Knee Flexion Angle and its Influence on VMO:VL Ratios During Isometric Quadriceps Contraction

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KNEE FLEXION ANGLE AND ITS INFLUENCE
ON VMO:VL RATIOS
DURING ISOMETRIC QUADRICEPS CONTRACTION

By
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William D. Allan SPT

THESIS

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KNEE FLEXION ANGLE AND ITS INFLUENCE ON VMO:VL RATIOS DURING ISOMETRIC QUADRICEPS CONTRACTION

ABSTRACT

Patellofemoral Pain Syndrome (PFPS) is a major cause of knee pain and is caused by lateral patellar tracking. Treatment consists of strengthening the vastus medialis obliquus (VMO). While many exercises strengthen the VMO, simultaneous vastus lateralis (VL) strengthening often occurs and patellar malalignment remains. The VMO must, therefore, be strengthened independently or to a greater extent than the VL. Thus, the VMO:VL ratio of activity must be considered rather than VMO activity alone. This study compared isometric knee extension electromyographically at 0, 20, 60, and 90 degree angles to determine which angle produced the greatest VMO:VL ratio of activity. Results of this study indicated no significant differences among angles tested for VMO:VL ratio during isometric knee extension. Further research is needed to investigate the possibility of significant associations between VMO:VL ratios and gender, pathology, and angles not included in this study.
ACKNOWLEDGMENTS

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PREFACE
Definitions of Terms

**Patellofemoral Pain Syndrome (PFPS)**—pain resulting from a dysfunction of the patella’s ability to track in the femoral groove

**Isometric quadriceps sets**—a contraction of the quadriceps in which tension is developed but no joint movement or change in muscle length occurs. This contraction is performed at terminal knee extension

**Short-arc quadriceps sets**—an exercise where the leg is moved through the last 35 degrees of extension

**Isometric knee extension**—a contraction of the quadriceps in which tension is developed but no joint movement or change in muscle length occurs. This contraction can be performed at any angle.

**Q-angle**—the acute angle formed between intersecting lines drawn from the anterior-superior iliac spine through the mid-portion of the patella, and from the anterior tibial tuberosity through the mid patella. Normally 15 degrees

**Subluxation**—an incomplete or partial dislocation

**Pes planus**—condition of the foot in which the medial longitudinal arch is decreased. Also known as pronated or flat foot

**Genu recurvatum**—a condition characterized by a hyperextension of the knee

**Biofeedback**—training technique utilizing visual and audio output regarding muscle activity via electromyography. Subjects are, therefore, trained to selectively stimulate or inhibit a specific
muscle
electromyography (EMG)-technique in which muscle activity is detected and recorded through an electrical medium

hip adduction-movement of the femur toward the midline of the body
goniometer—a device used to measure joint angles
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CHAPTER 1
INTRODUCTION

According to Malek and Mangine,1 “Patellofemoral Pain Syndrome (PFPS) is the number one cause of knee pain in a majority of the knee clinics in sports medicine centers around the country.” Many researchers agree that the major underlying cause of PFPS is a malalignment of the patellofemoral joint causing the patella to track laterally in the patellofemoral groove. Malalignment is due to a variety of causes. These causes include abnormal architecture and articulation of the patellofemoral joint, a tight lateral retinaculum, and a muscular imbalance between the vastus medialis obliquus (VMO) and the vastus lateralis (VL). The result of these abnormalities is a laterally tracking patella causing pain for the patient.

The VMO has been identified as the only structure with the ability to pull the patella medially. Theoretically, strengthening of the VMO will correct malalignment thus relieving pain. Exercises recommended by researchers and therapists to strengthen the VMO include isometric quadriceps sets, straight leg raises,
short-arc quadriceps sets, isometric knee extension, and various types of squats and step ups. Many of these protocols have been found to successfully strengthen the VMO. However, while strengthening the VMO, these exercises may also strengthen the VL to the same degree. Even though the VMO is strengthened, it may still not be able to pull the patella medially because of the simultaneous strengthening of the VL pulling the patella laterally. For an exercise to be efficient in altering malalignment and reducing pain, it is necessary to strengthen the VMO independent of the VL or at least strengthen it to a significantly greater degree than the VL. When identifying an exercise that corrects malalignment, the researcher should look at the VMO:VL ratio of activity rather than simply VMO activity.

