

Running head: Fine Wire Insertion Reduces Muscle Strength in LBP**Title:** Individuals with Recurrent Low Back Pain Exhibit Significant Changes in Paraspinal Muscle Strength after Intramuscular Fine Wire Electrode InsertionSzu-Ping Lee, PT, PhD¹Vincent Dinglasan, PT, DPT^{1,2}Anthony Duong, PT, DPT¹Russell Totten, PT, DPT^{1,3}Jo Armour Smith, PT, PhD⁴¹Department of Physical Therapy, University of Nevada, Las Vegas²Boulder City Hospital³Advanced Healthcare of Reno⁴Department of Physical Therapy, Chapman University**Acknowledgement:** This study was partially supported by the University of Nevada, Las Vegas, Department of Physical Therapy, 2016 Student Opportunity Research Grant. The authors declare no conflict of interest.

The study protocol was approved by the University of Nevada, Las Vegas Biomedical IRB. Written consent was obtained from each study participant.

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ABSTRACT

Objective: To examine how insertion and presence of intramuscular fine-wire electromyography electrodes (IFWE) in lumbar multifidus affect paraspinal muscle strength, endurance, and activation in persons with and without recurrent lower back pain (RLBP) during activities that require high levels of muscle contraction.

Design: Case-control with randomization of conditions.

Setting: Clinical Research Laboratory

Participants: Forty participants age 18-40 were recruited (18 female; mean age = 25.5 years); 20 with a history of RLBP were compared to a matching control group of 20 without RLBP.

Interventions: Each participant was tested under three conditions over three sessions. On Session 1, the baseline condition, we assessed muscle performance without IFWE insertion. On Sessions 2 and 3, participants were randomly alternated between two experimental conditions: a) wire-in, in which the IFWE was inserted and remained within the muscle during testing, and b) wire-out, in which the IFWE was inserted and immediately removed.

Main Outcome Measures: Lumbar spinal extensor peak strength, endurance, and normalized EMG amplitude during the endurance test.

Results: Individuals with RLBP showed a significant decrease in peak strength during conditions that involved IFWE insertion and tend to experience more pain during muscle testing. Both groups exhibited similar levels of performance and muscle activation during the endurance test.

Conclusion: Our findings indicate that individuals with RLBP exhibited reduced lumbar extensor strength in response to IFWE insertion to the deep paraspinal muscles. This behavior is different from those without RLBP. Researchers should carefully consider the use of IFWE electromyography in individuals with RLBP during high exertion activities.

Key Words: muscle performance; electromyography; low back pain; multifidus

Abbreviations:

RLBP: Recurrent Low Back Pain

EMG: Electromyography

IFWE: Intramuscular Fine-Wire EMG Electrode(s)

VAS: Visual Analog Scale

FABQ: Fear-Avoidance Beliefs Questionnaire

ODI: Oswestry Disability Index

ST: Sorensen's Test for back extension muscle endurance

MVIC: Maximal Voluntary Isometric Contraction

INTRODUCTION

Low back pain affects 84% of the world's population at some point during the lifespan[1]. Following an acute episode of low back pain (LBP), many individuals develop persistent symptoms, with trajectories of back pain over time that may be chronic[2] or recurrent[3]. Individuals with persistent LBP experience impairments such as increased back muscle fatigability[4], decreased strength[5] and endurance compared to those without LBP[6]. Persistent LBP has been attributed to weakness of muscles supporting the spine, particularly the lumbar multifidi[7]. The morphology of the multifidi -- a tight cluster of short muscle bundles that connect the spinous processes and lamina of each lumbar vertebrae inferiorly to the mamillary processes and sacrum spanning 2-5 levels -- makes them an important intersegmental muscle group[8]. Researchers have studied the effects of their atrophy[7], changes in cross-sectional area[9,10,11,12], neuromuscular control[13], and activation[14,15] in relation to the occurrence and severity of persistent LBP.

