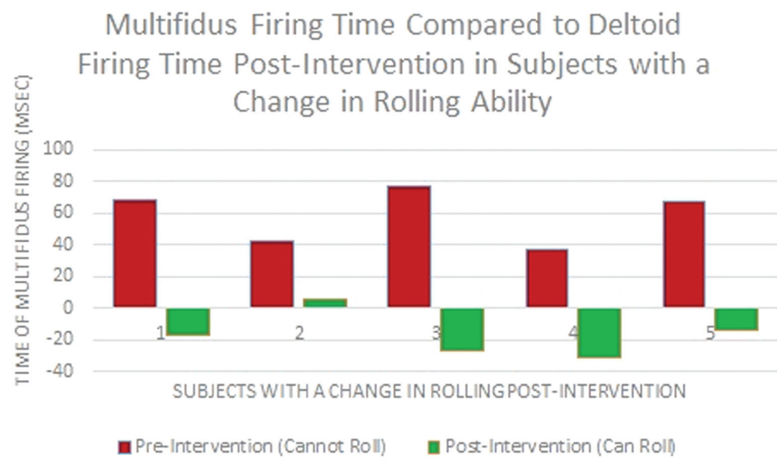

Figure 7. *Pre-intervention data is in green and post-intervention data is in red, with the subjects identified on the X-axis. The Y-axis depicts the onset of firing time of the lumbar multifidus compared to the anterior deltoid, with a time of zero indicating the onset of firing time of the anterior deltoid. All positive values represent a latency in firing time of the lumbar multifidus and all negative values represent the lumbar multifidus firing prior to the anterior deltoid.*

the multifidus prior to the activation of the anterior deltoid was associated with the demonstration of successful segmental rolling. Hodges and Richardson found that individuals with low back pain had delayed onset of local stabilizer muscles including the lumbar multifidus and transverse abdominus in an arm raise task.[18] Although the subjects in this study did not have pain, it is possible that a previous episode of pain could have altered their firing patterns. In addition, based on previous research related to back pain and poor motor control of the local and global stabilizers,[1,3,4,18] there is an argument that the individuals in this study with altered rolling patterns and associated multifidi latency may be prone to low back pain in the future due to poor ability to stabilize the spine segmentally.

Five subjects from cohort B who could not segmentally roll received an intervention to retrain lumbar multifidus firing and segmental rolling motor planning. Post-intervention, all subjects were able to segmentally roll without compensation or excessive effort. All subjects also demonstrated a change in firing pattern from pre-intervention to post-intervention, with a faulty firing sequence pre-intervention and an efficient firing sequence post-intervention. These findings suggestive that a change in segmental rolling ability is related to a change in faulty firing sequence to proper firing sequence of the lumbar multifidus and the anterior deltoid.

Clinically, segmental rolling can be utilized to identify the inability to appropriately stabilize the spine, which could be a result of limited spinal motion or inefficient dissociation of the trunk and the extremities. In the case of this study, all subjects with limited spinal motion were excluded, thus, subjects with the inability to roll were unable to do so due to motor sequencing difficulty. Utilizing segmental rolling as an assessment tool for sequencing of local and global musculature, as well as, rotary stability can provide immediate information in how patients are able to perform a functional movement pattern. As indicated in the affiliated pilot study, it appears that the segmental rolling pattern can be refined to meet the standards of a correct, uncompensated segmental roll, as well as restore appropriate onset firing time of the multifidus compared to a global stabilizer. Appropriate timing of multifidus contraction is important when developing appropriate trunk stability to allow for increased freedom of the extremities, and for increased force transfer through the trunk to the limbs. This is significant for sport and for daily life. Utilizing the segmental roll, a clinician has the ability to evaluate and treat motor coordination of local and global stabilizers of the trunk.

One limitation to this study was a bias that may have occurred during convenience sampling through word of mouth and e-mail in the community. The results cannot necessarily be generalized to people outside of the current study's subjects' age range of 19-25 and outside of the demographics limited in the current study. In addition, this study was limited to subjects who were pain-free and had no reported functional limitations.

Future research beyond this study and pilot study should utilize the findings and develop more direct exploration of rolling with regard to uses in the clinic. This study demonstrated an association between muscle firing times and segmental rolling when looking at a single limb movement in isolation. Future studies should examine the relationships between these firing sequences in functional whole body patterns such as forward and backward bending or multi-segmental rotation in a standing position. The results of this study in combination with that of Hodges and Richardson,[18] could be utilized to design a study looking at the use of segmental rolling to decrease pain in subjects with lower back pain. Additional considerations should be made to compare the ability to segmentally roll as well as the latency times of segmental stabilizers in different populations such as gender, age, and activity level. The pilot study identified that a change in segmental rolling ability could be made through intervention, but without incrimination of specific exercises. Further research into what specific interventions should be utilized to modify the lumbar multifidus firing timing should be performed. Based on the findings in this study, the utilization of segmental rolling ability as the indicator for firing time of the lumbar multifidus may be warranted. Utilizing the concept of dissociation and force transfer, further research should evaluate compensatory patterns occurring in segmental rolling as they relate to dysfunction in functional movements, especially in sport. It is possible that the ability to restore the motor sequencing through segmental rolling could improve the ability of an athlete to perform a functional movement or sport skill. In addition, the pilot study demonstrated an ability to change the segmental rolling ability and firing sequence through intervention in a small number of subjects, future research should investigate the duration that the intervention lasts, and the amount of time it takes for the subject to revert to the faulty firing sequence and rolling pattern, if that were to happen. Expanding on this research, the effects of an intervention over a period of time should be examined to see if these changes can be made permanent.

CONCLUSION

Segmental rolling ability is associated with the firing sequence of the lumbar multifidus and the anterior deltoid, where subjects with the inability to segmentally roll demonstrated a significantly different firing sequence with a multifidus muscle onset latency relative to the activation of the anterior deltoid, when compared to subjects who could roll. In subjects who could segmentally roll, the multifidus muscle activation consistently preceded that of the prime mover muscle activation. These results suggest that a segmental rolling assessment could be utilized as a method to examine firing sequence of the lumbar multifidus compared to prime movers.

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