Finding an exercise that can specifically strengthen the VMO and thus relieve pain would be of great benefit to many people. It has been estimated that the incidence of PFPS in the general population is as high as one in four. A proven protocol in combating PFPS would also save the therapist much time and anguish and possibly influence reimbursement by third party payors.
Several authors have recommended an isometric contraction of the quadriceps to facilitate strengthening of the VMO. Many believe that this contraction should be performed at terminal knee extension. Others believe that isometric quadriceps contractions should be performed at 20 degrees of flexion. More recently researchers have suggested that these isometric quadriceps contractions should be performed between the range of 60 and 90 degrees of knee flexion. The problem is that there is little scientific data that indicates the VMO is strengthened to a greater degree than the VL in any of these ranges of motion (ROM) during an isometric contraction. The purpose of this study is to compare the activity of the VMO relative to the activity of the VL at various points between 0 and 90 degrees of knee flexion during isometric contraction. Our hypothesis is that isometric quadriceps contractions between 60 and 90 degrees of flexion will result in larger VMO:VL ratios than at other ranges of motion in the knees of healthy college age males and females.
CHAPTER 2
LITERATURE REVIEW

The majority of this literature review relates to the exercises and theories surrounding the selective strengthening of the VMO. For a better understanding of these exercises and theories, it is important that the reader have a background in the prevalence and causes of PFPS, the anatomy of the patellofemoral joint, and the role of the VMO.

Prevalence and Causes of PFPS

Patellofemoral pain syndrome (PFPS) presents as a significant problem for many athletes involved in sporting activities and is classified as a dysfunction of the patella's ability to track properly in the femoral groove. PFPS has been called the number one cause of knee pain in a majority of the knee clinics in sports medicine centers around the country, and its incidence in the general population is as high as one in four. This syndrome is characterized by pain in the anterior portion of the knee and can be attributed to many different causes. The end result, however, appears to be excessive lateral pressure on the patellofemoral (PF)
articulation.6

One of the major causes of PFPS is malalignment of the PF joint.1-6,8 Kramer 6 lists the four main causes of malalignment as 1) architectural abnormalities of articulation, 2) muscle imbalance between VMO and VL, 3) retinacular abnormalities, and 4) an increased Q-angle. Kettlekamp5 agrees with these same four causes adding laxity of the medial retinaculum and atrophy of the VMO as underlying causes of malalignment. Fulkerson3 states that PF malalignment may cause repeated mild to moderate subluxation and relocation of the patella which causes chronic strain and tightening of the lateral retinaculum. This in turn increases the Q-angle which can lead to PFPS.

Other causes of an increased Q-angle include foot pronation, pes planus, genu recurvatum, and wide hips.6 Women, therefore, are more prone to PFPS due to larger pelvic width.

Other major conditions leading to PFPS include degenerative disease, repeated microtrauma, acute severe trauma,1 iliotibial band tightness,8 and medial retinacular rupture.2 These conditions may cause lateral tightness and medial weakness of connective tissue
surrounding the patella predisposing the patient to a bony malalignment between the femur and tibia. This bony malalignment will cause the patella to track improperly in the patellar groove. Thus, it is evident that a proper balance between medial and lateral structures must be maintained for maximal alignment of the PF joint.

A balance of strength between the VMO and VL muscles is imperative for this balance to be maintained.\textsuperscript{9} Individuals affected by PFPS differ from healthy individuals in regards to their VMO:VL activation patterns. While the VMO:VL activation patterns of the healthy individual are close to equal, the patterns of PFPS patients show decreased activation of the VMO during EMG assessment.\textsuperscript{24,25} Conservative treatment is, therefore, aimed at selective strengthening of the VMO.

Due to the prevalence of this syndrome it may be assumed that an effective exercise protocol is currently in widespread use. In truth, however, no such protocol exists due to lack of evidence of exercises that selectively target the VMO. Thus, PFPS also poses a problem for the clinician attempting to treat this disorder.
Anatomy of the Patellofemoral Joint

The anatomy of the PF joint also makes this syndrome particularly difficult to treat. According to Norkin and Levangie, "together with the femoral surface on which it sits, the patellofemoral joint is...the least congruent joint in the body." These authors also define the patella as the largest sesamoid bone in the body which functions as an anatomical pulley to reduce friction between the quadriceps tendon and the femoral condyles. In order to perform this function without limiting knee motion, the patella must slide on the femoral condyles while remaining seated between them in the intercondylar groove. This groove corresponds to the vertical ridge on the posterior aspect of the patella thereby providing a tracking mechanism for the PF joint to maintain proper alignment. This mechanism is under control of two restraining mechanisms crossing at right angles: a group of transverse stabilizers and a group of longitudinal stabilizers. For simplicity, the longitudinal stabilizers will be defined as the quadriceps tendon superiorly and the patellar tendon inferiorly. Norkin and Levangie have described the transverse stabilizers as the medial and lateral
extensor (patellar) retinaculae. In general, the function of the retinaculae are to connect the patella to dense connective tissues around the knee. Laterally these include the fascia lata and iliotibial band as well as the vastus lateralis muscle. Similarly, the medial retinaculum functions to connect dense connective tissue and the vastus medialis to the medial patellar border. Lieb and Perry found the pull of the VL to be 12 to 15 degrees lateral to the long axis of the femur, with the distal fibers even more angulated. The angulation of the VM pull depends on which portion of the muscle is assessed. The upper fibers of the VM are angulated 15 to 18 degrees medially to the femoral shaft, while the distal fibers are angulated approximately 50 to 55 degrees medially. It is because of this drastic difference in fiber orientation of the upper and lower portions of the VM muscle that it is categorized into two components: vastus medialis longus (VML) whose fibers originate from the intertrochanteric line and medial lip of the linea aspera of the femur and vastus medialis oblique (VMO) whose fibers originate primarily from the adductor magnus tendon. This difference in fiber orientation between the VMO and VL may be a
reason why difficulties in treatment have been experienced.