A key method for studying spinal muscle activation is electromyography (EMG), which records action potential propagation during muscle contractions. Surface EMG (SEMG) electrodes, when used to assess paraspinal muscle activation, collect from a large area and therefore may be subject to "crosstalk" from superficial and adjacent muscles[16]. Researchers of LBP have used intramuscular fine-wire EMG electrodes (IFWE) to specifically assess activation of the multifidi[6,15,17,18]. While this method

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provides more specific sampling of the muscle activation signal[16], the use of IFWE may produce unintended side effects due to the pain and microtrauma caused by insertion of the needle used to guide the IFWE into the target muscle and/or the discomfort due to the presence of IFWE during muscle contractions[17,19,20]. These factors may alter muscle performance through disrupted agonist/antagonist coordination, especially during activities that requires high levels of exertion[21]. The impact of pain on muscle performance is particularly significant for patients with persistent LBP who may exhibit altered sensitivity to nociceptive stimuli[22,23]. Furthermore, anticipation and fear of reproducing pain can lead people experiencing LBP to alter their motor control strategy such as avoiding high level paraspinal muscle recruitment[24]. To validate the use of IFWE insertion for studying multifidus activation during activities that require high level of paraspinal muscle activation, this potentially confounding factor must be investigated. In particular, it is important to establish if IFWE alters muscle performance in individuals with LBP even during periods of time when they are in symptom remission.

In a recent study, Lee et al. showed that the application of IFWE does not significantly affect spinal muscle performance in individuals with no current back pain.[25] However, there is currently a lack of information regarding how the insertion and presence of the IFWE affect muscle performance in individuals with persistent LBP during high exertion muscle contractions. Therefore, the purpose of this study was to

determine how the insertion and presence of IFWE affect paraspinal muscle strength, endurance and muscle activation in this population. It is important to investigate these factors since they can confound research findings obtained with the IFWE methods.

METHODS

Subjects

Forty subjects between the ages of 18 and 40 participated in the study (22 male, 18 female). The required number of subjects (20) for each group (control and recurrent low back pain - RLBP) was calculated *a priori* ($\alpha=0.05$ and $\beta=0.95$) based on effect size ($d=0.17-0.32$) estimated from da Silva et al. using a back extensor fatiguing test outcome [4] Subjects were recruited as a sample of convenience and provided written consent prior to participating. Subjects were included in the RLBP group if they reported a history of recurrent episodes of LBP defined as at least two activity-limiting episodes in the last 6 months[3], and a current pain level of 5 out of 100 or less on the visual analog scale (VAS)[20]. The minimal pain level at the time of testing is important to ensure current pain did not confound and inhibit muscle recruitment. Subjects were included in the control group if they had no history of LBP in the last 6 months. All exclusion criteria for both groups were detailed in Table 1. The study protocol was approved by the Institutional Review Board of University of XXX.

Prior to performing the muscle tests, subjects in the RLBP group completed the

Fear-Avoidance Beliefs Questionnaire (FABQ) and the Oswestry Disability Index (ODI) to quantify pain-related fear and disability during everyday activities[26,27]. During all 3 conditions, each subject's pain level was assessed during the experimental procedure using a 100 mm VAS pain scale immediately after the tests.

Instrumentation

The Humac Norm™ Isokinetic Extremity System^a was used to measure spinal extensor strength. This instrument was previously validated for assessing trunk muscle strength, with intra-rater reliability of 0.8-0.92 (ICC)[28]. A wireless EMG system^b was used to collect SEMG data during the muscle performance assessments. Each SEMG sensor had four silver contact bar electrodes with an inter-electrode distance of 10 mm. SEMG signals were collected at a sampling rate of 2000 Hz using a data acquisition software^c. To insert the intramuscular fine wire electrodes (paired hook-wire, insulated nickel alloy wires^d), a 27 gauge, 30 mm hypodermic guide needle was used^d.

Procedure

Participants attended three separate sessions of testing. Each testing session was scheduled 7 to 14 days apart to allow resolution of muscle soreness, microtrauma, and other effects between sessions. Subjects were rescheduled if they reported more than 5 out of 100 of pain on the VAS scale prior to testing.

