1998

An Electromyographic Study of Forward and Backward Walking in Normals and in Subjects following Anterior Cruciate Ligament Repair

Christopher C. Kraemer
University of North Dakota

AN ELECTROMYOGRAPHIC STUDY OF FORWARD AND BACKWARD WALKING IN NORMALS AND IN SUBJECTS FOLLOWING ANTERIOR CRUCIATE LIGAMENT REPAIR

by

Christopher C. Kraemer
Bachelor of Science in Physical Therapy
University of North Dakota, 1997

An Independent Study

Submitted to the Graduate Faculty of the

Department of Physical Therapy

School of Medicine

University of North Dakota

In partial fulfillment of the requirements

For the degree of

Master of Physical Therapy

Grand Forks, North Dakota
May
1998

This Independent Study, submitted by Christopher C. Kraemer in partial fulfillment of the requirements for the Degree of Master of Physical Therapy from the University of North Dakota, has been read by the Faculty Preceptor, Advisor, and Chairperson of Physical Therapy under whom the work had been done and is hereby approved.

(Faculty Preceptor)

(Graduate School Advisor)

(Chairperson, Physical Therapy)

PERMISSION

Title	An Electromyographic Study of Forward and Backward Walking in Normals and in Subjects Following Anterior Cruciate Ligament Repair.
Department	Physical Therapy
Degree	Master of Physical Therapy

In presenting this Independent Study Report in partial fulfillment of the requirements for a graduate degree from the University of North Dakota, I agree that the Department of Physical Therapy shall make it freely available for inspection. I further agree that permission for extensive copying for scholarly purposes may be granted by the professor who supervised my work or, in his/her absence, by the Chairperson of the department. It is understood that any copying or publication or other use of this Independent Study Report or part thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and the University of North Dakota in any scholarly use which may be made of any material in my Independent Study Report.

Signature ____________________

Date 12/18/97

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

I would like to thank my preceptor and advisor, Tom Mohr, for his support, guidance, consultation, and enthusiasm. I, also, wish to thank John Frappier and PT/OT Associates in Fargo, ND, for their assistance during data collection. A great deal of thanks is necessary for my co-author, Matthew Johnson, for his assistance and patience throughout the many hours this study required. And finally, special thanks are needed for my family, friends, classmates, and Jennifer for support, encouragement, and faith in me throughout my years at the University of North Dakota.

ABSTRACT

Physical therapy strives to incorporate innovative and efficient protocols for rehabilitation of anterior cruciate ligament (ACL) surgeries. Research supports the benefits of closed kinetic chain exercises (distal segment of extremity is fixed) over the traditional open kinetic chain exercises (distal segment not fixed). It is theorized that backward walking on inclined surfaces will recruit the knee musculature to a greater extent than forward walking, but there is little research to support this theory. The purpose of this study was to utilize electromyography during treadmill walking to analyze the muscle activity in the lower extremity of individuals were normal and who have had an ACL repair. Seventeen subjects (11 males, 6 females) at the mean age of 25 participated in the study.

The results for all subjects were that the muscle activity of the vastus medialis, vastus lateralis, semitendinosus and biceps femoris increased during backward walking in comparison to forward walking. The semitendinosus muscle activity remained relatively equal for forward and backward walking. Increasing the angle of treadmill incline during forward and backward walking generally increased muscle activity. The subjects were classified into two groups, the normal group (N=5) and ACL group (N=12). The results from the two groups varied, however, with small subject number in each group being a large reason for the differences. Future research will need to use a larger number of subjects from both types of repair populations.

CHAPTER I

INTRODUCTION

Because the ACL is protected in a closed kinetic chain, backward walking is a valuable rehabilitation tool utilized in ACL rehabilitation protocols.[1]

Problem Statement: Little published data exists that clearly documents the electromyographic activity of specified muscles during backward walking in comparison to forward walking in patients following ACL reconstruction.

The Purpose of this Study: To analyze and compare EMG activity during backward and forward walking in subjects who were both post ACL reconstruction surgery and normal.

Significance of Study: The results of this study will help confirm the efficacy of using backward walking in a clinical setting for the ACL population, in order to strengthen the affected lower extremity musculature.

Research Questions: 1) Will a change in walking direction affect the level of muscular activity in the lower extremity? 2) Will an alteration in treadmill incline affect the level of muscular activity in the lower activity?

Hypothesis: (Null Hypothesis) It is the researcher's belief that backward walking, as well as increasing the angle of the treadmill, will produce increases in activity within all the muscles tested.

CHAPTER II

LITERATURE REVIEW

Steidler[2] initially defined the concept of the closed kinetic chain as an occurrence in which the terminal joint meets with a considerable external force or resistance, which forbids or restricts its free motion. An example of this phenomenon is the performance of a squat. When lower extremity closed chain exercises are performed, motion occurs at the knee joint as well as at the hip and ankle joints. Conversely, open kinetic chain knee extension is hallmarked by a mobile foot and motion at the knee joint autonomous of the motion at the hip and ankle joints.[3]

The use of closed kinetic chain exercises, particularly in knee rehabilitation, has recently gained significant popularity among physical therapists and athletic trainers.[4] Closed kinetic chain exercises manifest an incredible therapeutic benefit in the application of functional stresses on a specific joint which resemble activities of daily living.[1, 3, 5, 6] Closed kinetic chain exercises are not plagued with the limitation of the axis of motion to one joint, but are associated with movement that occurs both proximally and distally to the joint.[3, 6] The recruitment of several muscle groups within one movement is another characteristic of closed kinetic chain exercises. This recruitment is synonymous with movement that is possessed by normal activity.[3, 5, 6] Additionally, the individual's own posture is greatly relied upon for stabilization within closed chain exercises. This emphasis on posture for stability is far more functional than an external strap or brace, which is utilized by many exercise machines.[3] Therefore, due to the stabilization of the extremity, proprioception training will result.[6] Another advantage that closed kinetic chain exercises possess is that they can be altered to mimic sport specific skills or training needs simply because they do not rely upon equipment design.

Anteroposterior (A/P) shear forces of the tibia on the femur are greatly diminished during closed chain knee exercises. This is accomplished in two ways. First, compressive forces occurring when the person's body weight compresses all the joints in the extremity are increased. [7, 8] When these forces load the extremity, there is a subsequent increase in joint stability, and more strenuous strengthening workouts are allowed. Therefore, the degree of shearing forces that occur with conventional open kinetic chain exercises is significantly reduced. Secondly, the activation of the hamstrings (a biarticular muscle) during closed kinetic chain exercises, will subsequently cause a reduction in anterior/posterior shear forces. This contraction of the hamstrings not only induces a flexion moment at both the hip and knee, but also acts to stabilize the hip while the quadriceps stabilize the knee. Co-contraction of the hamstring muscles also facilitates a neutralization of the anterior pull of the quadriceps.[1, 3, 9]

Closed kinetic exercises further provide a benefit by decreasing joint forces on the patellofemoral joint.[1, 3, 8] When performing an open chain leg extension exercise, the flexion moment (or torque) increases during movement of the knee from 90 degrees of flexion to full extension; therefore, a subsequent increase in the quadriceps and patellar tendon tension will result. The patellofemoral contact area decreases as the knee moves toward full extension, resulting in an increased contact stress per unit area. In a closed kinetic chain exercise, the flexion moment increases as the knee flexes, causing increased quadricep and patellar tendon tension. As a result, patellofemoral joint reaction forces will increase. This increase in joint reaction forces is much like the one observed with open kinetic chain exercises; however, in a closed kinetic chain exercise the contact stress upon the joint surfaces is minimized through force distribution over a larger patellofemoral contact area.[1, 8]