**Role of the VMO**

The role of the VMO as a dynamic medial stabilizer providing proper patellar alignment is strongly supported in the literature.\(^{10,11,27,29,30}\) Lieb and Perry\(^{11}\) state that the only selective function attributable to the VMO is patellar alignment.

A second and questionable role of the VMO is terminal knee extension. Fiebert et al\(^{31}\) claim that the VMO becomes most active near terminal knee extension. Basmajian\(^{10}\) also found that the VMO appears to increase activity toward the end of unweighted extension, but found no significant difference between the VMO and other quadriceps components during squatting exercises. This is supported by other research that claims the best exercises for PFPS are ones performed with full knee extension.\(^{12,17,19}\)

Despite these claims, other research indicates the VMO does not account for the last few degrees of terminal extension.\(^{22}\) Lieb and Perry\(^{11}\) report that all four quadriceps heads increase activity in terminal extension. They state the VMO helps perform terminal extension but does not individually account for the final 15 degrees.
In another study by Brownstein et al., it was found that the VMO is actually least active in the extended position. Finally, a study by Ingersoll and Knight showed that terminal extension exercises do not produce medial relocation of the patella. Interestingly, they reported that these exercises actually seem to predispose patients to PFPS.

**Selective Recruitment of the VMO**

Currently, biofeedback has the most promise in facilitating the selective recruitment of the VMO. Wise et al. studied the effects of biofeedback in conjunction with exercise (straight leg raise, quad sets, and terminal knee extension) and functional activities (ambulation, bicycling, and stair climbing). Results of this study showed that biofeedback is effective in producing significantly greater activation of the VMO than VL in all activities.

Ingersol and Knight used a protocol established by Wise et al. and compared the effects of biofeedback to the effects of a progressive resistance routine using a short arc quadriceps exercise. Their study suggests that, "quadriceps group strength changes are not enough to fully rehabilitate patellar tracking dysfunctions. The
use of EMG biofeedback training to selectively strengthen the vastus medialis obliquus appears to be essential in correcting faulty patellar tracking." Thus it appears from the literature that the incorporation of biofeedback into a rehabilitation program is extremely advantageous. Biofeedback, however, is not often available for a home program, and research into the effectiveness of exercises without biofeedback is still needed.

The McConnell taping and exercise protocol is another avenue in the rehabilitation of PFPS which holds potential. In this protocol, the patella is taped into proper alignment. Once taping is completed, the patient performs a number of weightbearing exercises with emphasis on the eccentric contraction of the quadriceps group. During the contractions the patient is instructed to contract the VMO and to relax the lateral hamstrings and the VL as much as possible. The hip is also adducted during exercise to, theoretically, aid in selective VMO recruitment. The use of McConnell taping to increase VMO activity is validated by King et al.. King et al. found that mechanically altering the alignment of the patella facilitates the neural drive of the VMO and reduces the activity of the VL. At
this time, however, few therapists are well versed in patellar taping techniques. Also, more research needs to be done to verify McConnell's claim of a success rate of over 90%.

Because of the VMO's attachment to the adductor magnus tendon, many researchers believe that hip adduction can be used to help selectively strengthen the VMO. They believe this can be accomplished through either isolated hip adduction or hip adduction accompanied by a quadriceps contraction. Hanten and Schulthies\textsuperscript{35} had subjects perform maximal isometric hip adduction against a resistance pad. Measurements of VMO and VL activity were taken and results were expressed as a percentage of the maximal voluntary isometric contraction (MVIC). Significantly greater activity was found in the VMO (61.75\%) compared to the VL (45.63\%). From this research it appears that isometric hip adduction selectively strengthens the VMO relative to the VL. Westfall and Worrell\textsuperscript{20} however, criticize these findings questioning the high ratio of VMO activity without knee extension. Thus, more research needs to be done to confirm these findings and determine whether a hip adduction protocol can increase the VMO:VL ratio with any
clinical significance.

The influence of hip adduction on the VMO during quadriceps contraction is less clear. King et al.\textsuperscript{34} tested patients concentrically and eccentrically at 30 degrees per second over a range of motion of 10 to 100 degrees with a Kincom dynamometer. Testing subjects with and without concurrent hip adduction they found that 1) hip adduction had no effect on the activity of the VMO and 2) the VMO:VL ratio remained unchanged.