On Session 1, the baseline condition, we obtained measures of muscle strength,

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endurance, and activation without IFWE placement. On Sessions 2 and 3, the participants were randomly assigned to alternate between the two experimental conditions: a) wire-in, in which the IFWE was inserted and remained within the muscle; b) wire-out, in which the IFWE was inserted and immediately removed.

EMG Placement

Skin over each participant's the paraspinal muscles was lightly abraded and disinfected with a disposable fabric alcohol wipe. For placing the IFWE on Sessions 2 and 3, a diagnostic ultrasound imaging unit (General Electric NextGen LOGIQe, GE Healthcare Co., Milwaukee, Wisconsin, USA) was used to identify the lumbar multifidus muscle and to insert the IFWE housed within a guide needle into the deep fibers of multifidus (L4 level). The use of real-time ultrasound imaging allowed precise placement of the IFWE in the muscle so the tip of the needle was just shy of touching the laminal periosteum (Figure 1)[15,29]. One investigator (an experienced physical therapist and clinical researcher who received prior training to perform the intramuscular insertion to multifidus muscle) performed all insertions to ensure consistency. Following placement of the IFWE, the participant was asked to perform submaximal lumbar extension contractions to set the electrodes in the muscle. The SEMG was placed to the right of the L4 spinous process at the same level of the IFWE insertion[30]. The subjects were informed they may or may not feel the placement of the IFWE after the guide needle was removed.

Back Extension Strength Assessment

Performance testing began with the strength assessment. This assessment was performed in prone, consistent with previous literature [17,31] to maximize stabilization and to ensure that the IFWE were not dislodged during participant movement. The participant laid prone on the dynamometer table with ankles and lower thighs secured to the table with straps (Figure 2). One investigator held the participant's ankles to provide additional support. The axis of the dynamometer was aligned with the L4-5 level [32]. The dynamometer lever was positioned against the back just inferior to the spine of scapula then fixed in place. From the prone position, participants were instructed to push up against the padded lever as hard as they can for 5 seconds. The participant performed a submaximal practice trial followed by three, 5-second trials of maximal voluntary isometric contractions (MVIC) of back extension. Each MVIC trial was separated by a 1-minute rest period. After strength testing, the participant rested for a period of at least 5 minutes before the endurance test.

Sorensen's Test (ST) for Back Extension Endurance

The participants performed the ST in a prone position on a platform table with the upper body (trunk above the level of anterior superior iliac spine) unsupported off one end of the table. The participant's pelvis and legs were supported and secured to the table with straps and by an investigator. A ball attachment was placed around the participant's neck with length of the string adjusted so the spine neutral position

coincided with the ball lifted just off a bench below. The start of the test was defined as when the participant assumed a back extension posture position raising the ball off the bench surface, and ends when the participant volitionally stopped the test or when the ball made contact with the bench surface. In addition to the ST performance (time in seconds), paraspinal muscle activation was recorded using the SEMG during all strength and endurance trials for all conditions. Normalized EMG amplitude during the first and last 30 seconds of the ST were analyzed (see Data Analysis for details).

Data Analysis

During strength testing, maximum voluntary isometric torque, measured in Newton-meters, was recorded for three trials in each condition. The mean value from the 3 trials was recorded as the average peak torque representing the back extensor muscle strength within the condition. The muscle endurance was assessed as time elapsed during the ST. The SEMG data during the ST were analyzed using a customized Matlab program (Mathworks, Inc., Natick, Massachusetts). The signal was band-pass filtered using a digital Butterworth filter (4th order, 10-350 Hz, based on power spectrum analysis of the pilot EMG data), then full-wave rectified. The time-series data from MVIC trials were further processed using moving average with a window size of 1 second. Within each condition, percent activation was normalized to the highest 1-second EMG amplitude obtained from the MVIC trials of the session as a percentage (%MVIC). Because ST time varied among subjects, average EMG amplitudes during

the first and last 30 seconds of the test were analyzed.

