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A Comparative Electromyographic Study of the Effect of Four Selected Closed Chain Squat Exercises on Vastus Medialis Oblique and Vastus Lateralis

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A COMPARATIVE ELECTROMYOGRAPHIC
STUDY OF THE EFFECT
OF FOUR SELECTED CLOSED CHAIN SQUAT EXERCISES
ON VASTUS MEDIALIS OBLIQUE
AND VASTUS LATERALIS

By
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THESIS

Submitted to the Department of Physical Therapy
at Grand Valley State University
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in partial fulfillment of the requirements
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MASTER OF SCIENCE IN PHYSICAL THERAPY

1998
A COMPARATIVE ELECTROMYOGRAPHIC STUDY OF THE EFFECT OF FOUR SELECTED CLOSED CHAIN SQUAT EXERCISES ON VASTUS MEDIALIS OBLIQUE AND VASTUS LATERALIS

ABSTRACT

Patellofemoral dysfunction (PFD) usually involves patellar maltracking. Vastus medialis oblique (VMO) and vastus lateralis (VL) are two key muscles that help maintain patellar alignment. Open kinetic chain (OKC) studies suggested that the optimum ratio of VMO:VL is about 1:1. With PFD the VMO becomes much weaker. Purpose: To determine which of four partial squat exercises, often used in rehabilitation, best favors VMO firing: partial squat, partial squat squeezing a ball between knees, partial squat with pulley resistance and partial squat with 45° oblique pulley resistance. Analysis of EMG for 31 normal subjects randomly performing all four exercises using repeated ANOVA were insignificant (p<.05) except for 10 males performing plain partial squat. In all 4 closed kinetic chain exercises VMO:VL mean ratios (1.30-1.43) were greater than the reported 1:1 OKC norm. Conclusion: No partial squat exercise was any better at favoring VMO over VL output except males performing partial squat.
ACKNOWLEDGEMENTS

The investigators would like to extend their appreciation to their committee members for graciously donating their time and assistance in the development and completion of this thesis research. These members include: Ms. Natalie Howard, Dr. Paul Stephenson, and Dr. Arthur Schwarcz. In addition to the committee member, the investigators would like to thank Marcella Clone for her assistance with the statistical analysis. A special thank-you to Dr. Schwarcz, committee chairperson, whose enthusiasm, organization, and many hours of assistance have helped provide a valuable learning experience.
DEFINITION OF TERMS

AFFERENT—the nerve impulses traveling away from a body part, and toward the central nervous system.

ARTIFACTS—a type of nooise that emits false EMG signals elicited by electrical mechanical motion.

CLOSED KINETIC CHAIN (CKC) ACTIVITY—occurs whenever the terminal segment of an extremity is fixed (35).

CO-CONTRACTION—the simultaneous contraction of the agonist and antagonist muscles surrounding a joint.

CROSS-TALK—electrical activity originating from muscles other than the muscle under investigation (55).

DIGITIZATION—sampling of the EMG signal at regular intervals and expressing the amplitude value at each point as a binary value, then storing this value (4).

ELECTROMYOGRAPHY (EMG)—a measure of electrical signals from muscle that provides an indirect indicator of muscular function. The electrical signals, which accompany the chemical stimulation of the muscle fibers, travel through the muscles and adjacent soft tissues indicating motor unit activation (44).

FULL WAVE RECTIFICATION—a method of processing the EMG signal involving transposition of all negative signals to the positive side of the zero line (44).

GOLGI TENDON ORGAN—a sensory mechanism located in the tendon of a muscle that responds to muscle contraction or excessive stretch of the muscle.

INTEGRATED EMG—summing the digitized, rectified EMG signals over a time interval appropriate for the clinical function being tested (44).

MECHANORECEPTOR—a specially adapted ending to a nerve’s axon that responds to physical stimuli.

MOTOR UNIT—a neuromuscular structure containing the motor neuron, neuromuscular junctions, and all the muscle fiber the neuron innervates.

NOISE—any unwanted signal, which is detected with the desired signal (4).
NORMALIZATION-- 1) removal of electrode sampling differences (44) 2) accommodation to individual variations in the number and mixture of motor units sampled by the electrode (44).

OPEN KINETIC CHAIN (OKC)-- a position in which an activity occurs when the terminal segment of an extremity is free to move (35).

PERIARTICULAR SOFT TISSUE--those tissues, excluding bone, that surround a joint (e.g. joint capsule, ligaments, and tendons).

PROPRIOCEPTION--the sense of a body part's position in space including movement and pressure sense.

QUANTIFICATION--transformation of EMG signals into numerical values (44).

Q ANGLE-- the angle formed by two intersecting lines, one from the ASIS to the midpatella, the other from the tibial tubercle through the midpatella (32).
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CHAPTER 1

INTRODUCTION

Background of the Problem

Knee problems are very prevalent in society. In fact, knee disorders are the most common musculoskeletal problem seen by practitioners in the United States (21). Many of these knee pathologies involve the patellofemoral joint (PFJ). Patellofemoral joint syndrome (PFJS) is considered the number one cause of knee pain in a majority of sports medicine knee clinics around the United States (38). The incidence of PFJS is as high as one in four with respect to the general population, and is even higher in the athletic population (24). Due to this high incidence of patellofemoral joint pathology, finding effective ways to treat this problem is of great importance. Even if the PFJ is not the primary site of the pathology, it must be considered when performing rehabilitation exercises to the lower extremity (60). A rehabilitation program cannot be effective unless the PFJ is stabilized and functioning in its biomechanically correct fashion (38,60).

The pull of the quadriceps femoris muscle group is believed by many researchers (21,22,28,29,33,34,38,47,60) to determine patellar tracking. In addition, conditions such as excessive pronation, increased Q angle, tight iliotibial band or a shortened lateral retinaculum can influence patellar tracking. Any one of these factors could lead to PFJS, but several studies have reported that quadriceps muscle imbalance will also cause PFJS (11,16,21,23,28,32,48,52,60). PFJS is considered to be one of the most commonly reported problems involved in knee pathology, however, the exact mechanism leading to
this syndrome is not completely understood. The quadriceps, especially the vastus medialis oblique (VMO) and the vastus lateralis (VL), strongly influence horizontal stabilization and therefore the tracking of the patella within the patellofemoral groove (22,27,28,29). Anatomically, the VMO is thought to counter the laterally directed VL force with respect to the frontal plane (22). Studies of muscle fiber orientation suggest that the VMO force component is directed approximately $55^\circ$ medially and the VL force component is directed approximately 12-15° laterally with respect to the longitudinal axis of the femoral shaft (1,27,33,34,47). Thus, the VMO muscle fibers are oriented in a manner that is not mechanically advantageous to act as a synergist along with the other members of the quadriceps group in performing knee extension (1). Instead, the VMO checks the action of the VL with regard to patellar alignment. The muscle balance between the VMO and the VL, along with the periarticular soft tissue structures acting on the patella, is a major component in the control of normal patellar alignment and function (20).

When considering the cause of PFJS, the majority of clinicians look to the patella’s role in knee biomechanics. The primary function of the patella is to increase the angle of insertion and thus the mechanical advantage of the quadriceps during knee extension. The patella also distributes the compressive forces at the joint allowing the extensor mechanism to be subjected to several times the body’s weight, as is required for activities such as stair climbing (21,24,38,59). An additional role of the patella is to protect the anterior surface of the knee and deep structures within the knee joint (21,38,60).
To aid the patella in these roles, various static and dynamic stabilizers act on the PFJ. The main static stabilizers include the joint capsule, patellofemoral ligaments, patellotibial ligaments and the joint shape itself (38,60). The joint shape is particularly important at knee angles beyond 20-30° of flexion. In this position, the patella is deeper in the patellofemoral groove and resistance to excessive lateral patellar movement is provided by the groove’s higher lateral ridge (24,60). The main dynamic stabilizer of the PFJ is the VMO (21,24,38,60). The importance of the VMO cannot be overstated because its dynamic resistance to lateral patellar forces makes it crucial to normal PFJ function (21,60).

The patellar shape, along with its stabilizers, plays a part in maintaining proper patellar tracking in the patellofemoral groove. Any changes in patellar tracking influence the magnitude of force acting at the PFJ and can lead to damage of surrounding tissue (21). Possible causes of maltracking may be due to changes in neuromuscular control around the knee, swelling in the joint, or muscle atrophy, which occurs most notably in the VMO. Such conditions usually result in the patella tilting and/or shifting relative to the femoral groove (21,24,38). Lateral tracking is the most common maltracking problem (21). An increased Q angle and a weak VMO lead to lateral tracking of the patella that can result in pain (24,38,58,60). This pain is due to synovial irritation or pressure on neural structures in underlying subchondral bone (60).