Grabiner et al.\textsuperscript{36} monitored VMO and VL activity of subjects under two sets of conditions. First, they simultaneously performed hip adduction and an isometric quadriceps contraction at 20 degrees of flexion. Second, they performed the isometric contraction without hip adduction. The researchers found that the effect of hip adduction was not significant.

Hodges and Richardson\textsuperscript{37} refute the notion that hip adduction has no influence on selective strengthening of the VMO. In their research, "hip adduction was superimposed onto the contraction of the quadriceps femoris in a weight bearing and a non-weight bearing position at three levels of hip adduction force." They found VMO
activity increased relatively more than the VL with the addition of each level of hip adduction in weight bearing. The results were not as dramatic in non-weight bearing with differences being seen only at maximal hip adduction. Still, their research indicates that hip adduction is advantageous to VMO strengthening.

Obviously, with all the discrepancies in the literature, more research is needed to determine the actual role of hip adduction. Even though the current body of literature is limited, research seems to indicate that the effects of hip adduction may differ depending on the type of exercise being performed.

Isokinetic knee extension is another exercise often prescribed in the treatment of PFPS. Sczepanski et al. investigated the effects of arc of motion, angular velocity, and type of contraction on VMO:VL ratio during isokinetic knee extension. They found a significant difference in VMO:VL ratio depending on the arc of motion. A significantly greater VMO:VL EMG ratio occurred at 60-85 degrees of flexion than at 35-60 or 10-35 degrees of flexion. Results also indicated concentric contractions produce a greater VMO:VL ratio than eccentric contractions and faster velocities (120
degrees per second) enhance VMO:VL ratio better than slower velocities (60 degrees per second). These findings were supported by the work of Boucher et al.\textsuperscript{22} who compared the VMO and VL activity between 0 and 90 degrees. They specifically measured EMG activity at 15, 30, and 90 degrees and concluded that VMO:VL ratios are greatest at 90 degrees of knee flexion and the VMO is facilitated in that specific ROM.

While dynamic exercises are usually prescribed in the later stages of rehabilitation, many researchers have recommended a protocol consisting of isometric quadriceps contractions during the initial stages.\textsuperscript{1,12,14,18-20} The belief is that isometric quadriceps contractions will maintain or enhance VMO strength during the period when dynamic exercise may still be too painful to perform. As Woodall and Welsh\textsuperscript{19} state, “the initial phase of rehabilitation is to increase joint motion, and to get the VMO under good, active, voluntary control, and to decrease patellofemoral joint irritation.”

Many therapists of the past have attempted to strengthen the VMO by isometric quadriceps contractions at full knee extension. This was based on older research which claimed that the VMO was
chiefly responsible for the last 10 to 15 degrees of knee extension.\textsuperscript{11,39} Using amputated limbs and an elaborate pulley system to replicate the force vectors of the quadriceps heads, Lieb and Perry\textsuperscript{11} demonstrated that the VMO did not contribute any more than the other quadriceps heads to knee extension. They found that the only selective function attributable to the VMO was patellar alignment. This research was more recently supported by an electromyographical study by Basmajian.\textsuperscript{10} He concurs that the only selective function of the VMO is patellar alignment. Basmajian also found that the VMO appeared to increase activity toward the end of extension in unweighted limbs, but this activity was not greatly different from that of the other heads of the quadriceps. This indicates that even though VMO activity is increased, isometric quadriceps contraction at 0 to 15 degrees of knee flexion is not an efficient exercise for PFPS because the VMO:VL ratio is not changed significantly.

Other authors have prescribed isometric quadriceps contractions at 20 degrees of flexion.\textsuperscript{18,19} This position is chosen because, "it is here that the patella actively begins to centralize in
the femoral sulcus. With more flexion, about 45 degrees, the main
arthritic zones of the patella are present so this area is avoided,
especially if pain or specific pathology is present." While this
position is successful at reducing pain, there is no research to
indicate that it is efficient at increasing the VMO:VL ratio.

Westfall and Worrell\textsuperscript{20} recommend isometric quadriceps
contractions in the range of 60 to 85 degrees of flexion based on
research by Brownstein et al.\textsuperscript{23} and Boucher et al.\textsuperscript{22} Brownstein et
al. attempted to locate the position of peak torque of the quadriceps
complex to establish a normalization protocol. Subjects performed
maximal isometric contractions every 10 degrees from 10 to 90
degrees of knee flexion. The researchers recorded the torque of each
individual quadriceps head as well as the torque of the quadriceps
complex as a whole. The study showed peak VMO torque occurred
between 60 and 90 degrees of knee flexion. While Brownstein et al.
recorded the torque of the VMO and VL, they neglected to calculate
the VMO:VL ratios. Boucher et al.\textsuperscript{22} performed an isokinetic study and
found, similar to the Brownstein et al.\textsuperscript{23} isometric study, that peak
torque occurred at 90 degrees of flexion. Although Brownstein
et al. did not figure the VMO:VL ratio, and the Boucher et al. study was done isokinetically, Westfall and Worrell\textsuperscript{20} still believe that 60 to 90 degrees of knee flexion is the optimal position for selectively strengthening the VMO during an isometric quadriceps contraction.