Statistical analysis

Characteristics of the two groups were compared using independent t-tests. Two-way (2 by 3) repeated-measures ANOVAs were used to examine the main effects and interaction of group (control vs. RLBP; 2 levels) and condition (Baseline vs. Wire-in vs. Wire-out; 3 levels) on peak torque, ST time, and %MVIC during ST. Greenhouse-Geisser correction was applied when the assumption of sphericity was violated based on Mauchly's Test. When significant main effects or interaction were detected, post-hoc comparisons were performed using a pairwise comparison (with Bonferroni correction of up to 3 multiple comparisons among the 3 condition levels) or one-way repeated measures ANOVA to examine the subgroup differences. The frequency of experiencing notable pain and discomfort (defined as >5 mm on the VAS) during the muscle performance tests between the groups are analyzed using Chi-square tests with Fisher's Exact statistics (2-sided). All statistical analyses were performed using SPSS software version 23.0 (IBM Co., Armonk, New York, USA) with significance levels set at $p < 0.05$ (including the Bonferroni corrected p values).

RESULTS

There were no significant differences in age ($p=0.209$), height ($p=0.944$), weight ($p=0.981$), and BMI ($p=0.995$) between the control and RLBP groups. Number of

episodes of back pain, ODI, FABQ scores for work (FABQW) and physical activity (FABQPA) of the RLBP group are shown in (Table 2).

Muscle Strength

The two-way ANOVA detected a significant group-by-condition interaction ($p=0.001$; Figure 3) on peak spinal extensor torque. Further, the test revealed no significant group main effect ($p=0.788$), but a significant condition main effect ($p=0.027$). Post-hoc analyses showed a significant difference across conditions that peak torque at Baseline was significantly greater than at both Wire-in and Wire-out conditions in the RLBP group only (Baseline: 133.81 ± 47.94 vs Wire-in: 115.63 ± 48.42 Nm, $p<0.001$; Baseline: 133.81 ± 47.94 vs Wire-out: 116.215 ± 43.49 Nm, $p=0.001$). There was no significant between-group difference in spinal extensor strength at Baseline (RLBP: 133.81 ± 47.94 vs. Control: 116.20 ± 37.32 Nm, $p=0.203$).

Muscle Endurance (Sorensen's Test Time)

The two-way ANOVA on ST time revealed no significant interaction between group and condition ($p=0.303$), and no significant main effects for group ($p=0.396$). However, a significant main effect was observed among the conditions ($p=0.001$). Post-hoc comparisons revealed the ST time at Baseline was significantly shorter than in Wire-in and Wire-out conditions (Baseline vs. Wire-in, $p=0.011$; Baseline vs. Wire-out, $p=0.008$; Figure 4) regardless of groups. There was no difference in ST time between the Wire-in and Wire-out conditions ($p>0.99$; Figure 4).

Muscle Activation

There were no significant group or condition main effects in %MVIC during the first 30 seconds of the ST ($p=0.821$ and $p=0.141$, respectively) and no significant interaction ($p=0.413$; Figure 5A). Two-way ANOVA analysis on the last 30 seconds also revealed no significant group and condition main effects ($p=0.522$ and $p=0.129$, respectively) and no significant interaction ($p=0.275$; Figure 5B). Average %MVIC during the first and last 30 seconds of ST for all subjects were 48.39% and 55.89%, respectively.

Pain during and after Muscle Performance Tests

In general, the pain level experienced by participants during the experimental procedures of all 3 conditions ranged from none to moderate (0-50 mm on VAS). We observed significant group main effect where the RLBP group reported significantly greater pain than controls after endurance test (10.33 vs. 1.17 mm; $p=0.002$) and a trend after strength test (2.17 vs. 0.17 mm; $p=0.077$; Table 2). Moreover, we observed a statistical trend that participants in the RLBP group tended to perceive notable pain (>5 mm on VAS) at a higher frequency during both the strength and endurance tests ($p=0.096$ and 0.054 , respectively; Table 2)

DISCUSSION

This study is the first to specifically investigate the effects of IFWE insertion to

the lumbar multifidi on the strength, endurance, and activation of spinal muscle extensors in individuals with and without RLBP. Our results showed that IFWE insertion reduced maximal back extensor strength performance in individuals with RLBP. However, IFWE insertion did not alter lumbar extensor endurance or paraspinal muscle activation level in individuals with RLBP. Furthermore, participants with RLBP reported greater pain, and higher percentages of them experienced notable pain during both muscle performance tests.

