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The Efficacy of Two Conservative Rehabilitation Programs for the Treatment of Patellofemoral Pain Syndrome

by

Lara C. McClelland

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Abstract

The purpose of this single blinded, randomized clinical pre-test, post-test clinical study was to evaluate the differences between a 42 day home exercise program (HEP) and a 42 day physical therapy (PT) program for patients diagnosed with patellofemoral pain syndrome. The primary outcome measures being used were the subjective reporting of pain and the subjective reporting of function. The secondary measures of interest were the peak force values exerted by the quadriceps during a maximal voluntary isometric contraction and the ratio of muscle activity from the quadriceps during 60% and 30% submaximal contraction conditions. Fifteen subjects completed the HEP, 15 subjects completed the PT program, and 16 control subjects were monitored over the 42 days. Subjects were tested on days 1, 21 and 42.

The subjects' VAS pain scores in the PT group [day 1 (1.67 ± 1.97), day 21 (0.73 ± 0.9), day 42 (0.26 ± 0.37)] showed a significant decrease over the forty-two days (p=0.012). The subjects' VAS pain scores in the HEP group [day 1 (1.89 ± 2.16), day 21 (2.67 ± 2.48), day 42 (0.64 ± 0.67)] did not result in a significant decrease over the forty-two days (p=0.025), as determined using a correction for multiple t-tests (p=0.0125). The between group analysis revealed there was no statistically significant difference in the changes in the levels of pain between the two programs (p=0.829). The functional knee scores in the PT group [day 1 (34.5 ± 8.02), day 21 (39.53 ± 6.34), day 42 (44.13 ± 5.52)] resulted in a significant increase over the 42

days (p=0.004). The functional knee scores in the HEP group [day 1 (36.3 ± 6.26), day 21 (37.7 ± 7.7), day 42 (39.4 ± 8.9)] did not reveal a significant increase over the 42 days (p=0.2854). The between group analysis of knee function scores revealed that the changes in the PT group were not statistically different than the changes in the HEP (p=0.076). The peak quadriceps force values in the PT group [day 1 (62.48 ± 24.26 Nm) day 42 (76.22 ± 31.06 Nm)] showed a significant increase over the 42 days (p=0.0005), as well did the peak force values in the HEP group [day 1 (68.61 ± 19.65 Nm) and day 42 (77.23 ± 18.92)] (p=0.003). A between group comparison of the changes in peak quadriceps force revealed there was no statistically significant difference between the two programs (p=0.204). There were no significant differences in the ratio of quadriceps muscle activity in either rehabilitation program over the 42 days for the 60% [PT day 1 (0.970 ± 0.187), day 42 (0.976 ± 0.25), HEP day 1 (0.915 ± 0.150), day 42 (0.995 ± 0.26)], or the 30% [PT day 1 (1.12 ± 1.11), day 42 (1.77 ± 1.9), HEP day 1 (0.80 ± 0.261), day 42 (0.889 ± 0.35)] submaximal contraction conditions. The between group comparisons revealed there was no statistically significant difference between the two programs in either the 60% (p=0.627) or the 30% (p=0.634) contraction conditions. There were no significant changes in the control group in any of the four variables throughout the 42 days.

The results from this study suggest that both a physical therapy program and a home exercise program are efficacious for the treatment of patellofemoral pain syndrome. The PT program resulted in significant changes in both pain and function, whereas the HEP did not. Although, the changes in the PT group were not large enough to be statistically different than the changes in the HEP group. Therefore, the home exercise program is a lower cost alternative and could be clinically prescribed as an effective initial route of management for PFPS.

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CHAPTER ONE

INTRODUCTION

Pain in the anterior region of the knee is a common clinical symptom often encountered in general practice, sport medicine and orthopaedic settings (Mann et al., 1988, Malek & Mangine, 1981, Kannus et al., 1987, O'Neill et al., 1992, Garrick, 1989 and McConnell, 1986). The incidence of knee pain in the general population is not well documented, although it is a frequent complaint in the physically active (Milgrom et al., 1996, Messier et al., 1991, Hughston, 1968 and Kujala et al., 1986), and it affects males and females of all ages (Cutbill et al., 1992, Edeen et al., 1992, Reider et al., 1981 and Matheson et al., 1989). There are numerous factors that contribute to the onset and/or perpetuation of pain in the anterior knee region. These range from a single traumatic event to repetitive overuse.

Generalized pain that is not caused by a traumatic event often poses a great challenge for the managing clinician. This challenge is even further compounded by the numerous diagnostic terms that are available under the umbrella of generalized anterior knee pain. Many of these diagnostic terms are used interchangeably in the scientific literature and clinical settings. Examples of such diagnoses are: patellofemoral pain syndrome (Kannus & Niittymaki, 1994, Karlsson et al., 1996 and Messier et al., 1991), chondromalacia patellae (Levine, 1979, Insall, 1979 and Aglietti et al., 1983), recalcitrant anterior knee pain, (Edeen et al., 1992), patellofemoral stress syndrome, (O'Neill, et al., 1992), patellar compression syndrome (Doucette & Goble, 1992 and Larson et al., 1978), patellofemoral arthralgia (Gerrard, 1989 and Whitelaw et al., 1989) or femoropatellar pain syndrome (Shelton, 1992). There is currently no documented consensus in the scientific literature or in the clinical community as to the definition, etiologic mechanisms or management protocols specific to each of the above listed diagnostic terms (Cutbill et al., 1997). The author has chosen to use patellofemoral pain syndrome (PFPS) as the preferred diagnostic term to be reviewed and cited throughout this document. The term PFPS is encompassing of the pain at the patellofemoral articulation, acknowledges the disorder as a syndrome and does not attempt to describe more than the name entails.

PFPS is characterized by pain at the peripatellar or retropatellar aspect of the knee that becomes exacerbated during certain activities, specifically stair ascension and descension, and prolonged sitting and running (Kannus & Niittymaki, 1994, Werner & Eriksson, 1993, Callaghan & Oldham, 1996 and Arrol et al., 1997). The etiology of PFPS remains enigmatic, although many researchers have suggested any of the following causes: anatomic abnormalities (shallow intercondylar sulcus, irregularities in the patellar facets, increased Q-angles, genu recurvatum, laxity of medial retinaculum, iliotibial band tightness, lateral retinacular tightness and imbalance in the surrounding musculature) and/or repetitive microtrauma (overuse) to the connective tissue (Javadpour et al., 1991, Fulkerson & Hungerford, 1990, Ficat & Hungerford, 1977, Hughston et al., 1984 and Fox, 1975). The foremost difficulty with PFPS is that there is not one defined precursor that aids in the onset or perpetuation of the disorder. Rather, it may be a physiological, biochemical, biomechanical and/or anatomical property working individually or collectively to cause pain.

PFPS is often mistakenly used as an all-encompassing diagnosis that includes softening of the articular cartilage, inflammation of the connective tissue, meniscal damage, ligament instability, loose bodies or osteoarthritis. The lack of documented etiological mechanisms, variance in the use of diagnostic measures and the varying availability of diagnostic tools creates difficulties in universally defining and/or diagnosing patients with patellofemoral pain. For this study, the author has defined PFPS as follows:

'A disorder presenting with a history of peripatellar or retropatellar pain originating from the patellofemoral joint that worsens with activity or prolonged flexion, not a consequence of sudden major trauma and/or osteoarthritis. Physical examination reveals medial facet tenderness with or without retinacular or lateral facet tenderness and absence of articular or bony deformities or dysfunction in connective tissue.'

The author cautions against using PFPS as a 'catch-all' phrase and recommends using the term within the confines of the above definition.

1.1. OVERVIEW OF THE PROBLEM

Patellofemoral pain syndrome is diagnosed in 30% (Derscheid & Feiring, 1987) to 33% (Milgrom et al., 1996) of all patients seen in sport medicine settings. It is a common cause of impairment in the running population (Clement et al., 1981 and Messier et al., 1991) and up to 25% of runners have been diagnosed with the disorder (James et al. 1978). During a basic military training program, 15% of infantry recruits developed patellofemoral pain (Milgrom, 1991). These statistics may suggest that overactivity is a primary precursor to PFPS. Although, the intensity and/or type of activity may not be directly correlated to patellofemoral pain onset, as both Hughston (1968) and Kannus & Jarvinen (1989) discovered a high incidence of PFPS in both inactive adolescent women and inactive patients respectively. Research on the physically active and the general population has been unable to accurately define a specific precursor that may lead to the development and/or onset of PFPS. This paucity of information makes it difficult to establish a targeted treatment program aimed at alleviating patellofemoral pain.

1.2. MANAGEMENT OF PFPS

The management for PFPS is somewhat anecdotal and presents a broad spectrum of treatment protocols. The initial and most often prescribed treatment by physicians is non-operative management, which has been documented to bring resolution of pain to the majority of patients with PFPS

(Galea & Albers, 1994, Malek & Mangine, 1981, O'Neill et al., 1992, Whitelaw et al., 1989, Kannus et al., 1987, Doucette & Goble, 1992 and Callaghan & Oldham, 1996). If non-operative measures are unsuccessful over a prolonged time period, surgical intervention may become an option.

Non-operative or conservative care may include any of the following: physical therapy, home exercise programs, stretching exercises, strengthening exercises, activity modification, massage therapy, chiropractic therapy, acupuncture, taping, bracing, orthotics, non-steroidal anti-inflammatories, icing and rest. The presence and utilization of such a wide range of treatments makes it difficult to determine which treatment or what combination of treatments are the most efficacious for PFPS patients. The most successful non-operative programs are usually a combination of the above and have resulted in over 75% success with PFPS (Doucette & Goble, 1992, Gerrard, 1989, Malek & Mangine, 1981 and Whitelaw et al., 1989). Two routes of non-operative management frequently administered in a clinical setting to PFPS patients are: a physical therapy program or a home exercise program (Thabit & Micheli, 1992 and Bennet, 1993).

A common course of physical therapy for PFPS usually incorporates education, on-going activity modification, progressive strengthening exercises primarily focused on the quadriceps, stretching, taping and various modalities administered over one to ten weeks (Peterson & Renstrom, 1986, Ficat &

Hungerford, 1977, Malek & Mangine, 1981 and Shelton, 1992). In contrast, a clinically administered home exercise program is a structured progressive program prescribed by a physician or physiotherapist during a patients initial and one-time consultation. A home exercise program allows the clinician to educate the patient, prescribe rehabilitative strengthening and stretching exercises, and make recommendations on activity modification.

There is a paucity of literature that compares the efficacy of non-operative measures (Malmivaara et al., 1995 and Kuukkanen & Malkia, 1996). Numerous papers in the English literature cite the positive results of physical therapy for patients diagnosed with PFPS (Doucette & Goble, 1992, Gerrard, 1989, Malek & Mangine, 1981 and Whitelaw et al., 1989), although there are no scientific papers that comparae their results to any alternative care protocols, such as a home exercise program.

1.3. PURPOSE OF THE STUDY

The purpose of this randomized controlled clinical pre-test, post-test study was to determine if there was a difference in the effect of a course of physical therapy versus the effect of a home exercise program on PFPS patients, as determined by subjective and objective variables. The primary measures of analysis in this study were the subjective reporting of pain, and the subjective reporting of functional ability. Secondary measures of interest were the changes in peak quadriceps force during maximal voluntary isometric contractions, and the changes in the ratio of muscle activity as defined by the vastus medialis oblique and the vastus lateralis during submaximal isometric voluntary contraction conditions.

1.4. RESEARCH HYPOTHESIS

The presiding null hypothesis (Ho) of this study is that there will be no significant differences between the effects of a course of physical therapy versus the effects of a home exercise program on PFPS patients, as determined using the above listed four outcome measures.

CHAPTER TWO

BACKGROUND AND OVERVIEW OF PATELLOFEMORAL PAIN SYNDROME

A United States census of 14,000 Orthopaedic surgeons cited the knee joint as the most frequent anatomic site of dysfunction, with the average physician seeing 26 knee patients out of 100 overall patients (National Centre for Health Statistics, 1994). A review of the U.S. health statistics also reveals that approximately 5 million patients are seen each year for knee related disorders (National Centre for Health Statistics, 1994). Patellofemoral joint problems comprise over one quarter (25.8%) of the total injuries presented to sport medicine settings, and over 10% of these injuries present with patellofemoral pain (Derscheid & Feiring, 1987, Malek & Mangine, 1981, & Kannus et al., 1987). There are many factors that may influence the onset, treatment and/or perpetuation of PFPS, which range from the anatomy and how it influences lower limb function, to the variance in pathologies within or surrounding the patellofemoral joint.

2.1. FUNCTIONAL ANATOMY OF THE PATELLOFEMORAL JOINT

The patellofemoral joint consists of the trochlear groove of the femur and the medial, lateral and odd facets of the patella (Fulkerson & Hungerford, 1990)(Figure 2.1.). The patella is the largest sesamoid bone in the human body and is located anterior to the knee joint within the quadriceps/patellar tendon (Goodfellow et al., 1976 and Fox et al., 1985). The inferior pole of the patella has a non-articulating surface which is approximately 25% of its' height. The superior portion, approximately 75% of its' height, articulates with the femur and is completely covered with hyaline cartilage. The patella has two primary functions: first, to protect the femoral articular surface (Fox et al., 1985), and second, to act as a fulcrum to increase the efficiency of the quadriceps femoris (QF) muscle by lengthening the lever arm (Fulkerson & Hungerford, 1990; Maquet, 1984 & Fox, 1985).

'Normal' functioning of the patellofemoral joint depends on adequate stabilization and guidance of the patella. This is assisted by the surrounding static, dynamic and bony structures (Fox et al., 1985). The static structures include the patellar tendon, the tissues of the medial and lateral retinacula, the medial and lateral patellofemoral ligaments, the patellotibial band and the iliotibial band. The dynamic structures refer to the quadriceps musculature and the iliotibial band. The quadriceps are comprised of four distinct muscles (rectus femoris, vastus lateralis, vastus medialis and vastus intermedius) that join to form the trilaminer quadriceps tendon and insert onto the patella.

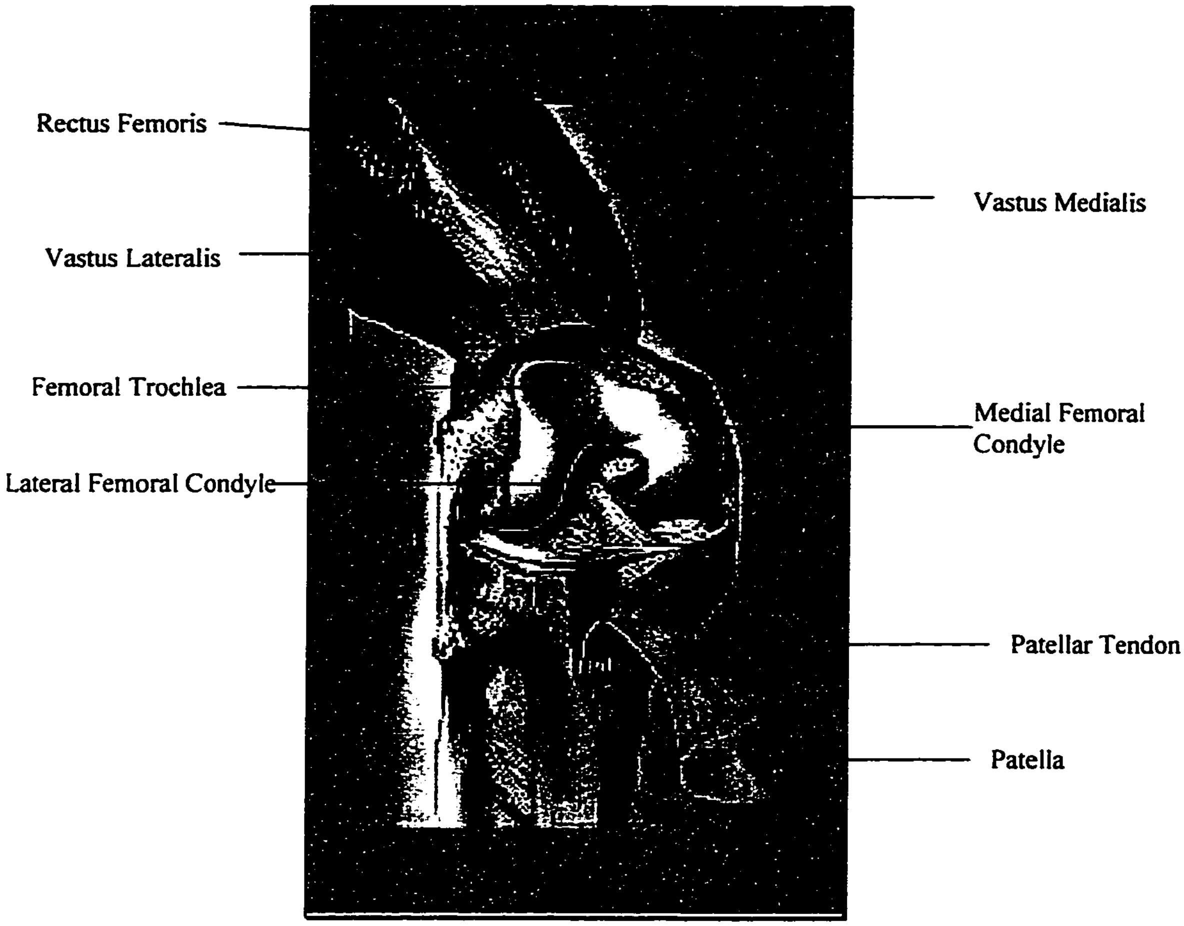

Figure 2.1. Gross Anatomy of the Patellofemoral Joint, Anterior View

(Adapted from The Centre for Orthopaedics & Sport Medicine's website on 'Knee Disorders, ' 1998, (www.arthroscopy.com))

The course of the patellar tendon is slightly oblique laterally, which adds to the laterally directed displacement of the patella (Fulkerson & Hungerford, 1990). The prevention of lateral patellar movement is aided by the lateral femoral condyle, static tethering of the medial retinaculum, static tethering from the patellofemoral ligament, medial meniscopatellar ligament, and dynamic pull of the vastus medialis (Fulkerson & Hungerford, 1990). The prevention of medial patellar movement is controlled by the medial femoral condyle, lateral peripatellar retinaculum, lateral patellofemoral ligament, patellotibial band, iliotibial band and lateral musculature of the quadriceps (Fulkerson & Hungerford, 1990).

During activity the patellofemoral joint is the least congruent of the major weight-bearing joints, but mediates forces created by the largest muscles that insert upon the longest lever arms in the human body (Merchant, 1990). As the knee undergoes flexion, the quadriceps compress the patella into the femoral sulcus gradually increasing PF joint forces to as high as seven times body weight during deep squatting (Reilly & Martens, 1972). The forces at the patellofemoral joint are among the highest per unit area of any joint within the body (Ruffin & Kiningham, 1993 and Merchant, 1990).

Anatomic studies of the extensor mechanism have shown that the vastus medialis (VM) and vastus lateralis (VL) are each sub-divided into two muscles separated respectively by a fascial plane or a thin layer of fat (Lieb & Perry, 1968 and Javadpour et al., 1991). The two components of the VM are also separately innervated by branches off the femoral nerve.

Lieb & Perry (1968) conducted a mechanical study on the extensor mechanism and demonstrated that the differing muscles of the VM and VL have distinct functions. The oblique components of the VM and VL are called the vastus medialis oblique (VMO) and vastus lateralis oblique (VLO) and assist in patellar stabilization and alignment. The fibres off the VMO insert horizontally upon the superomedial and medial aspect of the patella at approximately 42° - 65° and the VLO fibres run acutely at approximately 12° - 16° on the superolateral and lateral margins of the patella (Lieb & Perry, 1968). The longitudinal fibres comprise the vastus medialis longus (VML) and vastus lateralis longus (VLL) and are each shown to assist in extension of the knee joint (Lieb & Perry, 1968).

The distribution of mechanical stresses imparted to the joint between the VMO and VLO are not always uniform and tend to favour a slight laterally directed vector (Fulkerson & Hungerford, 1990 and Maquet, 1984). Fulkerson & Hungerford (1990) describe this lateral predisposition as the law of valgus. The authors suggest that valgus forces may be created by the muscles orientation along the femur, resulting in the quadriceps angle. In addition, the lateral dynamic and static stabilizers (ie. iliotibial band and VL) are considerably stronger and more fibrous than the medial counterparts, this accentuates the inherent lateral predisposition (Fox, 1975).

As outlined above, the quadriceps do not travel along a straight line from the femur to the tibia, rather, they pass approximately 10° (the broader the pelvis, the greater the deviation) laterally from a perpendicular through the joint axis during stance (Cox, 1990). This angle has been termed the quadriceps angle (Q-angle), and is determined by intersecting a line from the middle of the patella to the center of the tibial tubercle and a line from the center of the patella to the anterior superior iliac spine (Figure 2.2.) (Ficat & Hungerford, 1977 and Messier et al., 1991).

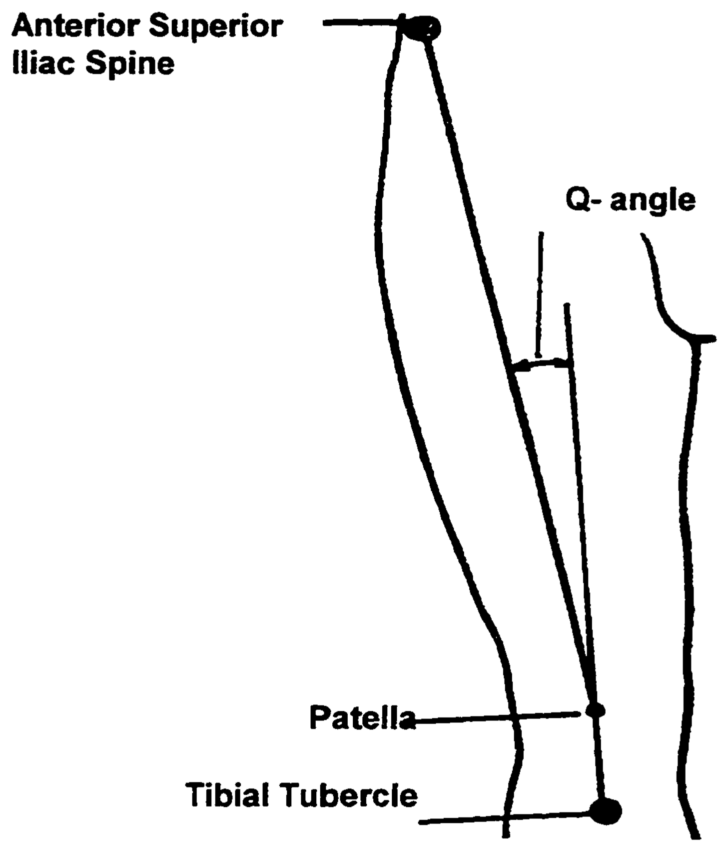

Figure 2.2.

Figure 2.2. Q-Angle: Location Points of Anterior Superior Iliac Spine (ASIS), Centre of the Patella and the Insertion of the Patellar Tendon on the Tibia - (Adapted from Woodall & Welsh, 1990).

This angle results in a bowstring effect, and combined with the potential phylo-genetic weakness of the VMO, predispose the joint to a lateral patellar drift (Fox, 1975 and Lieb et al., 1968). 'Normal' Q-angles cited for males are approximately 10° and for females 15° (Messier et al., 1991 and Arno, 1990). Messier et al. (1991) have suggested that individuals with PFPS often exhibit an increased Q-angle.

A direct correlation between increased Q-angles and patellofemoral pain has not been established, and Fulkerson & Hungerford (1990) and Woodall & Welsh (1990) recommend that clinicians do not overly focus on the Q-angle in their physical examination. An increase in Q-angle may be the result of the following biomechanical factors: increased external tibial torsion, femoral torsion, lateral displacement of the tibial tubercle, lateral retinacular tightness, genu valgum and/or genu recurvatum (Post & Fulkerson, 1992 and Fox, 1975).

