MUSCLE PERFORMANCE POST KNEE SURGERY: UNDERSTANDING THE LONG-TERM EFFECTS

BMED 3110 Final Report

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ABSTRACT

Knee surgery is a prevalent medical intervention in the United States, with around 790,000 surgeries performed annually[1]. Shortly after surgery, patients undergo physical therapy as part of their rehabilitation. Despite mandatory post-surgical care, postoperative deficits are still reported as patients return to their preinjury activity levels. The gap stems from a lack in understanding if rehabilitation techniques bring the muscles around the knee back to full strength. This study aims to investigate whether there are differences in muscle performance parameters between the surgical knee and the non-surgical knee. The goal is to identify whether there are long-term consequences post-surgery and understand the role leg dominance plays in recovery. The research focuses on three parameters: force output, peak muscle activation, and fatigue. Understanding discrepancies between the legs could potentially help optimize rehabilitation strategies to achieve full restoration of knee performance. This investigation holds promise for informing doctors and physical therapists about the need to tailor individual rehabilitation strategies as opposed to a one-size-fits-all knee injury recovery plan. The goal is to maximize knee recovery and, in turn, improve the overall quality of life for patients.

INTRODUCTION

The knee is a complex joint that consists of muscles, ligaments, and tendons created for stability and mobility[2]. When an injury occurs, such as an anterior cruciate ligament (ACL) tear, the natural biomechanics of the knee can be disrupted, leading to compensatory movements, and altered neuromuscular patterns. Despite successful surgery, some individuals may experience persistent issues with muscle activation, proprioception, and overall joint mechanics following surgery. Around 25% to 45% of ACL patients fail to return to preinjury activity level[3]. These individuals face undesirable neuromusculoskeletal deficits (i.e. muscle weakness) that contribute to an increased risk for reinjury and decreased quality of life[4]. Given that the goal of knee surgery is to help patients return to their preinjury activity levels, it's imperative to understand the neuromuscular function of these patients along with their knee biomechanics after going through these medical interventions. It's not just ACL repair; the effects of knee reconstruction on quadriceps and femoris muscle groups were also observed to have signs of strength loss even years after the surgery[2].

Understanding the changes that are happening to the knee post-surgery is crucial to enhance long-term knee health and potentially optimize post-surgical physical therapy. Therefore, this study focuses on investigating the discrepancies in muscle performance parameters between the surgical and nonsurgical knee. One aim of this study is to determine whether there is a noticeable difference between the peak muscular activation levels between the two legs. Changes in these activation patterns could characterize joint stability and overall leg performance. Another goal of this study is to assess the difference in force output. This could affect dynamic stability, which can be used by clinicians on the capabilities of the knees. Also, for both aims leg dominance is considered. Leg dominance can influence biomechanical and neuromuscular parameters, potentially influencing the post-operative outcomes of the patients. We hypothesized that there is a significant difference in leg muscle activation of a knee that has undergone knee surgery compared to its counterpart unaffected knee.

MATERIALS & METHODS

Study Design

The muscles of interest in the leg were quadriceps and hamstrings. Participants underwent assessments in the following order: quadriceps isometric voluntary force contraction, quadriceps fatigue test, hamstrings isometric voluntary force contraction, and hamstrings fatigue test. Between each test, the participant had a five-minute break. Surface EMG and a dynamometer were used to collect neuromuscular signal and force output respectively. The dynamometer was strapped to the participants' ankles. The configuration of EMG electrode placement for the hamstring and quad was found at SENIAM.org[5]. To transmit this data to the computer, an Arduino was used to transmit the EMG signal and force output to the computer. Data processing was done in MATLAB and Excel spreadsheets. Before doing the exercises, all participants had written consent forms and filled out a survey with questions about their knee surgery experience.

Participants

Individuals who had knee surgery only on one of their legs and were cleared from post-surgical therapy were included. The inclusion criteria were fully recovered from surgery, not participating in physical therapy or any process of post-surgical rehab and being a Georgia Tech student or faculty member. The exclusion criteria were no pre-existing medical conditions, must have only had surgery to one knee, and no additional lower body joint surgery.