Many activities of daily living such as walking, stair climbing, and rising from seated position involve at least one foot in contact with the ground, and can consequently be considered closed chain activities. When examining these activities, the functionality of locomotion in the form of forward and backward walking is apparent. It has been proposed that additional benefits may be manifested within backward walking that lie beyond those obtained during forward walking only.[10-13]

Walking backward requires a higher oxygen demand and energy consumption than forward walking.[10] Additionally, studies have suggested that backward running possess lower impact forces than those observed during forward running, which may facilitate protection of the joints of the lower extremity from injury. Running backward may also be a key in the rehabilitation of patellofemoral syndrome in runners, because a reduction in compressive forces at the patellofemoral joint is imposed.[11] Threlkeld et al[13] found ground reaction force stress to be lower in backward runners when compared to forward runners. Therefore, runners, who have sustained joint trauma to the lower extremity, may utilize backward running in a rehabilitation program that will provide sport specific training along with a diminished risk of trauma.

Running backward further displayed a significant increase in the power of the upper leg musculature in subjects who trained for three months.[12] Both anterior lateral rotatory instability and anterior cruciate ligament instability benefited from the backward running program, when observing those same subjects. It was suggested by Threlkeld et al[13] that when assessing a patient isokinetically, backward running should be incorporated into a forward runner's program in order to increase peak quadricep musculature torque. In agreement with numerous other studies, his study suggests that running backward may create more quadricep muscle activity.[13-16] Additionally, Flynn et al[17] concluded the same results for retrograde walking.

It has been suggested that backward walking is a simple reversal of forward walking. Winter and Pluck[18] determined that the hip, knee, and ankle joints all possessed similar joint angle and moment patterns. In fact, images of joint patterns were almost opposite each other, proposing a basic reversal between concentric and eccentric contractions. Similar muscle activation patterns (EMG averages) were also observed in the muscles studied, with the exception of the rectus femoris and vastus medialis.

Researchers have described some specific differences between forward and backward gait.[10, 14, 19] Different joint kinematics have been noted along with a decreased stride length, and an increased cadence with walking backward in comparison to walking forward. Other authors have observed an increase in cardiopulmonary expenditure with backward walking versus forward walking,[10] along with an increase in quadricep activity (especially the rectus femoris, vastus medialis, and vastus lateralis).[15,17, 18] The existing literature on backward walking suggests that retrograde walking and running are beneficial for patients who have undergone anterior cruciate ligament repair.

The implementation of closed kinetic chain exercises is emphasized 2 to 3 weeks after surgery in many of the accelerated ACL rehabilitation protocols.[1, 6, 7, 20, 21] In addition, negative effects on the ACL graft appear to be minimized during lower extremity closed kinetic chain exercises.[1] Closed chain or weightbearing exercises reportedly reduce undesirable elongation of the ACL to a greater extent than open chain or non-weightbearing exercises.[19] Additionally, closed kinetic chain exercises elicit a reduction in A/P shear force through the activation of a co-contraction of the hamstrings and through axial loading during weight bearing exercises.[3]

CHAPTER III

METHODS

Subjects

Seventeen subjects (12 who had undergone an anterior cruciate ligament surgery, and 5 who had were classified as normal), ages 17-42, volunteered for this study. The normal group was composed of 2 females and 3 males. The subjects, who were nine to sixteen weeks post-operative anterior cruciate ligament reconstruction, included 4 females and 9 males (Table 1 and 2). All subjects were informed of the purpose of this study and their rights as a human subject. The subjects' approval of participation was obtained by completion of a consent form approved by the Institutional Review Board at the University of North Dakota, Medical Park, and Orthopedic Associates (Appendix).

Instrumentation

Electrodes were placed according to the motor point location on the vastus medialis (VM), vastus lateralis (VL), semitendinosus (ST), and biceps femoris (BF) of the involved lower extremity. These points were defined as one-fifth the distance from the medial knee joint line and the ASIS for the VM, one-fourth the distance between the lateral femoral condyle and the ASIS for the VL, one-half the distance between the lateral femoral condyle and the ischial tuberosity for the BF, and one-half the distance between the medial femoral condyle and the ischial tuberosity for the ST, respectively.[22] The hair over the motor points was clipped if necessary, and the skin cleansed with alcohol. Once the skin was prepared, two pre-gelled, self-adhesive electrodes (Multi Bio-Sensory, El

Table 1. ACL subject character table.

Subject	Age	Gender	Height	Weight	Extremity	Type of Surgery	Wks post surgery
1	21	MALE	6’3”	185 lbs.	RIGHT	PATELLAR	15 weeks
2	31	FEMALE	5’3”	120 lbs.	LEFT	PATELLAR	12 weeks
3	23	MALE	5’9”	165 lbs.	LEFT	PATELLAR	12 weeks
4	20	MALE	6’1”	224 lbs.	LEFT	PATELLAR	9 weeks
5	27	FEMALE	5’8”	135 lbs.	LEFT	PATELLAR	9 weeks
6	36	MALE	6’1”	182 lbs.	RIGHT	PATELLAR	9 weeks
7	22	MALE	6’0”	171 lbs.	RIGHT	HAMSTRING	16 weeks
8	20	FEMALE	5’6”	130 lbs.	RIGHT	HAMSTRING	11 weeks
9	42	MALE	5’10”	195 lbs.	RIGHT	HAMSTRING	10 weeks
10	18	MALE	6’2”	160 lbs.	RIGHT	HAMSTRING	12 weeks
11	17	FEMALE	5’6”	170 lbs.	LEFT	PATELLAR	11 weeks
12	27	MALE	5’10”	206 lbs.	RIGHT	PATELLAR	14 weeks

Table 2. Normal subject character table.

Subject	Age	Gender	Height	Weight
1	22	FEMALE	5’5”	117 lbs.
2	26	MALE	5’10”	195 lbs.
3	26	MALE	5’7”	155 lbs.
4	22	MALE	5’7”	155 lbs.
5	22	FEMALE	5’5”	115 lbs.

Paso, TX, 79913), were applied to the skin, two centimeters apart over the motor points, parallel to the muscle fibers. The distance between surface electrode placement attempted to minimize volume conduction between muscle groups, increasing the accuracy of specific muscular activity at each motor point.[23]

Foot switches (Noraxon USA, 13430 North Scottsdale Rd., Scottsdale, AZ, 85254) were used to determine the phases of the gait cycle. The switches were placed over the following anatomical points: 1) heel, 2) first metatarsal head, 3) fifth metatarsal head, and 4) great toe. The electrodes were secured to the skin with tape to prevent migration during treadmill activities. The subjects remained barefoot for the entire treadmill walking portion of the study.

A Penny & Giles M180 electrogoniometer (Penny & Giles Inc., 2716 Ocean Park Blvd., Santa Monica, CA, 90405) was applied over the lateral aspect of the involved knee joint in order to obtain knee range of motion during ambulation. The electrogoniometer was centered over the joint axis with the proximal end of the electrogoniometer aligned with the longitudinal axis of the femur, and the distal end aligned with the longitudinal axis of the fibula. The electogoniometer was secured to the skin with double-sided adhesive tape to avoid migration during data collection. The electrogoniometric zero was obtained by having the subject stand stationary with their lower extremities in full extension.