When treating PFJS conservatively, clinicians try to correct the laterally directed VL dominance by facilitating the VMO to activate prior to the VL and/or by getting the relative activation of the VMO to be greater than that of the VL (21). Exactly how to do
this is not clear, but various progressive resistive exercises have been used. Patients who improve with this type of conservative treatment usually do not have significant interarticular PFJ problems (60).

Though many factors contribute to patellofemoral alignment, muscle balance between the VMO and the VL is an essential component for maintaining this alignment. Problems arise when this balance is disturbed such as with atrophy or hypertrophy of one muscle greater than another, timing of neurological recruitment, pain accompanying muscle contraction, and joint effusion (22,27,28,29,46,47,57,61). Since PFJS is a result of improper tracking mechanisms, treatment is focused on the correction of these tracking problems to ultimately reduce pain and restore the normal function of the knee, i.e. gait and stabilization issues (22,27,32,35,49,58). Clinically, much time is spent attempting to strengthen the VMO while simultaneously limiting or maintaining VL activity. This is done in an attempt to regain the balance between the VMO and the VL to restore normal patellofemoral tracking.

Therapists have used and will continue to use a variety of therapeutic interventions to achieve pain free tracking of the patella within the patellofemoral groove. McConnell taping techniques are used in an attempt to help correct patellar position and tracking during knee motion by providing cutaneous proprioceptive cues that may help with subconscious correction of abnormal patellofemoral biomechanics (39). This taping does not reposition the patella, but it could partially eliminate pain during daily functional activity (5,30,54). Isometric quadriceps contractions in terminal extension have been used alone or in combination with a straight leg raise (SLR) in targeting the VMO. Since the VMO originates from the adductor longus and magnus tendons and the medial
intramuscular septum, with the majority of fibers originating from the adductor magnus tendon, the combination of hip adduction with knee extension has also been proposed to increase VMO activity and thus aid in proper tracking (1,11,23). Although some of these exercises may show an increase in VMO activity, they are performed in open kinetic chain (OKC). Since most everyday activities are the closed kinetic chain type (CKC), OKC exercises may not be as effective as CKC exercises for functional carryover.

CKC exercises usually involve concentric, eccentric and isometric muscle actions. The biomechanics involved in CKC movements are considered by some researchers as being more functional because weight bearing provides normal loading and proprioception and the agonist and antagonist muscles are working more synergistically than in OKC movements (15,53). CKC exercise has also been found to increase the congruence of the patellofemoral joint, especially during full knee extension and through the first 20° of knee flexion (15). Compression of the patella is also minimized in CKC. Decreasing this patellar pressure is important because cartilage chondrocytes die under conditions of abnormally high pressure (16). According to Cerny, incorporating hip adduction during CKC wall squats with knee flexion in the 30-70° range, demonstrates increased VMO activity (11). However, in her study increased VMO activity was not statistically significant. Lateral step-up programs, another therapeutic activity, beginning with a step height of one inch and progressing to an eight inch step height improved lower extremity performance in CKC activities (61), but it is questionable as to whether this exercise program affects the VMO:VL ratio.
EMG biofeedback has been used effectively in combination with strengthening exercises to educate patients to consciously recruit additional activity in the VMO while maintaining or decreasing VL activity. Electromyography (EMG) is a type of measurement that provides an indirect indicator of muscular function by receiving and recording electrical signals that accompany the chemical stimulation of muscle fibers. These signals indicate motor unit activation (44). An EMG biofeedback study by Ingersol and Knight (25) proposed that such muscle reeducation could prevent lateral subluxation or dislocation by medially relocating the patella. Results of the same study however, indicated that terminal extension progressive resistive exercises do not relocate the patella medially if it is not combined with EMG biofeedback.

**Statement of Problem**

Clinicians are aware of the importance of VMO strengthening to address patellar maltracking. Various types of CKC squat exercises are frequently used to strengthen the quadriceps femoris muscle group in general and specifically to increase VMO:VL ratio. Despite their frequent clinical usage, there is little documented scientific research to validate the effectiveness of such squat exercises.

**Purpose of Study**

The primary purpose of this study was to compare the ability of four CKC partial squat exercises to increase the VMO:VL ratio via EMG data collection and analysis. The following exercises were the focus of this investigation 1) partial wall squat, 2) partial wall squat with adduction, 3) partial squat with anterior pull, and 4) partial squat with oblique 45° anterolateral pull.
Significance to Profession

Determination of the efficacy of the stated PFJS treatment exercises will decrease rehabilitation time in the clinic by providing clinicians with knowledge about the most effective CKC squat exercise. This will also provide necessary scientific evidence to third party providers, allowing for expedient reimbursement.

Hypothesis

The VMO:VL EMG activity ratio will be significantly greater in the partial squat with hip adduction and partial squat with oblique 45° pull when compared to the other tested squat exercises.
CHAPTER 2

LITERATURE REVIEW

Background

VMO strengthening has recently been the focus of several rehabilitation protocols attempting to decrease PFJS. Although this has been effective clinically, there is still controversy about the action of the VMO in relationship with the remaining quadriceps musculature. The vastus medialis (VM) was originally believed to be a single muscle and that it alone was primarily responsible for the last fifteen degrees of knee extension (33,34). Further research on the subject, however, has failed to support this idea.

In 1955, Brewerton (8), via palpation and voltage readings from skin electrodes, looked at each component of the quadriceps throughout the full knee range of motion (ROM). In both instances he found no significant differences in activity at any particular point of the range. Eight years later, Pocock (45) found that the VM was not solely responsible for terminal knee extension. In 1968, when studying the muscle fibers of each component of the quadriceps, Lieb and Perry (33) noted a marked distinction in the fibers comprising the VM. The distal fibers, which are now known as the VMO, are oriented obliquely at a 55° angle from the long axis of the femur. The proximal fibers, which are called the vastus medialis longus (VML) have a more vertical orientation and are at a 15-18° angle from the vertical axis of the femur (1,27,33,34).
In addition to fiber orientation, Lieb and Perry (34) noted that a fascial plane clearly separated the VML and VMO. Also, each portion of the VM was innervated individually. The combination of these factors led researchers to view this unique muscle as having more than one role. Since the VMO has a medial pull on the patella, it was believed to be a major contributor to guiding patellar tracking (6, 33, 34).

To further study the role of the VMO, Bose (6) examined its origin from the adductor magnus to determine how or if this origin contributed to its functional aspect. This attachment of the VMO to the adductor magnus was found to add resilience to the action of the muscle. Bose found that the VMO originated partially from the adductor longus and magnus tendons and a small portion originated from the medial intermuscular septum. Its insertion was found to be the medial portion of the patella.

Bose also described how the patella is stabilized. The quadriceps tendon gives support superiorly and the patellar tendon inferiorly. The lateral retinaculum, VL, and iliotibial band lend support on the lateral side, and the medial retinaculum and VMO stabilize the medial side. As the knee reaches full extension, most of the patella sits above and lateral to the intercondular groove of the femur. This alignment offers little support. Thus, in order to stabilize the patella, especially during the last 30° of knee extension, there must be a balance between horizontal forces created by the VMO and VL.

The VL fibers are oriented twelve to fifteen degrees lateral with respect to the shaft of the femur. The VL originates from the proximal femur and lateral intermuscular septum to insert onto the proximal, lateral aspect of the patella.
Mechanoreceptors

The knee joint is a richly innervated area. This innervation is supplied by branches of the obturator nerve, the saphenous nerve, tibial nerve, and the common peroneal nerve. There are also several, smaller, innervating branches that arise from nerves that supply the muscles of the lower limb (40,42). Pain, pressure, tension, position sense, and reflex activity are all part of the afferent information supplied to the central nervous system (CNS) that comes from the knee joint. The receptors sending afferent input have been categorized into four divisions, and then subdivided further into slow- and fast-adapting endings. Motion also determines the receptor classification; there are dynamic receptors (those that respond to joint movement, or changes in joint position), and static receptors (those that respond when the joint is at rest, or when the joint is moving at a steady velocity). All of these display a unique form that complements their function.

The first of these receptors are the Ruffini endings. These consist of a small bundle of two to six amorphous corpuscles that arise from a common axon. The corpuscles are usually encapsulated, though in most cases not completely. Ruffini endings have been identified in the knee joint capsule, the medial meniscus, and in both cruciate ligaments of the knee (20). They are slow-adapting and act as both static and dynamic receptors. They are capable of detecting static knee joint position, the pressure within the joint capsule itself, and the speed of joint movement. Interestingly, Ruffini endings have been found to be active at many midrange knee flexion angles, suggesting that midrange proprioception may be one of their primary functions (2).
The second of the four afferent receptors found in the knee are the Pacinian corpuscles. These are enclosed in a thick capsule and are pyramidal, or conically, shaped. Their threshold to mechanical stress is low and they adapt rapidly to stimuli. The Pacinian corpuscles have been identified in the knee joint capsule, the medial meniscus, and both cruciate ligaments of the knee (26). They are only active upon changes in joint velocity, therefore they are described as dynamic mechanoreceptors (2).