Biofeedback and McConnell Taping hold promise in the treatment of PFPS. Research also shows that dynamic exercises such as isokinetic knee extension and weight bearing eccentric exercises may selectively strengthen the VMO. Thus, these exercises would be useful in the later stages of PFPS treatment.

Traditionally, isometric exercises have been prescribed in the early stages of PFPS rehabilitation. The literature shows there is no consensus on the most beneficial position to perform these isometric quadriceps contractions. During this literature review the only research found on VMO:VL ratio during isometric quadriceps exercise was a study by Cerny.\textsuperscript{24} Cerny compared VMO and VL activity at 15, 45, and 60 degrees of knee flexion. Results indicated that maximal VMO and VL activity occurred at 45 degrees. There was, however, no significant difference in the VMO:VL ratio at any of the three positions.
Based on the literature, this study examined VMO:VL ratios at 0, 20, 60, and 90 degrees of knee flexion and compared obtained values. It is the intent of this study to add to the negligible body of research on VMO:VL activity and to further define the best position for selectively strengthening the VMO during isometric contraction.
CHAPTER 3
METHODOLOGY

Subjects

Subjects for this study consisted of 49 males and females ranging from 21 to 37 years of age with no history of hip or knee problems. The subjects, 31 females and 18 males, were selected via a sample of convenience using physical therapy students enrolled at Grand Valley State University. All testing was performed in the Human Performance Lab of the physical therapy department at the Allendale campus of Grand Valley State University.

Design

Simultaneous EMG readings were taken of the VMO and VL during isometric contraction at angles of 0, 20, 60, and 90 degrees of knee flexion. From the EMG values, a VMO:VL ratio was established for each trial. These ratios were then averaged to establish a mean VMO:VL ratio for each of the designated test angles. Finally, a repeated measures analysis of variance test was used to determine if a statistically significant difference exists among the VMO:VL ratios of the four angles.
Procedure

Following approval by the Human Subjects Review Board of GVSU, subjects were asked to sign a consent form informing them of their role in this study.Consenting subjects were tested isometrically at arcs of 0, 20, 60, and 90 degrees of knee flexion. To reduce any effects of fatigue or learning, the order in which the angles were tested was selected randomly by each subject. This was accomplished by writing each angle on a separate piece of paper. The papers were folded to conceal the number, and all four pieces of paper were placed into a hat. The subject was then instructed to take one piece of paper out of the hat and read the number written on it. The order the numbers were pulled out of the hat by the subject was the order in which each angle was tested.

Once the order of angles to be tested was selected, the subject's leg was shaved over the belly of the VMO and distal VL using a disposable razor. Each shaved area was then rubbed clean with an isopropyl alcohol swab to sanitize the skin and maximize electrode adherence. While the subject was seated in a CYBEX test chair, the researcher placed self-adherent surface electrodes to
each of these designated areas. The electrodes were then plugged into lead wires connected to a computer and the EMG data fed into MYOSOFT EMG software for Windows. The subject’s knee was then positioned at the first randomly selected angle using a standard goniometer. The padded resistance bar from the CYBEX was placed two finger widths proximal to the medial malleolus at the anterior ankle of the test leg for resistance and to maintain the knee at the designated test angle. When instructed, the subject performed a maximal isometric contraction of the quadriceps femoris for three seconds against the padded resistance bar. Subjects performed three consecutive trials at each angle with a one minute rest between trials.

**Instrumentation**

A Noraxon Myosystem 1200 Research EMG unit was used for the collection of raw data. Disposable silver-silver chloride self-adhering electrodes measuring one and three quarters inches were used on all subjects. Measurements of knee flexion were taken using a standard goniometer. The goniometer was aligned to specific anatomical landmarks suggested by Norkin and White with the
fulcrum of the goniometer over the lateral epicondyle of the femur, the proximal arm aligned with the greater trochanter and the distal arm aligned with the lateral malleolus.

**Validity and Reliability**

Research has shown a linear relationship between muscle tension and EMG microvolt output. The validity of using EMG surface electrodes as a measurement of isometric muscle tension is also well established in the literature.

To familiarize the testers with the Noraxon Myosoft 1200 Research EMG unit, a pilot study with 18 subjects was performed. During the actual study, the same tester positioned electrodes, measured angles of knee flexion, and gave instruction to all 49 subjects. The order of the testing angles was selected randomly to decrease the effects of fatigue and improve reliability.
CHAPTER 4
RESULTS/DATA ANALYSIS

Techniques

EMG data was collected on 31 females and 18 males using the Noraxon Myosoft 1200. Parameters for the unit were set with a trigger level of 10 microvolts, an onset time of 100 milliseconds, and a subsist time of 20 milliseconds. The Myosoft software package analyzed all data, giving a value in microvolts-squared of the total area underneath the graphical representation of the contraction and displaying the values in bar graph form.

\[
\text{Area (uV}^2) = \Sigma_i ([\text{EMG}]_i \times [\text{Sampling Interval}]_i)
\]

Figure 1. Representation of Noraxon Myosoft EMG output.
These values were then transferred by hand onto a data collection sheet (see Appendix B). The data were analyzed by a student from the GVSU Statistics Department using a repeated measures analysis of variance test on SAS software.