2.2. ETIOLOGY OF PFPS

There are many contrasting theories as to the origin of pain at the patellofemoral joint, such as: articular cartilage degeneration, mal-tracking of the extensor mechanism, overuse, underuse, central nervous system events and anatomic abnormalities. Many researchers and clinicians accept that the pain at the patellofemoral joint is secondary to precursory and/or perpetuating factors, although identifying these factors is difficult in PFPS.

In the majority of circumstances PFPS is multifactorial. In some cases, physicians diagnose the patient with idiopathic PFPS because no causative factors can be found. The factors that are most frequently highlighted as contributory to patellofemoral pain are discussed briefly below.

2.2.1. Chondromalacia Patellae

In 1936, Owre proposed that pain experienced in the anterior aspect of the knee should be diagnosed as 'chondromalacia patellae (CP)'. CP has since become a catch-all phrase synonymous with anterior knee pain and patellofemoral pain syndrome. Recent literature is critical of the use of CP as a diagnosis referring to generalized knee pain and confined it solely to a diagnosis describing articular cartilage degeneration (Fulkerson, 1983, McGinty & McCarthy, 1981, Metcalf, 1982, Radin, 1979 and Darracott & Vernon-Roberts, 1971). Changes to articular cartilage can best be seen through direct visualization techniques, such as arthroscopy, or the use of magnetic resonance imaging. Therefore, a physical examination without direct visualization is not sufficient to yield a diagnosis of CP.

The pathophysiology of CP remains unclear, although a significant percentage of literature affirms that altered mechanical loading to a joint may be the primary precursor to articular cartilage degeneration (Radin et al., 1991, Eckhoff, 1994, Goodfellow et al., 1976, Reimann, 1973, and Tetsworth & Paley 1994). Radin (1973) studied load conditions on articular cartilage and hypothesized that repetitive impulse loading causes a stiffening in the deep subchondral bone. Schouten et al., (1992) suggested that this stiffening results in the articular cartilage being subjected to higher stresses. The higher stresses may initiate horizontal splits which could significantly weaken the cartilage structure (Meachin & Bentley, 1978). Since Radin's initial studies, other researchers have discovered that during abnormal loading, the composition and micro-structure of the cartilage and deep subchondral bone undergoes change (Radin et al., 1973, 1990, 1991, Poole et al., 1993 and Goodfellow et al., 1976). Reimann (1973), in her animal model investigation, discovered that degenerative changes in articular cartilage can be induced by disturbing the mechanical axis and altering load bearing. Darracott & Vernon-Roberts (1971) looked at articular cartilage and found splitting and degeneration at the cartilage base of human and animal models that were exposed to shear longitudinal stresses and repetitive impulse loading. Basal degeneration within the articular cartilage may cause a biochemical breakdown of the cartilage matrix. Laurin et al. (1979) suggests that this breakdown releases chondrolytic enzymes that may irritate the synovium which may create an inflammatory synovitis.

Other investigators have concluded that the relationship between the presence and/or severity of chondromalacia patellae does not correlate well with the degree or presence of pain experienced in the knee joint (Abernathy et al., 1978, Fulkerson, 1983, Hughston et al., 1984 and Insall, 1976). Casscells (1979), Grana et al. (1984), Larson et al. (1978) and McGinty & McCarthy (1981), studied patients experiencing anterior knee pain that had arthroscopic surgery or a lateral retinacular release and found normal articular cartilage in these symptomatic patients. The mechanism that elicits the pain response is not known, as there are no nerve endings in articular cartilage. Pain receptors (nociceptors) in the patellofemoral joint have been found in the synovium, subchondral bone, retinaculae, ligaments, menisci, joint capsule, and tendon.

2.2.2. Excessive Lateral Pressure Syndrome

In 1975, Ficat proposed that pain in the patellofemoral joint stemmed from an excessively tight lateral retinaculum. He suggested that a tight lateral retinaculum causes a chronic lateral patellar tilt and adaptive lateral retinacular shortening. This causes hyper-pressure on the lateral patellar facet. Since then, Fulkerson & Shea (1990), Maquet (1984), Shellock et al., (1992) and Ogilvie-Harris & Jackson (1984) have studied lateral tracking of the patella and found a positive correlation between articular cartilage degeneration and overloading of the lateral facet.

Despite Fulkerson and Hungerfords (1990) statement that 'excessive tension in the lateral retinaculum is indeed a major contributing factor in most cases of excessive lateral pressure syndrome," there is little evidence available to prove this statement, as there are many people who have excessively tight lateral retinaculums who do not develop pain at the patellofemoral joint. An excessively tight lateral retinaculum may therefore be one of many factors contributing to pain in the patellofemoral joint and be a primary or secondary event. But, excessive lateral pressure syndrome as the sole causation for pain needs further review.

2.2.3. Neuromatous Degeneration

Fulkerson et al., (1985) described histologic evidence of neuroma's in tight lateral retinaculums of knee pain patients. They suggested that a tight lateral retinaculum undergoes excessive strain as the patella is drawn into the trochlea and the iliotibial band pulls posteriorly on the already strained lateral retinaculum. This excessive strain may precipitate small nerve damage and result in the development of neuromas. Fulkerson et al. (1985) suggest that neuroma's in the excessively tight lateral retinaculum may be the source of pain in PFPS. There are no published studies that replicate Fulkerson's results, although it is plausible that these neuroma's may be pain provoking, as is seen in other areas of the body.

2.2.4. Anatomic Abnormalities:

Anatomic anomalies of the lower limb appear to be one of the most commonly cited causes in both the literature and clinical settings for the development and/or perpetuation of PFPS (Guzzanti et al., 1994, Larson, 1979, Hughston, 1968, Aglietti et al., 1983, Carson et al., 1984, and Gerard, 1989). Anatomic variations can range from increased Q-angles to patellar 'maltracking' to increased foot pronation.

Thomee et al. (1995(a)) studied 20 asymptomatic control subjects and 40 symptomatic knee pain subjects for anatomic variations. They looked at Q-angles, pelvic width, knee hyper-extension, and distance between knees and foot pronation angles. Their results suggest there was no significant difference between the PFPS group and the control group in any of the above measurements. Similar findings were also reported by Fairbank et al. (1984), Sojbjerg et al., (1987), Galanty et al., (1994) and Kannus & Niittymaki, (1994). Fairbank et al. (1984) assessed Q-angles in an asymptomatic population and stated that approximately 60 - 80% of the general population would fall into the category of 'malalignment,' suggesting that anywhere from 17,978,000 to 23,970,800 persons in Canada would develop PFPS if malalignment is a direct correlation.

Aglietti et al. (1983) also studied the alignment of the lower limb in 150 asymptomatic subjects. This was one of the most intensive studies for establishing 'normal' Q-angle values. The investigators found that the mean Q-angle in asymptomatic men was 14° with Q-angles up to 20° and the mean Q-angle in asymptomatic women was 17° with Q-angles up to 23°. Many research articles in the scientific literature cite the average Q-angles for females as 15° and for males as 10° (Messier & Pittalla, 1988 and Brattstrom, 1964) which are less than Aglietti et al.'s results. Clinicians should therefore be cautioned that angles slightly above the accepted 'normal' values of 10° for males and 15° for females do not equate to the development or perpetuation of pain at the patellofemoral joint.

Subtalar pronation is another frequently cited anatomic prescursor to PFPS. Shelton & Thigpen (1991) and Wright et al. (1964) suggested that prolonged subtalar pronation causes the femur and tibia to internally rotate, thereby causing lateral displacement of the patella. McConnell (1986) makes the suggestion that subtalar pronation is the most significant predictor of pain in the patellofemoral joint in her practice.

The author acknowledges that malalignment may be a factor in the multifactorial disorder of PFPS. It remains unconfirmed as to whether an anatomic anomaly is the first 'domino' in the chain reaction of pain development, the result of other contributory factors, or if it is actually benign to the process of pain development.

2.2.5. Quadriceps Dysplasia

Extensor mechanism dysfunction is the other most frequently cited factor to development of PFPS (O'Neill et al., 1992, Bennett & Stauber, 1986, Souza & Gross, 1991, Doucette & Goble, 1992, Fox, 1975, Malek & Mangine, 1981 and McConnell, 1986). Dysfunction often refers to an over-developed or powerful vastus lateralis (VL) as compared to a weakened or dysfunctional vastus medialis oblique (VMO) (Bennett & Stauber, 1986, Malek & Mangine, 1981, Fox, 1975 and Wild et al., 1982). A common observation in PFPS is an imbalance between the lateral retinaculum, iliotibial band, and vastus lateralis, as compared to the medial retinaculum and VMO (Fulkerson & Hungerford, 1990 and Maquet, 1984). This imbalance tends to favour the lateral side, most likely due to the law of valgus (see section 2.1. Functional Anatomy), and can be accentuated by a weakened VMO, powerful VL, or tight lateral structures. Fox (1975) describes the VM as phylogenetically the weakest of the quadriceps and the first muscle to atrophy. The oblique fibres of the VM assist in patellar stabilization and centralization, and a weakened or dysfunctional VMO may contribute to a lateral patellar drift. Rehabilitative studies that focus on increasing the medially directed forces (ie. VMO) and stretching the lateral structures have seen a resolution of painful symptoms in 60% - 90% of patients (O'Neill et al., 1992, Whitelaw et al., 1989, Hodges & Richardson, 1993 and Karlsson et al., 1996).

2.2.6. Overview of the Etiology

The pathophysiology and genesis of PFPS remains somewhat enigmatic to both the clinical and research communities. Each of the aforementioned factors/etiologies have been reviewed and acknowledged in both scientific literature and clinical settings, although there is still no conclusive link between cause and effect. Many of the theories have an overlap or cascade effect on one another. For example: an excessively tight lateral retinaculum and weakened VMO may result in a lateral patellar tilt, resulting in a lateral patellar tracking disorder, and culminating with the onset of CP. The inter-relationships between these factors suggests that PFPS is multifactorial. The precursor to PFPS onset, the interplay of the above documented and other causative agents, and the factors in the perpetuation remain unknown.

Rehabilitation for PFPS aims to reduce patellofemoral pain through restoring and/or repairing the anatomic anomaly or the extensor mechanism dysfunction. Rehabilitation tends to work backwards from the therapeutic effect to the injury cause, primarily based on the premise that resolution of patellofemoral pain occurs when patients follow a strengthening and stretching program for their quadriceps.

2.3. CLINICAL CONSERVATIVE MANAGEMENT

Conservative management for PFPS focuses upon therapeutic exercises aimed at strengthening specific muscles (ie. quadriceps, hip adductors, etc.)

and/or stretching specific muscles and structures (ie. tensor fascia latae, vastus lateralis, etc.). The dynamic components surrounding the hip, knee and ankle are almost always targeted in PFPS conservative care, as the inter-relationships between these structures are a key role to the rehabilitative process. The various treatment plans and modalities utilized in physical therapy and home exercise conservative management programs are outlined below.

2.3.1. Physical Therapy

Physical therapy is the care and service by a physical therapist including examination of ability, alleviation of functional limitation or impairment, prevention of injury or impairment and patient education (American Physical Therapy Association, 1995). Physical therapy incorporates activity modification, therapeutic progressive exercises, manual therapy, patellar mobilizations, home exercises, neuromotor control, stretching, various modalities, patellar taping, and on-going education into a specialized program. Consecutive clinical sessions for PFPS usually require up to ten weeks of rehabilitation and allow the therapist to assess the patients progression, monitor their level of activity, apply modalities, educate the patient, enhance their home management programs and facilitate patient empowerment. Rehabilitative articles on PFPS indicate that physical therapy gives complete remission in peripatellar knee pain in 75% (Fulkerson, 1983) to 85% (Karlsson et al., 1996) of persons at one year and eleven years respectively, post-treatment.

2.3.1.1. Modalities

The efficacy of thermal and electrical modalities (transcutaneous electrical nerve stimulation (TENS), interferential current (IFC), ultrasound, cryotherapy, heat and laser) in rehabilitation of PFPS is somewhat anectdotal. Patients report reduced pain and swelling with the application of the majority of modalities (McConnell, 1994), although there are very few clinical studies published in scientific literature that prove the therapeutic benefits of electrotherapy (Hocutt et al., 1982, Delitto et al., 1992 and Enwemeka, 1988).

Heat and cold are the most commonly used modalities in the treatment of patellofemoral pain (Beckman et al., 1989, Antich & Brewster, 1986 and Lindsay et al., 1990). Heat is believed to mediate vascular changes which assist in causing an analgesic effect, increased nutrition at the cellular level, and removal of metabolites involved in the inflammatory process (Prentice, 1994). This physiological response also causes a relaxation in tension within the surrounding musculature (Arnheim & Prentice, 1993).

In contrast, cryotherapy (icing) is universally accepted as a means to decrease swelling and pain. Pain relief occurs due to a slowing of nerve conduction velocity which causes an increase in the motor nerve threshold to stimulation (Prentice, 1994). The reduction of swelling occurs by decreasing the rate of cell metabolism which aids in slowing inflammation (Prentice, 1994).

2.3.1.2. McConnell Taping:

A rehabilitative program specifically developed for PFPS patients was developed by Australian physiotherapist Jenny McConnell and is often used in physical therapy settings (McConnell, 1986). Her program focuses on increasing VMO control through applying a taping technique to assist with patellar tracking. She suggests that medially taping the patella to a neutral position coupled with biofeedback and mental imagery can correct subluxation, tilt and rotation, thereby enabling the patient to work within a pain-free range of motion (McConnell, 1994). McConnell (1986) commented that patellar taping combined with a quadriceps strengthening program showed a higher electromyographic VMO:VL muscle activity ratio than a program without taping, although these results are not published.

Her research on patellar taping has reported a 96% success rate in decreasing and/or eliminating pain at the patellofemoral joint (McConnell, 1986). McConnell's taping program has been replicated by other therapists and produced excellent results in as many as 86% of patients from the general population who were diagnosed with PFPS (Gerrard, 1989 and

Larsen et al., 1995). Larsen et al. (1995) in their study of McConnell's taping program, found that medially gliding the patella is beneficial during initial exercises, but the glide is not maintained following exercise.

2.3.1.3. Strengthening Exercises

There are numerous quadriceps strengthening exercises used in PT programs for PFPS. Some examples of these exercises are: quadriceps sets, straight leg raises, short arc extension, drop squats and weighted squats (Davidson, 1993; Ruffin & Kiningham, 1993, Shelton, 1992, Tria et al., 1992 and Beckman et al., 1989).

The quadriceps sets, straight leg raises and short arc extensions are open-kinetic chain exercises which allow free movement of the distal end of the limb. These exercises are commonly used in rehabilitation for strengthening the quadriceps and are believed to preferentially activate the muscle fibres in the VMO (Allington et al., 1966, Gough & Ladley, 1971, and Moller et al., 1986).

The preferential strengthening of the VMO remains a topic of controversy in electromyographic (EMG) studies. In Grabiner et al.'s (1991) EMG study of the VMO and VL on short-arc extensions, they found neither muscle to be selectively fatigued in maximal and submaximal contractions. The author's suggested that equal fatigueability of the muscles casts doubt on the hypothesis that short-arc extensions could preferentially strengthen either muscle. Cerny (1995) and Boucher et al (1992) evaluated EMG activity in the VMO and VL in open-kinetic chain exercises (quadriceps sets and knee extensions) and closed kinetic chain exercises (walk-up and step down, and the wall slide). They found that the vastus medialis oblique to vastus lateralis activity ratios were equal for all the above listed exercises and there was no preferential activation of the VMO. The introduction of different structural movements during exercise, such as hip extension and external tibial torsion, are other methods reported to selectively enhance the VMO (Hodges & Richardson, 1993 and Hanten & Schulties, 1990). Laprade et al. (1998), in their EMG study of the VMO and VL during open kinetic chain exercises, found no significant differences in the ratio of muscle activity in PFPS patients compared to controls. These results were also confirmed by Cerny (1995).

A review of current scientific literature reveals that progressive drop squats (PDS) are one of the most commonly advocated strengthening exercises (McConnell, 1986, Westfall & Worrell, 1992, Beckman et al., 1989, Hodges & Richardson, 1993, and Doucette & Goble, 1992). The drop squat is a closed kinetic chain activity (feet are planted on the ground) which mimics familiar and functional movement and loading patterns such as stepping up, rising from a chair, stair ascension and descension, bending and lifting. Ciccotti et al. (1994) suggest that functional exercises for knee injuries are the most beneficial exercise to the overall rehabilitation process. McConnell (1986) suggests that closed kinetic chain exercises, such as the drop squat, should be done in a weight bearing position which would allow a stabilizing effect of the VMO on the patella.

Selective hip adduction, gluteal exercises and abdominal exercises are also used in physical therapy programs for PFPS. Recent literature has found that VMO fibres originate off the adductor longus and magnus tendon, and through strengthening the adductors, a physiological stretch may be transferred to the VMO (Hodges & Richardson, 1993 and Reynolds et al., 1983). Mariani & Caruso (1979) also found that hip adduction in conjunction with a quadriceps contraction returns the VM:VL ratio within the normal limits of one to one. Although, as mentioned above, the preferential activation of the VMO remains inconclusive in EMG analysis studies (Laprade et al., 1998 and Cerny, 1995).

2.3.1.4. Stretching Exercises

Stretching improves the range of motion at a joint by increasing the extensibility of the muscle tendon unit (Arnheim & Prentice, 1993). For example, a tight hamstring will limit knee extension which may increase patellofemoral compression forces during the stance phase of walking (Basmajian, 1985). Similarly, inflexibility of the gastrocnemius and soleus cause compensatory pronation of the subtalar joint resulting in increased femoral rotation. This may lead to external tibial rotation and an increased Q-angle. Doucette & Goble (1992) studied the effects of rehabilitation on iliotibial band flexibility in patellofemoral pain patients. They reported that the patients who experienced a resolution of pain, also exhibited more significant improvements in their iliotibial band flexibility, as compared to the patients who still experienced pain at the end of rehabilitation. The authors' suggest that a tight iliotibial band may be a primary factor in the development and/or perpetuation of PFPS. Although, the assessment procedure used by Doucette & Goble (1992) introduces many factors of human error.

Rehabilitative programs often administer a stretching regime for the lateral musculature of the thigh, gluteals, hamstrings, gastrocnemius, and hip flexors as tightness in these structures are thought to be contributory in PFPS.

2.3.1.5. Education

Patient education is the process of giving information or providing skills so that the patient acquires knowledge or develops a competence in a given area (American Physical Therapy Association, 1995). Physicians and/or physical therapists most frequently impart information through both verbal and written information, audiovisual aids, demonstrative techniques, and 'hands-on' learning. Shelton (1992) comments that patient education is a fundamental and critical aspect to the overall success of a conservative program for PFPS, and Beckman et al., (1989) stated that a patient must understand the goals and methods of their PFPS treatment program to reach optimal success. LaBrier & O'Neill (1993) comment that a patient who is informed tends to be more compliant and motivated throughout the patellofemoral pain rehabilitation process, as compared to an uninformed patient.

2.3.2. Home Exercise Program

A home exercise program (HEP) adopts many of the same components used in physical therapy such as: strengthening exercises, targeted stretches, activity modification, patient education and post-exercise icing. The contrast to physical therapy is that a HEP usually eliminates the interaction with a caregiver, does not use electrical modalities, and allows the patient to work in their own familiar environment. It is usually a structured, progressive exercise regime prescribed during a patients initial visit to their physician or physiotherapist. The benefit to this program is the eliminated expense associated with consecutive clinical sessions and the ability to work within one's own environment throughout rehabilitation. The onus is obviously upon the patient to follow the prescribed program, motivate him/herself and monitor their activity level. Noncompliance to therapeutic regimes is considered to be one of the most significant problems in clinical practice (Haynes, 1987 & Meichenbaum & Turk, 1987). In Dexter's (1992) study of exercise for osteoarthritis, he found a 78% increase in patient compliance when activities are recommended by a physician or physiotherapist and printed materials are provided, as compared to patients that didn't receive information.

A standard home exercise program for PFPS focuses on quadriceps strengthening, stretches for the lateral structures of the thigh, hamstrings and gluteals, patient education, and post exercise icing (Thabit & Micheli, 1992, and Bennet, 1993). The stretching exercises are often those used in physical therapy sessions focusing on the lateral structures of the thigh, and activity modification consists of patients working within the limits of pain. The strengthening routine may be similar to some of the exercises prescribed in a course of PT and the exercises tend to be progressive in nature. Patient education for HEP patients is done during the patients initial visit and complemented with written material, such as brochures and booklets.

2.3.2.1. Progressive Drop Squat

A progressive drop squat (PDS) is one of the most commonly prescribed exercises for PFPS, and is frequently administered as the sole strengthening exercise in HEPs in Calgary, Alberta, Canada.

Curwin and Stanish (1984) were pioneers in using the drop squat. They prescribed it for patellar tendonitis and suggested that eccentric training with gradual increases in load and velocity would increase the tensile strength of the patellar tendon. It is a unique exercise because strength is being developed during the eccentric phase of movement. Bennett & Stauber (1986) evaluated eccentric exercises in the treatment for PFPS patients. They looked at quadriceps torque at various angles of extension, pre and post-exercise, and found that 86% of patients significantly increased their quadriceps torque at all testing angles. Dvir et al. (1990) and Werner & Eriksson (1993) also evaluated quadriceps torque in PFPS patients and compared them to matched asymptomatic controls. They discovered that PFPS patients had a significant loss of eccentric function as compared to the control population. Bennett & Stauber (1986) and Werner & Eriksson (1993) found that eccentric exercises are beneficial to restoring eccentric function as well as assisting in the development of quadriceps strength.

Hodges & Richardson and Duart Cinatra & Furlani (1981) evaluated the effect that weight bearing (semi-squat) and non-weight bearing positions had on VMO activity. Their results suggest that a weight bearing semi-squat position elicits greater VMO activity as compared to VL activity.

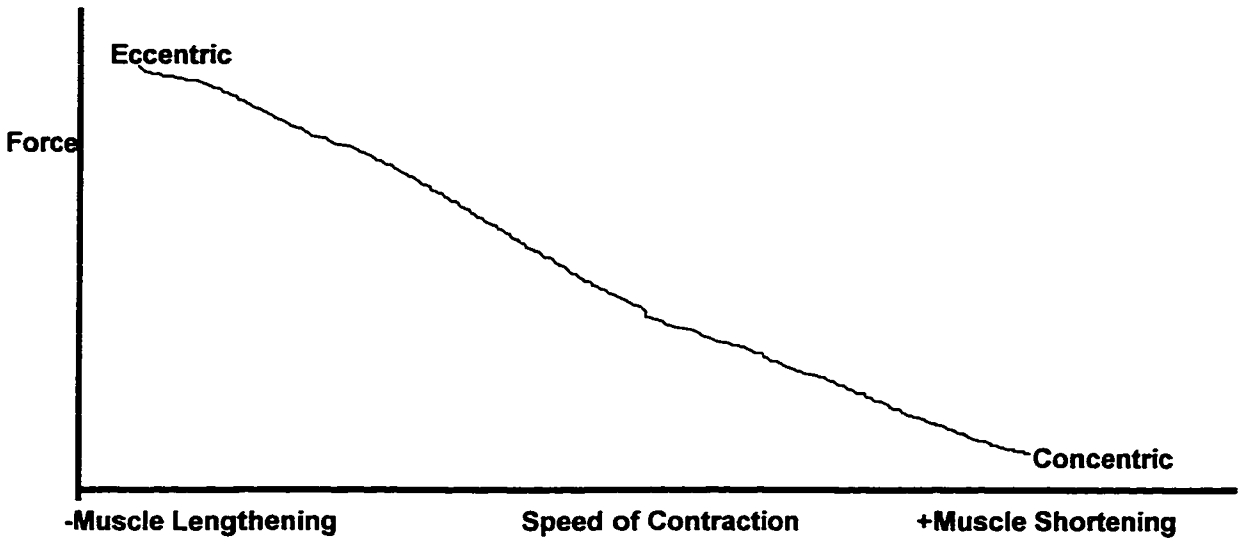

Figure 2.3: Force-Velocity Relationship in during Concentric & Eccentric Contractions. Adapted from "Tendinitis" by S. Curwin and W. D. Stanish, 1984, *Tendinitis: its etiology and treatment,* p.50.