The third, and largest of the mechanoreceptors are referred to as “Golgi Tendon Organ-Like Endings (GTOE).” They are considered to be homologous to the Golgi Tendon Organs found in the tendons of muscle groups, though they are employed in the articular areas of joints. Their capsule is usually thin, and they are categorized as slow-adapting receptors with high mechanical thresholds (20). It is postulated that the GTOEs send information regarding ligament tension to the CNS. Their optimal conditions for performing work are at the end-ranges of joint motion (18). They are inactive in the immobile knee joint.

The last of the sensory nerve endings of the knee are called, simply, free nerve endings. They send nociceptive messages to the CNS and are stimulated only via chemical insult or mechanical deformation (10). These free nerve endings are ubiquitous in articular tissue and are the body’s primary warning system of tissue damage by communicating pain signals.

These four types of receptors are not equally distributed throughout all areas of knee periarticular connective tissue. There have been large populations of dynamic and fast-adapting receptors (Pacinian corpuscles) found in both cruciate ligaments with the majority found at the bone attachment ends of these ligaments (7). The collateral
ligaments of the knee, on the other hand, are reported to contain only free nerve endings and slow-adapting receptors, sensitive to extremely low and extremely high amounts of mechanical stress (26). The joint capsule is populated with both slow- and fast-adapting receptors, with a heavier density of slow-adapting receptors. The menisci contain all types of nerve endings, but have a larger number of free nerve endings than of any other kind.

With such a variety of receptors contained in all types of connective tissue surrounding the knee, it must be noted that support is not the only task for these structures. It can no longer be assumed that the ligaments, capsule and menisci are simply passive components to an otherwise dynamic joint. Many studies have been performed on the anterior cruciate ligament (ACL), and it has been found that different parts of the ligament are taut at a large variety of knee positions. The ACL also acts differently under muscle loading than it does in a passive stretch (26). Keeping in mind the presence of many different types of receptors, as well as the discovery of the "midrange" receptors, it can be postulated that the ACL, and in all probability most other surrounding periarticular tissue, must supply the CNS with a constant stream of information (26) and that this stream may be disturbed or interrupted when damage occurs to these structures (e.g. tearing the ligament or muscle imbalance).

Periarticular Supportive Tissue

Not only does the human knee joint have a rich supply of innervation, it is also well supported by periarticular tissue. This periarticular support is a necessity for the knee because it has comparatively little bony support and relies wholly upon its soft
tissue to lend support and substance to the joint. A brief summary of the functions of these structures, as described by Norkin & Levangie (42) and Moore (40), follows.

The major components of this connective tissue support system include the menisci (medial and lateral), two sets of ligaments (internal and external in relation to the fibrous capsule) and the joint capsule itself. The non-contractile connective tissue supports of primary concern when considering patellofemoral problems and rehabilitation include the patellar ligament, the anterior cruciate ligament (ACL) and the posterior cruciate ligament (PCL).

The patellar ligament, external to the capsule, is actually part of the common tendon of the quadriceps femoris muscles. It contains within it the patella, a sesamoid bone, which acts as a pulley for the knee. The patellar ligament is well connected to the joint capsule and strengthens the capsule anteriorly.

The ACL and PCL lie within the knee joint capsule but are not included in the synovial cavity. The ACL's primary role is to limit anterior tibial translation; the PCL is responsible for checking posterior tibial translation, but some portion of both ligaments are tight throughout knee range of motion. Both cruciates work best to stop tibial translation in full knee extension. The cruciates together are important stabilizers of the tibia by controlling internal tibial rotation and tibial anterior and posterior glide.

**Exercises**

The delicate balance that is necessary between the structures acting on the patella determines proper patellar tracking. A muscle imbalance, tightness of lateral connective tissue structures, an increased Q angle, excessive foot pronation, or too much physiologic genu valgus could disrupt this tracking and cause PFJS.
Many knee injuries result in patellar tracking problems secondary to quadriceps atrophy (22). Since the VMO is the first of the quadriceps group to atrophy and the last to be rehabilitated, the patella is pulled more laterally, disrupting the normal alignment within the patellar groove (22,32). Additionally, several studies have shown that individuals with PFJS have a reversal in neuro-recruitment compared to subjects with no PFJS. In pain-free subjects, the VMO muscle fires before the VL. The reverse is true in the pathological knee (1,28,57,59). Atrophy, combined with inadequate or retarded neuro-recruitment leads to imbalanced muscle forces between the VMO and VL causing improper tracking, which can result in patellofemoral pain. The goal of treatment is to decrease the laterally directed forces and increase the medially directed forces to reestablish normal muscle balance and thus proper alignment. This can be measured by diminished or absent pain in the knee during the performance of functional activities.

Patellofemoral dysfunction has been managed successfully with conservative treatment directed toward strengthening of the quadriceps muscle with emphasis on the VMO (49). In the past, a variety of exercises have been prescribed and have traditionally included OKC as well as CKC exercises. In determining which type of exercise will best facilitate quadriceps strengthening, particularly VMO strengthening, characteristics of both types of exercises must be considered. OKC exercises have been found to be somewhat limited in their ability to strengthen the quadriceps. This is because these exercises do not emphasize co-contraction of the lower extremity musculature. They also increase patellofemoral compression, increase anterior shear forces at the knee, and put more tension on the ACL (35,51,61). CKC exercises are useful because they take advantage of lower extremity co-contraction (14,62) and train the eccentric functioning of
the quadriceps more so than OKC. CKC exercises are safe and functional and decrease lateral tracking and compression of the patella. They also aid in minimizing shear force and ligament strain. The articular surface pressure is thus distributed, preventing focal deterioration (3,13,49,61). A decreased ability to coactivate can be caused by deconditioned hamstrings or hypertrophied quadriceps. Thus, reduced risk of knee injury can be accomplished by creating a balance of strength between the agonist and antagonist musculature through CKC activity. It is also widely known that most functional lower extremity movements utilize both concentric and eccentric muscle contractions and this combination of contractions is best emphasized in the CKC.

**VMO:VL EMG Related Research**

Past EMG research studies that compare the VMO:VL ratio have focused on utilizing hip adduction. This adduction creates a varus force to the muscle to counteract the lateral forces at the knee through lateral hip rotation in combination with knee extension. Other studies have used terminal knee extension to elicit VMO activity.

Hanten and Schulthies (23) were early researchers who incorporated hip adduction with knee extension to selectively increase VMO activity (in comparison to VL activity). They also advocated for monitoring the activity of both the VMO and VL because they realized the implications both muscles have on decreasing patellofemoral pain (PFP). To decrease the lateral pull on the patella, all of the quadriceps must be strengthened with emphasis on increasing VMO activity to a greater degree than that of the VL.

Because the main portion of the VMO originates from the tendon of the adductor magnus and adductor longus muscles, it was believed that exercising these larger muscles
before or in combination with knee extension may generate increased tension in the VMO. Thus the VMO would be placed at a better mechanical advantage and subsequently, decreased lateral shear forces at the patella would result (1).

Rice et al (46) compared seated knee extension exercises with and without isometric hip adduction. They discovered that the VL activity decreased with isometric hip adduction, but VMO activity either did not change between the two exercises or slightly increased with the adduction exercise. Also the VMO:VL ratios for concentric and eccentric quadriceps contractions were not statistically significant between the two exercises. Although the results did not show a marked change in VMO:VL ratio, patients reported decreased pain with the use of the hip adduction exercises. Unfortunately, it is impossible to determine the cause of the decreased pain from this study. The researchers suggest the use of a pressurized gauge pillow to help monitor the force of isometric hip adduction for future studies. Monitoring the force of hip adduction may account for the variation in VMO activity while performing the adduction exercise.

Laprode et al. (31) did an EMG study comparing EMG activity of the VMO relative to the VL during five isometric OKC exercises. These exercises were 1) resisted simultaneous medial tibial rotation with knee extension, 2) resisted knee extension, 3) resisted medial tibial rotation with 70° knee flexion, 4) resisted simultaneous knee extension and hip adduction, and 5) resisted hip adduction. The researchers hypothesized that since the lower most fibers of the VMO are attached to the anteromedial aspect of the tibia via the medial extensor aponeurosis, it may act to resist lateral rotation of the tibia. Thus, they suggest that the VMO can be preferentially recruited with active medial
rotation of the tibia. No significant difference was found in VMO:VL ratio for any of the selected exercises. Both normal subjects and mild to moderate PFJS subjects were used. No significant difference in recruitment of muscle fibers was found between the groups. The method of EMG normalization was unique in this study with only 50% of maximum voluntary contraction being used. The authors suggested that the subjects may not have achieved a level of recruitment between 60-80% of a maximum voluntary contraction during the exercises, thus additional recruitment could not be achieved until hip adduction or medial tibial rotation are combined with knee extension at high intensities. If this is necessary to achieve results, it may not be appropriate exercise training for early to mid stages of rehabilitation.