A one-way within subjects ANOVA was conducted with the factor being angle and the dependent variable being the average ratio of VMO:VL. The descriptive statistics for the dependent variable broken down by the angle are presented in Table 1. One of the assumptions for the one-way within-subjects ANOVA is that the dependent variable is normally distributed in the population for each level of the within-subjects factor (angle). This was not satisfied at each of the angles (all tended to follow a right-skewed distribution). To adjust for the violation of this assumption, the square root transformation of the dependent variable was used. This means that the dependent variable used in the one-way within-subjects ANOVA was the square root of the average ratio of VMO:VL.

Another assumption for this one-way within-subjects ANOVA is the homogeneity of variance assumption which, according to Portney and Watkins\textsuperscript{44} "states that the variances within each of
these sets of difference scores will be relatively equal and correlated with each other." According to Mauchly's criterion, this assumption was not satisfied.

To adjust for the fact that this assumption was not satisfied, the degrees of freedom for the F-distribution were adjusted by the Greenhouse-Geisser correction factor. The results for the repeated measures ANOVA, therefore, indicate that there is not a significant angle effect (F = 2.26, df1 = 2.14, df2 = 102.73, Adj G-G value = .106). Therefore, there is not sufficient evidence at the 0.05 level to say that there is a difference in the average VMO:VL ratio among the angles studied.

**Hypothesis/Research Question**

Our original hypothesis that VMO:VL ratios would be largest in the sixty to ninety degree range was not supported by the statistical analysis. Testing the null hypothesis, that there would be no difference between mean VMO:VL ratios between angles, a P-value of 0.106 was calculated. Because this value is greater than .05, there is not sufficient evidence to conclude that there is a difference in the mean average VMO:VL ratio among the angles studied. This may
be due to the fact that a larger sample size is necessary to detect small differences between the VMO:VL ratios. A larger sample size would reduce the standard deviation (SD) and better determine if the small differences are statistically significant. These small differences are shown in Table 1.

Table 1.

**Descriptive Statistics Table for Avg VMO:VL Measurements**

<table>
<thead>
<tr>
<th>Angle</th>
<th>N</th>
<th>Mean</th>
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<th>SD</th>
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**Other Findings and Observations of Interest**

During data collection we found several unexpected items of interest. Through informal conversation with subjects between test trials, we found that subjects exhibiting high VMO:VL ratios often reported participating in sports. There were, however, a few
subjects who were not involved in sporting activities who displayed VMO:VL ratios similar to "athletic" subjects.

We also noticed a difference in VMO:VL ratios between genders. Generally, men tended to have higher mean ratios at all angles compared to women (see Table 2). Again, this was not true for all female subjects since one of the highest ratios was registered by a

<table>
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twenty-four year old female who had not been active in sports for an eleven month period. These differences in VMO:VL ratio may explain why more women than men are treated in the clinic for PFPS.¹,¹⁸

We also observed many subjects had difficulty performing isometric contractions at 0 degrees. These subjects, however, often had their highest VMO:VL ratios at this angle. Why this occurred is unknown.
CHAPTER 5
DISCUSSION AND IMPLICATIONS

Discussion of Findings

Although our findings did not support our hypothesis, we feel this study is significant for several reasons. First, it adds to the literature regarding knee flexion angle and VMO strengthening. According to our literature review, some researchers hypothesize that selective strengthening of the VMO may be achieved isometrically at terminal extension (0 degrees). Still, other studies suggest the VMO may be strengthened isometrically at larger angles of knee flexion including 20, 60, and 90 degrees. Due to these inconsistencies, all research pertaining to selective VMO strengthening is beneficial inasmuch as it adds to the small body of knowledge in this area.

Second, our findings and much of the existing literature suggest that there is no single angle that may be universally prescribed to selectively strengthen the VMO (See Table 1). Our data suggests that most people have a specific angle for optimally strengthening the VMO.
Although many subjects had similar VMO:VL ratios at all four test angles, other subjects displayed distinctly higher values at certain angles. We believe this occurs as a result of differences in muscle recruitment patterns between individuals.

Third, this study is helpful clinically because it provides a starting point for developing an isometric protocol for PFPS. Because EMG is necessary in determining the optimal angle for isometric strengthening, an EMG study must be performed on each patient to determine which angle produces the highest VMO:VL ratio. Isometrically strengthening at this angle will individualize treatment and provide the greatest benefit for the patient.