Muscle Strength

Smith et al. demonstrated that during gait, individuals with RLBP did not exhibit significant changes in lumbar kinematics following IFWE insertion into the lumbar multifidus when compared to those without back pain[20]. However, this study involved only a sub-maximal walking task and did not investigate muscle performance. Our findings suggest that at near maximal levels of paraspinal activation, IFWE insertion reduced maximal back extensor strength performance in individuals with RLBP. Interestingly, whether the IFWE remained within the lumbar multifidus muscle made no significant difference -- the process of IFWE insertion alone was enough to cause diminished torque in those with RLBP, perhaps due to pain or microtrauma associated with the insertion of guide needle. Experimentally induced pain has been shown to reduce maximal force in various muscle groups[33,34,35]. Puta et al. found that when compared to healthy individuals, people with LBP exhibited enhanced sensitivity and

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hyperalgesia to punctate mechanical pinprick stimuli, a sensation similar to needle insertion[36]. It appears that over time, the recurrence of back pain episodes may disrupt nociceptive regulation at the spinal level or above, making this population more susceptible to the nociceptive sensation from IFWE insertion. Our findings that higher percentages of participants in the RLBP group experienced pain during the muscle strength and endurance tests supported this premise.

Several previous studies have also observed an association between anticipated pain and reduced performance for both submaximal activities[37] and quantified muscle strength[38] in the RLBP population. Crombez et al. showed pain-related fear as the best predictor of performance for a trunk extension-flexion task[39]. Therefore, although the RLBP group presented comparable with pain ratings to the control group prior to the experiment, anticipation of pain during activities requiring near maximal exertion may still have contributed to their reduced strength performance.

Muscle Endurance

In the current study, a reduction in maximal torque was observed in individuals with RLBP, however, we observed no significant difference between groups in muscle endurance. This may be due to that during the endurance task the paraspinal muscles were only submaximally activated[40], requiring only ~50% paraspinal muscle activation[35] compared to the near 100% activation required during strength testing. Tucker et al. found that in healthy subjects, submaximal strength was not affected by

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experimentally induced pain[41]. The authors suggested the nervous system employs a strategy to maintain force despite acute, experimentally induced pain by recruiting new populations of motor units[41]. The RLBP group in the current study may have utilized a similar strategy, resulting in little difference between the fatigability of the two groups.

Muscle Activation

Activation of paraspinal muscles as a percentage of MVIC increased from ~50% to ~60% during the first and last 30 seconds of ST. The observed normalized EMG amplitudes were similar to those reported by Ng et al.[42] One concern was that IFWE insertion and presence during the ST may reduce paraspinal muscle activation level during MVIC, thereby artificially increasing the relative % MVIC in those conditions. We don't believe this to be the case since ST performance were not significantly reduced from Baseline to Wire-in and Wire-out conditions (Figure 4), and that the normalized EMG amplitudes were consistent between the conditions (Figures 5A-B). This indicated that the muscle activation did not significantly differ between groups and that the IFWE insertion did not affect normalized EMG amplitudes during the beginning and toward the end of the fatiguing task among the 3 conditions. Abboud et el. previously demonstrated that individuals with chronic low back pain were able to maintain motor performance comparable to controls mainly due to altered motor control and motor unit recruitment within and between muscles during a similar trunk holding task[43]. Because the EMG assessment in the current study was not intended to assess recruitment of individual

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motor units, it is not possible to distinguish the recruitment patterns between groups in this study. Future research may investigate differences in motor unit firing patterns between individuals with and without a history of persistent LBP under different pain conditions.

Most existing literature utilizing IFWE to compare individuals with back pain and healthy controls has investigated activities that are associated with postural, gait, or other tasks involving submaximal activation of the spinal extensors. This study supports the validity of IFWE methodology for submaximal tasks. However, group comparisons between individuals with and without back pain may be problematic in studies that investigate tasks involving maximal or near-maximal spinal extensor force production (i.e. heavy lifting). Therefore, surface EMG may be a more appropriate methodology for these types of investigations. Additionally, studies utilizing IFWE of the spinal extensors should quantify and report the pain associated with IFWE insertion in both healthy participants and individuals with back pain. This will ensure that results can be interpreted in the light of any experimentally-induced pain.