Cerny (11) conducted research evaluating a variety of OKC and CKC exercises including quad sets, knee extensions, isometric holds, walk-stance/step down and wall slides. The only exercise that resulted in a higher VMO:VL ratio was knee extension with medial femoral rotation (compared to lateral rotation). Cerny also found that an increased VMO:VL activity occurred during quad sets more than in any other open chain activity. Although VMO activity increased when adduction was added to the wall slide (from 13% to 30%) the results were not statistically significant.

There are more benefits to CKC exercises. Closed chain activity is also believed to minimize anterior tibial translation (ATT) secondary to compressive forces, and co-contraction of the hamstrings. Activities such as squatting, climbing stairs, and rising from a chair are examples of activities performed as the knee is vertically loaded by weight bearing and the relative pull of the quadriceps and hamstrings together limit the amount of translation during knee flexion (41). More et al (41) studied human cadaveric
knees incorporating muscle loads of the quadriceps and hamstrings to simulate a squatting activity. When the hamstrings were simultaneously loaded with the quadriceps, there was a limited amount of tibial translation that occurred as the knee was flexed and a decreased internal rotation of the tibia was noted during flexion. Also with simultaneous quadriceps and hamstring contraction, the shear force was directed posteriorly except when nearing full extension. These findings imply that squatting exercise causes no increase in load to the ACL.

Tussing and Howard (56) investigated the effects of ATT in facilitating quadriceps activity during isometric closed chain unilateral squats. Their results indicate that ATT does indeed facilitate quadriceps femoris activity in the closed chain.

In an attempt to increase VMO:VL activity, clinicians have commonly prescribed terminal knee extension exercises such as quad sets, short arc quad sets, or CKC mini squats to promote strength of VMO while avoiding excessive pain (47). Short arc quad sets have long been used to rehabilitate the knee following ACL reconstructions and are part of PFJS protocols. In PFJS cases, these short arc quad sets are used to assist in the strengthening of the quadriceps muscle group in the 0-30° range while preventing excessive patellofemoral joint compression forces. Ironically, this same range puts maximal strain on the ACL (35). Isometric knee extension exercises at 0° and 22° elicited five to seventeen times more strain on the ACL than weight bearing exercises such as walking, jumping rope, biking or squatting (43). Lieb and Perry (33) reported from their amputated limb studies that terminal extension in OKC (15-0°) requires 60% more force production from the quadriceps than the force needed up until that point. This inefficiency is evident in that the force required by the VL decreased by 13% when the
patella was kept centered in the femoral groove. By keeping the patella in its proper physiological alignment the VMO may not act in force production for knee extension, but its ability to pull the patella medially allows for better mechanical efficiency of the remaining long components of the quadriceps.

In addition, Signorile et al (50) conducted a study investigating the effect of knee and foot position on electromyographical activity of the superficial muscles. Results indicate that the VM is active throughout the range of motion, and not only at terminal extension. In fact, at an isometric open chain knee extension at 90°, the VM was just as active as the VL and rectus femoris. Thus, using exercises that concentrate on the last fifteen to thirty degrees of extension are unwarranted. Their study also determined that using a neutral foot position was best to increase quadriceps activity in the 30 to 5° range of OKC isometric knee extension. Yet, it is questionable whether these results would be consistent given a CKC exercise.

**EMG**

Measuring the level of a muscle's activity can be accomplished through a variety of means, ranging from the rather crude method of palpation to the more advanced technology of electromyography (EMG) with indwelling electrodes. When determining a muscle’s activity, choosing the most appropriate measurement tool can be difficult. EMG is often considered an adequate tool for the assessment of muscle function because integrated EMG is believed to closely parallel muscle force production (23). Perry (44) alludes to this same idea when he states that EMG signal records, after analysis, can estimate resulting muscle force under limited circumstances.
EMG is not synonymous with muscle force (47), but it is an indirect indicator of muscle function (44). The EMG signal is an electrical manifestation of motor unit activation (4,44). An increased amount of required muscle force production calls for an increase in the number of motor units recruited and/or an increased frequency of motor unit stimulation. Visually, a taller and denser EMG recording is an indication of the increase in the number of active motor units (44). Increases in muscle force also depend on the cross-sectional area of the muscle and the angle of insertion of its fibers, two components that EMG does not measure (47).

Additional considerations in the use of EMG are that the raw data cannot be used immediately, but must be quantified and normalized. Also, other variables can contaminate the signal of the muscle being studied such as electrical supply, mechanical artifacts, or cross-talk (4,44,55). These three variables will be discussed later in this chapter. Despite the imperfections of EMG, it is still considered one of the best measurement tools for muscle activation. This is evident in numerous research studies (9,11,13,17,22,27,28,31,47,55,57) that include EMG and use the acquired data to improve physical therapy practice.

When using EMG as the measurement tool, there are two basic types of electrodes that can be employed to detect the electrical signal of the muscle. These two main types are indwelling electrodes or surface electrodes. EMG signals from both types of electrodes have confirmed the reliability of electromyography in studies where electrodes remain attached to the subject during the entire testing session (19). Despite the electrode type chosen for EMG recording, there is no significant difference seen (in the statistical
analysis) between surface and indwelling wire electrodes in both dynamic and isometric/static conditions (19).

Many researchers prefer to use surface electrodes because of certain advantages over indwelling electrodes. Surface electrodes can be quickly and easily applied. They cause no discomfort to the subjects because they are noninvasive (4,19,44,51). After minimal training on application and skin preparation, most researchers can use surface electrodes with fairly good reproducibility (4,19,51). Surface electrodes are ideal to use when studying the gross EMG of numerous motor units in a superficial muscle (4,55). Because of the large number of motor units represented, the EMG signal is assumed to represent the activity occurring in the entire surface muscle (12). The most common type of surface electrode used is the silver-silver chloride disc (19,44). The silver chloride provides a stable interface between the subject's skin and the electrode by diminishing polarization (4,44).

If a very small muscle or activity level of single motor unit is under observation, researchers would be better inclined to use an indwelling wire or needle electrode for detection of electrical activity. This is also true for deep, relatively inaccessible muscles. The indwelling type of electrode is very specific to a small area (4,19,55). They are also less prone to electrical artifact, mechanical artifact, and cross-talk when compared to surface electrode signals (55). Indwelling electrodes are invasive, however, and often cause pain or discomfort to the subjects. This aspect of indwelling electrodes can be a primary consideration in a researcher's selection process (4,19,44,55).

To minimize skin impedance, proper preparation includes shaving any hair, cleansing the skin with a 70% alcohol solution, and applying a light abrasive to the area.
Active surface electrodes also minimize impedance by decreasing electrode sensitivity to changes in electrical resistance of the electrode-skin interface. These active surface electrodes also have built-in amplifiers and provide a clearer signal for recording. To better improve electrical contact, a saline gel or paste is used between the electrode and the skin (4,44,55). The optimal placement of surface electrodes, in relation to the muscle they are monitoring, is generally thought to be over the muscle's motor point (19,44).

The configurations to consider with this placement are either monopolar or bipolar. Monopolar electrode configuration involves one electrode over the muscle to be observed, and one indifferent, reference electrode over a nonmuscular part or unrelated muscle (4,55). This placement will detect all electrical signals from the vicinity of the electrode making it one of the least specific means of EMG recording.

Bipolar electrode design is generally preferred by researchers. Two electrodes are placed over the muscle of interest. The optimal distance between these electrodes is believed to be one centimeter (4,44). The potential between the electrodes is recorded (4,55). This configuration has an added filtering effect in that the amplifier compares the potentials, eliminating the "common mode" components of the two signals (4,55).

Although the bipolar arrangement offers a filter effect, there still remains a variety of noise that must be taken into account. Electrostatic fields are ever present. This "static electricity" can reach levels high enough to interfere with EMG reception of muscle activity by producing extra input (4). Such a situation could result if a subject is wearing polyester clothing or if the air has a low humidity level. Thermal noise can occur because of the physical properties of metal and/or semiconductors resulting from the electrodes or amplifiers respectively. The electrodes can create thermal noise proportional to the square
root of the resistance of the detection surface (4, 55). Fortunately, this can be minimized by cleaning the electrode contacts. The thermal noise created by the amplifiers can also be minimized by using low power amplifiers.

Another noise that interferes with EMG signals is mechanical or motion artifact often seen in dynamic studies. This disturbance can occur at two locations, the electrode-skin interface, or the lead-amplifier connection. Any movement of the electrodes in relation to the skin surface or movement of the lead wires in the amplifier, generally secondary to movements of body tissue, can create this mechanical artifact. Abrasion of the skin can decrease this noise with respect to the movement at the electrode-skin interface, and the lead-amplifier component is relatively small. Taping the wires against the skin will also decrease the noise that contributes to motion artifact. When considering mechanical artifact, the researcher should note that the frequencies will be no greater than 30 Hz. This frequency limit is because the noise is secondary to tissue movement and the human body does not oscillate at frequencies higher than 30 Hz (4, 55).