The drop phase in the PDS is the primary focus. The muscle force and load increase as the velocity of the contraction increases (Curwin & Stanish, 1984)(Figure 2.3.). Therefore, the patients goal is to allow their body weight to drop freely, stopping the movement with a quadriceps contraction. It is the stop phase of the drop squat that results in a stabilizing effect on the patella, thus eliciting contractions of the VMO and VLO.

2.4. OVERVIEW OF HOME EXERCISE AND PHYSICAL THERAPY PROGRAMS

It remains unclear why patellofemoral pain decreases with therapeutic exercises, specifically exercises for the quadriceps. Clinical researchers have suggested that therapeutic exercises may result in improved patellar tracking and decreases in patellofemoral contact forces (Bennett & Stauber, 1986, Werner & Eriksson, 1993 and McConnell, 1986).

Both HEPs and PT programs serve to alleviate patellofemoral pain. The effect of therapeutic exercises, absent of a clinical setting, has not been evaluated. Therefore, a prospective, randomized, controlled trial that compares the two rehabilitative approaches may assist in allowing physicians to provide optimal management strategies for PFPS. As well, this comparison may aid in allocating/utilizing heath care dollars more efficiently, as well as prompting governing health agencies to evaluate management procedures for disorders such as PFPS. A course of physical therapy ranges between four and twelve clinical sessions (Timm, 1998 and McMullen et al., 1990), which costs between $140 - $420 in Calgary, Alberta. To date, there is no published data quantitatively documenting a comparison between physical therapy and a home exercise program.

2.5. STUDY INSTRUMENTATION

2.5.1. Knee Pain Measurement

The only documented clinical symptom associated with PFPS is pain. Therefore, one of the most obvious markers for the effectiveness of a rehabilitative program is the resolution of pain. The visual analogue scale (VAS) is the most frequently used method of assessing pain in the clinical environment (Carlsson, 1983 and Flandry et al., 1991). It is a graphic continuous method where the patient determines their magnitude of pain. It consists of a 10 centimetre horizontal or vertical line where the polar ends are indicative of minimum to maximum extremes of their own perceived pain range. A graded ruler or cover template converts the mark into a numerical value. Visual analogue scales have been validated by numerous investigators and have been found to be superior to discontinuous verbal or numeric descriptions (Harms-Ringdahl et al., 1986, Huskisson et al., 1976, and Freyd, 1923). Test-retest reliability measures in VASs are high and determined effective in measuring sensory stimulus intensity (Harms-Ringdahl et al., 1986). The VAS system is cited as bringing greater sensitivity and statistical power to data collection and analysis (Flandry et al. 1991 & Chesworth et al., 1981). Flandry et al. (1991) and Hoher et al. (1995) found that VAS scores for PFPS have a higher level of validity and sensitivity (>.80) than other interval scales.

The advantage of implementing a VAS system for pain is that patients are not required to interpret their limits of mild, moderate or severe pain, as is required in the graded scale system. As well, the ratio scale properties of the VAS make it easy to describe one group of patients as being several times that of another in pain measurement (Carlsson, 1983). Katz & Melzack (1992) cite the main disadvantage of using the VAS system is that pain is not a uni-dimensional experience and there can be a variety of pain qualities.

A pain measurement system specific to PFPS is currently unavailable in the scientific literature. Studies that evaluate the level of pain in PFPS patients usually do so with a pain function scale that monitors pain during specific activities (Lysholm & Gilquist, 1982, Noyes & McGinnis, 1985 and Flandry et al., 1991). These knee pain function scales tend to be more catered to surgical patients, and are not applicable to a PFPS population. Examples of questions included in their scales are: a) Do you wake up at night feeling pain in your knee?, b) Does your knee hurt when you wake in the morning? and c) Does your knee hurt when you are lying down?. The recording of pain is commonly asked in one question on a VAS system during or following a designated activity, and a separate functional activity scale usually complements the pain question. (Chesworth et al., 1989, Gerrard, 1989 and Werner, 1993).

2.5.2. Functional Knee Score Scale

As mentioned previously, the majority of functional knee score scales are a combination of pain measurement and functional ability (Lysholm & Gilquist, 1982 and Noyes & McGinnis, 1985). There are only two discrete functional knee score scales specific to PFPS documented in the scientific literature. These are the Chesworth et al. scale (1989) and the Werner (1993) scales. Both scales address activities that PFPS patients commonly report difficulties with or inability to perform. These areas are: a) walking, b) climbing stairs, c) squatting, d) kneeling, e) sitting for an extended period of time, and f) running. Hoher et al. (1995) polled orthopaedic surgeons and residents on the level of importance of twenty-eight functional activities to a diagnosis of PFPS. Their results found that going downstairs, going upstairs, squatting and kneeling were in the top ten ranking of activities impaired by PFPS.

Chesworth et al.'s (1989) scale was adapted for PFPS patients from a general knee function scale and produced poor reliability values ($r=0.483$). Werner's (1993) scale was developed specifically for PFPS patients and has been used extensively in her studies on PFPS rehabilitation (Werner & Eriksson, 1993, Werner et al., 1993 and Werner, 1995). Her pilot studies have produced a positive reliability value ($r > .60$).

Werner's scale is a graded questionnaire that assesses eight areas of function. Each area of function corresponds to a numeric value that correlates with the magnitude of the patients dysfunction.

2.5.3. Peak Quadriceps Force

An inherent property to all muscles is their ability to produce force. As a muscle produces force, it also causes movement. Movement through contractions of skeletal musculature is the focus of the following section.

A skeletal muscle is comprised of many progressively smaller units, ranging from the muscle bundle to the basic muscle unit called the sarcomere. A sarcomere has both thick and thin filaments that slide over one another toward the sarcomere's centre during a contraction (in accordance to Huxley's (1957) sliding filament theory).

The contraction of the sarcomere causes force production within the muscle. The amount of force that is produced by a given muscle is dependent upon two events:

1) Wave Summation. When an action potential is propagated along a muscle fibre, the amount force produced rises and falls which is called a twitch. If a second stimulus activates the motor unit before the first response has subsided, the two twitches summate. This summated twitch generates more tension than a single twitch. If the stimuli are repeated at a high level of frequency, summation of all the twitches can occur. This summation results in the motor unit being in a maximal state termed tetanus (Nigg & Herzog, 1994).

2) Multiple Motor Unit Summation. During a graded contraction, the smaller motor units are often the first to be activated. As the amount of force required for activity steadily increases, so do the number of motor units being recruited. The maximal tension that can be exerted by a muscle occurs when all the motor units of the given muscle are activated (Nigg & Herzog, 1994).

The Kincom (Chattanouga Group Inc., Tennessee) apparatus assesses the amount of force exerted against a load cell by a given muscle. The effect of therapeutic strengthening exercises on quadriceps peak torque is frequently evaluated using the Kincom (Chattanouga Group Inc., Tennessee) machine (Kannus, 1990, Bennett & Stauber, 1986, Werner et al., 1993 and Kramer et al., 1993). Increases in peak quadriceps torque throughout rehabilitative or strengthening programs are often purported to be a result of increased quadriceps strength (Jone & Rutherford, 1987 and Narcici et al., 1996). Jones and Rutherford (1987) looked at peak quadriceps force in healthy individuals during a six week quadriceps strengthening program. The authors reported up to a 65% increase in peak force in eccentric, concentric and isometric contraction conditions. The author's hypothesized that the increase in quadriceps strength was due to a learning effect (neuromotor) and/or increased activation of the muscle as a result of change to motor unit firing patterns. Draper and Ballad (1991) studied quadriceps strength gains in patients with knee disorders and found a 38% - 46% increase in peak torque after six weeks of rehabilitation. The author's suggest that these strength gains were also due to increased neuromotor adaptation. Tesch and Karlsson (1985) also evaluated peak torque values after an eight week strength training program for elite athletes. They found significant increases in peak torque. Muscle biopsies also showed preferential hypertrophy of Type II fibres, but the author's are unsure if this training effect would occur in non-athletes.

2.5.4. Electromyography

Electromyography (EMG) studies muscle activity through the analysis of the electrical signals elicited during a muscular contraction (Basmajian, 1985). EMG is universally accepted for measuring muscle activity, and is frequently used in rehabilitative studies for knee disorders (Soderberg & Cook, 1984 and Basmajian, 1985).

When a muscle undergoes contraction, an action potential travels along the muscle fibres producing an electromagnetic field that is detected using EMG. This change is called a motor unit action potential (MUAP).

The instrumentation used in detecting these MUAPs usually consists of: electrodes, amplifiers, filters and a data acquisition device (Basmajian, 1985). Muscle activity can be monitored using surface or intramuscular electrodes. Intramuscular electrodes are invasive and are often criticized for a slight pain response in patients and a lack of representation from muscle bulk (Soderberg & Cook, 1984). Surface electrodes pick up a fairly large detection area and are best used to assess gross muscle activity. Some of the difficulties associated with the use of surface electrodes are: a) they are not selective enough for small muscles, b) proximity to other muscles may result in cross-talk, c) they are susceptible to movement artifact, and d) they may experience contact pressure fluctuations (Buchthal, 1957 and Kimura, 1989).

The electrode is the site of information transfer between the muscle and the data collection system. The reduction of impedance between the skin-electrode surface can be done through shaving the skin's surface and abrasive scrubbing with an alcohol swab to remove dead skin and oils (Kimura, 1989). The configuration of the electrodes is also pivotal to proper muscle activity detection. Electrodes can be used in a monopolar or bipolar configuration, which refers to the number of electrodes monitoring the muscle activity. A bipolar configuration is most commonly applied and uses two electrodes proximal to one another over the muscle belly and a third electrode on an electrically quiet area, ie. a bony surface with few muscle fibres. The two signals emitted from the muscle travel into a differential amplifier where the difference between the two signals is amplified, and ideally only the signals from the muscle are displayed.

The muscle activity is often visually displayed on an oscilloscope, strip chart recorder, or computer. A computer software package is often the best data collection tool, and it can be digitally filtered and processed allowing for further analysis.

The analysis and processing of the EMG signal involves many steps. The first step to processing the information is rectifying the signal. This can be done through half wave rectification which eliminates negative deflections, or full-wave rectification which takes the absolute value of the signal through inverting the negative deflections. Full-wave rectification is often preferred because the entire signal is retained (Nigg & Herzog, 1994).

The second step in analyzing EMG data is establishing relevant and reflective numeric values from the muscle contraction. A mean absolute value (MAV) or a root mean square (RMS) can be obtained. The MAV averages the level of activity by smoothing the rectified signal, eliminating high frequency content through low-pass filtering. The RMS establishes the magnitude of the signal, and therefore does not require rectification.

EMG data can be very powerful if the limitations associated with its use are accounted for. There are many unavoidable difficulties in the set up of the apparatus and the analysis of EMG data. Examples of such are: 1) differing skin preparatory techniques result in reduction of impedance between 1000 to 10Ω (Kimura, 1989), 2) electrode wire movement of millimetres can result in recording artifact, 3) cross talk from neighbouring muscles will be recorded as activity from the tested muscle (Koh & Grabiner, 1992) and, 4) reliability results of within day and between day testing conditions is very poor (Soderberg et al., 1984). Soderberg et al. (1984) cite the average within day reliability to be 62% for maximal muscle testing and between day testing results in reliability of less than 22%.

Electromyographic (EMG) studies of the quadriceps in PFPS and control subjects have reported a decreased ratio of VMO to VL activity in the PFPS population while undergoing various angles of knee flexion (Boucher et al., 1992). Boucher et al., (1992) explained this result as being due to a neuromuscular imbalance between the VMO and VL. Narici et al. (1996) evaluated peak quadriceps torque in maximal voluntary isometric contractions and integrated electromyography (IEMG) over a six month training program. The author's found a mean increase in isometric torque of 30%, although there was no significant change in IEMG values. The author's postulate that the insignificant changes to the IEMG values may be due to hypertrophy of the muscle fibres, rather than increased motor unit activation. This study is one of very few studies that evaluate muscle activity pre and post exercise using electromyography.

2.6. CONTRASTING REHABILITATIVE PROTOCOLS

There are many articles within English literature that comment on the prescribed use of home exercises in a course of physical therapy, although the papers do not differentiate between the effects of the physical therapy and the home exercise programs (Kowall et al., 1996, Almekinders & Almekinders, 1994, Kannus & Niittymaki, 1994, Finestone et al., 1993, Zappala et al., 1992, Fulkerson, 1983, Malek & Mangine, 1981 and Pevsner et al., 1979).

The author's impetus for evaluating the efficacy of rehabilitative protocols for PFPS stemmed from Malmivaara et al.'s (1995) study on 'The treatment of low back pain - bed rest, exercises, or ordinary activity.' Malmivaara et al. (1995) randomly assigned 186 subjects diagnosed with acute back pain to one of three treatment groups: i) bed rest, ii) physical therapy, and iii) normal activity within the limits permitted by their pain. The outcome measures they analyzed were: functional status, quality of life, duration of absence from work, and an economic evaluation. At the completion of the twelve week testing period, the group that worked within their painful limits had significantly better function, quality of life measures and fewer absences from work than those prescribed bed rest or physical therapy. This was one of the first evaluative studies that compared treatment programs for musculoskeletal disorders.

In 1996 Kuukkanen & Malkia compared a PT program to a home program for patients with chronic low back pain. Ninety subjects were assigned to three testing groups: home exercise (HEP), intensive training (PT) and control (no treatment). The subjects were measured over three months for changes in muscle strength, muscle endurance and pain intensity. There was a significant difference in all measures between the control group and the exercise groups, although there was no overall significant difference between the two exercise programs. Both the HEP and the PT program showed significant increases in muscle strength, endurance and a decrease in pain intensity. A follow-up analysis at three, six and twelve months revealed that more permanent changes occured within the HEP group as compared to the PT group. The authors suggested that a HEP for low back pain is as effective as a PT program and should be used more regularly in clinical settings.

The above evaluative studies on low back pain compare the differences between HEPs and PT programs, although similar studies for generalized knee pain are not available in the current scientific literature. Two studies conducted by Whitelaw et al. (1989) and O'Neill et al. (1992) investigated the use of HEP's, but did not contrast them with PT.

2.6.1. Physical Therapy and Home Exercise Programs for PFPS

Whitelaw et al., (1989) studied patients diagnosed with PFPS that were absent of fracture, osteoarthritis, meniscal tear, ligamentous injury, bursitis or articular cartilage pathology. They analyzed knee function and level of activity over a six week course of physical therapy combined with a HEP. During the post-treatment follow-up interview, 68% of subjects showed improvements in PFPS symptoms. Fifty percent of the overall subjects followed a HEP at least twice weekly and fifty percent of subjects did not follow the HEP. In the HEP adherent group, 71% of subjects increased their level of knee function, as opposed to the non-adherent group, where only 41% of patients showed increases in knee function. Whitelaw et al.'s absence of a sole home exercise program population makes it difficult for the reader to determine the effects between the two treatment protocols. It remains unclear for example, if the physical therapy treatments were responsible for improvement, the combination of PT with home exercises, or if a HEP alone would be sufficient for obtaining success with PFPS.

O'Neill et al. (1992) studied the efficacy of a HEP in patients diagnosed with patellofemoral stress syndrome (peripatellar pain without anatomic malalignment, history of patellar instability or trauma, or clinical evidence of patellofemoral crepitus). Thirty-four patients performed one standard strengthening exercise (progressive weighted straight leg raise) and two standard stretches (targetted at the hamstring and iliotibial band), at least three times per week for a minimum of six months. At one year post-initial exercise treatment, 35 of the 44 (80%) involved knees showed improvement as indicated by reduced patellar pain. These results suggest that a home exercise program is effective in reducing patellar pain in knee pain patients. Although, O'Neill et al. (1992) recruited skeletally immature patients in their study. This introduces the argument that the closure of the physis and the natural progressive strengthening of the surrounding musculature over one year may have decreased PFPS symptoms in skeletally immature patients regardless of the prescribed home exercise program.

Timm (1998) evaluated the effect of a four week trial of Protonics on patellofemoral pain, patellofemoral function and patellofemoral congruence angle. One hundred subjects were randomly assigned into either a physical therapy and protonics exercise group (high volume of submaximal concentric quadriceps contractions), or a no treatment group. Subjects in the treatment group experienced significant decreases in pain (47% decrease between pre and post value), significant increases in function (108% increase between pre and post value), and an increase in patellofemoral congruence angle as determined by x-ray. There was no significant changes in the no treatment group over the four week period. Timm (1998) suggests that the Protonics exercise program may be sufficient for decreasing pain, increasing function and increasing patellofemoral congruence angles. This study did not differentiate between a Protonic group and a physical therapy group. Therefore, there is not adequate data to suggest a sole Protonics exercise program would be sufficient.

These studies are among a small group of research articles that compare alternative rehabilitation protocols to physical therapy.

CHAPTER THREE

METHODS

3.1. SUBJECTS

PFPS subjects were recruited from six practicing physicians in Calgary, Alberta. Four of the physicians worked in a sport medicine setting, and two were family physicians working at the University of Calgary Health Services Centre. The primary investigator met with each physician to give him/her a brief introduction to the study and an information package. The meeting and information package was an attempt to standardize all diagnoses of PFPS. The information package contained a letter outlining the inclusion/exclusion criteria (section 3.1.1.), the definition of PFPS as previously outlined, reminder posters for each examining room, and the primary investigators business cards for PFPS patients. Follow-up letters were also mailed to physicians approximately once every two months to remind them of the study guidelines.

The asymptomatic control subjects were recruited from the University of Calgary campus community using bulletin posters, and from the community of Calgary through word of mouth.

Ethical approval for conducting this study was received from the Faculty of Kinesiology at the University of Calgary in April, 1996.

3.1.1. Subject Participation Criteria

The inclusion/exclusion criteria for PFPS patients were:

1. The patient must have experienced patellofemoral pain for a minimum of three weeks and a maximum of one year. This was done to assist in ensuring that patients with articular cartilage degeneration (eg. osteoarthritis) would not be included in the study, and to ensure subject homogeneity.
2. Patients with PFPS secondary to major sudden trauma, instability, osteoarthritis and/or bursitis or tendinitis were excluded.
3. Patients that had a prior history of knee disorders and/or were treated non-surgically or surgically for a knee disorder were excluded from the study.
4. The use of non steroidal anti-inflammatories was prohibited throughout the six week rehabilitative program.
5. Differential diagnoses of PFPS, where the primary investigator was concerned about confounding factors were referred to the sponsoring sport medicine physician at the University of Calgary Sport Medicine Centre.
6. Each patient was eighteen years of age or over, and therefore was assumed to be skeletally mature.

Asymptomatic Subjects:

1. Control subjects must have shown no previous history of PFPS or other diagnosed knee disorders, and
2. No previous history of non-surgical or surgical management for knee disorders.

3.2. STUDY PROTOCOL

Patellofemoral pain syndrome patients made an appointment with the primary investigator in her office at the University of Calgary Sport Medicine Centre. They were briefed about the study, signed the informed consent (Appendix A), had the benefits and limitations of the study explained to them, and were informed of the investigator's expectations. The patients were then referred to the McCaig Health Sciences Centre for their initial testing session.

The initial testing session included: 1) completion of a protocol sheet (Appendix B), 2) a standardized fifteen minute warm-up on the Monark 818 (Monark, Sweden) stationary bicycle, 3) completion of the visual analogue scale (VAS), 4) completion of the functional knee score scale (Appendix C), and, 5) participation in nine contraction conditions where force and electromyographic (EMG) data could be collected.

At the conclusion of the initial testing session, patients were randomly assigned by envelope raffle to a physical therapy or a home exercise program to avoid selection bias. The primary investigator was blinded to the designated treatment protocol until completion of their rehabilitation, thus ensuring internal validity. There were sixteen PT envelopes and sixteen HEP envelopes which were subdivided into groups for male and female patients (eight PT and eight HEP envelopes for each gender group), this ensured equal gender representation. The first sixteen PFPS males and the first sixteen PFPS females were recruited to participate.

The three groups tested in this study were: 1) **PFPS - PT:** PFPS patients randomly assigned into the physical therapy program, 2) **PFPS - HEP:** PFPS patients randomly assigned into the home exercise program, and 3) **Control:** the asymptomatic subjects that continued daily activities. Figure 3.1. outlines each phase of this study.

After the initial testing session, subjects met with the primary investigator at three and six weeks into their respective rehabilitation program. The three week test was approximately twenty minutes in length and was an abbreviated version of the the initial testing session (EMG and quadriceps torque was not collected). The final testing session was six weeks into their respective program and marked the completion of their formalized rehabilitation. This session was identical to the initial testing session. The testing sessions were standardized as best as possible. Each session was conducted on the same day of the week, same time of the day and the subjects were instructed not to undergo any physical activity the day of their testing session.

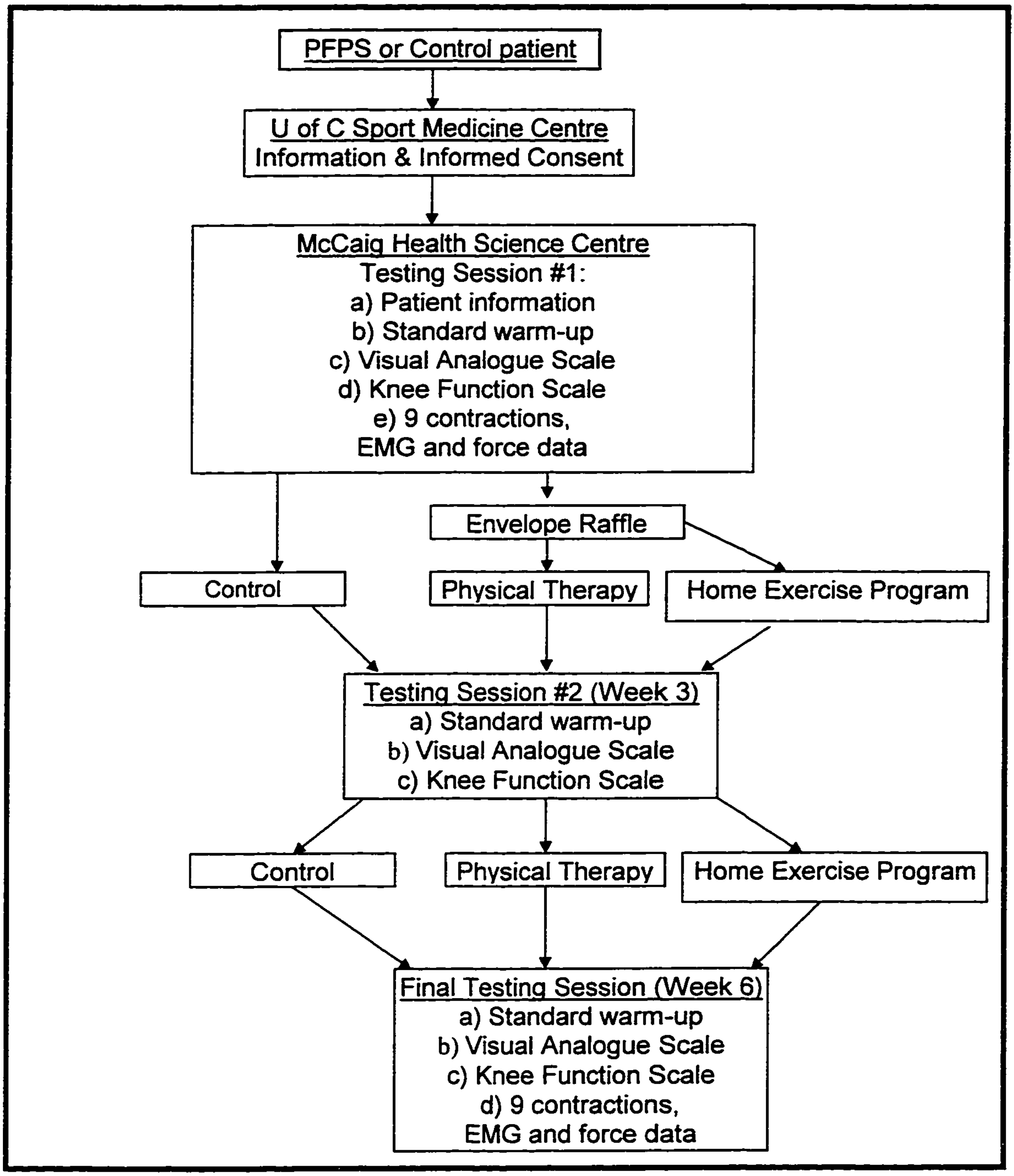

Figure 3.1. Subject Pathway for Participation in the Study

Patients with unilateral knee pain were tested for muscle activity and force on their pathological knee throughout the study. In the case of bilateral knee pain, the most painful limb was tested. The control subjects underwent testing of the right limb.