Study Limitations

The average age of subjects in the current study was younger than the age group that experiences the highest prevalence of RLBP (45-64 year of age)[1]. Additionally, the study investigated individuals with a recurrent rather than chronic pattern of LBP symptoms. We speculate that the group differences would be even more

evident in individuals with more frequent, chronic symptoms. The IFWE insertion was made to only one site, precluding generalization of our results to experiments that uses multiple IFWE placements. The investigators were not blinded to the participant conditions which may lead to unintentional bias of results.

Conclusions

Research investigating the effects of IFWE on multifidus in people with persistent LBP has been limited to evaluating activation during low exertion activities such as walking. In this study, we examined the effect of IFWE on muscle performance in this population during high-exertion muscle activation. Our findings showed the invasive procedure of IFWE insertion can reduce spinal extensor maximal strength performance despite the participants reporting only minimal to moderate pain. However, the use of IFWE during activities that require submaximal contractions (up to 50-60% of MVIC) appears viable. The frequency of experiencing significant pain was higher in the RLBP group. Researchers need to take these factors into consideration when using IFWE to assess individuals with RLBP.

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Suppliers

- a. Humac Norm Isokinetic Extremity System; Computer Sports Medicine, Inc., Stoughton, Massachusetts.
- b. Delsys Trigno Wireless System; Delsys, Inc., Natick, Massachusetts.
- c. Vicon Nexus 2, Vicon Motion Systems, Ltd. Oxford, UK.
- d. Natus Neurology, Middleton, Wisconsin, USA.

Figure Legends

Figure 1: Axial ultrasound image and schematic demonstrating insertion of the IFWE and guide needle.

Figure 2: Back Extension Strength Assessment

Figure 3: Peak spinal extensor torque (Nm) of the two groups across three conditions (* denotes significant reductions in spinal extensor torque in Wire-in and Wire-out conditions from Baseline in RLBP group only).

Figure 4: Mean Sorensen's Test Time (s) of the two groups across three conditions (* denotes significant difference from Baseline condition across both groups).

Figure 5A-B: Percentage activation of paraspinal muscles as measured by SEMG of the two groups across three conditions (during first [5A] and last [5B] 30 seconds of Sorensen's Test).

TABLE 1. All Exclusion Criteria

1.	Diabetes mellitus
2.	Rheumatic joint disease
3.	Clotting disorder or other bleeding problem
4.	Polyneuropathy
5.	Lower back surgery
6.	Bilateral leg pain
7.	Radiological/clinical diagnosis of spinal stenosis
8.	Radiological/clinical diagnosis of structural scoliosis
9.	Spinal malignancy
10.	Spinal infection
11.	Lumbar radiculopathy
12.	Pregnancy
13.	Fear of needles (defined as prior adverse responses to needle insertion)
14.	Diagnosed immunodeficiency or history of recurrent unexplained infections

TABLE 2. Mean anthropometric characteristics of the two groups.

	RLBP (n=20)	Control (n=20)	p-value
Age (years)	24.4 ± 2.95	26.7 ± 3.47	0.209
BMI (kg/m ²)	24.77 ± 3.14	24.78 ± 5.03	0.995
Height (m)	1.73 ± 0.09	1.73 ± 0.09	0.825
Weight (kg)	74.15 ± 12.89	74.26 ± 14.33	0.981
Number of episodes of back	3.45 ± 2.84	N/A	

pain (within past 6 months)

FABQW 5.7 ± 6.81 (13.6%) N/A

FABQPA 8.0 ± 5.51 (33.3%) N/A

Oswestry disability index (%) 4.2 ± 4.15 N/A

Pain level during strength test (0-100 VAS)	2.17	0.17	0.077
Pain level during endurance test (0-100 VAS)	10.33	1.17	0.002
% reporting significant pain during strength test	50%	20%	0.096
% reporting significant pain during endurance test	65%	25%	0.054

Abbreviations: N/A, not applicable; RLBP, recurrent low back pain; FABQW, Fear Avoidance Belief Questionnaire Work subscale (out of possible 42 points, lower is less fear avoidance); FABQPA, Fear Avoidance Belief Questionnaire Physical Activity subscale (out of possible 24 points, lower is less fear avoidance).