Cross-talk, or the electrical activity that originates from muscles other than the ones being investigated (55), is another potential contaminant to the EMG signal. This should be particularly noted when the muscle under observation is working at moderate to low levels (44). The existence of cross-talk tends to blur onset and cessation times of the muscle. With surface electromyography, cross-talk will often falsely imply co-contraction.

Once the electrical signal from the muscle has reached the electrode and has been amplified, it must be quantified to make it meaningful to the researcher. This process begins with digital sampling, also known as digitization. The key to digitization is the
rate of sampling. It must be quick enough to adequately reproduce the signal without collecting and storing extremely large volumes of data (4,44). Following digitization is full wave rectification. This involves making all values positive with respect to the zero line (44,55). Finally, the integration of data can be used to measure the area under the curve. When looking at the area under the curve, the amplitude, duration, and frequency are the main characteristics to consider (55).

Data from the EMG must also be normalized, allowing it to be used in comparisons within and among various subjects and studies (44,47,55). This process accommodates for variations such as muscle fiber size, fiber type, dispersion of motor units, fibrous tissue separating muscle fiber bundles, and variations in individual muscle contours (44). Normalization data is usually ratio data expressed as a percentage of some reference value (11,44). This reference value is usually the EMG output registered during a maximum isometric contraction effort (11,44). By expressing EMG activity of a particular muscle as a ratio of its current activity over its maximum activity, comparisons can be made between subjects as well as retests of the same individuals on different days, or from study to study.

By combining quantification and normalization, muscle effort can be designated as a percentage of the maximum registered with that particular electrode placement (44). This percentage can then be used to clinically identify significant information regarding the muscle’s relative effort (44).

According to Perry (44), the preferable system of recording is via the computer. When using a particular computer program it is important to note the sampling rate of its recording channels. Turker (55) recommends each channel have a sampling rate for the
analog-to-digital conversion component of at least two times the highest expected EMG frequency (44,55).

The reliability of the data from an EMG recording is only as good as the measures taken to minimize the contaminants (i.e. artifacts and noise) of the EMG signal. Choosing the size and placement of the surface electrodes, skin preparation, and adhering to an established set of rules to determine electrode configuration can minimize the vast number of factors that can cloud the electromyographical data. Factors that are harder to control are variations in body size and soft tissue differences amongst subjects. Gender differences must also be considered; for example, the Q-angle changes between the sexes for lower extremity studies.

Another way to limit contamination of data is to collect all of the data from a particular subject in one day. This method eliminates any between-day discrepancies that could crop up during the study (i.e. health issues, sleep changes, muscle soreness, etc.). The same-day method is most reliable when measures are taken to keep the electrodes firmly in one position, with no variation between skin surface and electrode surface. Taping the electrodes in place is a simple, cost-effective way of assuring no placement variations occur. Choosing an appropriate, non-muscular site for the ground electrode reduces, though does not eliminate, the existence of noise from the EMG signal. In summary, the greater the consistency and control of artifacts, noise and other contaminants, the more valid and reliable the EMG data becomes.

Summary and Implications

In examining the literature on PFJS and its treatment, little research could be found that studied the combination of CKC exercises, such as a squat with an added hip
adduction component as a means of selectively strengthening the VMO. Anterior tibial translation during CKC squat exercises has shown an increase in quadriceps muscle activity, but isolated VMO activity was not determined.

The fact that the VMO has an explicit role in maintaining patellar alignment has been identified in the literature. This role is to counter the lateral pull created by the VL, keeping the patella tracking correctly in the patellofemoral groove. Although the knee’s periarticular soft tissue structures could shorten and contribute to an excess lateral pull, most research focuses on creating a balance between the muscular components of this joint.

This study attempted to compare the ability of four CKC partial squat exercises to increase the VMO:VL ratio as measured via EMG data collection and analysis. When all exercises were compared, the VMO:VL EMG ratio was expected to be significantly greater in the partial wall squat with hip adduction and partial squat with oblique anterolateral 45° pull. The squat is a CKC exercise and most of our activities of daily living incorporate CKC motions. This warrants the squat more functional than the previously prescribed short arc quad sets or quad sets.
CHAPTER 3

METHODOLOGY

Study Site

This study was conducted in the Therapeutic Exercise Laboratory of the physical therapy department at Grand Valley State University. Approval for use of this facility was sought from the director of the school of physical therapy. Subjects reported to this facility during the months of January and February 1998 for a single visit test performance.

Subjects

Thirty-one volunteer subjects, twenty-one females and ten males, between the ages of 18 and 35 were recruited primarily from the general university population. Exclusion criteria of pregnancy within the last six months, history of any unresolved knee pathologies or any knee surgeries to the right knee, or neurological disorders were screened via a questionnaire (Appendix A). Each subject read and signed an informed consent (Appendix B) that was approved by the Human Subjects Review Board of Grand Valley State University.

Apparatus

One Vigor multiadjustable height pulley\(^1\) was used to create both the anterior tibial force and the oblique force directed anterolateral at a 45° angle. A spring scale\(^2\)

\(^1\) Vigor Equipment Inc., 4915 Advance Way, Stevensville, Michigan 49126

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was used to measure the force of each subject's maximum quadriceps muscle contraction at 50° of knee flexion (9). Two identical standard bathroom scales were used in this study. One was used to measure the subject’s body weight, and both were used simultaneously to monitor weight distribution between the lower limbs during squatting activities. A standard goniometer was used to measure the position of 50° knee flexion on each subject. A pole anchored on two side bars was set up for each subject to indicate the 50° endpoint of the flexion portion of the squat exercise. A metronome was used to control the speed of the exercise. A template for foot placement was drawn on the bathroom scales, with the feet placed at 10° external rotation (ER) in reference to the sagittal plane. A Stabilizer Pressure Biofeedback cushion was used during the hip adduction squat exercise to monitor the force of the adduction. The biofeedback cushion was attached to a seven and one half inch foam roller to increase the diameter of the cushion during adduction.

A multiple channel Myosoft/Myosystem 1200 EMG system and disposable silver-silver chloride surface electrodes were used to measure muscle activity. The surface electrodes were 1.0 centimeter diameter discs mounted on flexible silver chloride adhesive and covered with a saline gel. The silver chloride provided a stable skin-electrode interface by diminishing the polarization, while the saline gel provides quality signal transmission (44).

2 Sunbeam-Oster Company Inc., Shubuta, Mississippi 39360
3 Terraillon Corporation, Stamford Connecticut 06902
4 Wittner/ West Germany
5 Chattanooga Pacific Pty Ltd, Queensland, 12 Staple St., Seventeen Mile Rocks, Brisbane, Qld Australia 4073
6 Noraxon USA, Inc., 13430 N. Scottsdale RD., Suite 104, Scottsdale AZ, 85254
7 Empi Inc., 599 Cardigan RD., St. Paul, Minnesota 55126-4099
Testing Procedures

Each volunteer subject was given a questionnaire to fill out. This questionnaire was used as a method of screening potential subjects, so the study only included those subjects that met the inclusion criteria. Those selected subjects were then given a consent form to read and sign.

Right lower extremities were tested on all subjects to maintain consistency and to avoid moving the equipment. Each subject’s dominant side was noted. Test sequence for performing the four exercises was established using a predetermined randomized chart (Appendix C) that was made by first separating the four exercises into two categories 1) pulley squats and 2) wall squats. Once the sequential order for assignment to either the pulley squat or wall squat exercise category was determined, a coin was flipped to determine the order of the two squat exercises within each category. For the wall squat exercises, heads represented the partial wall squat while tails represented the wall squat with adduction. For the pulley squat exercises, heads represented an anterior pull while tails represented an oblique pull. This was done until there was a sequence of exercises for a total of thirty-six subjects.

Each subject was weighed and their weight was recorded on the recording sheet (Appendix D) and divided in half. Five percent of each subject’s weight was also calculated to determine the range of weight distribution to be supported by each lower extremity during the exercises. The distance between the subject’s acromion processes or shoulder width was measured and recorded.
The spring scale was hooked to the pulley system’s frame by one end while the other end was attached to a padded cuff that was placed around the subject’s lower leg. The cuff was at the height of the subject’s tibial tubercle. For the CKC maximal quadriceps contraction, the subject was positioned in the 50° angle of knee flexion, then instructed to try to straighten his knee as hard as he could. The subject held the contraction for 3 seconds while the maximum force was recorded. The subject performed this maximal quadriceps contraction three times with a minute break between each trial. The three maximum values were then averaged. The measurement of 25% of this average, as determined by the spring scale, was used to create the anterior and oblique tibial forces for each individual subject during the pulley exercises. The amount of 25% was chosen because this may encourage revascularization to the active muscles, a level that weakened muscles often need to attain to begin muscle rehabilitation. Sixty percent of the maximum force has been shown to be the minimum stimulus required for strength gains for the average healthy individual, so a lower percentage would likely be necessary to initiate a strengthening program if the individual has a pathological knee (21).