Maximum Force Contraction

To have an isometric contraction for the muscle of interest, specific lower body exercises were chosen to only engage that muscle. For the quadriceps, the exercise was quad extension while sitting up. For the hamstring, the exercise was a hamstring curl laying abdomen-side down. All exercises used isometric resistance; no weight equipment was used. Both exercise procedures followed this template:

1. Connect EMG wires, electrode pads, and dynamometer to the left leg of the participant.
2. Participant gets in position to perform the exercise.
3. Participant performs the exercise with maximum voluntary contraction.
4. Record data and repeat steps 1-3 with the right leg.

<u>Fatigue Test</u>

Specific isometric exercises were selected to engage the quadriceps and hamstring. The fatigue test involves participants performing a specific exercise until fatigue. For quad fatigue, the exercise was a single leg raise and for the hamstring, it was the floor bridge exercise. Due to the nature of the floor bridge exercise, both legs were tested simultaneously for hamstring fatigue. All exercises used natural body weight; no equipment was used. Both exercise procedures followed this template:

1. Connect EMG wires, electrode pads, and dynamometer to the left leg of the participant.
2. Participant gets in position to perform the exercise.
3. Participant performs the exercise until failure or the stopping point of their choosing.
4. Record data and repeat steps 1-3 with the right leg (quad fatigue only).

<u>Statistical Analysis</u>

The data collected during the maximum force contraction and fatigue tests was first analyzed by finding the difference between the two values measured in each leg of participants. To find the difference between the maximum force output readings, the values produced by the dynamometer were converted to pounds. This was accomplished by testing the values produced by a variety of weights of known mass, and then creating a line of best fit to match the values produced by the dynamometer with the real-world weight in pounds. the maximum force output of the right leg was subtracted from the maximum force output of the left leg.

Finding the difference in the peak muscle activation data proved more difficult. First, the values collected by the electrode sensors were converted into millivolts (mV). Then, the peak activation for each leg was found by determining the maximum mean muscle activation value every 0.25 seconds. After finding the maximum moving mean value from each leg, the maximum moving mean value of the right leg was subtracted from the maximum moving mean value of the left leg.

Finally, the difference for the fatigue testing was determined using the line of best fit for the EMG data on each leg. Then, the slope of the line of best fit from the right leg was subtracted from the slope of the line of best fit from the left leg.

The difference values from each test were then analyzed using two multinomial logistic regression models. One model features data from controls and participants with surgery in their dominant leg, while the other model represents data from controls and participants with surgery in their non-dominant leg. These models determined which factors were correlated with a participant having knee surgery. The model produces a log coefficient value for each factor, which is essentially the "weight" of the factor in determining whether a participant has had knee surgery. The high positive log coefficient value signifies high positive correlation; a low negative log coefficient value signifies high negative correlation; and a log coefficient value close to zero signifies little correlation. Additionally, each of these log coefficient values was assigned a p value. Our α-value for this test was 0.05, so any of the log coefficient values that were statistically significant needed to have a p value lower than 0.05.

FIGURES

Visualization of Difference in Force Output between Legs (Surgery in Dominant Leg)