The subjects wore a waist belt containing a pre-amplified Noraxon Telemo8 telemetry unit (Noraxon USA, 1340 North Scottsdale Rd., Scottsdale, AZ, 85254), which received information from the EMG electrodes, the electrodes, the electrogoniometer, and the foot switches. The EMG signals were transmitted to a Noraxon Telemyo8 receiver and then digitized by a DT2801-Analog to a digital interface board installed in a NET 486DX computer. The digitized EMG signals were analyzed using the Myosoft data collection software that accompanies the Telemyo8 EMG system. The Myosoft software allows for several forms of data analysis once the EMG signals are collected.

Procedure

The treadmill was calibrated using a Veeder-Root 6611 Calibrater to 3.0 m.p.h. The subjects were tested for their maximal voluntary contraction (MVC) of the VM, VL, ST, and BF on the involved lower extremity to obtain a base line of activity. The data was used to normalize EMG data collected during forward and backward walking.

The MVCs of the vastus medialis and vastus lateralis were obtained with the subjects sitting with legs over the edge of a plinth. The subjects were allowed to lean backward and grasp onto the edge of a plinth. The subjects were allowed to lean backward and grasp onto the edge of surface for support. The knee was positioned in slight flexion, and stabilization was provided proximally to the knee joint without applying pressure over the quadriceps. The force of resistance was given proximal to the anterior ankle and for a duration of five seconds. The MVC for the semitendinosus and biceps femoris was obtained in the same position as the vastus medialis and vastus lateralis, using the same stabilization method and duration. The force of resistance was applied proximally to the posterior ankle.

Prior to experimentation, each subject's age, height, weight, gender, physician, date of surgery, type of surgery (specifically patellar or hamstring graft), and resting peripheral pulse rate. The subjects were then instructed on safety precautions while walking on the treadmill, on the use of the support rails for forward and backward walking, and on the application of the safety harness belt worn during backward walking. They were instructed on the proper procedure for getting on and off the treadmill for both forward and backward walking. The subjects were given warm up trial prior to the test, to become familiar with forward and backward barefoot walking on the treadmill. Data was collected from ten second trials of forward and backward walking at 3.0 miles per hour, and at 0,10,15 degrees of incline. Subjects were allowed a one-minute rest period between trials.

Once data collection was completed, the electrodes, foot switches, and electrogoniometer were removed and the skin cleansed with alcohol. Each subject was questioned via a brief interview to determine if the subject experienced any pain during any portion of the study. The subjects' pulse rate was again taken after the treadmill portion of the study. This concluded the subject's participation in the study.

Data Analysis

A descriptive analysis of the EMG data was performed using the Mysoft and Norquest software to make comparisons between forward and backward walking. The data collected from the normal subjects was analyzed separately and was compared to the results of the post-reconstructed anterior cruciate ligament patients. The normal subjects were obtained from a previous unpublished study conducted by Yoshimoto[24] and were reanalyzed. Ten of the twelve ACL subjects analyzed were obtained from an unpublished study by Litt.[4]

Normalization of EMG data is necessary to allow comparison between subjects (Noe[25]). The EMG data for the trials was normalized using the muscle activity that occurred during forward walking at 0% grade.

The ambulation data was quantified by selecting three consecutive phases of gait during forward and backward walking. The Myosoft and Norquest software was used to calculate the average activity using the fifty highest peaks during the three cycles. One gait phase was defined as the amount of activity between initial contact to initial contact of the same foot.

To obtain the normalized value, the average EMG activity obtained for each muscle during the three trials was divided by the average EMG activity obtained during forward walking at a zero degree incline and expressed as a percentage.

$$\%\text{Activity} = \frac{\text{Average EMG Activity During Exercise}}{\text{Average EMG Activity During Forward Ambulation } 0\,\%} * 100$$

CHAPTER IV

RESULTS

Muscle Recruitment for all Subjects:

Data was collected at a ten degree incline for all subjects. However, due to the similarities of the electromyographic activity at ten and fifteen degrees, this data was not analyzed. All quantitative data can be observed in table 3 on page 16. When observing FW15, BW0, and BW15, all muscles displayed an increase in activity as compared to forward walking at a zero percent grade (Figure 1). The activity level observed during backward walking was greater than that found during forward walking at fifteen degrees, regardless of treadmill inclination. Backward walking at fifteen degrees elicited the greatest increase in muscle activity for all muscles tested. The VM and VL muscle activity levels surpassed the activity in the ST and BF during backward walking at both zero and fifteen degrees.

Muscle Recruitment within the ACL Sample:

During FW15, the VL, ST, and BF achieved a higher level of activity than FW0, however, the VM demonstrated a slight decrease. All muscles display an increase in activity when walking backward, with the exception of the BF during BW0. Backward walking at zero degrees produced increases in muscle activity within the VM and VL, which surpassed the activity level in those same muscles during forward walking at fifteen degrees. In addition, the quadriceps tested displayed a greater increase in EMG activity than did the hamstrings when walking backward at zero and fifteen degrees (Figure 2).

Muscle Recruitment within the Normal Sample:

Compared to forward walking at zero degrees, an increase in muscle activity was noted during FW15, BW0, and BW15 in all the tested muscles. The greatest amount of activity was consistently observed within the vastus medialis during all activities. Backward walking at zero degrees elicited a greater amount of muscle activity than FW15 in all of the tested muscles. The activity within the quadriceps was greater than that observed within the hamstrings when walking backward (Figure 3).

Table 3. Electromyographic activity of lower extremity muscles during forward and backward walking. The values are given as a percent of forward walking at 0 degrees.

Normal Subjects

	Vastus Medialis	Vastus Lateralis	Semitendinosus	Biceps Femoris
FW 15 degrees	173.0%	104.5%	85.5%	134.6%
BW 0 degrees	245.1%	180.6%	94.0%	170.2%
BW 15 degrees	528.0%	482.6%	130.0%	238.4%

ACL Reconstructed Subjects

	Vastus Medialis	Vastus Lateralis	Semitendinosus	Biceps Femoris
FW 15 degrees	-13.9%	7.4%	14.5%	6.2%
BW 0 degrees	111.3%	25.8%	9.2%	-6.2%
BW 15 degrees	153%	84%	28.3	20%

All Subjects

	Vastus Medialis	Vastus Lateralis	Semitendinosus	Biceps Femoris
FW 15 degrees	79.6%	56.0%	50.0%	70.5%
BW 0 degrees	178.2%	103.2%	51.6%	82.0%
BW 15 degrees	340.5%	283.3%	79.2%	129.2%