The subject’s skin was prepared for electrode placement by shaving the area when needed and then vigorous cleaning of the site by rubbing an alcohol swab against the area until a pink coloration of skin was noted (gentle skin abrasion to decrease impedance). A bipolar electrode configuration was used in an effort to decrease noise and artifact. Noise from the recording system was canceled out by the Myosoft program at the beginning of each test. The electrodes were applied with the subject in a standing position. Two electrodes were placed over each muscle belly of the VMO and VL at a center to center
distance of 2.5 centimeters apart in parallel with the muscle fibers, $55^\circ$ medial to the sagittal plane of the lower extremity for the VMO and $15^\circ$ lateral to the sagittal plane for the VL. The bipolar electrode placement for the VMO was at 3 and 5.5 cm superomedial from the superomedial border of the patella (23). The VL bipolar electrode placement was superior to the lateral knee joint line with the inferior of the two electrodes placed at the point that was 25% of the distance from the joint line to the anterior superior iliac spine. The ground electrode was placed on the shaft of the tibia. The electrodes were connected to the EMG via its channel wires.

Figure 1 – Electrode Placement

A CKC maximum isometric quadriceps contraction at a $50^\circ$ angle of knee flexion was then performed to determine the maximum EMG output (9). This exercise was performed with a cuff around the subject’s lower leg in the previously mentioned position, but the cuff was connected directly to the pulley system’s frame. The same subject positioning and the same instructions were given with one exception. The subject was told to hold onto the frame with one or both of his upper extremities to help stabilize his upper body, enabling him to produce maximal EMG activity in his quadriceps.
Resting muscle activity did not need to be taken because the Myosoft software automatically zeroed out muscle activity at the beginning of each recorded exercise.

For each of the squat exercises, the subject placed his feet on the foot templates of each scale. A template angle of 10° external rotation was selected because it was in the range of 5-18° of ER, which is optimal for balance in standing and gait (37). The scales were arranged so that the posterior aspect of the templates were separated by a distance equal to the subject’s measured shoulder width. To eliminate the effect of varying trunk position on resistance to knee extension, a researcher monitored the subject’s posture and cued the subject to keep his trunk as close to perpendicular to the floor as possible. The subject was asked to squat down keeping his trunk in an upright position. The scales monitored weight distribution. A bar was set in front of the subject’s knees to act as a stopper when the subject reached 50° of knee flexion as premeasured via a goniometer.

![Figure 2 - Setup for pulley system](image)

The order of the exercises for each subject was according to a pre-randomized chart developed by the researchers, as described earlier. A metronome, set at 80 beats per minute, was used to control speed during the exercises. The subject was instructed to descend and ascend from the squat at a speed of two beats for each direction. This
equaled a speed of one squat per three seconds. During all exercises, the scales monitored weight distribution. It was considered acceptable if the weight reading of each scale was within 5% of the subject's body weight. Directions for each exercise were read to the subject before a new exercise was initiated. The subject was allowed to practice each squat exercise until he/she could accomplish the squat to the beat of the metronome. An average of four squats were required by the subjects. After the practices were complete, the investigators began the test sequence of three consecutive squats for the squat exercises being tested. The weight distribution was monitored during each test sequence, and it was recorded on the recording sheet whether the subject was able to remain within the designated range. If the subject was unable to maintain this range, the amount of deviation was also recorded. A yes on the recording sheet indicated that weight distribution was kept within the determined range, min indicated the subject deviated 1-5 pounds out of that range, mod indicated a 6-10 pound deviation, and max indicated a deviation greater than 11 pounds out of the determined range. After each squat exercise, a three minute rest period was implemented prior to beginning the next exercise. This rest allowed a time interval in which to reposition the subject for the next exercise and to prevent fatigue from factoring into the study.

For the partial wall squat exercise, subjects were set up in the previously described manner and then asked to squat down. The subject was instructed to squat down until his knees touched the stop bar which was set to stop the motion at 50° of knee flexion and thus cue the subject to return to an erect position. The rate of the descent and ascent for each squat remained the same, two beats down and two beats up.
For the partial wall squat with hip adduction exercise, a pressurized cushion attached to a seven and one half inch diameter foam roller was placed between the subject's knees/thighs, with the cushion contacting the test extremity. The roller/cushion was at a height equal to that of the VL electrode placement. The subject squeezed the roller/cushion so pressure ranged between 40 to 60 mm Hg. This amount of adduction force was attempted to be maintained while squatting as above.

For the squat with an anterior pull, the pulley cuff was placed below the knee, with the top of the cuff located at the level of the tibial tubercle. Twenty-five percent of the force created in the standing maximal quadriceps contraction was used as the amount of resistance. The pulley rope was directed directly anterior in relation to the knee. The pulley was adjusted so that resistance was perpendicular to the tibia at the beginning of the squat exercise. The subject then squatted as previously described to a 50° knee flexion angle.

For the squat with an oblique pull, the pulley cuff was applied to the lower leg as previously mentioned. The pulley rope was directed at an angle of 45° anterolaterally to the sagittal plane. The resistance was 25% of the maximal quadriceps contraction. The subject was instructed to maintain a straight forward position of his knees, keeping his knees directly over the feet. The squats were then performed at a speed of two beats down and two beats up. The subject reached an angle of 50° of knee flexion each time.

Each subject took approximately thirty minutes to complete the test protocol in this study. A pilot study was used to determine and correct potential problems.
CHAPTER 4
DATA ANALYSIS

Techniques

The EMG software collected and recorded the electrical activity of both the VMO and VL in milliVolts during each partial squat exercise. The software also computed the area under the curve obtained during each exercise. The area was representative of the amount of electrical activity in each muscle. The activity was indicative of the frequency and velocity of motor unit recruitment. The rectified EMG data was normalized by obtaining a percentage of the maximal voluntary quadriceps contraction output. This was accomplished by dividing the average of the total EMG activity during each three second squat by the average of the total EMG activity during the three second maximal isometric contraction. By normalizing the data in this manner, it was possible to compare the VMO:VL EMG output ratios among the subjects in our study as well as with those of other studies. Once normalized, the VMO:VL ratio was determined for each selected variation of the squat exercises. The mean ratio for each exercise was then determined.

Since the data displayed a non-normal distribution, it was transformed by using a natural logarithm. The transformed data more closely followed a normal distribution. Since the transformed data can be assumed to follow a normal distribution, it was appropriate to apply repeated measures ANOVA, as opposed to a non-parametric approach. Subjects’ transformed data were then separated by gender and a repeated measures ANOVA was again applied. ANOVA with repeated measures showed a
significant difference for the male group only. A paired t-test was then used to compare any differences in mean VMO:VL ratio between exercises in this group. Differences were accepted as significant when p < .05. The statistical analysis was performed on a computer using the Statistical Package for the Social Sciences Software.

Results

The data did not support the hypothesis that the VMO:VL EMG activity ratio would be significantly greater in the partial squat with hip adduction and partial squat with an oblique 45° anterolateral pull when compared to the other selected exercises. This is shown by the following data.

Table 1 provides the mean, median, standard deviation and interquartile range of VMO:VL ratio for each exercise performed. These measures were analyzed for the entire group without regard to gender differences. The number given is the VMO:VL ratio with the VL always having the value of 1. The means (m) of the tested exercises were as follows: wall squat was 1.59, wall squat with adduction was 1.39, squat with anterior pull was 1.41, and the squat with oblique pull was 1.39 (Table 1). Using this data, the p value (p = .97) demonstrated no statistical significance for the group as a whole. For further analysis, the data was divided into two groups according to gender. With p = .78, no statistical significance was found among female subjects. Analysis of the male subjects data was statistically significant as p = .01.