**Application of Practice**

Considering that PFPS is very common\(^1\), it would benefit clinicians to have an established protocol for this disorder. As mentioned above, this study provides a foundation for establishing a protocol exclusive to each patient by first analyzing individual muscle recruitment patterns. Thus, individual characteristics pertaining to recruitment patterns must be considered before issuing isometric exercises. Not only will the patient benefit from
this approach but third party payors will also be more likely to reimburse for a research-based protocol.

**Limitations**

The first limitation of this study is in the measurement of the angles of knee flexion. Goniometry is a very subjective measurement prone to human error. Norkin and White\textsuperscript{40} refer to 3 to 5 degrees of error when measuring angles as “acceptable.” These small differences between the actual angle and our measured angle may have caused some discrepancies in our data.

Another possible limitation due to human error is the placement of the electrodes. It is virtually impossible to place the electrodes in the exact same spot on every subject. While a trained researcher should be able to properly place electrodes with great consistency, subtle variations in anatomical landmarks between subjects make this difficult.

A third limitation is that only four angles were tested due to time constraints and the possibility of subject fatigue. This limited our study because the VMO:VL ratio may be greatest at an angle other than 0, 20, 60, or 90 degrees.
Also, only subjects between the ages of 21 and 37 years of age with healthy knees were used in this study. This limits the use of our results. The results gained with this research may not be applicable to populations outside the 21 to 37 year old age bracket or to subjects with knee pathology.

Another limitation is that although the testing order of joint angles was randomized, this did not mean the effects of fatigue and learning were eliminated or minimized. It is possible that low third trial values were due to fatigue. On the other hand, high third trial values may be due to learning effects. Fatigue and learning associated with the three trial test design may, therefore, be a limitation of this study.

A final shortcoming of this study was the inability of some subjects to maintain an isometric contraction above the EMG threshold level for 3 seconds. When this occurred, the Noraxon Myosoft software recorded a separate muscle contraction each time a subject's muscle activity dropped below the threshold. As a result, a single trial was recorded as multiple contractions and data accuracy was compromised.
Suggestions for Further Research

Our study was one attempt to devise a way to selectively recruit the VMO during isometric exercise using four different angles. Although analysis revealed no significant difference in average VMO:VL ratios between the angles tested, several findings noted in our study may have significant impact on further research.

One area warranting further study is recording VMO:VL ratios of subjects with PFPS. Our study was limited to “normal” knees of young, healthy subjects with no previous history of injury, disease, or surgery. A study of pathologic knees may reveal significant differences between average VMO:VL ratios at different angles in comparison to healthy knees. It is possible that subjects with PFPS experience pain secondary to a significant imbalance in VMO:VL ratios. Further research is necessary to determine if this is true.

A second area for further research involves studying VMO:VL ratios at angles other than those studied here. Although we believe our study was thorough by involving angles throughout the full range of motion, it is possible that angles different than those in our study could produce statistically significant results. This could be
achieved by testing VMO:VL ratio at every 5 degrees. The problem here, however, would be fatigue from testing so many angles at once. Thus, future studies may involve greater numbers of subjects to allow each 5 degree increment between 0 and 90 degrees to be measured.

A third recommendation for further research is a study similar to ours but involving only female subjects or only male subjects. Through informal observation during data collection we noticed differences in recruitment patterns between men and women. Because of these observations and because women are anatomically more susceptible to PFPS, we conducted further analysis separating VMO:VL ratios by gender. This analysis showed that men have a greater VMO:VL ratio than women (see Table 2). The difference in VMO:VL ratio by gender is a possible explanation for the lack of significant differences in average VMO:VL ratios among the angles tested. We did not, however, analyze the data to determine if an optimal angle for VMO strengthening exists for each gender.

Conclusions

This study investigated the possibility of a relationship
between knee angle and VMO and VL activity. The findings of this study indicated there is no significant difference among the tested knee angles for the VMO:VL ratio during isometric knee extension. Generalizations from these data, however, should be made carefully because of the characteristics of our study group. Further research is needed to investigate the possibility of significant associations between VMO:VL ratios and gender, pathology, and angles other than those tested in this study.
REFERENCES


APPENDIX A.

Informed Consent Form
KNEE FLEXION AND ITS INFLUENCE
ON VMO:VL RATIOS
DURING ISOMETRIC QUADRICEPS CONTRACTION

I understand that this study compares the electrical activity of two muscles during the performance of exercise at four different angles of knee flexion and that knowledge gained from this research can be used to better treat individuals with chronic knee pain.

I also understand that:
1. participation in this study will involve one 30 minute session during which electrodes will be adhered to two 1 by 2 inch shaved areas of my thigh before being asked to perform 12 trials of a five second exercise.

2. I have been selected for this study because of my age and history of no previous knee injury.

3. it is possible that I could experience some muscle soreness one to two days after the study and also some slight discomfort due to razor burn.