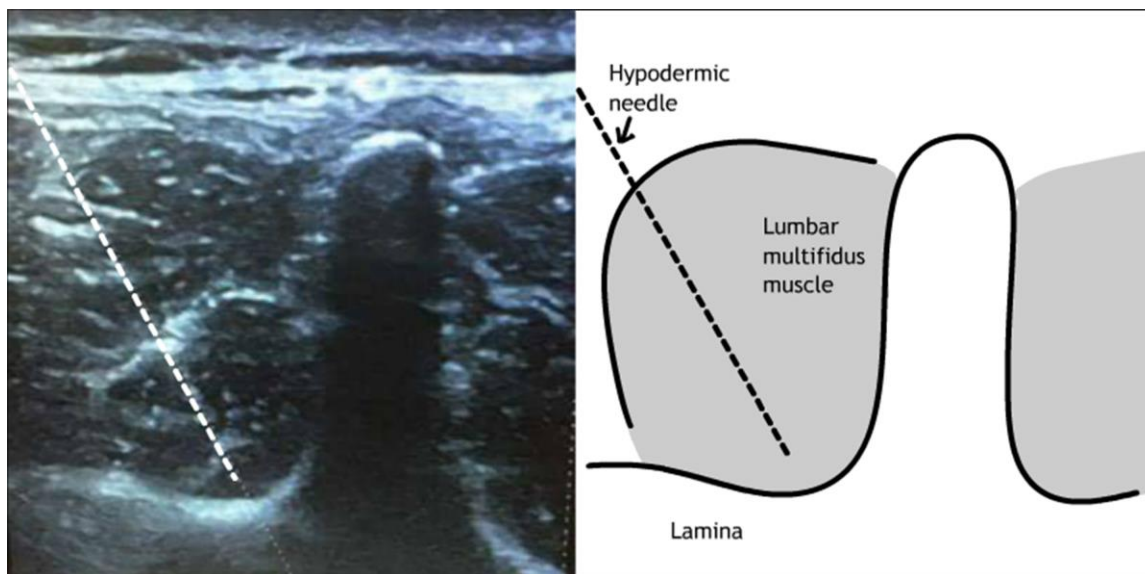




FIGURE 3

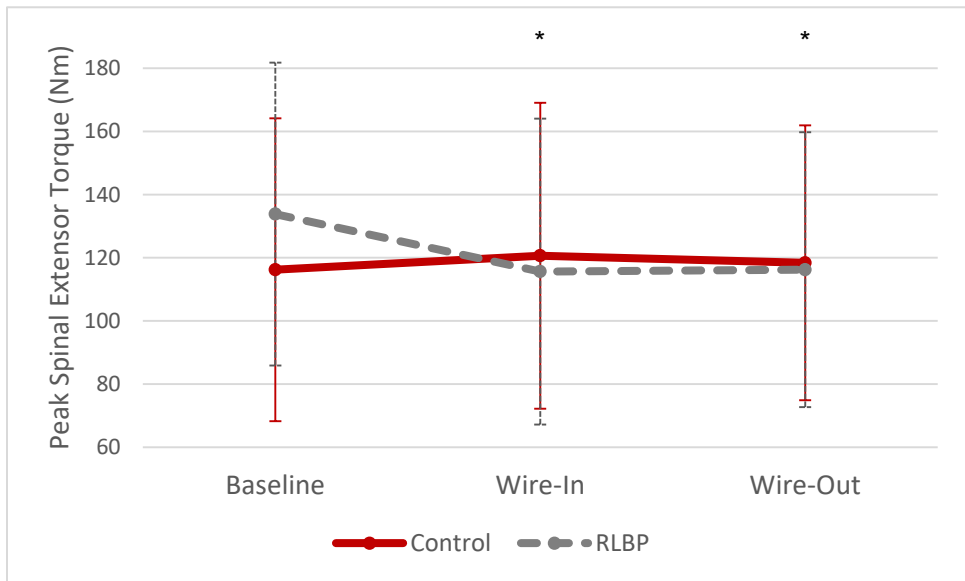


FIGURE 4