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1 SPSS Inc., 444 North Michigan Ave., Chicago IL, 60611
Table 1

VMO:VL ratios for four selected partial squat exercises for the entire group (n=31)

<table>
<thead>
<tr>
<th>exercise</th>
<th>wall squat</th>
<th>adduction</th>
<th>anterior pull</th>
<th>oblique pull</th>
</tr>
</thead>
<tbody>
<tr>
<td>m</td>
<td>1.59</td>
<td>1.39</td>
<td>1.41</td>
<td>1.39</td>
</tr>
<tr>
<td>md</td>
<td>1.06</td>
<td>1.0</td>
<td>1.14</td>
<td>1.10</td>
</tr>
<tr>
<td>sd</td>
<td>2.33</td>
<td>1.04</td>
<td>1.01</td>
<td>1.28</td>
</tr>
<tr>
<td>IR</td>
<td>.94</td>
<td>1.04</td>
<td>1.26</td>
<td>1.02</td>
</tr>
</tbody>
</table>

m = mean VMO:VL ratio (mean % VMO activity / mean % VL activity = m : 1)
md = median VMO:VL ratio
sd = standard deviation of VMO:VL ratio
IR = interquartile range of VMO:VL ratio

A series of paired t-tests showed that the wall squat exercise was statistically significant for the male subject group when compared to the other 3 exercises. Table 2 displays the mean VMO:VL ratio for all exercises performed with regard to the male subject group. For the wall squat exercise, the mean VMO:VL was 1.01. The wall squat with hip adduction had a mean VMO:VL ratio of 1.40. A mean VMO: VL ratio of 1.30 was found for the squat exercise with anterior pull and 1.26 was the ratio found for the squat with an oblique pull.

Table 2

Male Subjects: Mean VMO:VL ratio for four selected partial squat exercises (n=10)

<table>
<thead>
<tr>
<th>exercise</th>
<th>wall squat</th>
<th>adduction</th>
<th>anterior pull</th>
<th>oblique pull</th>
</tr>
</thead>
<tbody>
<tr>
<td>m</td>
<td>1.01*</td>
<td>1.40</td>
<td>1.30</td>
<td>1.26</td>
</tr>
</tbody>
</table>

m = mean VMO:VL ratio
* significant difference (p > .05)
Findings of Interest

Looking at the group of subjects as a whole, the mean of the VMO:VL ratio in all of the four exercises was significantly higher than expected. Although the reason for this is unclear, outliers may have contributed. Because outliers were suspected, the medians were used to see if the data centered around a 1:1 VMO:VL ratio. By examining the medians, the effect of the outliers appears less prominent. Upon looking at the median data, all medians did center around 1.0. This provides some support for the theory that outliers affected the resulting mean ratios.
CHAPTER 5

DISCUSSION AND IMPLICATIONS

Discussion of Findings

The primary purpose of this study was to compare the ability of four CKC partial squat exercises to increase the VMO:VL ratio via EMG data collection and analysis. The hypothesis that the VMO:VL EMG activity ratio would be significantly greater in the partial squat with hip adduction and partial squat with oblique 45° pull when compared to the other two tested squat exercises could not be proven true in subjects with non-pathological knees. Many physical therapists and certified athletic trainers believe this hypothesis to be true and utilize these exercises in the clinic. This was an unexpected finding. However, other researchers have come up with similar results to those found in this study (47,22,11,27,52,31).

In a step-up/step-down exercise, Souza and Gross (52) found no statistical difference in VMO:VL ratios. The researchers looked at concentric, eccentric, and submaximal isometric quadriceps femoris activity via EMG data. Both healthy subjects and subjects with PFJS were used with no statistical difference in VMO:VL ratio seen between type of knee condition or muscle contraction condition. However, results did indicate a significant difference between isotonic quadriceps muscle contractions as they elicited greater VMO:VL EMG ratios compared to the isometric condition. This greater VMO:VL ratio may partially explain the higher ratios found in our study compared to the
majority of other VMO:VL ratio EMG studies which look primarily at isometric muscle activity.

Karst and Jewett (27) also explored the possibility of concurrent hip adduction with knee extension for increasing VMO:VL ratio via EMG activity. Although they used isometric OKC exercises and a different method of EMG normalization, they too did not detect a statistically significant difference with concurrent hip adduction to preferentially strengthen the VMO, thereby increasing the VMO:VL ratio. The VMO:VL ratios Karst and Jewett obtained from their tested isometric exercises ranged from approximately 0.8 – 1.0. This may lend support to Souza and Gross’s hypothesis that isotonic exercises elicit greater VMO:VL ratio than isometric exercises.

The conclusion of a recent study involving OKC isometric exercises conducted by Laprade, Colham, and Brouwer (31) found that hip adduction in conjunction with knee extension beginning at an angle of 50° resulted in very low levels of VMO and VL activity and that no preferential recruitment of the VMO over VL was demonstrated. Both nonpathological knees and knees with PFJS were studied and compared. Again, no significant differences were found between the control and PFJS groups. These results are similar to those reported by Souza and Gross. This study found a ratio of VMO:VL activity being approximately 1.0, which is lower than that attained in this study. Once again this supports the idea that isotonic exercises elicit greater VMO:VL ratios than isometric exercises.

In an elaborate study by Cerny (11) on subjects with nonpathological knees and PFJS, VMO and VL EMG activity was recorded during various OKC and CKC exercises.
Cerny also found no significant difference in VMO:VL EMG activity when comparing a wall squat to a wall squat with hip adduction in either group. When comparing these two exercises, Cerny found an increase in both VMO and VL activity during both exercises but no significant difference in the ratios.

However, there are studies that did support the idea that adduction does increase VMO activity in OKC. Hanten and Schulthies (23) concluded that hip adduction with knee extension significantly increased activity of the VMO when compared to the VL. This comparison was not put in ratio form, so the data is difficult to correlate with that of our study. Like many other studies, the exercises that were tested were OKC isometric contraction exercises (9,11,22,23,31).

Fiebert, Hardy and Werner (17) also found a significantly greater total EMG activity for the VMO when compared to the VL. Although these results contradict the results of this present study, the design of Fiebert et al.'s study was considerably different. Fiebert et al. studied eccentric muscle contraction using an isokinetic machine and did not use a VMO:VL ratio but rather compared the integrated EMG activity for the studied muscles. Since the data was not normalized, it is difficult to compare the results to other studies and it also raises a question as to the validity of the reported results. Normalization is necessary because it accommodates for variations in each subject's muscle fiber size and type, dispersion of motor units, and/or variations in muscle contours.

Though no statistical significance was found in any of the four exercises in the female population, it is interesting to note that in the male population significance was found in the wall squat exercise when compared with the other three exercises (see Table
2). The significance was apparent in the mean VMO:VL ratio with the wall squat exercises. This lower ratio could be due to either an increased VMO level of EMG output with no change in VL output, a decreased VL output with no change in VMO, or an increase in VMO output accompanied by a decrease in VL level of output. Although one of these postulates may be true, it is impossible to extrapolate which if any is in fact true from the data.

Application for Practice

The results of this study did not support the use of any one of the tested exercises as preferentially increasing VMO activity in an effort to restore muscle balance thereby eliminating patellar pain. Because of these results, further investigation of currently used exercises needs to be performed in order to support their clinical use. None of the posed questions have been answered regarding which CKC exercise favors greater VMO facilitation and thus might be a more effective treatment for PFJS. However, further questions have been raised. Do isotonic exercises increase the VMO:VL ratio in such a way as to selectively strengthen the VMO or do they only decrease VL activity, giving an increased VMO:VL ratio? Do we need to try to specifically focus on the VMO? Are isotonic CKC exercises preferential over OKC in general for increasing VMO strength?

Limitations of the Study

There were a number of limiting factors in this study. This study did not include pathological knees. Thus, the researchers can not directly correlate the results of the normal knee with that of the PFJS population. According to some studies, the pathological knee has different EMG activity as far as timing and magnitude of EMG
signals when compared to the nonpathological knee. Swelling and edema may also inhibit quadriceps strength. Thus, pathological knees may respond differently when subjected to the various stresses of the squat exercises performed.

The subject sample size and age range are also a draw back. Only 31 subjects were used ranging from 18 to 35 years. Of the 31 subjects in this study, only ten were male. With such a small male sample, the significance of the squat exercise information may not be representative of the overall male population, even for the age range of 18 to 35 years. Further research is warranted. The age range of the subjects limits the patient population of which this data directly applies. Most subjects came from the university population, which is not representative of the general population.

Balance was also a factor to consider in this study. The subjects were asked to maintain similar weight distribution on each lower extremity while performing the squat exercises. Those subjects with a wide variability in their normal weight distribution could have had altered VMO and VL activity because they may have been preoccupied with efforts to maintain the designated distribution of weight on each lower extremity.

Some subjects had difficulty following the rhythm of the metronome during their squat exercises. If the subject’s timing was inconsistent then the time spent in each phase of the squat would have been altered along with the fluidity of the squat. Since data collection was also correlated with the metronome, this could have slightly altered the results.

Subject stature could have impacted the results of the study, particularly in the squat exercises with hip adduction. The foam roller used with this exercise was 7 ½ inches in diameter. The subjects were instructed to maintain a pressure reading of 40 to
60 mm Hg on the cushion monitor gauge. Subjects who were of a short, stout physique had difficulty maintaining the designated adduction pressure due to their thighs being in close proximity. Their build, along with the foam roller diameter, contributed to an overshooting of the desired pressure range upon extension. For this reason, such subjects were not providing an adduction force. They may have actually abducted the hips during the squat. These factors also hindered such subjects in reaching full knee extension during the initial standing position and when rising from the squat.