3.2.1. Sample Size

Sample size calculations were based upon a 0.05 level of significance, (α = 0.05), indicating the probability of a Type I error (false positive). The power of the analysis was set at 80% (P=0.8, β=0.2) for using the FKS and the VAS. The principal investigator was looking for a treatment effect on function of six points, indicating improvement in at least two areas of the scale. The treatment effect on the level of pain was chosen to be 1.5., and the standard deviation values were determined based upon VAS scores in studies by Suter et al. (1998) and Timm (1998). The calculations to estimate minimal sample size for the FKS and VAS with two-tailed tests with α = 0.05 and a power of 80% can be found in Appendix D (Lieber, 1990).

The sample size calculations determined that 15 subjects would be required in each treatment group when using the FKS, and 10 subjects would be required in each treatment group with the VAS (Appendix D). Rehabilitative studies on PFPS that measure pain and function have frequently recruited a total of 16 to 30 PFPS patients (Cerny, 1995, O'Neill et al., 1992, Werner, 1993 & Souza & Gross, 1991). Sixteen subjects were anticipated for each group, which would allow for a one subject attrition regarding the FKS.

Attrition was not expected to be as high in this study compared to other rehabilitative studies, as the treatment program costs are covered for all PFPS subjects, and the rehabilitation period was only six weeks. Participation in this study saved the PFPS subjects anywhere from $10.00 for booklets of information to $420.00 for physical therapy sessions.

The total pre-determined number of subjects requested for participation in this study was forty-eight (n=16 PFPS - PT, n = 16 PFPS - HEP, n = 16 controls). Males and females would be equally distributed with 24 males and 24 females [n=24 females (8 PFPS - PT, 8 PFPS - HEP, and 8 controls) n=24 males (8 PFPS - PT, 9 PFPS - HEP, and 8 controls)].

3.3. PROTOCOL OF THE REHABILITATIVE PROGRAMS

3.3.1. Physical Therapy Program

One physical therapist administered all the PT sessions to ensure a standardized treatment. The participating physical therapist was employed at the University of Calgary Sport Medicine Centre, and has been practicing in the areas of sport medicine and orthopaedics for over seven years. She has received many advanced levels of certification and is a Canadian Academic Manipulative Therapist (CAMT - fellow), completed post-graduate studies in Queensland, Australia focusing on Orthopaedic Manipulative Therapy, and is trained in the McConnell taping program.

The subjects that were randomly assigned to PT contacted one receptionist at the University of Calgary Sport Medicine Centre. The receptionist scheduled the appointments and ensured that all subjects adhered to the study protocol of attending a minimum of one and maximum of three PT sessions per week. The initial clinical assessment was approximately one hour in duration and patients were administered an individualized progressive rehabilitative program. The individualized programs were dependent on the contributory factors that may be causing the patients pain and/or dysfunction.

3.3.2. Home Exercise Program

The PFPS-HEP subjects were referred to the University of Calgary Sport Medicine Centre for a one-time personal standard consultation administered by one exercise consultant. He was a Master of Science student in the faculty of Kinesiology at the University of Calgary Sport Medicine Centre. The exercise consultation was approximately fifteen to twenty minutes in length and subjects were given information about the disorder (ie. incidence of the disorder, possible factors of causation, success with conservative management, information on modification of activity, and importance of adherence to a rehabilitation program), a demonstration of the designated exercises, a PFPS educational booklet (Appendix E) and a Home Exercise Program Scheduler for recording adherence to the program (Appendix F). The patients were requested to practice the HEP a minimum of five times per week for approximately twenty minutes per session. This consultation attempted to mimic clinically prescribed HEPs, although this HEP was a more detailed program than most physician prescribed HEPs. As well, the exercise consultation was slightly longer than what physicians are able to provide due to clinical time constraints.

The HEP was developed from a combination of current rehabilitative literature focusing on strengthening exercises, clinically prescribed HEPs, and exercise brochures currently given to PFPS patients. A user-friendly sixteen page information booklet was provided to each patient (Appendix E). This booklet underwent nine revisions in a pilot review with PFPS patients and healthy subjects for: a) ease of understanding, b) applicability to the PFPS population, and c) amount of interest in the overall content.

The HEP information booklet addressed the following: a) an overview of the Home Exercise Program, b) an easy-to-understand definition of PFPS, c) overview of proposed causes of PFPS, d) general statistics on PFPS, e) general anatomy and physiology of the knee joint, f) explanations and illustrations of the progressive drop squat, g) explanations and illustrations of the stretching exercises (seated spinal rotation, supine hip external rotation, and standing quadriceps stretch), h) recommendations and information on post-exercise icing, and, i) recommendations and information on activity modification.

The HEP strengthening exercise was the progressive drop squat (PDS). The speed of descent in the drop squat, the introduction of weights and the use of one-legged drop squats were progressive stages. Table 3.1. details each phase of the drop squat program.

Table 3.1. Progressions of the Home Exercise Drop Squat

Day of Program	Changes to the Progressive Drop Squat
1 - 3	A slow drop squat using a three second descent and a five second ascent
4 - 7	A fast drop squat using less than one second for the drop phase and three seconds for the ascent
8 - 28	Progressive introduction of hand weights starting with a 2.5 pound weight in each hand and progressing to a 10 pound weight in each hand
Day 29 - 35	Introduction of a lunge squat using 2.5 pound weights
Day 36 - 42	One legged drop squats

The PDS is one of the most predominant exercises prescribed by sport medicine physicians in Calgary, Alberta and it is used in two of the city's largest sport medicine clinics (University of Calgary Sport Medicine Centre & Lindsay Park Sport Medicine Clinic). Rehabilitative studies have also recommended the drop squat as it is both a functional activity and a closed kinetic chain exercise making it a more familiar movement pattern (Ciccotti et al., 1994 and McConnell, 1986).

The three stretching exercises were targeted at the lateral structures of the thigh, gluteals and the quadriceps. These exercises were: a) spinal rotations,

b) hip rotations, and c) quadriceps stretching. They were adapted from exercise and stretching books (Beckman et al., 1989 & Bennett, 1993) and are commonly advocated in rehabilitative articles for PFPS.

Post-exercise icing around the knee was recommended at completion of exercise by using a frozen bag of vegetables or crushed ice. Activity modification consisted of instructing the patients to participate in activity within the limits of pain.

A Home Exercise Rehabilitation Scheduler was also distributed to each subject (Appendix F). This was a forty-three page booklet that could be used as a patient diary. Each page included a motivational component, a visual analogue scale so the patient could monitor their own progress, and a detailed description of their phase of the PDS. Patients were asked to monitor the duration of time spent doing each exercise and mark it in their scheduler.

3.4. SELECTION AND ADMINISTRATION OF MEASUREMENT TOOLS

Four measures were selected for analysis throughout the study. The primary measures were the VAS and the KFS. The secondary measures of interest were peak quadriceps force in a maximal isometric contraction and changes in the ratio of VMO:VL muscle activity using EMG data.

3.4.1. Visual Analogue Scale

A 100 millimeter horizontal line where the polar ends indicate minimum and maximum extremes of pain magnitude was placed immediately below the question "Rate the pain in your knee as it usually feels" (Figure 3.2. (a-c)).

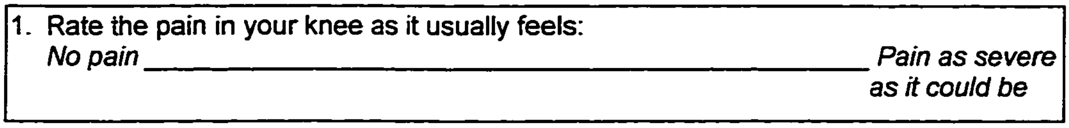

Figure 3.2.(a). The Visual Analogue Scale

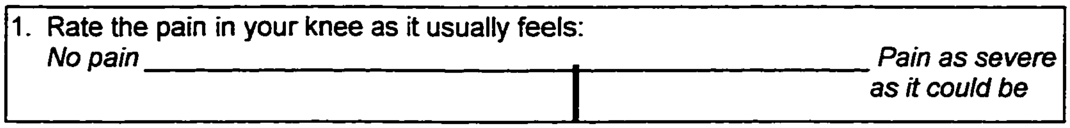

Figure 3.2.(b). A Patient's Response on the Visual Analogue Scale

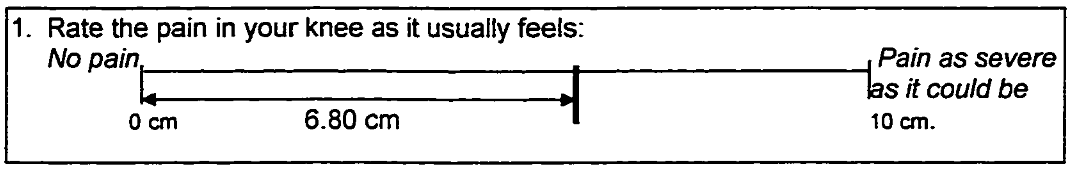

Figure 3.2.(c). Recording the Patient's Response

Patients were instructed to mark a vertical line to represent their pain intensity at that time. The less pain the patient felt, the lower the VAS score, and the more pain the patient felt, the higher the score. The lowest possible score could be 0 and the highest possible score could be 10. The VAS is the most frequently implemented method of assessing pain in the clinical environment (Carlsson, 1983 & Flandry et al., 1991). It has been shown to have a higher level of validity and sensitivity, while allowing a broader range of responses than interval pain scales (Flandry et al., 1991, Hoher et al., 1995 and Thomee et al., 1995(b)).

The VAS was administered immediately following the standard warm-up in all testing sessions.

3.4.2. Functional Knee Score Scale

The KFS (Werner, 1993) was also utilized at each testing session (Appendix C). Patients were asked to respond to their functional ability in eight areas relating to knee disorders: a) *pain,* b) *occurrence of pain,* c) *walking upstairs,* d) *walking downstairs,* e) *sitting with knees flexed for greater than 30 min.,* f) *squatting,* g) *catching, and* h) *patellar instability.*

If the patient had not recently undergone the listed activity, they were instructed to attempt it at that time. The overall score was calculated and the maximal possible score was 53, indicating normal function. The lowest possible score was 0, indicating dysfunction in all of the tested areas. Werner's FKS was developed with a maximal possible score of 50. Although, her scale did not make adjustments for PFPS patients who became fully functional or the control patients. This was evident in the 'occurrence of pain' category where there was no response for subjects without pain during the listed activity. Therefore, a weight of 18, as the increments were in three, was given to subjects with no pain during these activities.

The KFS was administered following the VAS, and prior to quadriceps force and EMG analysis.

3.4.3. Peak Quadriceps Force

The Kincom 125 AP (Chattanouga Group Inc., Tennessee) was used to record peak isometric force values during nine contraction conditions. The subjects were seated at 80° hip flexion and 30° knee flexion. The 30° angle of knee flexion was determined by straightening the leg to 180°, inputing this value into the Kincom machine for calibration by the goniometer, and flexing the knee 30°. This hip flexion angle is commonly used in torque and force measurement studies on PFPS (Kramer et al., 1993, Narici et al., 1996, and MacIntyre & Wessell, 1988). The knee flexion angle of 30° was chosen to avoid excessive compressive forces, stress and increased joint pressure-volume at the patellofemoral joint, all of which increase with angles over 30° knee flexion (Huberti et al., 1984 and Eyring & Murray, 1964).

The mechanical axis of the dynamometer lever arm was aligned to the center of the lateral femoral condyle and the force resistance pad was attached to the anterior tibia approximately 2.5 centimeters above the most superior aspect of the medial malleolus. Body position was maintained with a double cross seat belt covering the torso and pelvis. The contraction conditions were standardized by maintaining exact body position throughout contractions, presenting the same information to all patients, and giving the same level of verbal encouragement. As well, only the primary investigator tested the patients throughout the entire study.

The force data were measured through a variable resistance strain gauge yielding an electrical signal proportional to the force applied to it. The signal was acquired on-line using an analog-to-digital interface (12 bit resolution) at a sampling rate of 100 times per second. The signal was displayed in the CODAS (Dataq Instruments Inc., Ohio) recording software in Volts (v). Reliability of strength testing when using the Kincom has shown correlation coefficients ranging between 0.96 to 0.99 (Lindle et al., 1997 and Highgonboten et al., 1988). Farrell & Richards (1986) have also reported that the measurement of the lever arm position, the lever arm velocity and the measurement of force with the Kincom system is valid and reliable.

Subjects were instructed to undergo one trial maximal voluntary isometric contraction (MVIC). This trial contraction would assist patients in becoming familiar with the equipment and permit selection for appropriate amplification. The testing conditions consisted of three five second MVICs, interspersed with three minute rest intervals. The isometric contraction condition was chosen to avoid excessive limb movement that may cause artifact in EMG recording. As well, isometric contractions have shown the highest peak torque values, as compared to isokinetic contractions (Kannus, 1990, Jones & Rutherford, 1987 and Thorstensson et al., 1976). The submaximal contractions were determined from the MVIC and displayed on the Tektronix 2213A (Tektronix, England) oscilloscope. The subjects watched the fluorescent line on the monitoring screen to adjust their contraction to 60% and 30% submaximal force.

The subjects underwent three five second submaximal contractions of 60% of their maximal peak force, and three submaximal contractions of 30% of the maximal peak force interspersed with three minute rest intervals. The submaximal contractions were accompanied by EMG collection from the VMO and VL.

A contraction was repeated if the force data exceeded the CODAS scale, if the patient was using his/her upper body or lifting off the seat during the contraction, or if they did not maintain the contraction for five seconds. The peak force values during the MVICs were used to monitor the effect of rehabilitation on quadriceps strength.

3.4.4. Electromyography

The EMG instrumentation consisted of a pre-amplifier (M.S.E. Medizintechnische Systems, West Germany), a four channel main amplifier (M.S.E. Medizintechnische Systems, West Germany), and electrocardiogram (ECG) infant sized electrodes (Conmed Adnover Medical, Massachussets).

The EMG collection system included a high performance I/0 module (Dataq Instruments Inc., Ohio) and the CODAS (Dataq Instruments, Ohio) software system. This apparatus was used to record muscle activity from the VMO and VL. The subjects skin was prepared for recording by shaving the skin along the anteromedial and anterolateral aspects of the thigh with a disposable razor, followed by abrasive rubbing with an isopropyl alcohol swab. This was done to ensure oils and hair were removed to reduce the skin's impedance (Kimura, 1989). The electrode placement was originally marked with an indelible Securline (Precision Dynamic Corporation, California) fine tip surgical skin marker, and also mapped with relation to the medial and lateral femoral condyles and superior iliac spine on the anatomic recording sheet (Appendix B) so repeat analysis could be done on day forty-two.

Two ECG electrodes were securely affixed and taped to the patient in a bipolar configuration over the muscle belly of the VMO, two electrodes were placed along the VL (lateral to the rectus femoris on the distal half of the thigh), and two grounding electrodes on the electrically neutral patella. Inter-electrode distance was maintained between 3.0 and 5.0 centimeters, centre to centre of the 1.5 centimeter in diameter electrodes. Electrode placement was marked with the Securline pen (Precision Dynamic Corporation, California) at completion of the contractions. Each patient was given the surgical marking pen to maintain the electrode placement, and were instructed to re-apply the ink each morning and evening over the entire six week period. This was done as an attempt to maintain the exact electrode site on both testing days.

Three plastic shielded cables leaving the six electrodes were attached to a pre-amplifier and both the cables and pre-amplifier were taped to the head of the Kincom dynamometer to avoid movement artifact. The differential pre-amplifier increased the signals amplitude by 1000. The signal was futher magnified by a main amplifier with gain up to 10,000, with a common mode rejection ratio of 100 dB, and a band pass filter of 10 to 1,000 Hz. Signals were displayed real time and five seconds of muscle activity was recorded on the hard drive.

Each subject underwent one trial MVIC so the EMG recording amplitude could be adjusted. This ensured higher amplification activity would not be lost. Nine files of data (3 MVICs, 3 submaximal contractions at 60% of MVIC and 3 submaximal contractions at 30% of MVIC) were collected on day one and on day forty-two of the study. Submaximal contraction conditions are more reflective of the muscle activity required in exercise or day-to-day events (Basmajian, 1985), therefore changes in submaximal ratios of muscle activity were analyzed.

3.5. DATA ANALYSIS

3.5.1. Subjective Reporting of Pain

The VAS responses were tabulated from the zero mark with a standard ruler to the nearest tenth of a centimeter. The responses from each testing session were input into a Microsoft Office Excell (Microsoft Corporation, Washington) spreadsheet.

3.5.2. Functional Knee Score Scale

The FKS scale response was calculated with a standard Sharp 376 calculator and input into a Microsoft Office Excell (Microsoft Corporation, Washington) spreadsheet for further analysis.

3.5.3. Peak Quadriceps Force

Each file of raw data was analyzed in the WINDAQ playback software (Dataq Instruments Inc, Ohio) so that maximal peak force values could be established. During a steady state of force, the event marker scrolled through the data points to determine a peak value. The value for each contraction condition was recorded and input into a Microsoft Office Excell spreadsheet. The values obtained from the CODAS (Dataq Instruments Inc., Ohio) software were converted into Nm using the following equation:

F = 7.4855 + 204.39 (x - volt value)
Nm = F * the moment arm
(Calibrated by Suter, 1997)

The mean of the three MVICs was calculated and used for further statistical analysis.

3.5.4. Electromyographic Data

One second of raw EMG data from each of the three maximal and submaximal contractions was extracted from a steady state condition, as determined by the level of force. The one second of VMO and VL muscle activity was extracted and saved in a binary file. This file was converted into ASCII and imported into MATLAB (The Mathworks Inc, Massassachusetts) for further analysis.

The root mean square was calculated for each extracted data segment to account for each individuals level of recording amplitude during the testing session (Appendix G). The RMS values were input into an Excell (Microsoft Corporation, Washington) spreadsheet for normalization. The most common method of normalization is to compare the myoelectric activity of a given contraction to the activity of a maximal voluntary isometric effort (Knight et al., 1979). Therefore, the EMG activity for each muscle was normalized to the mean maximal voluntary isometric contraction value of the given muscle for the respective testing session. The ratio of VMO:VL activity for the submaximal 60% and 30% contractions were further determined by dividing the normalized VMO activity by the normalized VL activity. The normalized mean VMO:VL ratios were determined for the submaximal 60% and submaximal 30%, and recorded in Excell (Microsoft Corporation, Washington) for statistical analysis.

3.6. Statistical Analysis

Two-tailed multivariate analysis of variance (MANOVA) with repeated measures was done for between group comparisons and within group analyses were done with a one way analysis of variance (ANOVA). In the case of significant differences, post-hoc analyses were performed to see where the differences occured. Students t-tests were used to determine the acceptance of the research hypothesis for data with homogeneous variance (parametric data) and normal distribution, and the Wilcoxon Signed Rank test was used for the parameters that did not conform to the assumption of homogeneity of variance or normality. All statistical analysis was performed using Stataquest (Stata Corporation), with the exception of the MANOVA, which was done using the SPSS software. The critical alpha was set at $p<0.05$ for all tests, and was adjusted when using repeat multiple student t-tests ($p<0.0125$) (Pagano & Gauvreau, 1992).

CHAPTER FOUR

RESULTS

The null hypothesis stated that there would be no significant differences between the home exercise program population and the physical therapy program population over six weeks of rehabilitation in any of the following parameters:

- pain measurement as determined using a visual analogue scale
- functional ability as determined using the Functional Knee Score Scale
- peak quadriceps force during maximal voluntary isometric contractions and,
- ratio of VMO:VL normalized activity during submaximal isometric contractions

4.1. SUBJECTS

Forty-six subjects participated in this study. There were 16 control subjects, 15 PFPS-PT subjects and 15 PFPS-HEP subjects. Forty-nine subjects were originally recruited to participate. Three PFPS subjects withdrew from the study and their data could not be used. One PFPS-PT subject was a varsity athlete that preferred the frequency and availability of his team athletic therapist and withdrew from the study four days into his physical therapy program. Two PFPS-HEP subjects withdrew from the study. One of these subjects injured himself hiking and was diagnosed with a possible ACL tear resulting in cessation of his home exercise program two weeks into the study. The second PFPS-HEP subject moved out of Calgary due to employment prospects and ceased the program nineteen days into the study. The remaining 46 subjects are described in Table 4.1.

Table 4.1. Subject Demographics (Mean ± Standard Deviation)

VARIABLE	HOME EXERCISE GROUP	PHYSICAL THERAPY	CONTROL GROUP
AGE (years)	26.1 (± 2.29)	27.1 (±4.49)	25.4 (±1.88)
HEIGHT (cm.)	174 (±9.45)	174 (±9.45)	174 (±12.6)
WEIGHT (kg.)	67 (±12.13)	69 (±12.13)	73 (±12.72)
# OF FEMALES	8	8	8
# OF MALES	7	7	8

A MANOVA was performed on the subject characteristics to ensure there were no differences between the PT, HEP and Control groups in age, weight and height. No significant differences were found between any of the parameters ($p=0.528$). The two treatment groups and the control group can be considered statistically not different in age, weight and height.

The review of the University of Calgary Sport Medicine Centre patient database revealed that the PT subjects attended an average of eight physical therapy sessions (7.8 ± 1.03) over the six week duration. A review of the

HEP log books suggested that the HEP subjects underwent an average of twenty HEP sessions (20.2 ± 1.18) over the six week duration. Table 4.2. outlines the rehabilitative exercises and techniques used in the physical therapy program, as found in patient chart reviews.