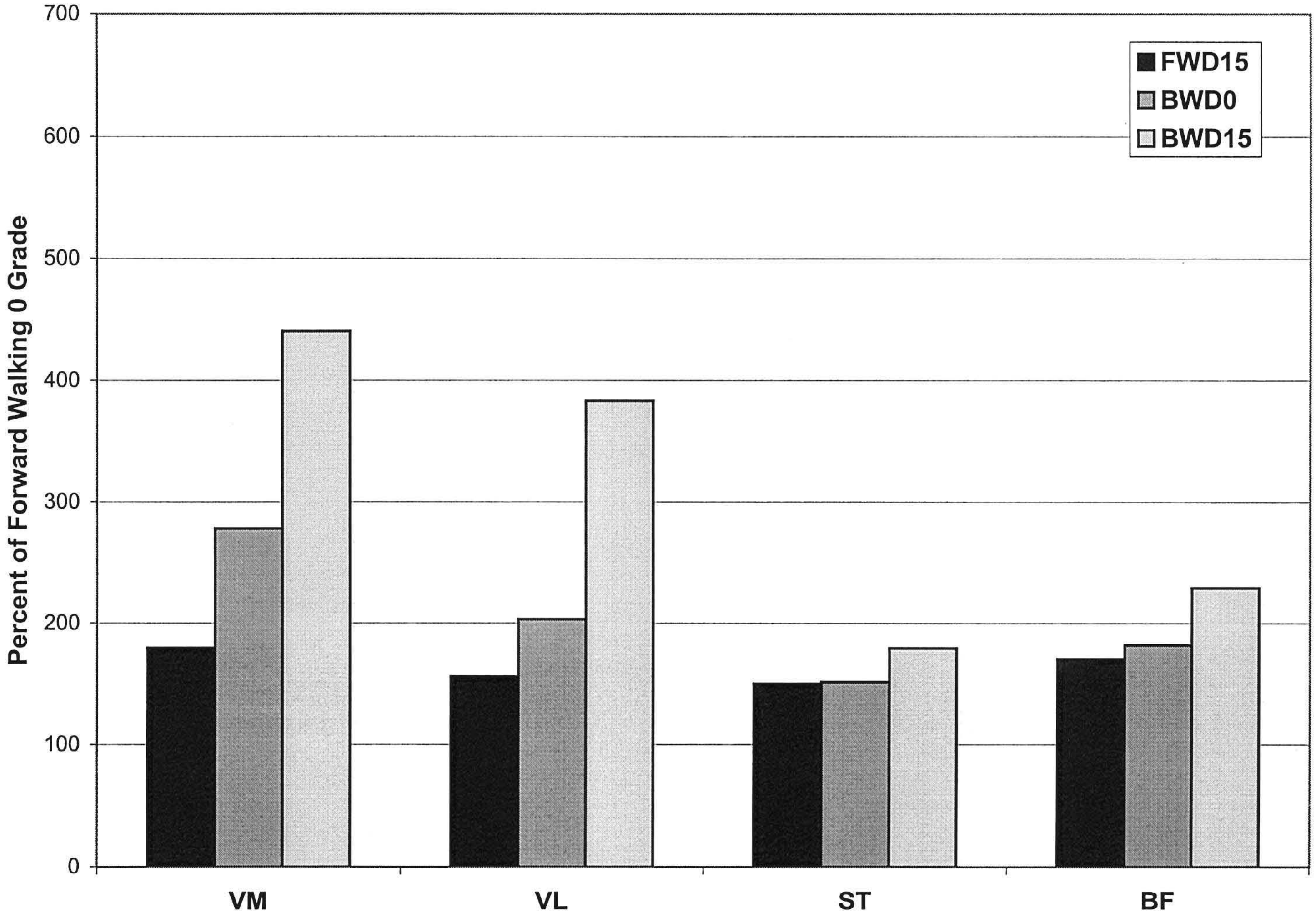

Figure 1. Electromyographic activity of the quadriceps and hamstrings during forward and backward walking in all subjects.

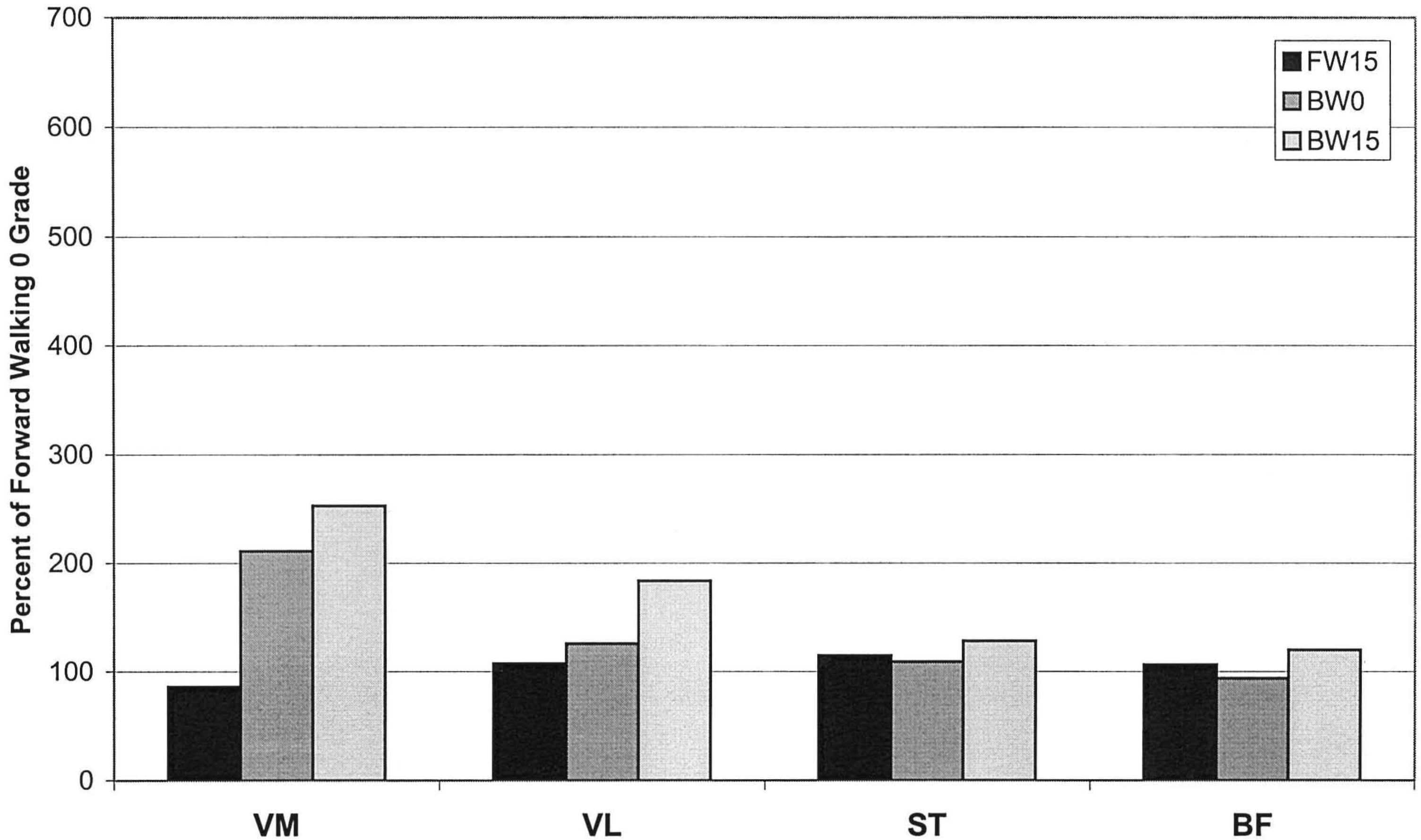

Figure 2. Electromyographic activity of the quadriceps and hamstrings during forward and backward walking in patients following ACL reconstructive surgery.