This study required a maximum voluntary contraction measure to be obtained for normalization purposes. As with any maximum voluntary effort, subject motivation may be a limiting factor. This was illustrated by wide variation between trials when a subject performed his maximum voluntary contraction since enough time was allowed between trials to eliminate possibility of fatigue.

The measurement of the maximum voluntary contraction was measured by a spring scale that allowed movement, preventing a true isometric exercise, which would have been the ideal measure. Also, the units of measure on the spring scale were in 5-pound increments, not allowing for precise measuring. Since the scale indicator oscillated among the numbers and recording of the force reading was performed by a researcher, human error was a constant factor. Accuracy is also in question.

As this study was performed in a therapeutic exercise laboratory, the facilities allowed for limited wall space near the pulley system. Therefore, subjects performed the two wall squat exercises on the corner of a wall outcropping situated between two windows. This only allowed for half of the subject’s back to be fully against a “wall.”
Multiple research studies were being conducted using the same EMG equipment over the same period of time that this study was conducted. As a result, excessive stress on the EMG leads contributed to a short occurring in one of the lead wires. This occurred approximately midway through the data collection process. Consequently, the shorted lead wire was replaced by switching to another available lead. It is unclear if or to what extent this equipment malfunction had on the data collection and results.

Due to the excess flexibility given in the upright bars used to hold the stop bar, the set stop at a 50° angle of knee flexion may have been exceeded by the subjects. The stop bar was adjusted for the 50° angle of knee flexion only at the beginning of each series of three consecutive squats. Knee angle was not constantly monitored and therefore a slight deviation from the measured 50° could have occurred.

Further Research

Due to the number of limitations in the procedure, it would be useful to repeat this study with better controls. The limitation of the foam roller with regard to subject stature could be addressed by selecting a minimum adduction pressure that must be exceeded instead of maintaining a limited range. This would ensure that the subjects are actually adducting, not merely having the natural alignment of their lower extremities create the pressure on the foam roller. Furthermore, instead of using a 7-½ inch foam roller, future researchers could have a variety of foam roller sizes available in order to accommodate for differences in subject stature and still allow an adequate adduction force.

The spring scale used in this study was not the ideal piece of equipment. A strain gauge would be a more appropriate device to use. One such gauge is a muscle strength
dynamometer. A digital dynamometer could record the maximum force and provide smaller increments of measure, adding precision. A dynamometer with a peak hold needle could also be used to allow for more accurate measurement than the aforementioned spring scale.

Future research should investigate various aspects of the squat exercise and its effectiveness by addressing some of the questions described below. 1) Are there any differences between bilateral versus unilateral squat exercises in a strengthening program? 2) Does using the constant weight of a pulley for the anterior or oblique forces differ from a fluctuating force that is created by elastic bands or rubber tubing commonly given to patients for home exercise use? 3) Is there a difference in muscle activity between genders? 4) Do isotonic exercises increase the VMO:VL ratio in such a way as to selectively strengthen the VMO or do they only decrease VL activity, giving an increased VMO:VL ratio? 5) Do we need to try and specifically focus on the VMO? 6) Should change in patellar tracking be investigated as opposed to change in VMO:VL ratio as the ultimate goal in rehabilitation? 7) Does adducting with a rubber ball between the subject’s thighs produce a different force than that of squeezing the stiff foam roller? 8) Are isotonic CKC exercises preferential over OKC in general for increasing VMO strength?

Conclusion and Summary

This study attempted to determine the efficacy of four selected partial squat exercises for the preferential strengthening of the VMO to restore muscle balance around the knee. Our data did not support the hypothesis that the VMO:VL EMG activity ratio will be significantly greater in a partial squat with hip adduction and partial squat with
oblique 45° pull when compared to the other tested squat exercises. However, male subjects demonstrated a significant difference in the wall squat when compared to the other three exercises. Further investigation is warranted to determine why. Future research controlling for the previously mentioned limitations may in fact be able to prove this hypothesis true. The results indicated that no one variation of the squat exercises examined in this study was any more efficient than any of the others at selectively activating the VMO. It is evident by examining this and other studies that isotonic CKC exercises increase VMO:VL ratio, so this mode of exercise may be preferential in PFJS rehabilitation. Also, CKC exercises are often less painful. Strengthening the adductor musculature of the hip may be beneficial independent of any increase in VMO:VL ratio because the adductor can provide a more stable origin for the VMO to facilitate greater control of patella as it tracks.
REFERENCES


Appendices
NOTE TO USERS

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UMI
Appendix B

Grand Valley State University
Department of Physical Therapy
Informed Consent

Project Title: A Comparative Electromyographical Study of the Vastus Medialis Oblique and Vastus Lateralis (two muscles in the thigh) Using Squat Exercises.

I understand that this is a research study involving 30 subjects, examining the EMG activity of two quadriceps muscles and that the data and knowledge obtained is expected to help in the clinical treatment of the quadriceps, focusing on increased vastus medialis oblique activation.

I also understand that:

1. My participation in this study is completely voluntary and will involve one 45 minute test session during which four different squat exercises with and without externally applied forces will be performed.

2. I have been selected for this study because I do not have any current or previous knee pain, injury or surgeries nor have I recently been pregnant.

3. I will be weighed, be required to perform a maximum isometric quadriceps contraction and hold for 3 seconds, and perform four partial squat exercises, two of which will include the use of a pulley system to create external forces. The weight of these forces will equal 40% of the maximum quadriceps contraction force.

4. Muscle activity will be recorded through the use of five surface electrodes placed on the inner and outer thigh and shin of the tested leg. The skin under the electrodes will be shaved and rubbed with an alcohol pad to assure decreased resistance to electrical flow and optimal electrode contact. EMG wires will be attached to the electrodes to receive and measure the muscle activity. Current will NOT be delivered to the subject.

5. Testing is not expected to present any risk of injury to the participant. Mild exercise effects of muscle soreness could occur, lasting 1-2 days. Subjects with sensitive skin could experience minor skin irritation from the shaving, alcohol rub, or self-adhesive on the electrode.
6. It is my responsibility to report any pain felt during the test procedure to the investigators, and I have the right to discontinue my testing at any time and for any reason without penalty.

7. The test results will be used in a Master's thesis for students in the Grand Valley State University physical therapy program, with all subject's names omitted for confidentiality purposes. The test results could also be used in scientific literature if the investigators so wish, with subject confidentiality maintained.

8. I will have the opportunity to ask questions of any of the investigators regarding the study at any time, and have these questions answered to my satisfaction. (E-mail addresses of investigators will be given upon request.

I acknowledge that I have read and fully understand the above stated information regarding this study by Barbara Campbell(454-8227), Michelle Krupiczewicz(454-6814), and Heidi Tolloff(735-1710). I voluntarily agree to participate in this study.

Name

______________________________________________

Signature

______________________________________________

Date

____________________________

Witness

______________________________________________

Dr. A. Schwarcz                      Professor P. Huizenga
Thesis Chairperson                  Human Subjects Research Review Board
P.T. Dept., GVSU                      GVSU, 895-2472
895-2675
## Appendix C

### Randomization of Exercise Sequence by Subject

<table>
<thead>
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<th>Exercise 2</th>
<th>Exercise 3</th>
<th>Exercise 4</th>
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<td>ADD</td>
<td>CON</td>
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**CON** = wall squat  
**ADD** = adduction  
**OBL** = oblique pull  
**ANT** = anterior pull
## Appendix C

<table>
<thead>
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CON = wall squat  
ADD = adduction  
OBL = oblique pull  
ANT = anterior pull
Appendix D

Record Sheet

Subject # ___________ Date __/__/98
Name ______________________ Side Dominance is ______ R  L
Weight ______ 1/2 Weight ______ 5 % Weight ______ Range on each scale _______-

Shoulder width

<table>
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<th>Max Voluntary Contraction</th>
<th>VMO (area under the curve)</th>
<th>VL (area under the curve)</th>
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<td>Trial 3</td>
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Max Force Production during Max Contraction

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<tr>
<th>Force (lbs)</th>
<th>Average (lbs)</th>
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<tr>
<td>Trial 1</td>
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<tr>
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<tr>
<td>Trial 3</td>
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</table>

25 % of Mean Max Force Production [Mean x .25 =] is _________(lbs)

Exercise Sequence

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<td>circle # for each</td>
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Partial Squat 2 = Squat with ADD 3 = Squat with ANT PULL 4 = Squat with OBLIQUE PULL

EMG data (area under the curve) for each trial

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<th>VL</th>
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<td>Partial Squat/OBLIQUE Pull</td>
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<tr>
<td>Trial 3</td>
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</table>

Yes = kept weight distribution within 5% range
Min = deviated 1-5 lbs out of range
Mod = deviated 6-10 lbs out of range
Max = deviated > 11 lbs out of range