Table 4.2. Rehabilitative Exercises and Techniques in the PT Group

EDUCATION	STRENGTHENING EXERCISES	STRETCHING EXERCISES	MANUAL THERAPY	MODALITIES
• Patient Education • Re: PFPS and causative factors and the goal of rehabilitation	• **Quadriceps:** double & single leg squats, wall press, lunges, leg lifts, tubing exercises, rowing a walk to run program, cycling and the shuttle machine	• **Quadriceps:** standing & sitting stretches (focus on the lateral structures), manual stretches, side standing stretch, and iliopsoas stretch	• Manual tensor fascia latae stretch	• **Taping:** McConnell technique
• Activity modification: type and time	• **Abdominals:** sets with alternating knee up, air cycling and semi curls	• **Hamstrings:** standing stretches and manual stretches		• **Interferential Current**
• Importance of adhering to the home exercises	• **Gluteals:** squats, lunges, gluteal raise with alternating knee up, and supine & prone gluteal exercises	• **Gluteals:** seated and standing stretch, and manual exercises for trunk flexibility		• **Ultrasound** • **Icing & Heat**
• Progress throughout rehabilitation	• **Other:** proprioceptive exercises: wobble board and step-down exercises	• **Gastrocnemius & Soleus:** standing stretches		• **Muscle Biofeedback and trans cutaneous nerve stimulation** with squats and lunges

4.2. VISUAL ANALOGUE SCALE RESULTS

The mean VAS scores and standard deviations for each population over time are illustrated in Figure 4.1. (individual results in Appendix H).

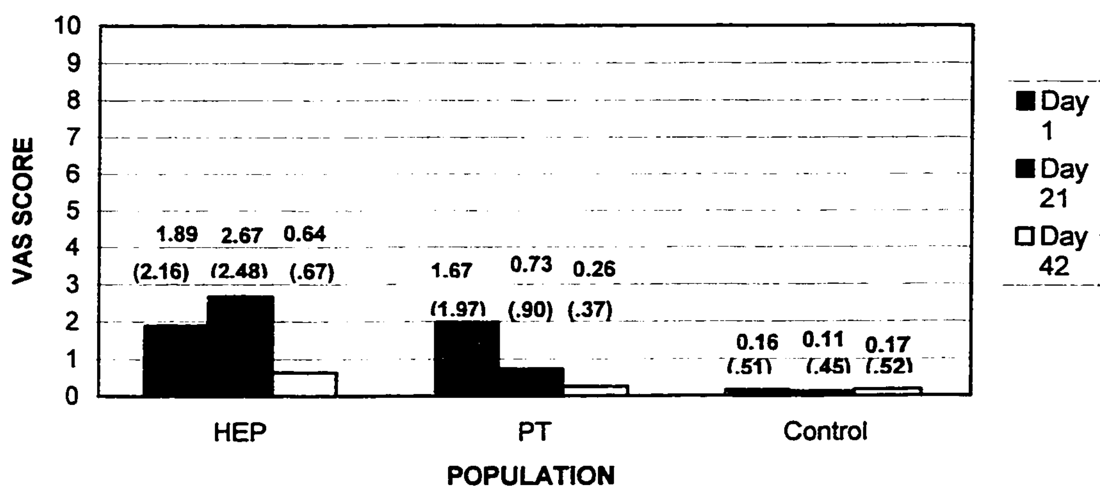

Figure 4.1. Mean Visual Analogue Scale Values (Standard Deviations) Between Day 1 and Day 42

Each of the three populations were plotted on a normal quantile plot to illustrate population variance. The assumptions of homogeneity were met for the two treatment groups and the control population, therefore parametric statistics were used.

There appeared to be a change in the mean VAS scores between day 1 and day 42 for both the PT and the HEP groups as illustrated in Figure 4.1.. A MANOVA with repeated measures was performed on the VAS data, the time intervals and the populations. A significant difference (p=0.001) between these parameters was found. Post-hoc students t-tests were performed on each population to determine whether the changes in the level of pain were statistically significant between testing sessions. The assumptions when using multiple repeat student t-tests were accounted for and the critical alpha was adjusted accordingly (p=0.0125). The following sections examine within population changes and the comparison between the two treatment groups.

4.2.1. Home Exercise Group - VAS

The HEP VAS scores for the three time intervals were analyzed with ANOVA, and a significant p-value (p=0.001) was found. Paired t-tests further analyzed the differences between time intervals of the VAS scores [Day 1 to Day 21 (p=0.095), Day 21 to Day 42 (p=0.004), Day 1 to Day 42 (p=0.025)]. The only significant difference occurred between day 21 to day 42 (p=0.004). This suggests that the HEP subjects experienced a statistically significant decrease in their pain during the last three weeks of their rehabilitation.

Figure 4.2. illustrates the individual changes in the VAS scores for the HEP between day 1 and day 42. The reference line denotes equal values for the pre-rehabilitation and post-rehabilitation VAS scores. Two subjects (4,8) reported an increase in their VAS scores and the remaining subjects reported a decrease.

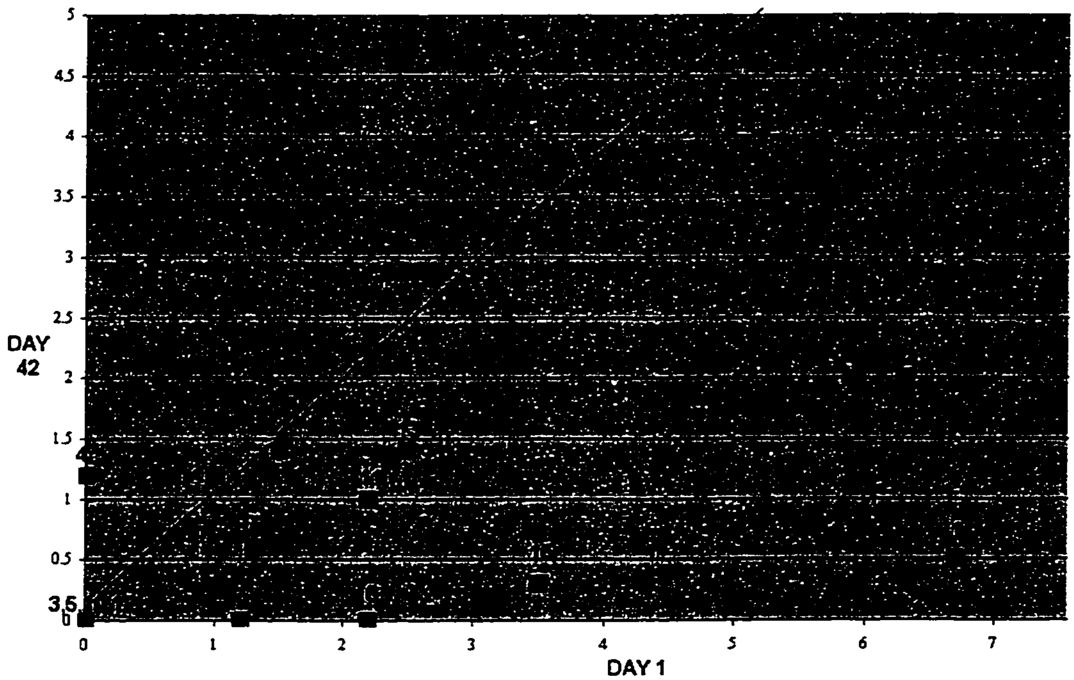

Figure 4.2. A comparison of VAS scores on day 1 to day 42 in the HEP population. The reference line denotes day 1 = day 42.

Four subjects (3,5,10,12) reported no pain throughout the course of rehabilitation. These subjects stated their pain was only elicited during running and/or cycling, and the discontinuation of these activities resulted in no pain on an average basis. Subject 4 experienced an increase in pain levels throughout the home exercise program, and was later referred to an orthopaedic surgeon who diagnosed this subject with a meniscal tear following arthroscopy.

4.2.2. Physical Therapy Group - VAS

The PT VAS values from each testing session were analyzed with ANOVA and a significant p-value (p=0.043) was found. Paired students t-tests analyzed the VAS scores between each time interval. There was a significant difference in VAS values between day 1 and day 42 (p=0.012), although significant differences were not found between day 1 to day 21 (p=0.0334), and day 21 to day 42 (p=0.0516). This suggests that the physical therapy program patients experienced a statistically significant decrease in their mean level of pain between the study's onset and the end of their rehabilitation.

Figure 4.3. displays the individual changes in VAS scores between day 1 and day 42. All subjects that are below the reference line reported a decrease in their VAS scores, and those subjects above the line reported an increased VAS score. Only one subject reported a slight increase (0.1 cm) in their VAS score over time.

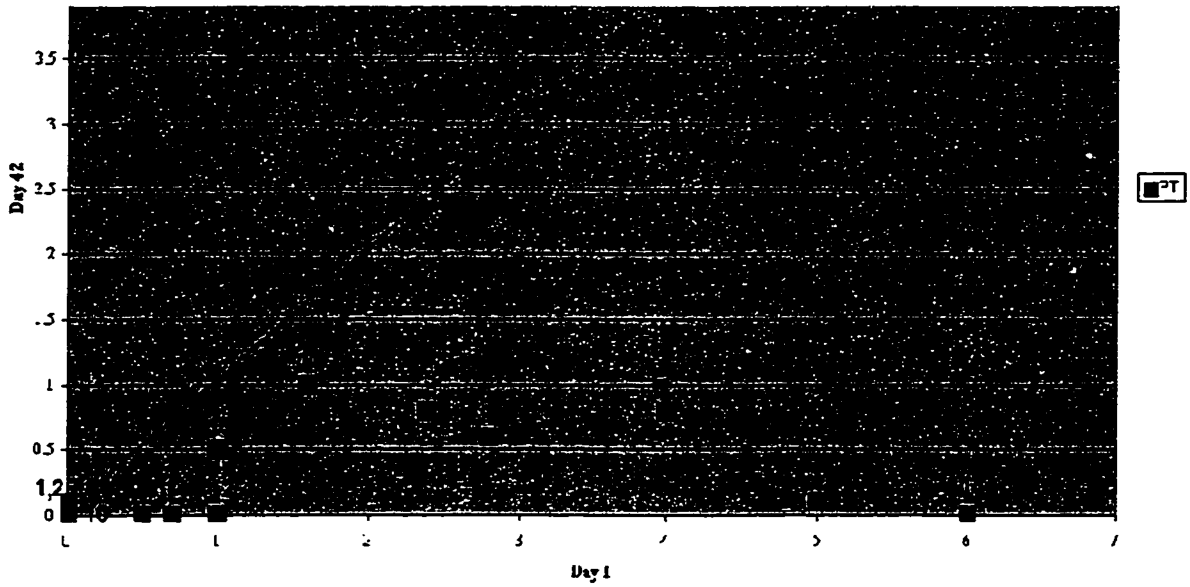

Figure 4.3. A comparison of VAS scores on day 1 to day 42 in the PT population. The reference line indicates day 1 = day 42.

Four PT subjects also reported no pain throughout the course of rehabilitation and stated this was due to the same reason as the four HEP subjects.

4.2.3. Control Group

The VAS scores for each testing session were analyzed with ANOVA. There was no statistically significant difference found (p=0.2151). Figure 4.4. illustrates the individual differences in VAS scores between day 1 and day 42 of two subjects. The remaining subjects reported no pain throughout the 42 days.

The day 1 VAS scores of the PT and HEP group were compared to day 1 of the Control group using an unpaired students t-test. The treatment groups

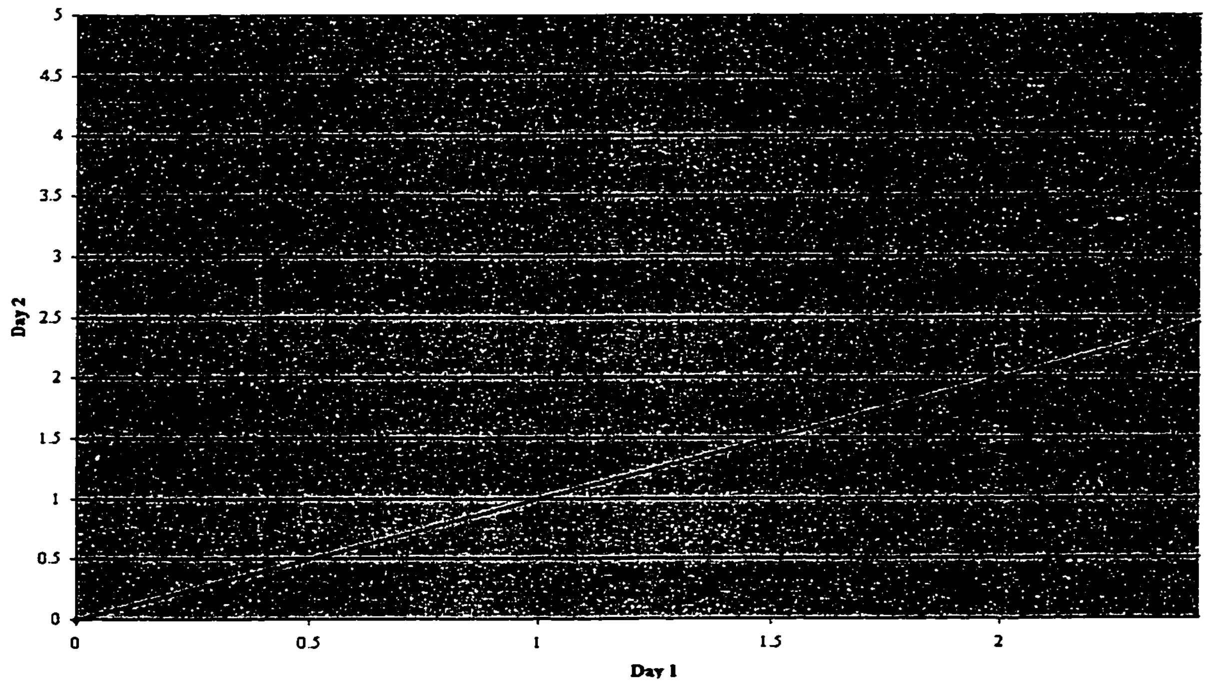

Figure 4.4. A comparison of VAS scores on day 1 to day 42 in the control population. The reference line indicates day 1 = day 42.

were statistically different on day 1 as compared to the control population (HEP p=0.004 and PT p=0.01).

Control subject 6 reported a pain level that was higher than the PFPS populations' mean values. This subject stated they had never experienced knee problems and the pain was 'more of an achy pain that only occurred after hockey.' The primary investigator believed this subject may have generalized knee pain.

4.2.4. Home Exercise Group versus Physical Therapy Group

An unpaired students t-test analyzed the differences in subjects VAS scores between day 1 and day 42 in the HEP versus the differences between day 1 and day 42 in the PT population. There was no statistically significant difference ($p=0.829$) between the decreases in the VAS scores in the HEP versus the decreases in the PT population between day 1 and day 42. Therefore, one population's improvements were not statistically greater than the other population's improvements.

4.3. FUNCTIONAL KNEE SCALE

The mean functional knee scale scores and standard deviations over the three testing sessions for each population are illustrated in Figure 4.5. Individual scores can be seen in Appendix I.

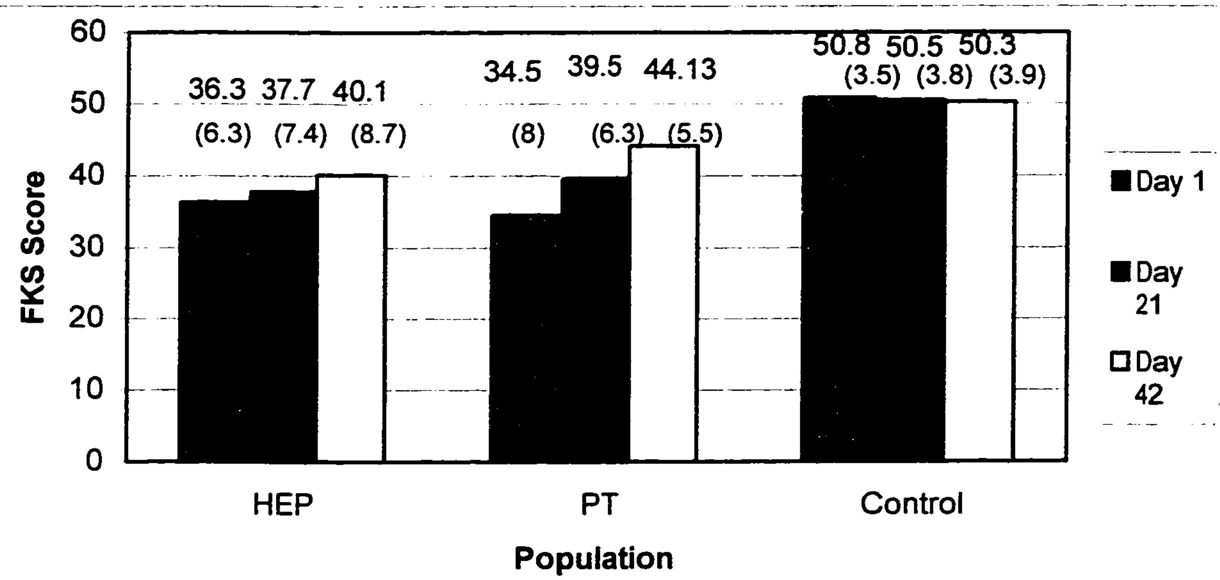

Figure 4.5. Mean (Standard Deviations) of the Functional Knee Scale Score Between Day 1 and Day 42

Each of the three populations data was input into a normal quantile plot to illustrate variance. The assumptions of homogeneity were met for each population with the FKS scores.

There appeared to be a positive increase in the mean FKS values from day 1 to day 42 for both the physical therapy and the home exercise groups as illustrated in Figure 4.5. A MANOVA was performed between the FKS data, the testing intervals and the three populations. A significant difference was found (p=0.0001). Post-hoc analyses were performed on each population to determine whether the changes in FKS scores within each group were statistically significant. The following sections analyze the interactions between time intervals, FKS data and the three populations.

4.3.1. Home Exercise Group - FKS

ANOVA on the FKS data for each time interval found there was no statistically significant difference (p=0.2854). This indicates that the HEP group did not significantly increase their functional ability score over the 42 days.

Figure 4.6. illustrates the individual results in the changes in the FKS scores between day 1 and day 42. All subjects that are above the reference line reported an increase in their FKS scores, and those subjects below the line reported decreased FKS scores.

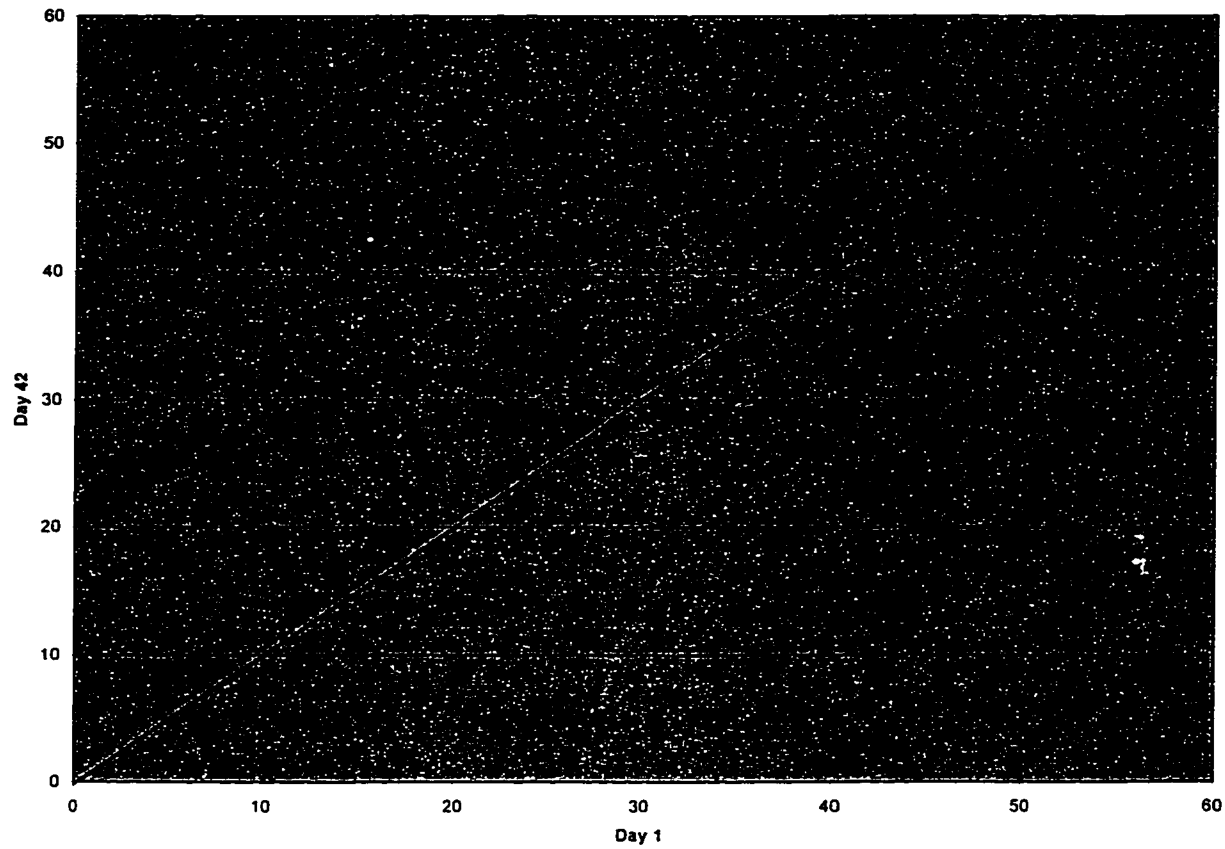

Figure 4.6. A comparison of FKS scores on day 1 to day 42 in the HEP population. The reference line indicates day 1 = day 42.

Subject 4, who was later diagnosed with a meniscal tear, reported decreased levels of functional ability. Subject 15 also reported decreased levels and lower overall knee function, although experienced over a 3.0 point decrease in pain levels. Interestingly, subjects 5 and 10 experienced decreased levels of function, although reported no pain throughout rehabilitation.

4.3.2. Physical Therapy Group - FKS

The mean FKS scores of the PT group from the three testing sessions were analyzed with ANOVA and a statistically significant difference was found ($p=0.0001$). Paired students t-tests were performed between the FKS data and each time interval. The changes between each time interval were significant: day 1 to day 21 (p=0.005), day 21 to 42 (p=0.011), and day 1 to 42 (p=0.0004). The significant p-values suggest that the PT group experienced a statistically significant increase in their functional ability throughout the six week rehabilitation program.

Figure 4.7. illustrates the individual changes in FKS scores between day 1 and day 42. Subjects that are above the reference line reported an increase in FKS scores and subjects below the line reported a decrease.