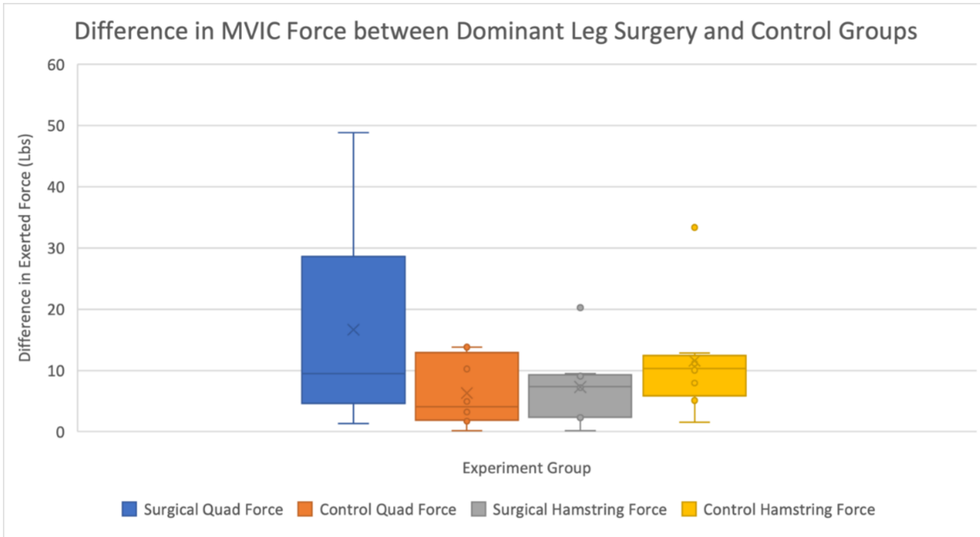

Figure 1: Difference in MVIC Force between Dominant Leg Surgery and Control Groups. This figure represents the absolute values of the difference between pounds of force exerted by muscles (quad and hamstring) of the right and left legs of two experimental groups. The Surgical group has a sample size of n=9. The Control group has a sample size of n = 8.

Visualization of Difference in Peak Muscle Activation between Legs (Surgery in Dominant Leg)

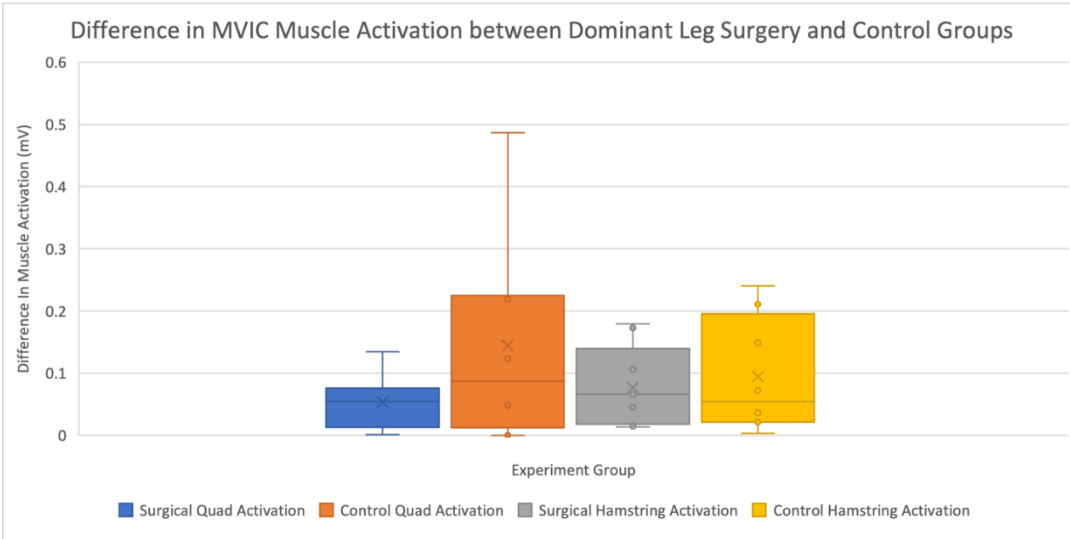

Figure 2: Difference in MVIC Muscle Activation between Dominant Leg Surgery and Control Groups. This figure represents the absolute values of the difference between mV of activation of the muscles (quad and hamstring) of the right and left legs of two experimental groups. The Surgical group has a sample size of n=9. The Control group has a sample size of n = 8.