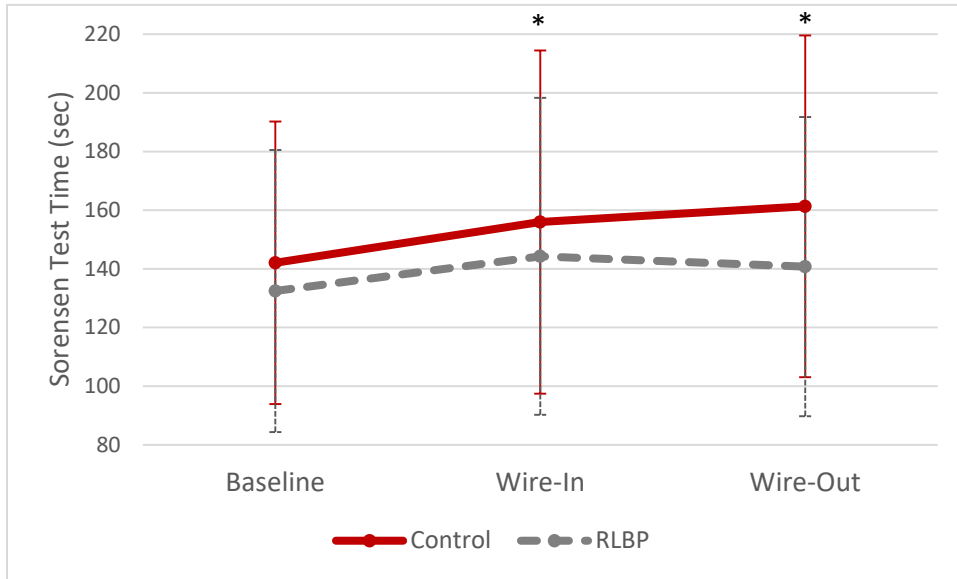
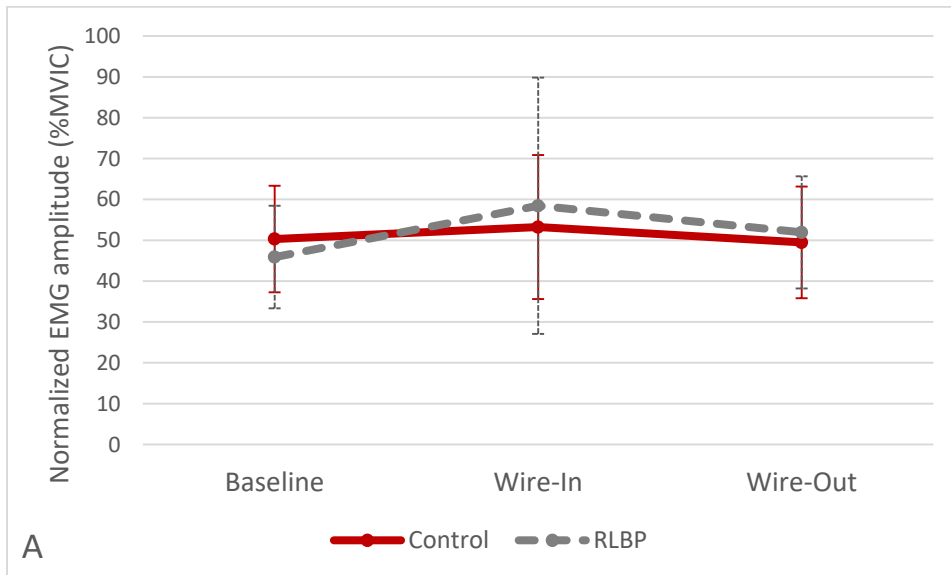


FIGURE 5A-B



A