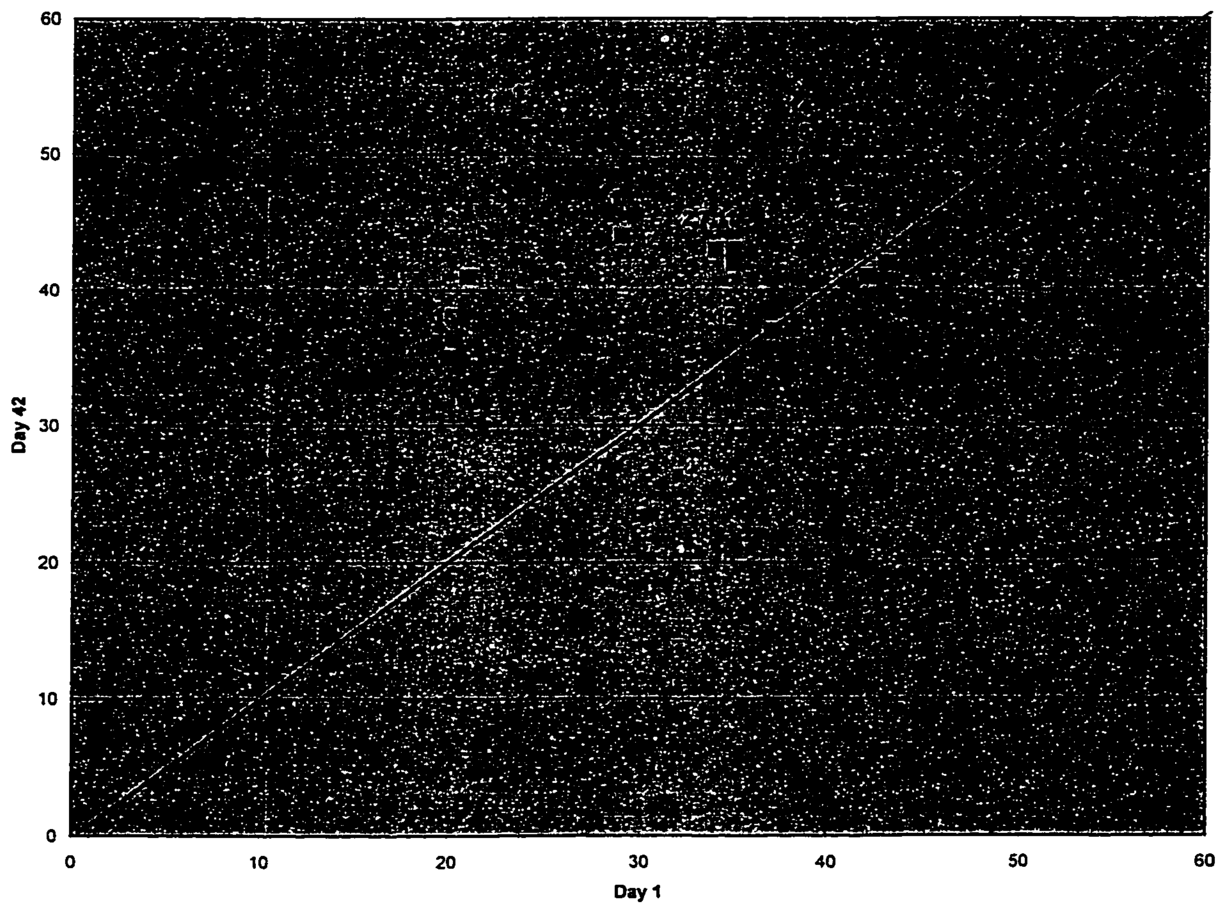

Figure 4.7. A comparison of FKS scores on day 1 to day 42 in the PT population. The reference line indicates day 1 = day 42.

Subjects 8 and 10 experienced a slight decrease in their FKS scores over the 42 day rehabilitation period. Interestingly, both subjects reported 'no pain' on the VAS on day 1, with subject 8 maintaining their report of 'no pain' throughout rehabilitation and subject 10 reported a slight increase in their VAS score.

4.3.3. Control Group - FKS

ANOVA showed no statistically significant difference (p=0.462) in the level of function in the control population throughout the forty-two day interval. Individual results are illustrated in Figure 4.8..

A comparison of the treatment groups on day 1 to the control group on day 1 resulted in a significant difference for the HEP group (p<.001) and the PT group (p<.001).

All of the subjects with the exception of subjects 2 and 9, that decreased their FKS scores, maintained their level of knee function throughout the 42 days. Subject 6 had less than full functional ability throughout the study which may further substantiate the possibility of the subject having a generalized knee pain disorder.

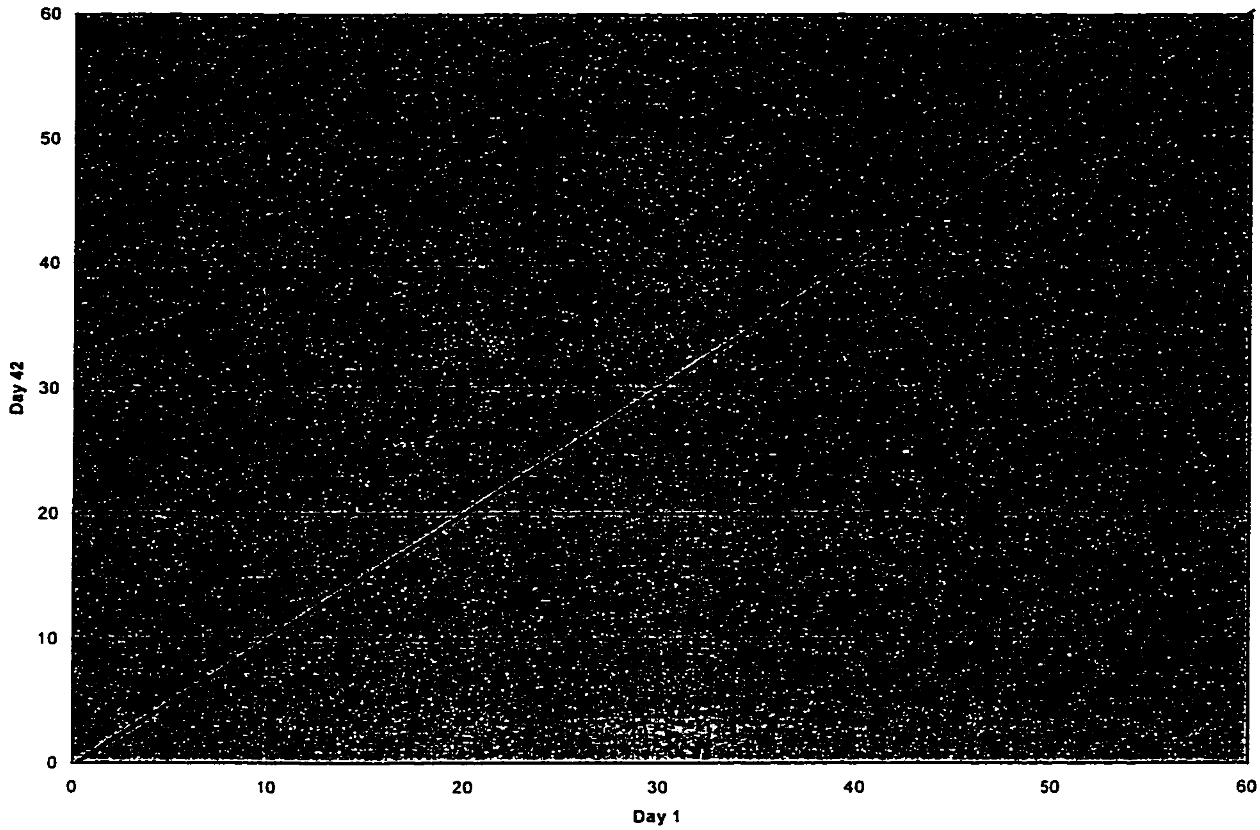

Figure 4.8. A comparison of FKS scores on day 1 to day 42 in the Control population. The reference line denotes day 1 = day 42.

4.3.4. Home Exercise Group versus Physical Therapy Group

The differences in the FKS values between day 1 and day 42 in the HEP were compared to the differences between day 1 and day 42 in the PT group using an unpaired students t-test. There was no statistically significant difference (p=0.0762). Therefore, the PT groups improvements were not statistically greater than the HEP groups improvements.

4.4. MAXIMAL ISOMETRIC QUADRICEPS FORCE

The mean and standard deviations of peak quadriceps force in the two treatment groups and the control group over time is illustrated in Figure 4.9. (individual results in Appendix J).

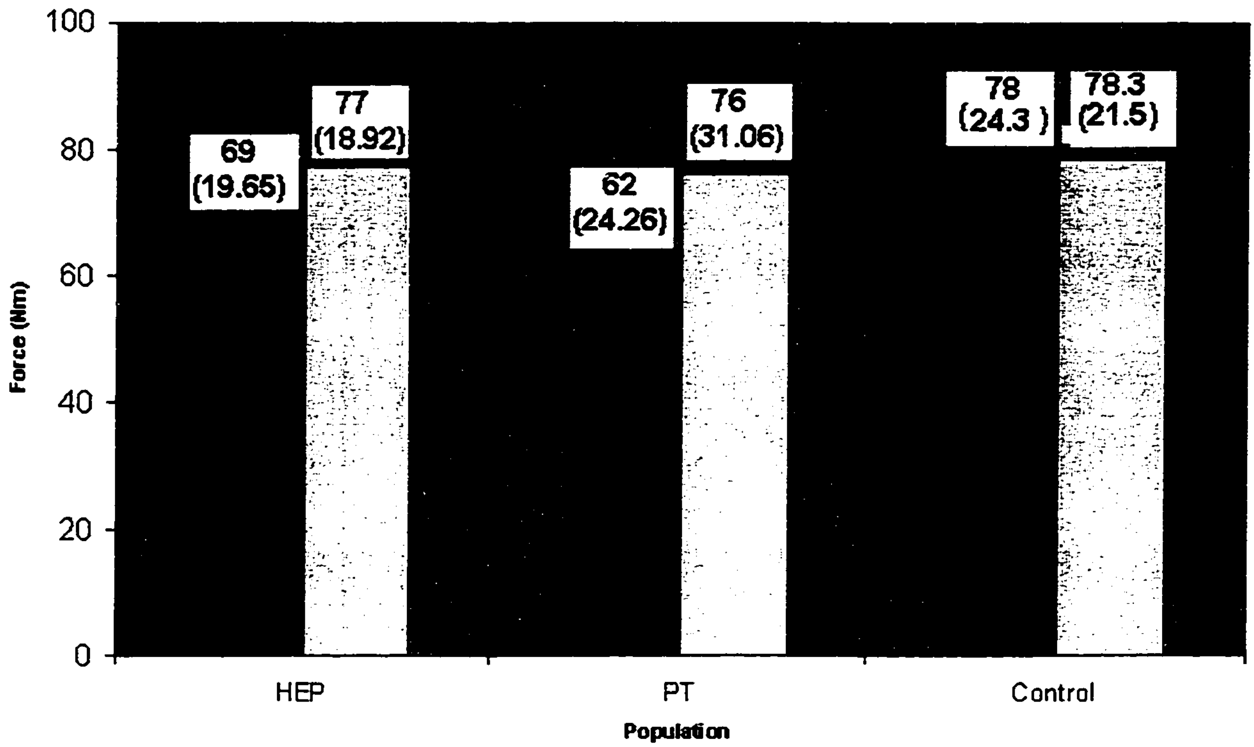

Figure 4.9. Mean (Standard Deviations) Peak Quadriceps Force Value Over Time

A MANOVA was performed between the three groups, the two testing sessions, and the peak force data. A statistically significant difference was found ($p=0.01$). Post-hoc within group parametric analyses were done to further determine the differences in peak force over time. The following sections outline the results of each population.

4.4.1. Home Exercise Group – Peak Quadriceps Force

A paired students t-test was performed on the pre and post mean quadriceps peak force values of the HEP population. There was a statistically significant ($p=0.003$) difference. This result suggests that the HEP experienced a statistically significant increase in their peak quadriceps force in the 42 days of rehabilitation.

Figure 4.10. displays the individual changes in peak quadriceps force between day 1 and day 42. Subjects that are above the reference line experienced an increase in their FKS scores. Only subject (9) was slightly below the reference line.

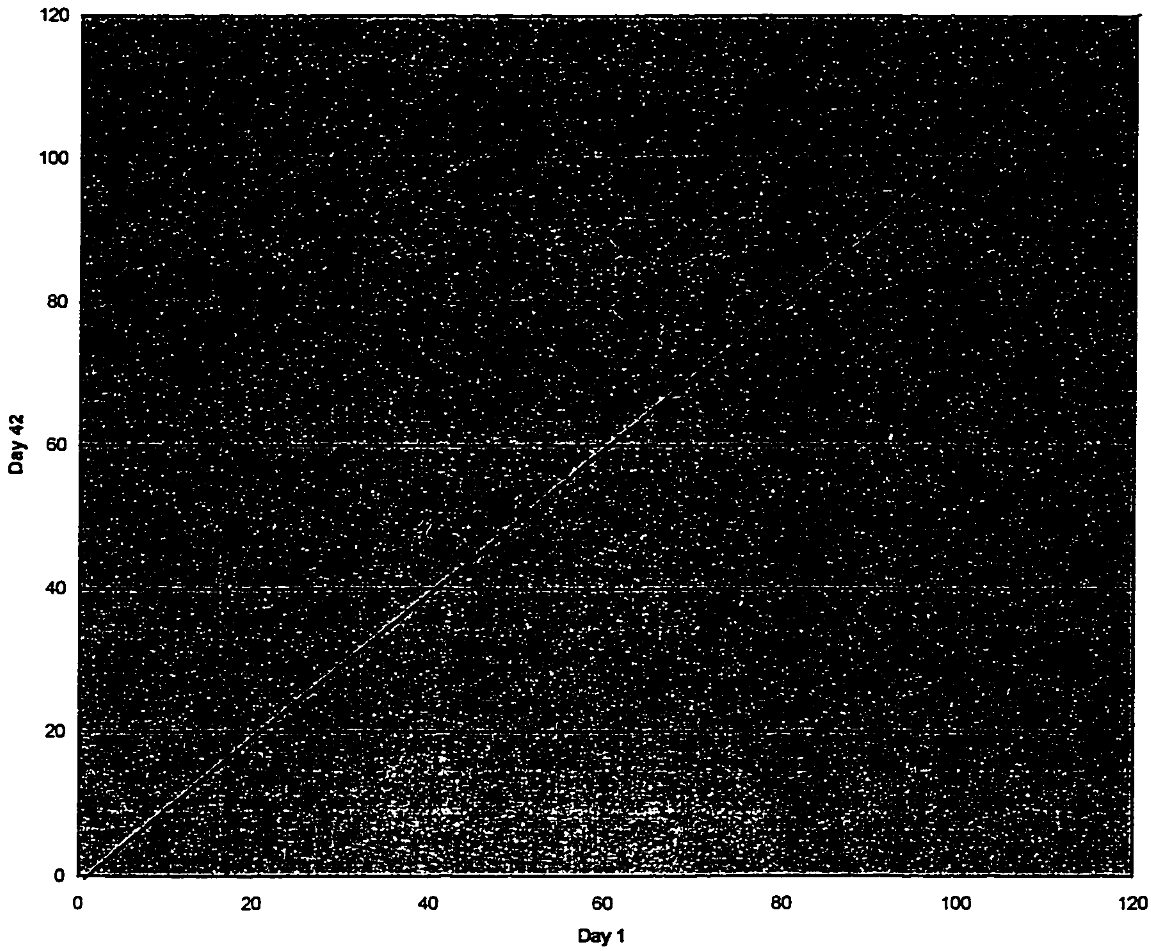

Figure 4.10. A comparison of peak quadriceps force on day 1 to day 42 in the HEP population. The reference line indicates day 1 = day 42.

Subject 4 maintained approximately the same value of peak force pre and post treatment, which gives further credence to the subjects overall failure in the rehabilitation program. Subject 8 experienced a 28 Nm increase in peak force, as well as a 17 point increase in functional ability, although the subject reported an increased VAS value over the six weeks. Subject 9 had a slight decrease in peak force, although exhibited improvement in function and decreased levels of pain.

4.4.2. Physical Therapy Group – Peak Quadriceps Force

A paired students t-test was performed on the pre and post mean quadriceps peak force values. There was a statistically significant difference (p=0.0005) between day 1 and day 42. This suggests that the PT subjects experienced a statistically significant increase in their peak quadriceps force over the rehabilitation program.

Figure 4.11. displays the individual changes in peak quadriceps force between day 1 and day 42. All subjects experienced an increase between their pre and post values.

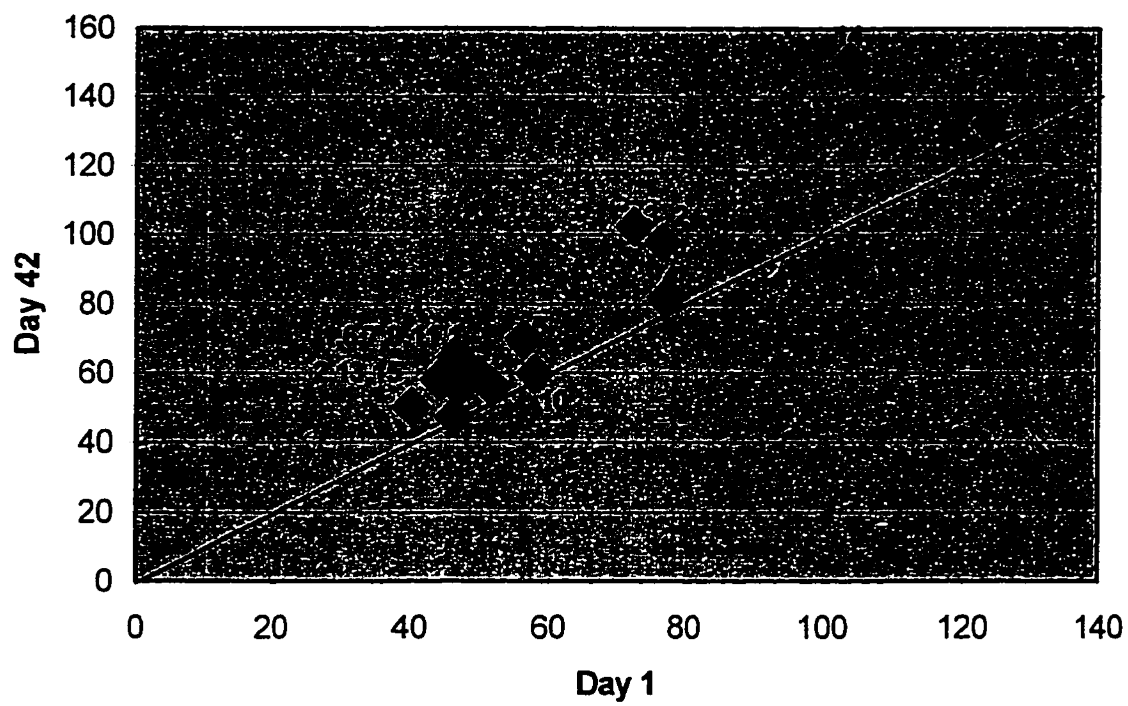

Figure 4.11. A comparison of peak quadriceps force on day 1 to day 42 in the PT population. The reference line indicates day 1 = day 42.

Subject 14 experienced a 50 Nm increase in peak quadriceps force, which was substantially higher than any other subject. This subject was a competitive mountain biker who was starting their season during the last three weeks of rehabilitation which may have contributed to the large increase in force.

4.4.3. Control Group – Peak Quadriceps Force

A paired students t-test between the pre and post mean peak quadriceps force values was not statistically significant ($p=0.961$) in the control population. This suggests the control subjects did not experience a statistically significant increase or decrease in peak quadriceps force over 42 days.

The day 1 peak force values of the PT and HEP groups were compared to the day 1 peak force values of the control group. The HEP ($p=0.07$) and PT ($p=0.22$) groups were not significantly different as compared to the control group.

Figure 4.12. illustrates the individual changes in peak quadriceps force between day 1 and day 42. All the subjects stayed very close to the reference line which indicates there was little spread in the pre and post peak force values. The data points are not labeled, as no common trends occurred in the control group.

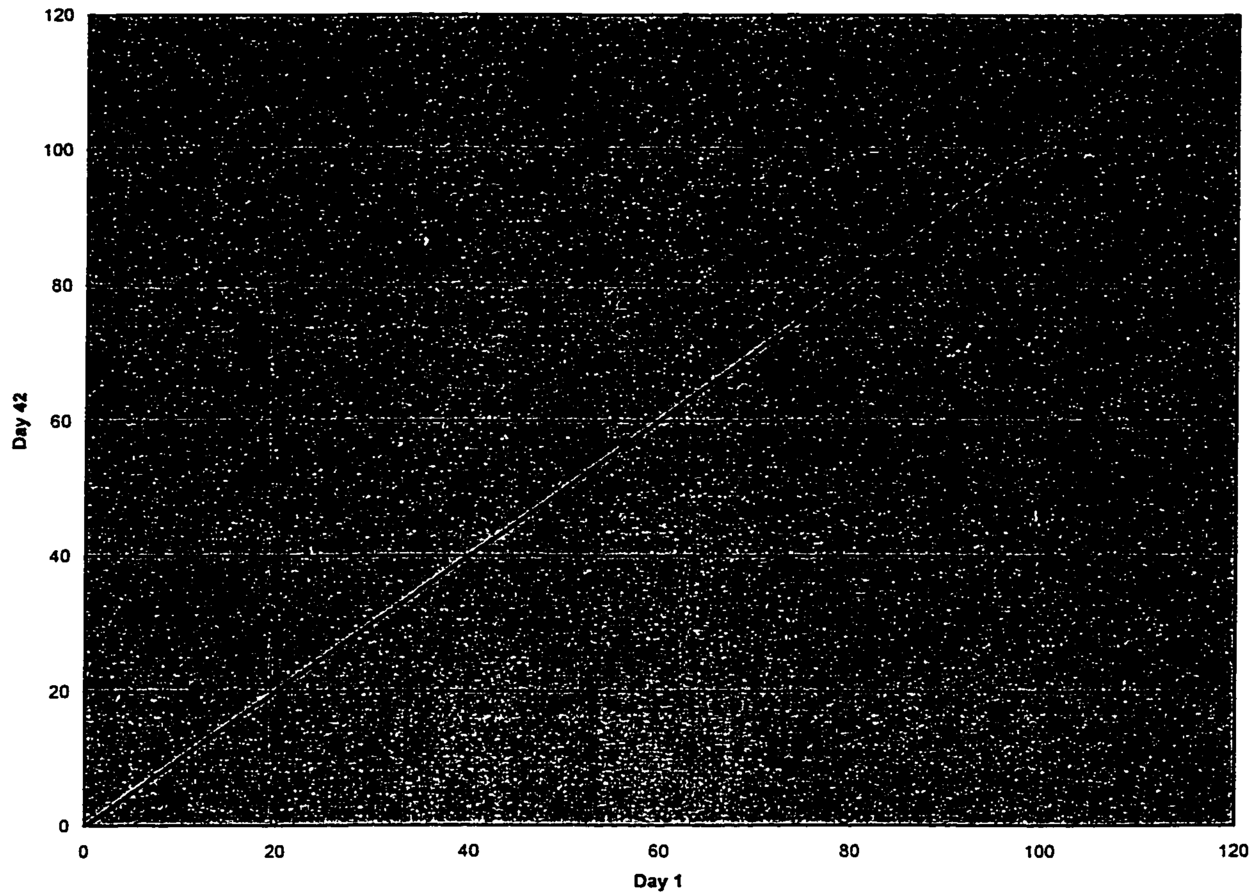

Figure 4.12. A comparison of peak quadriceps force on day 1 to day 42 in the control population. The reference line indicates day 1 = day 42.

Subject 4 revealed extremely low peak force values in comparison to both the symptomatic and control subjects. This subject was an inactive, 92 pound female, and it was unsure if she was doing the contraction correctly. Subject 12 experienced an 18 Nm increase in the peak quadriceps force, which was greater than many of the HEP and PT patients.

4.4.4. Comparison Between Home Exercise Group and Physical Therapy Group

The differences in the peak force values between day 1 and day 42 in the HEP were compared to the differences between day 1 and day 42 in the PT group using an unpaired students t-test. There was no statistically significant difference (p=0.204) found.

4.5. RATIO OF MUSCLE ACTIVITY (VMO:VL)

4.5.1. 60% Submaximal Contraction Condition

The normalized mean ratios of VMO:VL muscle activity in the three populations over time during the submaximal 60% contraction conditions can be seen in Figure 4.13. (individual data in Appendix K).