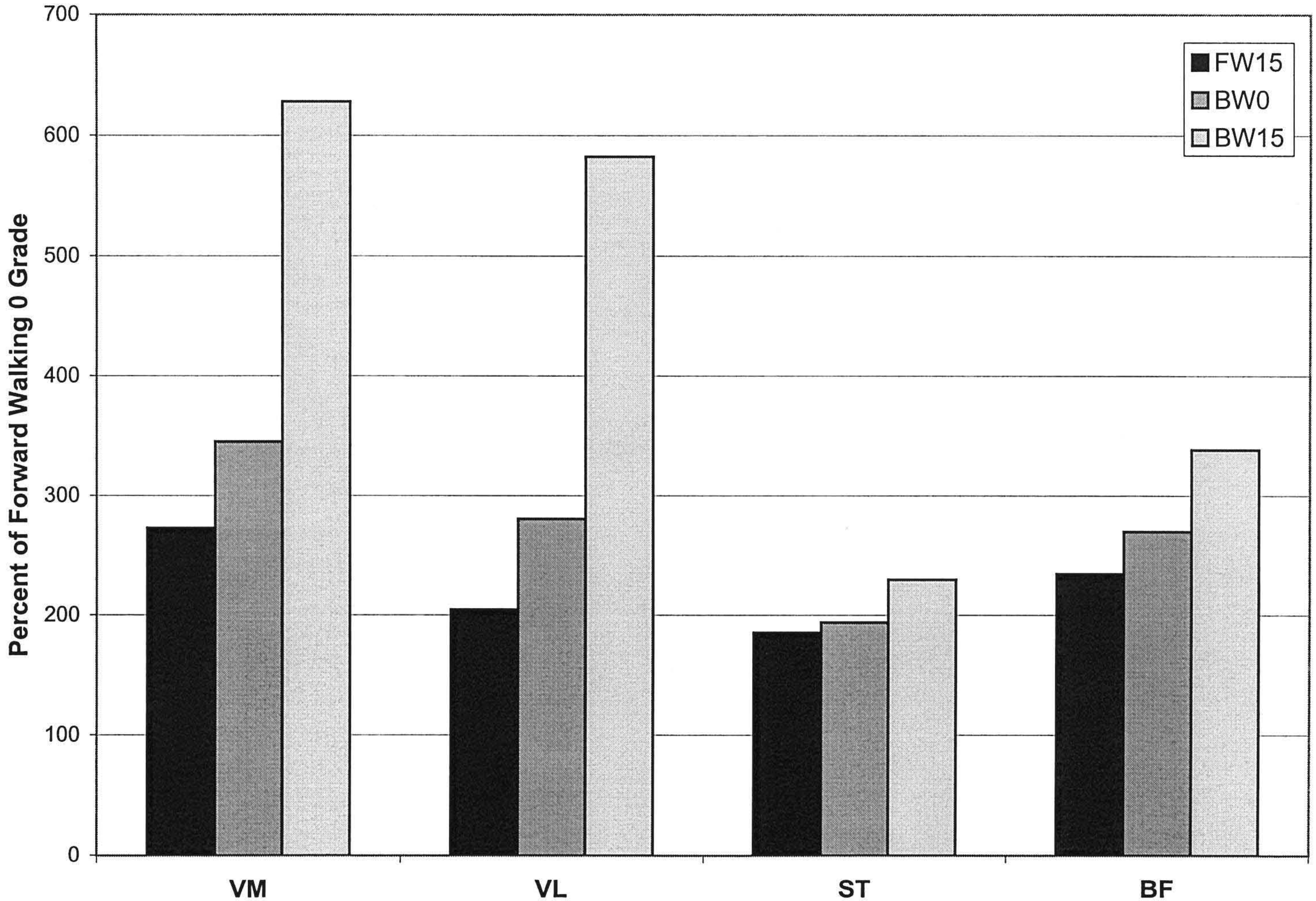

Figure 3: Electromyographic activity of the quadriceps and the hamstrings during forward and backward in normal patients.

CHAPTER V

DISCUSSION

Backward walking and forward walking are two distinct activities that possess many differences.[14, 24, 26] During backward walking, increases in activity within all of the muscles tested were noted when analyzing all of the subjects as a group. Increases in activity within the vastus medialis, vastus lateralis, and semitendinosus have been consistently observed by other researchers, as well.[15, 17, 19, 24] A reason for this may be that backward walking places functional demands on the body that are unique from those elicited by forward walking. One specific difference noted by Kramer and Reid[20] was that momentum is not as great during the backward swing phase; rather, there is an emphasis placed on pulling the leg backward. Consequently, during backward walking muscles are more active in pulling and stabilizing than during forward walking.

All Subjects:

When examining both subject samples together, the results of this study also support the findings of other authors that the activity within the quadricep musculature consistently exceeded that of the hamstrings at all levels of incline for both backward and forward walking.[17, 18, 24, 26] However, when examining the EMG activity of the semitendinosus, only small changes were not noted with variations of incline. The lower level of activity within the semitendinosus may be a result of the trauma placed on the tendon during graft removal in the semitedinosus/gracilis repair subjects. These results were consistent with those found in an unpublished study conducted by Litt[4]. In contrast, Cipriani et al[26] observed decreased semitendinosus activity in accordance with the degree of treadmill incline in normal subjects, especially at initial contact, midstance, and midswing phases of gait.

Normal subjects:

When observing the normal sample, an increase in muscle activity was noted at all angles of inclination during forward and backward walking in the vastus medialis, vastus lateralis, semitendinosus, and biceps femoris. The EMG activity present during backward walking surpassed that of forward walking at 0 percent incline in all muscles regardless of treadmill incline. There was also a subsequent increase in muscular activity as the angle of the treadmill was increased from 0 degrees to 15 degrees. These results were consistent with Yoshimoto's study.[24]

ACL sample:

Backward walking within the ACL sample elicited an increase in activity in all muscles tested, with the exception of the biceps femoris during backward walking at zero degrees. A slight decrease was noted within the vastus medialis during forward walking at fifteen degrees; however, all other muscles displayed a higher level of activity. Within the vastus lateralis and semitendinosus the electromyographic activity increased as the angle of the treadmill was increased during both forward and backward walking.

When comparing the results of this study to those obtained in an unpublished study by Litt[4], both similarities and differences can be observed. The electromyographic activity within the quadriceps was consistent with the results obtained by Litt[4]. There were a few discrepancies noted, however, in the activity of the vastus medialis and vastus lateralis. Litt[4] observed a greater amount of activity within the vastus medialis during forward walking at 15° than during forward walking at zero degrees and a decrease in activity during backward walking at 0° in comparison to forward walking at 15°. In addition, she found a decrease in activity within the vastus lateralis when forward walking at a 15° incline in comparison to forward walking at zero grade. Many differences can be noted between this study and Litt's[4] when observing the activity within the hamstrings. In fact, the only similarity in results detected for the semitendinosus is that the activity during backward walking at 0° is greater than that during forward walking at 0°. The electromyographic activity observed within the biceps femoris is also very different than that obtained by Litt.[4] The only consistency noted within this musculature is that the electromyographic activity during backward walking at 15° is greater than that at both 0° and 15° degrees of forward walking.