4. my name and my individual results will be kept strictly confidential.

5. a summary of the results will be made available to me upon request.

I acknowledge that:

"I have been given an opportunity to ask questions regarding this research study, and that these questions have been answered to my satisfaction."

"In giving my consent, I understand that I am one of sixty volunteers participating in this study and that I may withdraw
at any time during testing."

"The investigators, Bill Allan and Jeff Hendra have my permission to perform the above procedures on me."

"I hereby authorize the investigators to release the information obtained in this study to scientific literature. I understand that I will not be identified by name."

"I have the right to contact Paul Huizenga, Chair of Human Research Review Committee (895-2472), or Jane Toot (895-3605), at any time if I have questions.

"I acknowledge that I have read and understand the above information, and that I agree to participate in the study."

__________________________  ____________________________
Witness Signature          Participant Signature

__________________________  ____________________________
Date                        Date
APPENDIX B.

Data Collection Sheet
KNEE FLEXION AND ITS INFLUENCE ON VMO:VL RATIOS DURING ISOMETRIC QUADRICEPS CONTRACTION

Data Collection Sheet

SUBJECT # ______

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APPENDIX C.

Proposal Summary For
Human Subject Review Committee
Patellofemoral Pain Syndrome (PFPS) is the number one cause of knee pain in many clinics and sports medicine centers around the country. The major underlying cause of PFPS is a malalignment of the patellofemoral joint. The result of this malalignment is a laterally tracking patella causing pain for the patient.

The vastus medialis obliquus (VMO) has been identified as the only structure with the ability to pull the patella medially. Theoretically, strengthening the VMO will correct malalignment thus relieving pain. Several exercises have been recommended by researchers and therapists to strengthen the VMO. However, while strengthening the VMO, these exercises may also strengthen the vastus lateralis (VL) to the same degree. Even though the VMO is strengthened, it may still not be able to pull the patella medially because of the simultaneous strengthening of the VL pulling the patella laterally. For an exercise to be efficient in altering malalignment and to reduce pain it is necessary to strengthen the VMO independent of the VL or at least strengthen it to a significantly greater degree than the VL.

Several authors have recommended an isometric contraction of
the quadriceps to facilitate strengthening of the VMO. While some authors believe VMO strengthening occurs at terminal knee extension, others contend that exercise should be performed at varying degrees of knee flexion. The problem is that there is little scientific data that indicates the VMO is strengthened to a greater degree than the VL in any of these ranges of motion (ROM) during an isometric contraction. The purpose of this study is to compare the activity of the VMO relative to the activity of the VL at various points between 0 and 90 degrees of knee flexion during isometric contraction. Our hypothesis is that isometric quadriceps contractions between 60 and 90 degrees of flexion will result in larger VMO:VL ratios than at other ranges of motion in healthy college age male and female knees.

Testing will take place in the Human Performance Lab located in the Grand Valley State University Fieldhouse. Subjects for this study will consist of 60 males and females ranging from 18 to 35 years of age with no history of hip or knee problems. The subjects will be selected via a sample of convenience using physical therapy students enrolled at Grand Valley State University.

Simultaneous EMG readings will be taken of the VMO and VL
during isometric contraction at angles of 0, 20, 60, and 90 degrees of knee flexion. The EMG values of the three trials will then be averaged to establish a mean value for the VMO and VL. These mean values will then be used to calculate a VMO:VL ratio for each of the designated test angles. Finally, a repeated measures analysis of variance test will be used to determine if a statistically significant difference exists among the VMO:VL ratios of the four angles.

Consenting subjects will be tested isometrically at arcs of 0, 20, 60, and 90 degrees of knee flexion. To reduce any effects of fatigue of learning, the order in which the angles will be tested will be selected randomly.

Once the order of angles to be tested is selected, the subject's leg will be cleaned with an isopropyl alcohol swab and the bellies of the VMO and distal VL will be shaved using a disposable razor. Each shaved area will be rubbed again with a clean isopropyl alcohol swab to sanitize the skin and maximize electrode adherence. While the subject is seated, the researcher will place self-adherent surface electrodes to each of the designated areas. The electrodes will then be plugged into lead wires connected to a computer with
MYOSOFT EMG software for Windows. The subject’s knee will then be positioned at the first randomly selected angle. The padded resistance bar of a CYBEX machine will then be placed at the anterior ankle of the test leg for resistance and to maintain the knee at the designated test angle. When instructed, the subject will perform a maximal isometric contraction of the quadriceps femoris for five seconds against the padded resistance bar. Subjects will perform three consecutive trials at each angle with a one minute rest between trials. To familiarize testers with both equipment and procedure, a pilot study with 10 subjects will be performed. This will help establish reliability as well as facilitate subject safety. It will be explained to each subject that some muscle soreness will persist one to two days following participation in this study. It will also be explained to each subject that they have the right to withdraw their participation in this experiment at any time.