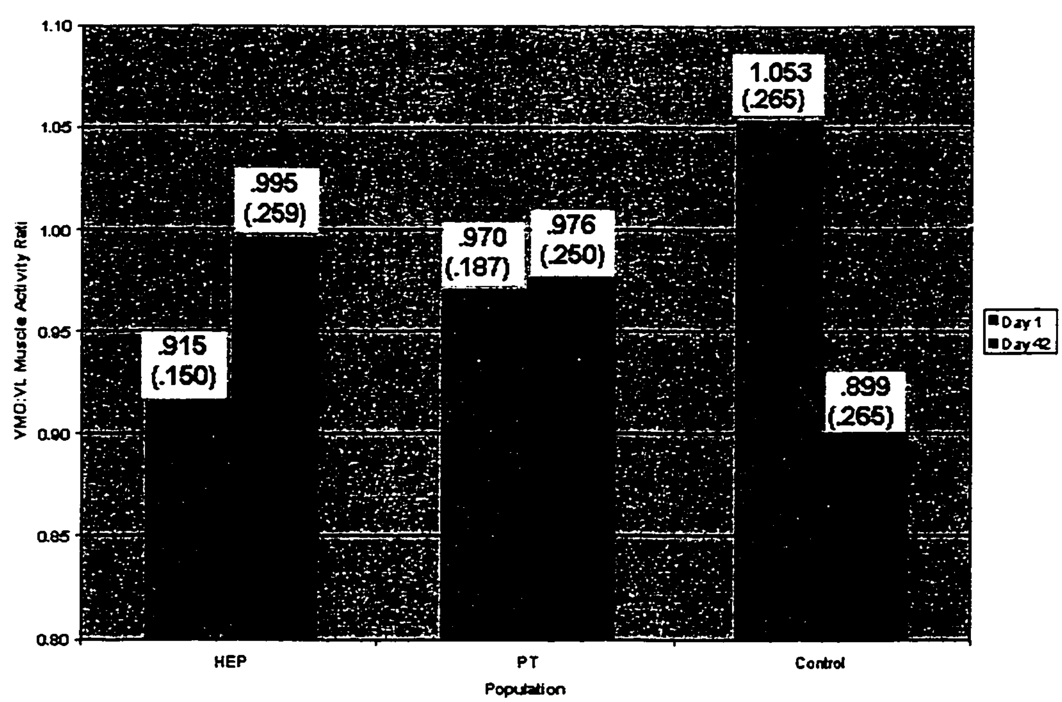

Figure 4.13. Mean (Standard Deviations) of VMO:VL muscle activity ratio during submaximal 60% contractions

A MANOVA with repeated measures was performed between the three groups, the two time intervals and the VMO:VL EMG activity ratios. There were no significant differences between these variables ($p=0.627$). There were no common trends in any of three groups as evident in Figure 4.14. (a), (b) and (c).

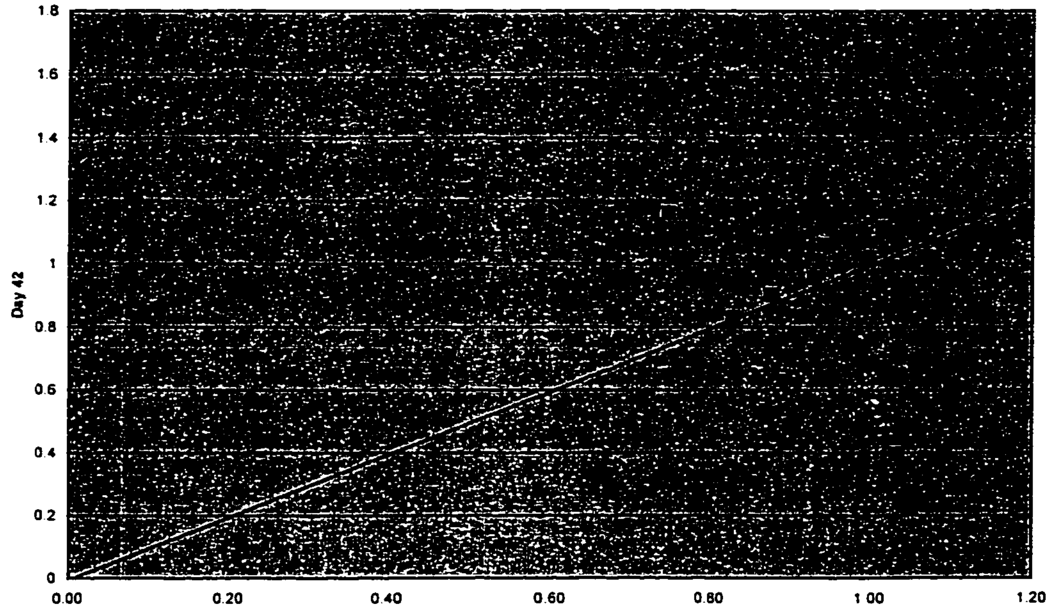

Figure 4.14. (a) – HEP population

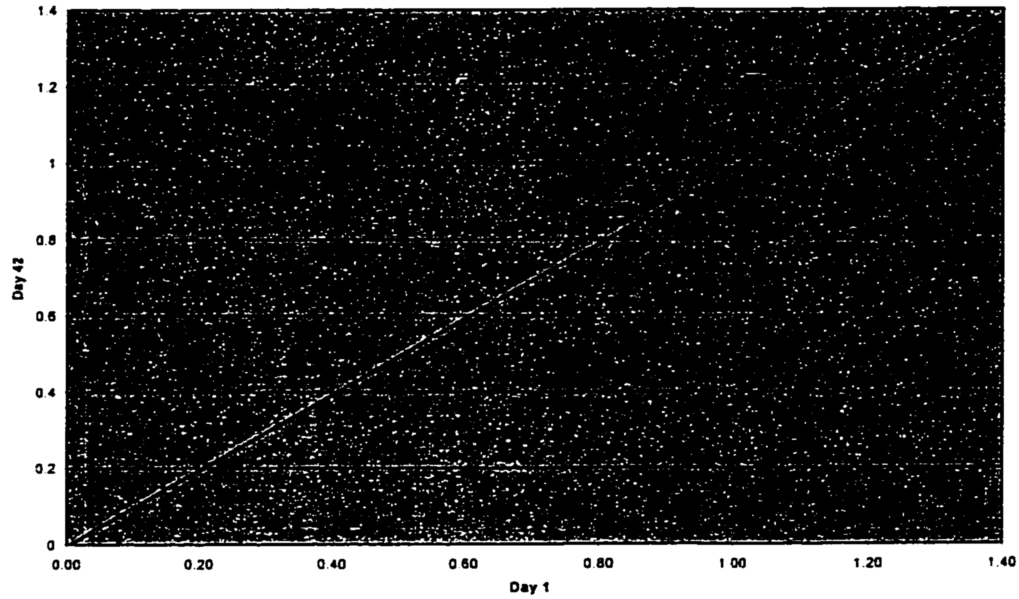

Figure 4.14. (b) – PT Population

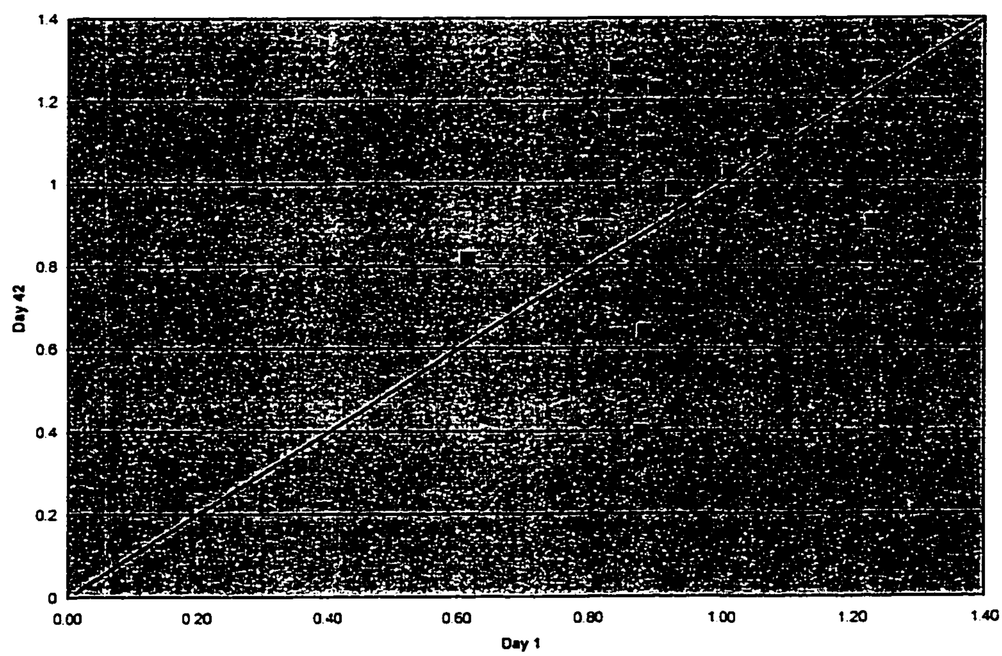

Figure 4.14. (c) Control Population

Figure 4.14. A comparison of Submaximal 60% VMO:VL muscle activity ratio on day 1 to day 42 in the HEP (a), PT(b), and Control (c) population. Reference line indicates day 1 = day 42.

The HEP individual point spread around the reference line suggests that the majority of patients experienced an increase in their ratio of VMO:VL activity, whereas the PT subjects individual point spread suggests that the majority of patients experienced a decrease in muscle activity. The majority of the control population appears to have increased their VMO:VL EMG ratio, as evident in Figure 4.14.(c). These patterns do not correlate with each populations changes in peak quadriceps force. The reliability of between-day use of EMG has been shown to be less than 25% (Soderberg et al. 1986) and between day use is not recommended by DeLuca (1992). The inherent limitations using EMG will be further discussed in Chapter 5.

4.5.2. 30% Submaximal Contraction Condition

The normalized mean ratios of VMO:VL muscle activity in the three populations over time during the submaximal 30% contraction conditions can be seen in Figure 4.15. (raw data in Appendix L).

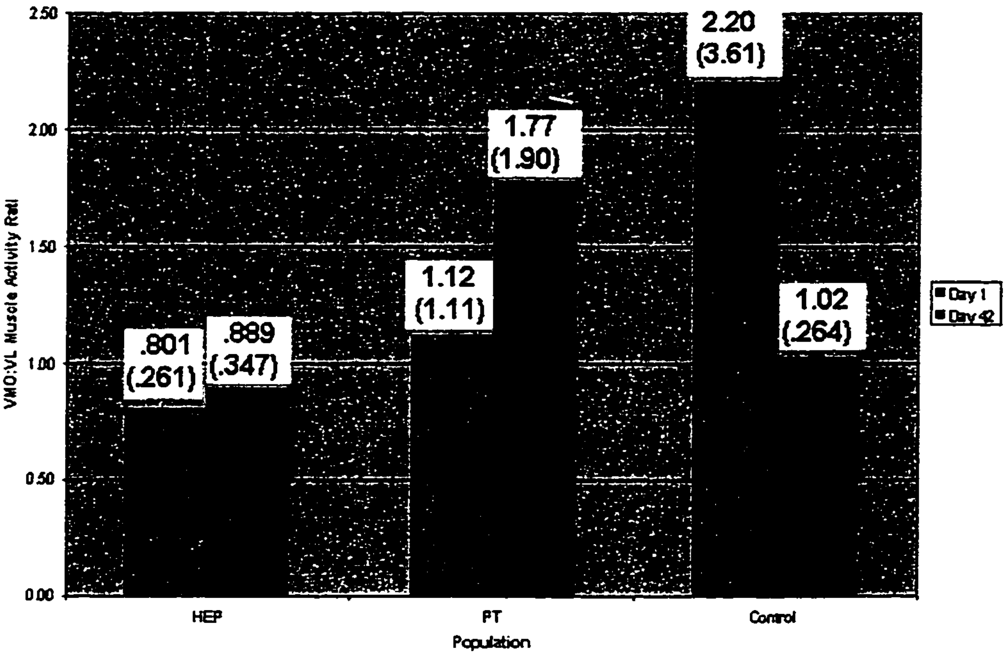

Figure 4.15. Mean Ratio of VMO:VL EMG Activity During Submaximal 30% Contraction Conditions

A MANOVA was performed between the three groups, the three time intervals and the ratios of EMG activity. There were no statistically significant differences found (p=0.634). There were no common trends in the pre and post therapy muscle activity ratios as seen in Figure 4.16 (a), (b) and (c).

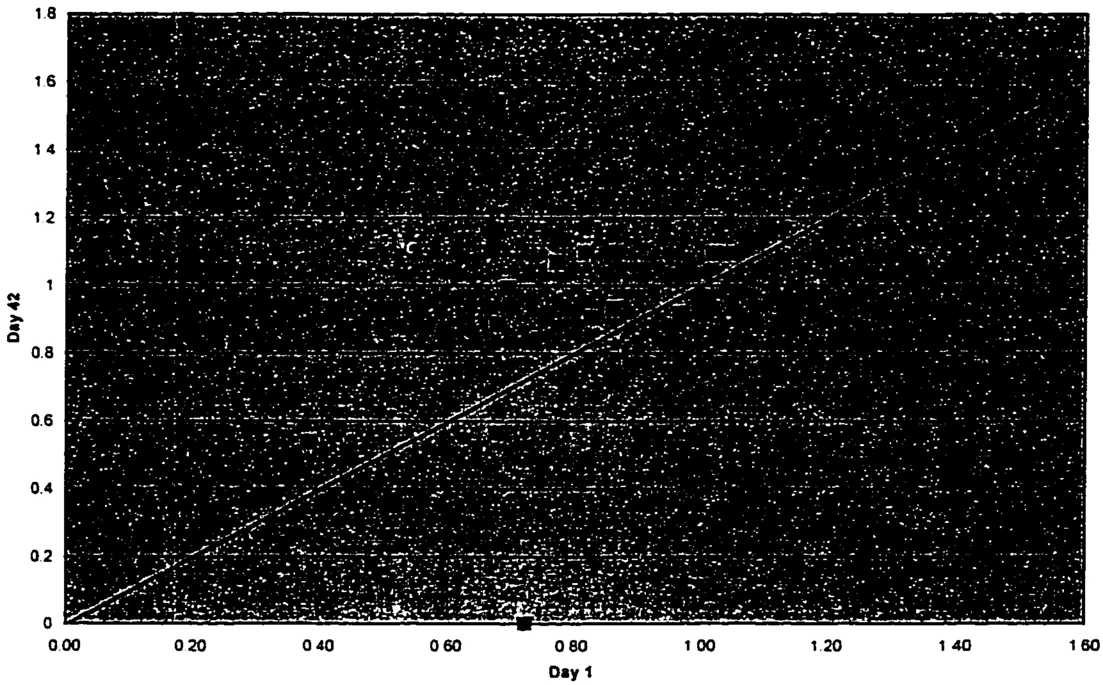

Figure 4.16. (a) HEP Population

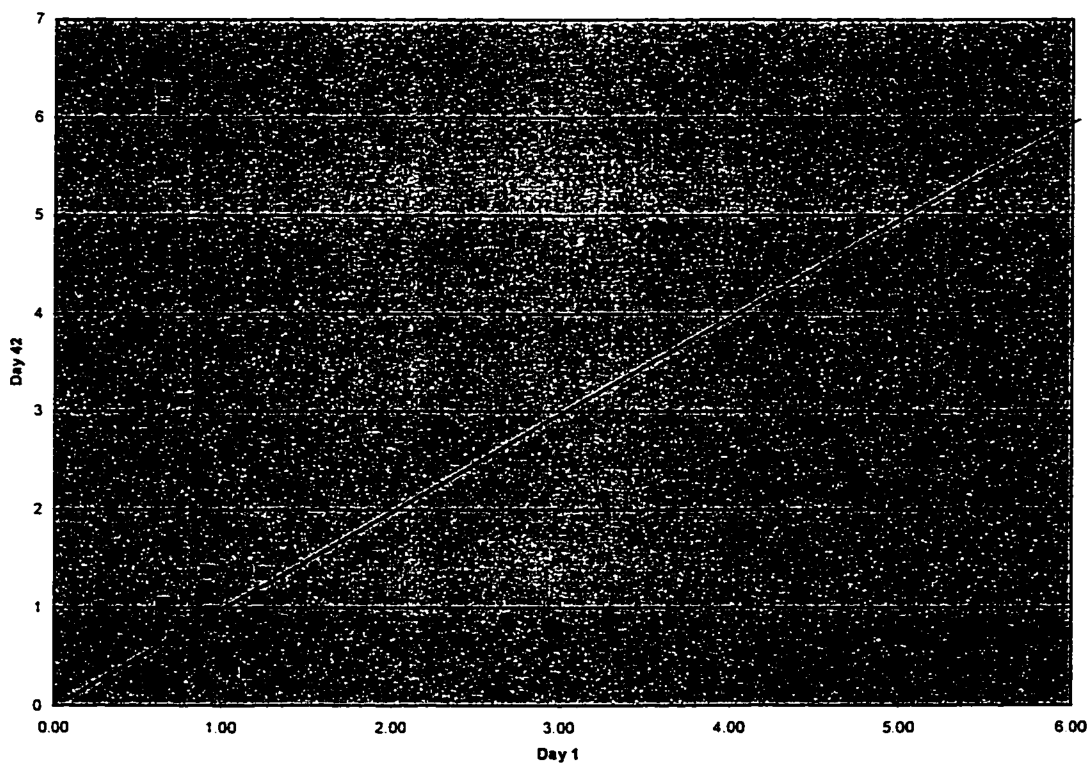

Figure 4.16. (b) – Physical Therapy Population

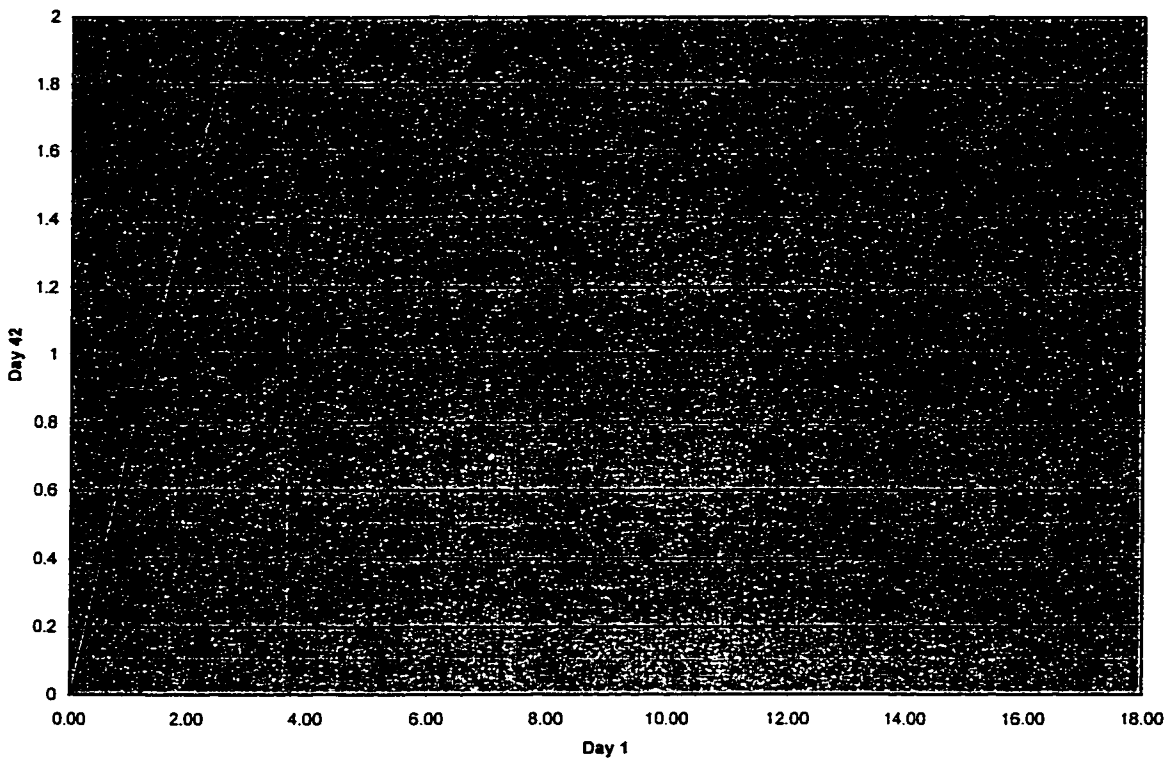

Figure 4.16 (c) – PT population

A comparison of Submaximal 30% VMO:VL muscle activity ratio on day 1 to day 42 in the HEP (a), PT(b), and Control (c) population. Reference line indicates day 1 = day 42.

The HEP individual point spread around the reference line suggests that the majority of patients experienced an increase in their ratio of VMO:VL activity during the submaximal 30% contraction condition, whereas the PT group appears to have decreased their ratio of VMO:VL activity (Figure 4.16. (c)). The majority of the control population appears to have increased their VMO:VL EMG ratio, as evident in the subjects individual point spread around the reference line. These patterns would suggest that the majority of the HEP subjects experienced an increased elicitation of the motor units, although the PT groups did not. Once again, the limitations of using EMG for between day analyses are extensive and will be further discussed in Chapter 5.

CHAPTER FIVE

DISCUSSION

This study was a single blinded, randomized, pre-test, post-test clinical trial. It was conducted to determine if there was a difference between the subjective reporting of pain and the subjective reporting of functional ability in PFPS patients participating in a course of physical therapy versus a home exercise program. Secondary measures of interest were peak quadriceps force during maximal voluntary isometric contractions and the ratio of muscle activity between the VMO and VL during 60% and 30% submaximal isometric contractions. The presiding null hypothesis (Ho) was that there would be no significant difference between a HEP and a PT program, as determined by the four parameters listed above.

5.1. VISUAL ANALOGUE SCALE

Fourteen out of 15 PFPS-PT subjects and 13 out of 15 PFPS-HEP subjects reported a decrease, or no overall pain, at the completion of their respective rehabilitation program. Overall, 90% of the PFPS subjects saw a decrease or maintained a level of no pain, and 47% of the PFPS subjects were pain free at the completion of rehabilitation.

Both PFPS groups experienced a decrease in their mean level of pain between the pre and post-treatment measures. The inter-group analyses revealed that the PT population experienced a significant decrease in mean

VAS scores from day 1 to day 42. Comparatively, the HEP population reported a significant decrease in their mean level of pain between day 21 and day 42, but this was the result of an increased mean VAS score between day 1 and day 21. Therefore, only the PT population exhibited a significant decrease in their level of pain throughout rehabilitation. The comparison between the changes of the two populations was not significant, which indicates that the decreased levels of pain in the PT group were not large enough to be different from the decreased levels of pain in the HEP group.

The mean VAS scores in this study are relatively low in comparison to the mean VAS scores in Timm's (1998) study (pre= 6.50 and post= 3.54) on rehabilitation of patellar pain. The difference between the two studies may be reflective of this study's comparatively stringent inclusion/exclusion criteria (ie. patients experiencing pain for over one year and patients with instability being excluded from the study), or the athletic population investigated in this study. The majority of the subjects in this study were referred from sport medicine settings or the university campus health services centre, and were students who regularly participated in recreational or competitive activity. Many subjects complained of pain only during activity, and modifications or reductions in activity irrespective of rehabilitation, would be reflected by reduced VAS scores. This trend was inherent in eight subjects participating in this study that cited 'no pain' throughout rehabilitation presumably as a result of reduced or modified activities.

Suter et al. (1998) investigated pain using a similar VAS question in anterior knee pain patients. The patient population in their study were recruited from similar clinical settings and therefore were relatively similar to the population in this study. The pre treatment mean VAS score in Suter et al.'s (1998) study was 1.1 cm., a value more closely related to the pre-treatment scores in this study (HEP 1.89, PT 1.67).

The percentage of subjects that experienced decreased levels of pain in this study (90% of PFPS subjects) is similar to other rehabilitation studies that evaluated decreased levels of pain in PFPS patients, as Gerrard (1989) reported a 90.5% (105 out of 116 patients) decrease, Doucette & Goble (1992) reported an 83% (22 out of 28 patients) decrease, and O'Neill et al. (1992) cite an 80% (24 out of 30 patients) decrease in pain levels after rehabilitation. The pain measurement techniques in these studies varied from an unpublished one question VAS (Gerrard, 1989), to a graded interval question describing the type of pain (sharp, dull, aching, throbbing or not at all) (Doucette & Goble, 1992), to a verbal response of the patients level of pain (O'Neill et al., 1992). Therefore, direct comparisons between these studies cannot be made due to the variance in measurement tools and methods, and the lack of data from the aforementioned studies.