When observing the activity within the hamstrings, the differences noted between the results of this study and those achieved by Litt[4] became more apparent. The reason for this large discrepancy may lie within the means of data analysis. A maximum voluntary contraction was utilized as a baseline for comparison of electromyographic activity within Litt's[4] study, whereas walking three miles an hour at zero percent grade was utilized for this study's baseline. Other possible sources that may have contributed to these large differences are the variations and compensations acquired in the gait pattern of ACL repaired individuals. Although only two additional subjects were added to the sample of analyzed data, the gait compensations that they may have possessed could have skewed the results in this manner.

Limitations:

There were several limitations within this study. Although each patient was allowed a trial warm up on the treadmill before being tested, one day of additional practice on the treadmill for the subjects should have been allowed in order to familiarize the subjects with the exercise and to help standardize the amount of experience on the treadmill between subjects. The small number of subjects that participated was a definite shortcoming as well. Because both normal subjects and subjects who had undergone an ACL repair were utilized, it was a necessity to compare and contrast the similarities and differences that each group possessed. This not only limited the sample size, but it also posed yet another limitation by placing an uneven number of subjects in each group. Twelve subjects were classified as those who had undergone an ACL repair, and only five made up the normal subjects group. Therefore, generalizations derived from the limited numbers utilized should be made with caution. Another limiting factor that may have affected the results was the determination of motor points. Although careful attention was paid to the application and placement of electrodes, it is not possible to accurately state that the muscle activity observed was from the actual motor point or that the muscles in close proximity to those tested were not detected. Lastly, the absence of accurate gait analysis was a limitation. The use of cinematography or motion analysis is highly recommended in order to provide the utmost accuracy when monitoring the lower extremity musculature during gait.

Clinical Implications:

This study has shown that when performing backward walking there is an increase in overall muscular activity around the knee. This was consistent with both the post ACL reconstruction subjects and normal subjects. The use of backward walking should continue to be utilized in anterior cruciate ligament protocols because the surrounding musculature can be strengthened while the tension on the graft is minimized.

APPENDIX

REPORT OF ACTION: EXEMPT/EXPEDITED REVIEW
University of North Dakota Institutional Review Board

DATE: October 8, 1997 **PROJECT NUMBER:** IRB-9710-067

NAME: Thomas Mohr, Chris Kraemer, Matt Johnson **DEPARTMENT/COLLEGE:** Physical Therapy

PROJECT TITLE: An Electromyographic Study of Forward and Backward Walking in Normal Subjects

The above referenced project was reviewed by a designated member for the University's Institutional Review Board on October 14, 1997 and the following action was taken:

☑ Project approved. **EXPEDITED REVIEW** No. 3. Next scheduled review is on October 1998.

☐ Project approved. **EXEMPT CATEGORY** No. ________. No periodic review scheduled unless so stated in the Remarks Section.

☐ Project approved **PENDING** receipt of corrections/additions. These corrections/additions should be submitted to ORPD for review and approval. **This study may NOT be started UNTIL final IRB approval has been received.** (See Remarks Section for further information.)

☐ Project approval **deferred. This study may not be started until final IRB approval has been received.** (See Remarks Section for further information.)

☐ Project **denied.** (See Remarks Section for further information.)

REMARKS: Any changes in protocol or adverse occurrences in the course of the research project must be reported immediately to the IRB Chairperson or ORPD.

cc: T. Mohr, Adviser
Dean, Medical School

Vicki [signature] 10/14/97

Signature of Designated IRB Member — Date
UND's Institutional Review Board

If the proposed project (clinical medical) is to be part of a research activity funded by a Federal Agency, a special assurance statement or a completed 310 Form may be required. Contact ORPD to obtain the required documents.

(3/96)

Red River Valley
Sports Medicine Institute

October 6, 1997

Dr. Tom Mohr, Chairman
UND School of Medicine
PT Depart. Box 9037
Grand Forks, ND 58202-9037

Dear Mr. Mohr,

I have had the opportunity to review the research proposal "An Electromyographic Study of Forward and Backward Walking in Normal Subjects." As the Medical Director of the Red River Valley Sports Medicine Institute, I approve and fully support this research endeavor. We look forward to working together with you.

Sincererly,

Mark A. Lundeen, MD
Medical Director RRVSMI

_x_ EXPEDITED REVIEW REQUESTED UNDER ITEM _3_ (NUMBER[S]) OF HHS REGULATIONS
___ EXEMPT REVIEW REQUESTED UNDER ITEM ____ (NUMBER[S]) OF HHS REGULATIONS

UNIVERSITY OF NORTH DAKOTA HUMAN SUBJECTS REVIEW FORM FOR NEW PROJECTS OR PROCEDURAL REVISIONS TO APPROVED PROJECTS INVOLVING HUMAN SUBJECTS

PRINCIPAL INVESTIGATOR: Thomas Mohr and Chris Kraemer and Matt Johnson **TELEPHONE:** 777-2831 **DATE:** 10/6/97
ADDRESS TO WHICH NOTICE OF APPROVAL SHOULD BE SENT: P.O. Box 9037, UND

SCHOOL/COLLEGE: Medicine **DEPARTMENT:** Physical Therapy **PROPOSED PROJECT DATES:** 10/15/97-5/31/98 (Month/Day/Year)
PROJECT TITLE: An Electromyographic Study of Forward and Backward Walking in Normal Subjects
FUNDING AGENCIES (IF APPLICABLE): ____

TYPE OF PROJECT (Check ALL that apply):

_X_ NEW PROJECT ___ CONTINUATION ___ RENEWAL ___ DISSERTATION OR THESIS RESEARCH _X_ STUDENT RESEARCH PROJECT

___ CHANGE IN PROCEDURE FOR A PREVIOUSLY APPROVED PROJECT

DISSERTATION/THESIS ADVISER, OR STUDENT ADVISER: Thomas Mohr

PROPOSED PROJECT: ___ INVOLVES NEW DRUGS (IND) ___ INVOLVES NON-APPROVED USE OF DRUG _X_ INVOLVES A COOPERATING INSTITUTION

IF ANY OF YOUR SUBJECTS FALL IN ANY OF THE FOLLOWING CLASSIFICATIONS, PLEASE INDICATE THE CLASSIFICATION(S):

___ MINORS (<18 YEARS) ___ PREGNANT WOMEN ___ MENTALLY DISABLED ___ FETUSES ___ MENTALLY RETARDED

___ PRISONERS ___ ABORTUSES _X_ UND STUDENTS (>18 YEARS)

IF YOUR PROJECT INVOLVES ANY HUMAN TISSUE, BODY FLUIDS, PATHOLOGICAL SPECIMENS, DONATED ORGANS, FETAL MATERIAL, OR PLACENTAL MATERIALS, CHECK HERE ____

IF YOUR PROJECT HAS BEEN\WILL BE SUBMITTED TO ANOTHER INSTITUTIONAL REVIEW BOARD(S),PLEASE LIST NAME OF BOARD(S): Red River Valley Sports Medicine, Fargo, North Dakota

Status: _X_ Submitted; Date 10/6/97 ___ Approved; Date ____ Pending

1. **ABSTRACT:** (LIMIT TO 200 WORDS OR LESS AND INCLUDE JUSTIFICATION OR NECESSITY FOR USING HUMAN SUBJECTS.