Visualization of Fatigue Data

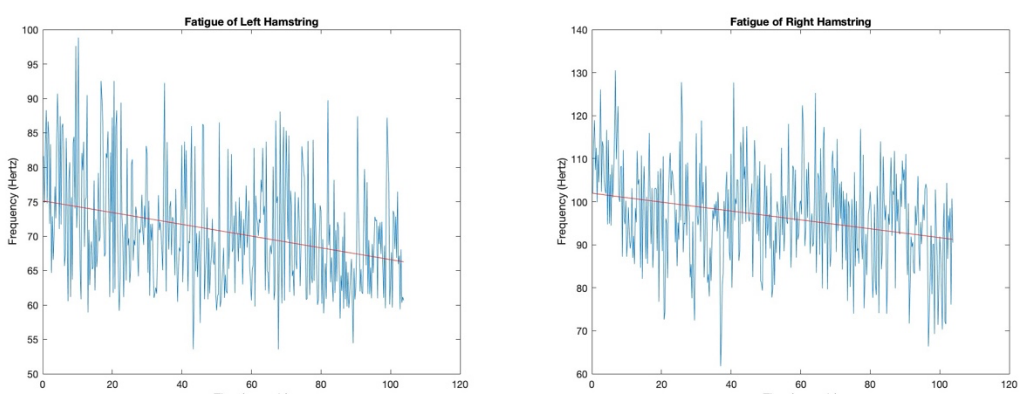

Figure 3: These graphs show the progression of fatigue in the left hamstring and the right hamstring of one participant. This is a way to visualize how the muscles fatigue over time, as seen by the slope of the red line. The difference in the slope was used as a parameter in our statistical

tests. The slope of the best fit line on the left is -0.0854; the slope of the best fit line on the right is -0.1032.

RESULTS

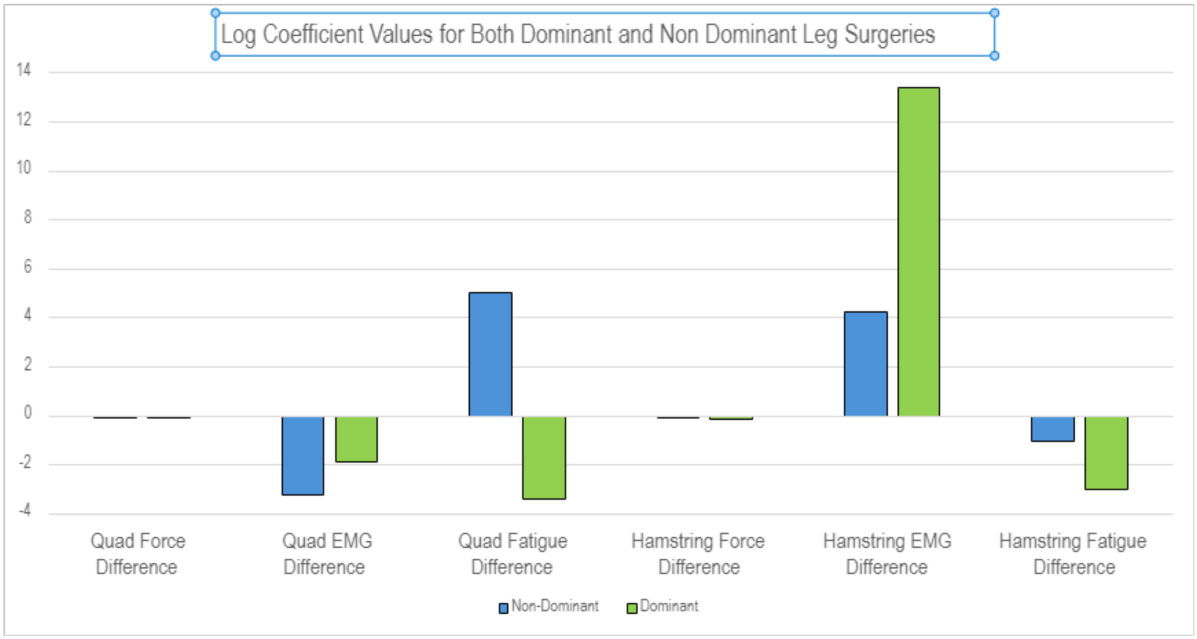

Figure 4: Log Coefficient Values for Both Dominant and Non-Dominant Leg Surgeries. This figure depicts the log coefficient values for each factor tested on. A large, positive value corresponds with a positive correlation between the factor and probability of surgery. None of the values had significant p-values ($p<0.05$).