It has become commonplace in many physical therapy clinics to employ both forward and backward treadmill walking in the rehabilitation programs of patients with post-anterior cruciate repairs. Although this technique is used, there is little evidence available as to the muscle activity required in backward walking as compared to forward walking. Some clinicians speculate that backward walking recruits lower extremity muscles in a different pattern than forward walking, and they claim that backward walking causes greater use of the hamstring muscles than does forward walking. There is little evidence to support any of the clinical claims, because there is no published research on this particular form of exercise. In an effort to provide clinicians with information as to the muscle activity in both forward and backward treadmill walking, we are proposing to study four knee muscles during treadmill walking; with both a level treadmilll and at several different inclines. Information gained from this study will help provide clinicians with information that will be useful to them in setting up exercise protocols for the patient populations. Since this technique is presently used clinically, it is necessary that we utilize human subjects for this study

PLEASE NOTE: Only information pertinent to your request to utilize human subjects in your project or activity should be included on this form. Where appropriate attach sections from your proposal (if seeking outside funding).

2. **PROTOCOL:** (Describe procedures to which humans will be subjected. Use additional pages if necessary.)

SUBJECTS:

It is anticipated that we will recruit 10 normal, healthy, male and female volunteers, ages 19 to 40 years. The subjects used for this study will be physical therapy students enrolled in the professional physical therapy program at UND.

METHODS:

We will measure the electromyographic (EMG) activity in these four lower extremity muscles: 1) vastus medialis, 2) vastus lateralis, 3) biceps femoris, and 4) semitendinosus. Knee range of motion, and foot-ground contact during treadmill walking will also be analyzed.

To record the EMG activity, surface electrodes will be placed over the muscle under study. The EMG signals will be transmitted to the receiver unit and then relayed into a computer for display and for recording data. Prior to beginning the experimental trials, each subject will be asked to perform a maximal voluntary contraction (MVC) of each monitored muscle. The activity recorded during the MVC will be considered as 100% EMG activity level, which the EMG activity during treadmill walking can be compared. This procedure is done to normalize the EMG data for later analysis.

An electrogoniomter will be used to measure knee range of motion during treadmill walking. The electrogoniometer will be attached to the thigh and leg above and below the knee joint, respectively using double sided adhesive tape. This will allow measurement of knee flexion during treadmill walking. The electrogoniometer will be calibrated prior to beginning the experimental trial to assure accuracy of measurement.

A footswitch device will be secured with tape to the foot at the following points: 1) heel, 2) 1st metatarsal head, 3) 5th metatarsal head, and 4) great toe. The switch will trigger a small signal that will be recorded during the various phases of the gait cycle.

Prior to the trials, each subject's age, height, and weight will be recorded. During the experimental trials, the involved lower extremity will be used for data collection. Before beginning the experiment, each of the subjects will be given a short training session on proper treadmill ambulation.

The actual experiment involves applying the electrogoniometer device and the footswitch apparatus to each subject. The skin of the lower extremity will be cleansed with alcohol before attachment of the self-adhesive pre-gelled EMG electrodes over the muscles. The subject will be asked to elicit a MVC of each monitored muscle which will be recorded on the computer as a reference voltage level. The actual experiment will consist of the following trials: 1) forward and backward walking at 0 degrees of incline, 2) forward and backward walking at 10 degrees of incline, and 3) forward and backward walking at 15 degrees of incline. Treadmill speed will be set at 3.0 m.p.h for all the trials.

Subjects will be asked to walk on treadmill for a trial period of 15 seconds during which time the EMG, electrogoniometer, and footswitch data will be collected and recorded. Subjects will be allowed one minute rest periods between the experimental trials to avoid a fatigue factor. Finally, the subjects will be given a rest period while the electrodes, electrogoniometer, and footswitch devices are removed.

DATA ANALYSIS:

Descriptive statistics characterizing the subject's anthropometric profiles will be provided. Statistical analysis (t-test & ANOVA) will be performed on the following dependent variables: 1) integrated EMG activity, and 2) electrogoniometric measurements.

3. **BENEFITS:** (Describe the benefits to the individual or society.)

The results of this study will help to determine if backward walking shows a different muscle recruitment pattern than forward walking. At the present time, there is no available research data on backward vs forward walking, and therefore its use in the clinic is unsupported. If backward walking is determined to increase muscle activity, it could validate its use in an ACL rehabilitation protocol. It is expected that the use of backward walking increases recovery rate and the return to full activities of daily living, thus decreasing the cost of lengthy rehabilitation. If this exercise proves beneficial, it may become a well accepted and integral activity in the rehabilitation of ACL repair.

4. **RISKS:** (Describe the risks to the subject and precautions that will be taken to minimize them. The concept of risk goes beyond physical risk and includes risks to the subject's dignity and self-respect, as well as psycho-logical, emotional or behavioral risk. If data are collected which could prove harmful or embarrassing to the subject if associated with him or her, then describe the methods to be used to insure the confidentiality of data obtained, including plans for final disposition or destruction, debriefing procedures, etc.)

The risk to the subjects in this experiment will be minimal. Treadmill walking is a safe form of exercise and the amount of time on the treadmill is minimal. During the course of the experiment, subjects will be accompanied on the treadmill by an assistant, and treadmill hand rails will be close by for added safety. The EMG, electrogoniometer, and footswitch equipment will cause no discomfort to the subjects, since they are only monitoring devices. The subjects will be asked to wear gym shorts during the experiment, and every effort will be taken to preserve subject dignity during the course of the experiment.

5. **CONSENT FORM:** A copy of the **CONSENT FORM** to be signed by the subject (if applicable) and/or any statement to be read to the subject should be attached to this form. If no **CONSENT FORM** is to be used, document the procedures to be used to assure that infringement upon the subject's rights will not occur.

Describe where signed consent forms will be kept and for what period of time.

The consent forms will be kept by Thomas Mohr at the University of North Dakota, Department of Physical Therapy, Room 1521, Medical Science Building for a period of three (3) years. A copy of the consent form is attached.

Copies of the original data will be archived on computer disk in the office of Dr. Thomas Mohr, Department of Physical Therapy, Room 1521, Medical Science North Building for a period of at least three (3) years.

6. For **FULL IRB REVIEW** forward a signed original and thirteen (13) copies of this completed form, and where applicable, thirteen (13) copies of the proposed consent form, questionnaires, etc. and any supporting documentation to:

Office of Research & Program Development
University of North Dakota
Grand Forks, North Dakota 58202-7134

On campus, mail to: Office of Research & Program Development, Box 7134, or drop it off at Room 105 Twamley Hall.

For **EXEMPT** or **EXPEDITED REVIEW** forward a signed original and a copy of the consent form, questionnaires, etc. and any supporting documentation to one of the addresses above.

The policies and procedures on Use of Human Subjects of the University of North Dakota apply to all activities involving use of Human Subjects performed by personnel conducting such activities under the auspices of the University. No activities are to be initiated without prior review and approval as prescribed by the University's policies and procedures governing the use of human subjects.

SIGNATURES:

Thomas Mohr, Matt Johnson [signature] 10/6/97

Principal Investigator Date

Project Director or Student Adviser Date

Training or Center Grant Director Date

(Revised 3/1996)

INFORMATION AND CONSENT FORM

TITLE: An Electromyographic Study of Forward and Backward Walking In Normal Subjects.

You are being invited to participate in a study conducted by Dr. Thomas Mohr, a Professor at the University of North Dakota. The purpose of this study is compare muscle activity in your lower extremity while you are walking on the treadmill. We hope to learn that backward walking will recruit the knee musculature to a greater extent than forward walking. Only normal, healthy subjects will be asked to participate in this study.

You will be asked to walk on a treadmill under the following conditions: 1) forward and backward walking at 0 degrees of incline, 2) forward and backward walking at 10 degrees of incline, and 3) forward and backward walking at 15 degrees of incline. The treadmill speed will be set at 3.0 m.p.h. Each experimental trial duration will be 15 seconds, and you will be allowed a one minute rest period between trials.

The study will take approximately one hour of your time. You will be asked to report to Red River Valley Sports Medicine in Fargo, ND at an assigned time. You will then be asked to change into gym shorts for the experiment. We will first record your age, gender, height , and weight. During the experiment, we will be recording the amount of muscle activity you have when you walk on the treadmill, measure the amount of movement that occurs in your knee joint, and record data from foot contact with the ground.

Although the process of physical performance testing always involves some degree of risk, the investigator in this study feels that the risk of injury or discomfort is minimal. In order for us to record the muscle activity, we will be placing nine electrodes on your lower extremity. The recording electrodes are attached to the surface of the skin with an adhesive material. We will also attach a measuring device to your knee with adhesive material. We will place footswitches on the sole of foot. None of these electrodes or devices penetrate the skin, and they should cause no discomfort. These devices only record information from your muscles and joints, they do not stimulate the skin. After we get the electrodes attached, we will give you a brief training session to teach you how to walk on treadmill. The amount of walking you will be asked to perform will be minimal compared to what you might expect of walking on a daily basis.

Your name will not be used in any reports of the results of this study. Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. The data will be identified by a number known only by the investigator. The investigator or participant may stop the experiment at any time if the participant is experiencing discomfort, pain, fatigue, or any other symptoms that may be detrimental to his/her health. Your decision whether or not to participate will not prejudice your future relationship with the Physical Therapy Department or the University of North Dakota. If you decide to participate, you are free to discontinue participation at any time without prejudice.

The investigator involved is available to answer any questions you have concerning this study. In addition, you are encouraged to ask any questions concerning this study that you may have in the future. Questions may be asked by calling Dr. Thomas Mohr at (701) 777-2831. A copy of this consent form is available to all participants in the study.

In the even that this research activity (which well be conducted at Red Rive Valley Sports Medicine) results in a physical injury, medical treatment will be available, including first aid, emergency treatment,and follow up care as it is to member of the general public in similar circumstances. Payment for any such treatment must be provided by you and your third party payor, if any.

ALL OF MY QUESTIONS HAVE BEEN ANSWERED AND I AM ENCOURAGED TO ASK ANY QUESTIONS THAT I MAY HAVE CONCERNING THIS STUDY IN THE FUTURE. MY SIGNATURE INDICATES THAT, HAVING READ THE ABOVE INFORMATION, I HAVE DECIDED TO PARTICIPATE IN THE RESEARCH PROJECT.

I have read all of the above and willingly agree to participate in this study explained to me by Dr. Thomas Mohr.

____

Participant's Signature Date

____

Witness (not the scientist) Date

REFERENCES

1. Fu FH, Woo Sly, Irrange JJ. Current concepts for rehabilitation following anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther.* 1992;15:270-278.

2. Steindler A. *Kinesiology of the Human Body Under Normal and Pathological Conditions.* Springfield IL: Charles C. Thomas Co.;1973.

3. Rivera JE. Open vs. closed kinetic chain rehabilitation of the lower extremity: A functional and biomechanical analysis. *J Sport Rehab.* 1994;3:154-167.

4. Litt, S. An electromyographic study of backward walking following anterior cruciate ligament repair. Unpublished data. 1997.

5. Panariello RA. The closed kinetic chain in strength training. *National Strength and Conditioning Association Journal.* 1991;13:29-33.

6. Case JG, DePalma BF, Zelko RR. Knee rehabilitation after anterior cruciate ligament repair/reconstruction: An update. Athletic Training, *JNATA.* 1991;26:22-31.

7. Shelborne KD, Nitz P. Accelerated rehabilitation after anterior cruciate ligament reconstruction. *Am J Sports Med.* 1990;18:292-299.

8. Yack JH, Collins CE, Whieldon TJ. Comparison of closed and open kinetic chain exercise in the anterior cruciate ligament –deficient Knee. *Am J Sports Med.* 1993;21:49-54.

9. Draganich LF, Jaeger RJ, Kralj AR. Coactivation of the hamstrings and quadriceps during extension of the knee. *J Bone Joint Surg.* 1989;71:1075-1081.

10. Myatt G, Baxter R, Doughery R, Williams G, Halle J, Stetts D, Underwood F. The cardiopulmonary cost of backward walking at selected speeds. *J Orthop Sports Phys Ther.* 1995;21:132-139.

11. Flynn TW, Soutas-Little RW. Patellofemoral joint compressive forces during forward and rearward running. *Med Sci Sports Exerc.* 1991;23:S6(abstract).

12. Mackie JW, Dean TE. Running backward training effects on upper leg musculature and ligamentous instability of injured knees. *Med Sci Sports Exerc.* 1984;16:151.

13. Threlkeld AJ, Horn TS, Worrowicz JG, Rooney JG, Shapiro R. Kinematics, ground reaction force, and muscle balance produced by backward walking. *J Orthop Sports Phys Ther*. 1989;11:56-63.

14. Vilensky JA, Gankiewicz E, Gehlsen G. A kinematic comparison of backward and forward walking in humans. *J Human Movement Studies*. 1987;13:29-50.

15. Thorstensson A. How is the normal locomotor program modified to produce backward walking? *Exp Brain Res*. 1986;61:664-668.

16. Flynn TW, Soutas-Little RW. Mechanical power and muscle action during forward and backward running. *J Orthop Sports Phys Ther*. 1993;17:108-113.

17. Flynn TW, Soutas-Little RW. Comparison of mechanical power and muscle activity during forward walking and backward walking. *J Orthop Sports Phys Ther*. 1994;19:63-64.

18. Winter DA, Pluck N. Backward walking: A simple reversal of forward walking? *J Motor Behav*. 1989;21:291-305.

19. Kramer JF, Reid DC. Backward walking: A cinematographic and electromyographic pilot study. *Physiother*. 1981;33:77-86.

20. DeCarlo MS, Sell KE, Shelborne D, Klootwky TE. Current concepts on accelerated ACL rehabilitation. *J Sports Rehab*. 1994;3:304-318.

21. Podesta L, Podesta G. Rehabilitation of the anterior cruciate ligament. *J Musculoskeletal Medicine*. 1994;11:54-64.

22. Zipp P. Recommendations for the standardization of lead positioning in surface electromyography. *Eur J Appl Physiol*. 1982;50:41-54.

23. Basmajian J, Deluca C. *Muscles Alive: Their Functions Revealed by Electromyography*. 5th ed. Baltimore: Williams and Wilkins; 1985.

24. Yoshimoto D, Mohr T, Palmgren A, Frappier J. An electromyographical study of quadriceps and hamstrings activity during forward and backward treadmill walking. Phys Ther. 1997;77;5:s36.

25. Noe DA, Mostardi RA, Jackson M, Poterfield JA, Askew MJ. Myoelectric activity and sequencing of selected trunk muscles during isokinetic lifting. *Spine*. 1992;17(2):225-229.

26. Cipriani DJ, Armstrong CW, Gaul S. Backward walking at three levels of treadmill inclination: An electromyographic and kinematic analysis. *J Orthop Sports Phys Ther*. 1995;22:95-102.