EMG and force sensor data did not produce significant results. The six different factors, listed in Figure 4, show no positive or negative correlation in predicting the probability of surgery in either the non-dominant leg or the dominant leg, per statistical analysis. Despite the lack of statistical significance, some trends were shown based on the multinomial logistic regression models for the dominant and non-dominant leg surgery groups. The log coefficient value was calculated at 13.41, the largest positive coefficient value. The p-value for this value was $p=0.1151$, the smallest p-value for our results. These values suggest the potential for the difference in hamstring activation predicting surgery in the dominant leg. A similar positive correlation, though not significant, is shown in the non-dominant leg with the hamstring EMG difference. The log coefficient for the non-dominant leg was 4.25 ($p= 0.75$). This would suggest that hamstring EMG difference could potentially be a predictor in the dominant leg, but not the non-dominant leg. Still, at a p-value of 0.1649, the hamstring force difference log coefficient of –0.1242 has potential to not predict surgery in the dominant leg. It has less potential than the hamstring EMG difference as its p-value was further from a significant value of $p<0.05$. The remaining factors, for dominant and non-dominant legs, had p-values ranging from 0.2721 to 0.8724. These high values denote that the log coefficient values for the remaining factors are inconclusive. We cannot confidently determine if these factors have a positive, negative, or no correlation with predicting surgery on the dominant or non-dominant leg.

DISCUSSION

The results of this experiment lead to the failure to reject the null hypothesis. Based on the statistical testing performed, the parameters tested are not significant predictors that indicate whether an individual has had knee surgery. This was contradictory to the expectations at the beginning of this process, as it was assumed that the leg that had undergone surgery and recovery may have lasting deficits. This expectation was the result of anecdotal evidence and prior research. Other researchers had found neuromuscular activation differences between muscles, knee joint position, and stability. Other findings also show discrepancies in both mechanical disruption and sensorimotor integrity between the surgical and non-surgical knee[2, 6-8]. Most literature showing specific deficits in variables focused on anterior cruciate ligament (ACL) surgery. The null hypothesis that the leg muscle performance of a limb that has undergone knee surgery is not different than the leg muscle activation of the unaffected limb was based heavily on these previous studies results. From the p-values obtained, none of the muscle parameters that were tested showed significant discrepancies between the surgical and non-surgical knee. Six different parameters were tested, but their indication of surgery on a non-dominant or dominant knee was inconclusive. The most promising parameter at predicting surgery was the difference in hamstring EMG, specifically for the dominant leg. This factor has the most potential to reject the null hypothesis if testing were continued and improved.

The unexpected results in this experiment may be due to the small sample size, the wide range of surgery types, or the differences in activity level and rehabilitation processes across the participants. The testing pool was limited to Georgia Tech students and faculty, so most of the surgeries were ACL or ACL/meniscus reconstruction surgeries. This created a challenge in finding a suitable number of participants; there were only 3 participants who had received surgery on their non-dominant leg. Also, ACL reconstruction surgeries are typically sustained by athletes who undergo physical therapy and recovery to gain back full function of the injured knee and return to high levels of activity. With that in mind, this experiment is not representative of all surgeries, especially knee replacement surgeries which are more common in later stages of life. There were also errors in testing that can be minimized in future efforts. One set of data had to be eliminated due to an unusable EMG data set. The testing procedures were not 100% consistent across all tests, particularly regarding periods of rest between different tests. For example, some participants waited longer than others between their maximum voluntary isometric contraction test and their fatigue test. In addition, another confounding variable could be the lack of control for strenuous exercise utilizing the leg muscles prior to testing. Various levels of activity might have affected the results and total effort given during the testing.

Implications for further research include more specific experimental groups based on surgery type, time since surgery, rehabilitation type and quality, and age. In more specific and future research, leg dominance could potentially show effects on the parameters. Given the high log coefficient value for peak hamstring activation as a predictor for having undergone knee surgery, there is potential for further research. It would also be beneficial to run appropriately different analytical tests on the data to see what additional information can be gathered.

CONCLUSION

In conclusion, our findings failed to reject the null hypothesis despite previous research on the long-term effects of knee surgery. Limitations of this study included a small sample size, varied surgical procedures among participants, and varied rehabilitation timelines. While the hamstring EMG difference showed promise as a potential predictor for surgery in the dominant leg, overall, the parameters tested did not yield statistically significant results. Despite the unexpected outcome, this study provided insight into understanding how surgical interventions affect neuromuscular activity in the legs. This study highlighted the complicated nature of knee recovery from surgery and thus continued research is critical to provide better quality of life for the patients.

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