5.2. FUNCTIONAL KNEE SCALE SCORE

Nine out of 15 PFPS-HEP subjects and 12 out of 15 PFPS-PT subjects reported a functional improvement at the end of their rehabilitation program. One PFPS-HEP subject and one PFPS-PT subject maintained their functional ability throughout the program, and five HEP and two PT subjects had decreased FKS scores on day 42. Overall, 60% of the HEP population and 80% of the PT population reported an increase in functional ability, and 13% of the HEP and 27% of the PT population reported full functional ability at the end of their program.

The inter-group analyses revealed that the PT group significantly increased their level of function and the HEP group did not. This may be the result of the individualized care provided in PT that targets the deficiencies or inabilities in function throughout the treatment program. The comparison between the changes in the HEP and the changes in the PT program revealed that there was no significant difference between the two programs. The improvements in the PT program were not large enough to be significantly different than the improvements in the HEP.

Werner & Eriksson (1993) utilized the FKS in their study of an eight week isokinetic training program, and Werner et al. (1993) implemented the FKS scale in their study on the effect of taping on quadriceps torque in patients with PFPS. The authors' found a significant increase in function in both studies ($p<0.05$), but did not present any descriptive statistics, nor did they provide any raw data. Therefore, it is difficult to compare the results of their study to this research study. In addition, a slight modification to one category of the FKS scale was made, which is detailed in the Limitations section 5.6. Functional ability questionnaire results from other studies that target dysfunction during sitting, running and walking are as follows. Whitelaw et al. (1989) reported that 57% of PFPS patients reported an increase in knee function when using their scoring scale. O'Neill et al. (1992) cite 53% of patients increased their knee function as determined by verbal responses. And lastly, Edeen et al. (1992) reported that 34% of patients became fully functional, as determined by the subjects ability to return to pre-morbid activities. Direct comparisons between the FKS scores in this study and the various measurement tools outlined above cannot be done. Interestingly, the percent of functional improvement in the above studies is much less than their cited percentages of decreased pain magnitude. This trend is also inherent to the results of this study.

5.3. PEAK QUADRICEPS FORCE

Fourteen out of 15 PFPS-HEP and all of the subjects improved their peak quadriceps force over the six week rehabilitation program (97% of PFPS subjects). The control population did not exhibit a common trend in their level of peak force over time.

The inter-group comparisons between the pre and post peak force values was significant, and the PT group exhibited a greater overall mean increase. The greater mean increase in the PT group was slightly skewed by one subject who displayed a 50 Nm increase in peak force.

The between group comparison resulted in neither program having significantly greater peak force improvements than the other. The day 1 values of the two treatment groups were compared to the day 1 values in the control population, and no significant difference was found amongst the three populations. This may be a result of the competitive and recreational activity levels in the treatment groups, as the majority of patients were referred from sport medicine settings. In comparison, the control population was recruited from the campus community and their level of activity may not have been as high or as regular as compared to the PFPS population.

MacIntyre and Wessell (1988) also reported no significant difference between PFPS patients and control patients when studying peak quadriceps force values. They attribute this non significant difference to either an overall active population base, or the low numbers in their study (n=18 PFPS patients).

The mean peak quadriceps force values in this study ranged from 65 Nm (day 1) in the PFPS population to 78 Nm (day 1 and day 42) in the control population. Other authors investigating peak quadriceps force reported mean values in a control population of 77 to 107 Nm (Richards, 1981 & Berg et al. 1986), and 50 to 95 Nm in a PFPS population (Bennett & Stauber, 1986 & MacIntyre & Wessell, 1988). Suter et al. (1998), in her study of peak quadriceps force in anterior knee pain patients, reported a mean peak quadriceps force value of 68 Nm in symptomatic patients and 83 Nm in the control population. Therefore, the values of this study are within the limits of other published studies.

The increased values of peak force in 29 out of 30 PFPS patients over the six week rehabilitation program may be a result of increased neuromuscular adaptation or, less likely, muscle hypertrophy. Both the PT and HEP program had a strong basis in quadriceps strengthening exercises. The majority of the PT population also experienced muscle transcutaneous nerve stimulation and patellar taping, which has been purported to selectively increase activation of the atrophied or weakened muscle fibres in the VMO.

5.4. RATIO OF VML:VL MUSCLE ACTIVITY

Eight of the 15 PFPS-HEP and 12 of the 15 PFPS-PT subjects experienced an increased ratio of VMO:VL muscle activity during the submaximal 60% contraction condition. Surprisingly, the control group was evenly split in the number of subjects that resulted in increased muscle activity ratios versus the number of subjects with decreasing ratios. During the submaximal 30%

contraction condition, 11 PFPS-HEP subjects showed increased ratios and 10 PFPS-PT subjects showed decreased ratios. The control group resulted in 9 subjects with increased muscle activity ratios and 7 subjects with reduced muscle activity ratios. The overall analysis and the within group analyses were not significant for any population during the 30% or 60% submaximal contraction conditions. The review of individual results were contradictory. Three HEP, 2 PT and 2 Control subjects displayed increased muscle activity ratios between day 1 and day 42 during the 30% contraction condition, although, during the 60% contraction condition, their muscle activity ratios decreased. Conversely, 3 HEP, 2 PT and 1 Control subject showed decreased muscle activity ratios in the 30% contraction condition between day 1 and day 42, but showed increased muscle activity ratios in the 60% contraction condition.

For the purpose of curiosity, the pre and post EMG ratios were compared against the results of peak quadriceps force. A value of 20 Nm was arbitrarily chosen and the patients that experienced a 20 Nm+ increase in peak force over the 42 days were reviewed for comparison of EMG values. Out of 13 subjects that showed over a 20 Nm increase in peak force, only 5 of these subjects consistently saw increased ratios of VMO:VL muscle activity in the submaximal contractions.

Overall, the results were not consistent. The results did not support the theory that increased ratios of VMO to VL muscle activity may reduce pain at the patellofemoral joint. Both groups experienced decreased levels of pain at completion of rehabilitation, although this was not related to a consistent increase in VMO:VL muscle activity ratios.

Narici et al. (1996) employed a similar EMG analysis technique to this study during a pre strength training and post strength training study in normal subjects. The authors found a significant increase in quadriceps torque after the 6 month training program, although there was no significant difference in the root mean square values of EMG activity of the VL, VM and rectus femoris pre and post program. Thorstensson et al. (1976) also employed EMG analysis in a pre and post study design analyzing the effects of strength training. Their results also revealed that there was no significant difference between pre and post training in the VL and rectus femoris. There are currently no PFPS rehabilitative studies that have evaluated VMO:VL muscle activity ratios over time.

Souza and Gross (1991) in their EMG analysis of VMO:VL ratios in PFPS and control subjects found that the ratio of VMO:VL activity in PFPS patients is not significantly different than a control group. Laprade et al. (1998) also compared VMO:VL ratios in PFPS patients and control subjects during isometric contractions. The author's found similar results to Souza and Gross

(1991), as there was no difference between the two groups with respect to VMO:VL muscle activity ratios.

Overall, the non-significance of the EMG evaluation could be the result of two possible factors. Firstly, the ratio of VMO:VL activity may not be a precursory or perpetuating factor to PFPS, as indicated in the EMG studies by Souza & Gross and Laprade et al. (1998). Secondly, the low reliability of between day use of EMG could have significantly affected the comparisons between day 1 and day 42.

5.5. LIMITATIONS

There were two inherent limitations to this study. The primary limitation was the use of EMG over time, and to a lesser extent, the FKS.

The inherent difficulty with Werner's (1993) FKS was that she did not develop a category for PFPS patients who have a complete resolution of pain while undergoing activity. A modification to this scale was therefore required to select PFPS patients post rehabilitation and the majority of the control subjects. The category, 'occurrence of pain,' had six intervals increasing in intensity of pain from running (a score of 15) to walking (a score of 0). The control subjects and select post-rehabilitation PFPS subjects did not experience pain during any of the listed activities and therefore could not circle any of the responses. These patients were given a value of 18, which would have been the next increment in the three point interval scale. This modification may have altered the reliability values that were inherent to this scale, and makes it difficult to compare these results to any other study that may implement this scale. The primary investigator contacted Werner (November 1997, February and May, 1998) via email and fax to request descriptive statistics from her published studies and discuss the modifications to the occurrence of pain category. Werner commented that she will continue to modify her FKS scale and is unable to provide descriptive statistics at this time. She is planning to submit her FKS score for publication with all relevant statistics in the winter of 1998. The author recommends that an alternate functional knee score scale be used in future trials until a further review of Werner's scale is available. Although, currently there are no other PFPS functional knee scales that are reliable and valid for the PFPS population.

The use of surface EMG has many inherent limitations that are often difficult to overcome despite precise efforts. The possibility of muscle cross-talk, movement artifact and procedures to reduce skin impedance may have differed between subjects and between testing sessions. Despite the principal investigator's attempt to maintain a consistent contraction condition on day 1 and day 42, the resultant muscle activity ratio may have been influenced by changes in skin impedance as a result of increased or decreased sweat at the skins surface, increases or decreases in subcutaneous tissue and/or increases or decreases in subject hydration levels. The author therefore suggests that evaluations of muscle activity pre and post rehabilitation should not use surface EMG.

5.6. FUTURE DIRECTIONS

There are two areas that require further investigation before either of the conservative rehabilitation programs (ie. PT and HEP) could be considered more effective in the management of PFPS. Firstly, a true control population should be investigated in a study design similar to this study. The integration of a PFPS population that does not receive treatment over the 42 days would allow investigators to solely monitor the effects of time. Secondly, it is unknown as to whether modifications to a patient's level or type of activity is sufficient for reducing patellar pain. And lastly, it is unknown if there is a mechanism of adaptation that may result in decreased levels of pain over time.

A second area of further investigation would be a longer term follow-up study of both patient populations. This would provide further information regarding the long term effects of the two treatment programs (ie. if the patients maintained decreased levels of pain, increased levels of function and increased quadriceps strength). Deveraux & Lachman (1984) found that 70% of PFPS patients have a recurrence of PFPS twelve months after treatment.

5.6. OVERVIEW

The results from this study suggest that both groups experienced positive changes in pain, function and quadriceps strength over the 42 days. The PT group's changes in the primary outcome measures (pain and function) were significant as compared to the non significant changes in the HEP group. The significant changes in the PT group may have been due to the individualized care and management for the patient's patellofemoral pain, the introduction of therapeutic modalities or the greater Hawthorne (1930) effect in PT, which suggests that the on-going interaction, motivation and encouragement provided in the clinical setting resulted in a more positive effect on rehabilitation.

Non-operative management for PFPS is the most commonly advocated initial route of care by family medicine practitioners, sport medicine physicians and orthopaedic surgeons. The overall goal of rehabilitation for PFPS is to resolve or reduce the symptoms manifested by the disorder so the patients quality of life can be enhanced. Therefore, the rehabilitative program that most consistently and over an extended period of time causes a cessation in the symptoms would be the most efficacious. Comparative analyses of health related services available for various disorders is an area that will continue to undergo further evaluation as changes to health care policies and procedures continue to occur.

The financial implications between the two programs should also be considered by clinicians. A full course of physical therapy for PFPS ranges from four to twelve clinical sessions (Timm, 1998 & McMullen et al., 1990), which results in $140.00 to $420.00 in Alberta, Canada (based on an average cost of $35.00 per session). In contrast, a HEP is essentially a low cost alternative. The decision regarding conservative care prescription should consider the following factors: a) the severity of PFPS, as increased severity and contraindications may require the individualized care provided in physical therapy, b) the financial ramifications of a physical therapy program to the patient, and if the patient is willing to pay for a course of physical therapy, and c) lastly, the patients level of motivation, as increased levels of motivation may result in increased levels of success with a HEP.

5.7. CONCLUSION

This study is the first randomized controlled trial comparing a six week course of physical therapy to a six week home exercise program alternative.

The within group analyses in this study suggest that the PT group experienced a significant decrease in their level of pain, a significant increase in their level of function, and a significant increase in quadriceps strength, whereas the HEP group only revealed a significant increase in quadriceps strength. The comparison between the changes in the two groups was not significant, which suggests that the changes in the PT group were not great enough to be significantly different from the changes in the HEP. Therefore, there was not enough evidence against the null hypothesis of this study. In conclusion, the HEP implemented in this study could be clinically prescribed as an effective initial route of management for PFPS.

This evaluative study on rehabilitation for PFPS may assist in providing a framework for evaluating further health care resources that are provided and/or prescribed for PFPS patients. In addition, this study will contribute to the current sparse body of scientific literature on evidence-based medicine in health care service evaluation for musculoskeletal disorders.

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APPENDICES

APPENDIX A

Study Title: The Efficacy of Two Conservative Rehabilitation Programs for the Treatment of Patellofemoral Pain Syndrome

Investigator: Ms. L. McClelland, B.P.E., MSc. Candidate

Participant Information:

This consent form, a copy of which has been given to you, is only part of the process of informed consent. It should give you the basic idea of what the research project is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this consent carefully and to understand the accompanying information.

Purpose:

The purpose of this study is to investigate the efficacy and cost efficiency of a home exercise program versus a physical therapy program in patients diagnosed with patellofemoral pain syndrome (PFPS). Program efficacy will be measured by decreases in level of pain, increases in knee function, and increases in muscle activity. Cost efficiency will look at the overall dollars spent in each program.

Patellofemoral Pain Syndrome:

PFPS is a disorder characterized by anterior knee pain. It is the most common abnormality involving the knee joint and is predominantly seen in physical active persons. The etiology of PFPS is unclear and many causes have been proposed ranging from anatomic abnormalities to repetitive microtrauma of the connective tissue.

Treatment:

Non-surgical management is the most commonly prescribed initial route for rehabilitation of this disorder. The rehabilitative process relies upon quadriceps strengthening, stretching, activity modification and education. There are two common routes advocated for alleviation of PFPS symptoms: physical therapy and a home-based exercise program.

The physical therapy program in this study will be a six week treatment plan incorporating: strengthening of the lower limb, stretching of the surrounding structures, activity modification, patient education, and application of thermal and electrical modalities. We would like you to participate in four clinical sessions at The University of Calgary Sport Medicine Centre in the first two weeks and four clinical sessions in the following four weeks.

The home-based exercise program will be conducted by a certified exercise practitioner familiar with PFPS rehabilitation. You will be required to come in for a one-hour consultation focusing on strengthening the lower limb, stretching the surrounding structures, and education on management. At this time an information log book will be provided to record your daily exercises over a six week interval.

Explanation:

To compare program efficacy and cost efficiency, patients will be randomly assigned to one of two groups: those attending a six week course of physical therapy and those participating in a six-week home exercise program.

If you give consent to participate in this study, a random envelope will be opened during your initial assessment by a sport medicine physician. Your first visit to either the home exercise consultant or the physical therapist will require two analyses. First, you will record your level of pain using a visual analogue scale and respond to function on a knee function questionnaire. Secondly, surface electromyographic (EMG) electrodes will be placed on your thigh as your perform two designated exercises. Measurements of muscle activity will be recorded at this time. We will require you to return to the Sport Medicine Centre again at three weeks into treatment and at the end of the six week program.

Benefits:

The potential benefits to you for participation will be more frequent contact with staff knowledgeable about PFPS and rehabilitation, as compared to patients not participating in this study. More frequent follow-ups will also allow you more opportunity to ask questions and have your concerns addressed more easily.

Confidentiality:

Information about your from this study will be kept confidential. Any reports coming as a result of this research will not have your name attached.

Requirements:

The costs to you to participate in this study are: time to attend an assessment by a sport medicine physician, time to attend three testing sessions, initial home exercise consultation, or eight physical therapy sessions.

Your signature on this form indicates that you have understood to your satisfaction the information regarding your participation in the research project and agree to participate as a subject. In no way does this waive your legal right nor release the investigators or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time without jeopardizing your health. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification of new information throughout your participation. If you have further questions concerning matters related to this research, please contact: **Lara C. McClelland 220-4966**

Name (print):____

Signature: ____

Name of Witness: ____________________________________

Signature of Witness: ________________________________

Date: ______________ **Signature of Investigator:** ________________

APPENDIX B

Protocol Sheet for PFPS Patient Testing

Date: ______________________________ Time: __________________

Patient Name: ____

Weight: ________________________ Height: ______________________

Testing Limb: Right Left Limb Weight: _______________________

Length of Level Arm: __________________

Application of VMO electrode: ________ Application of VL electrode: _________

Other Comments:

APPENDIX C

Functional Knee Score for Anterior Knee Pain

Suzanne Werner, PhD., P.T.P., Phys.Ed.
Dpt. Sports Orthopedic Surgery, Karolinska Hospital
S-171 76 Stockholm, Sweden

Please circle what applies to your knee:

Pain

None	5
Slight & infrequent	3
Constant pain	0

Occurrence of pain

During or after running	15
Walking stairs	12
After > 2 km walk	9
After < 2 km walk	6
During normal walk	3
During rest	0

Walking upstairs

No problems	5
Slightly impaired	4
Difficulties	2
Unable	0

Walking downstairs

No problems	5
Slightly impaired	4
Difficulties	2
Unable	0

Sit w. flexed knees > 30 min.

No problems	5
Slight impairment	4
Difficulties	2
Unable	0

Squatting

No problems	5
Slight impairment	4
Difficulties	2
Unable	0

Catching

Never	5
Sometimes	3
Frequently	0

Instability of patella

Never	5
Sometimes	3
Often	0

Sum of points:

Sample Size Calculations **APPENDIX D**

Formula: $n = 2 * (\sigma/\delta) * (t_{\alpha, v} + t_{2(1-P), v})^2$

Where:

n= sample size
α= significance level
σ= population standard deviation
δ= difference that is desired to be detected
v= degrees of freedom
t= t distribution value
p= the desired statistical power
a= number of populations/groups being investigated
N= degrees of freedom

1. Functional Knee Score Scale

I. Based on a rough guess of a sample size of ten, the degrees of freedom were:

N = a(n-1)
N = 3(10-1)
N = 27 degrees of freedom

II. Input 27 degrees of freedom into the above formula (t values of 2.052 and 1.314) for a 0.05 level of significance.

$n = 2\,(5/6)^2 * (2.052 + 1.314)^2$
n = 15.74

III. The degrees of freedom for a study of 16 subjects is:

N = a(n-1)
N = 3(15)
df = 45

IV. Input 45 d.f. into the formula (t values of 2.021 and 1.303) for a 0.05 level of significance

$n = 2(5/6)^2\,(2.021 + 1.303)^2$
n = 15.36

Approximately 15 - 16 patients should be recruited for this study.

2. Visual Analogue Scale

Repeat step I.

II. Input 27 d.f. into the formula (t values of 2.052 and 1.314) for a 0.05 level of significance.

$n = 2(1/1.5)^2 * (2.052 + 1.314)^2$

$n = 10.04$

III. The degrees of freedom for a study with 10 subjects is:

$N = a(n-1)$

$N = 3(9)$

$df = 27$

IV. Approximately 10 patients should be recruited for this study.

APPENDIX E
(pages 148 - 166)

Table of Contents

PATELLOFEMORAL PAIN SYNDROME
A Home Exercise Program

OVERVIEW OF THE PROGRAM

This booklet has been devised to help people diagnosed with Patellofemoral Pain Syndrome. It is an education and exercise training tool that will provide information, strengthening exercises, stretches and a daily log to monitor your activity. The program will help you learn about this disorder, present descriptions and illustrations of the exercises, and empower you in the rehabilitative process.

There are always differences in one's ability, goals and time availability. For this reason, the program provides information about each exercise and is very progressive in its design. The daily activity log is an easy and precise approach to keeping track of the time and intensity of your exercises. You will find it interesting to examine your progression throughout the following six weeks.

DEFINITION OF PATELLOFEMORAL PAIN SYNDROME

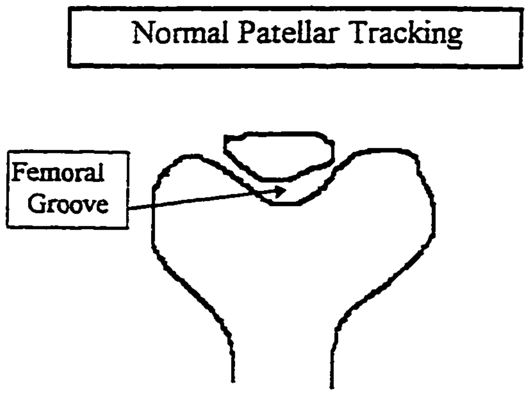
Patellofemoral Pain Syndrome (PFPS) is a lengthy term for a disorder referring to pain at or around the knee cap. The pain becomes worse with activity and/or prolonged flexion, such as squatting, sitting or walking up and down stairs. Patients diagnosed with PFPS do not usually reveal deformities in the bone. Rather, they have generalized pain which is often attributed to incongruencies in the muscle and connective tissue balance at the knee, hip and/or ankle. It is a difficult phenomenon to accurately define because the signs and symptoms do not clearly establish a cause.

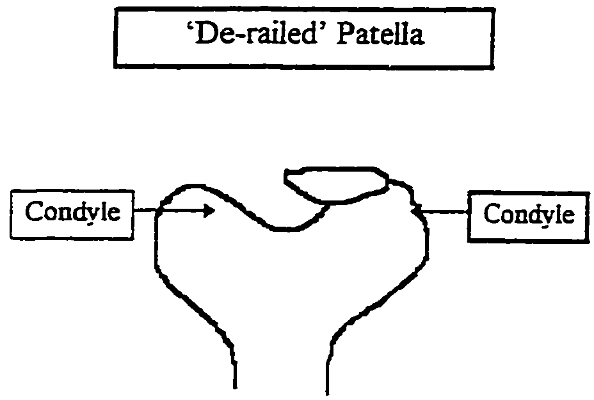
There are many terms used interchangeably with patellofemoral pain syndrome (e.g. anterior knee pain, chondromalacia patellae, patella arthralgia, patellofemoral stress syndrome) that also address painful symptoms, but may necessarily be PFPS. The disorder has been labeled a syndrome because it is a collection of symptoms where the cause or mechanism of injury remains unclear. Hence, the symptom has become the diagnosis.

PROPOSED CAUSES OF PATELLOFEMORAL PAIN SYNDROME

Numerous theories exist as to what causes PFPS; these theories range from anatomic problems (bone, muscle or connective tissue) to overuse of the surrounding structures. Anatomic problems associated with PFPS may be wide hips, knock knees, flat feet or inner rotation of the lower leg. The most common problem in patients with PFPS is an imbalance between the muscles and connective tissue of the thigh. The only ways to combat this problem are to change the forces being applied at the joint through surgery, and strengthening and/or stretching the surrounding structures (i.e. muscles & connective tissue).

Picture a passenger train traveling along its' tracks to visualize the patellofemoral joint. When the wheels of the train meet with the metal tracks, the passengers have a smooth and enjoyable ride. If the wheels of the train were to bump or overlap the tracks, the result would be an extremely uncomfortable and annoying trip. This scenario is similar to the movement in the patellofemoral joint. The patella is a moveable bone that glides within a groove created by two bumps (condyles) at the end of the femur (see illustrations on pg. 7 & 8). Similar to the train, the patella stays within these 'tracks' called the **femoral condyles**. The muscles and connective tissue of the quadriceps help move the patella. When there is an imbalance between these structures, the tracking of the patella can be affected. 'Maltracking' of the patella is often cited as being the cause of pain and/or inflammation. When the patella falls out of alignment or 'de-rails' within the groove, one of the results is Patellofemoral Pain Syndrome (PFPS) (see diagram on page 3).



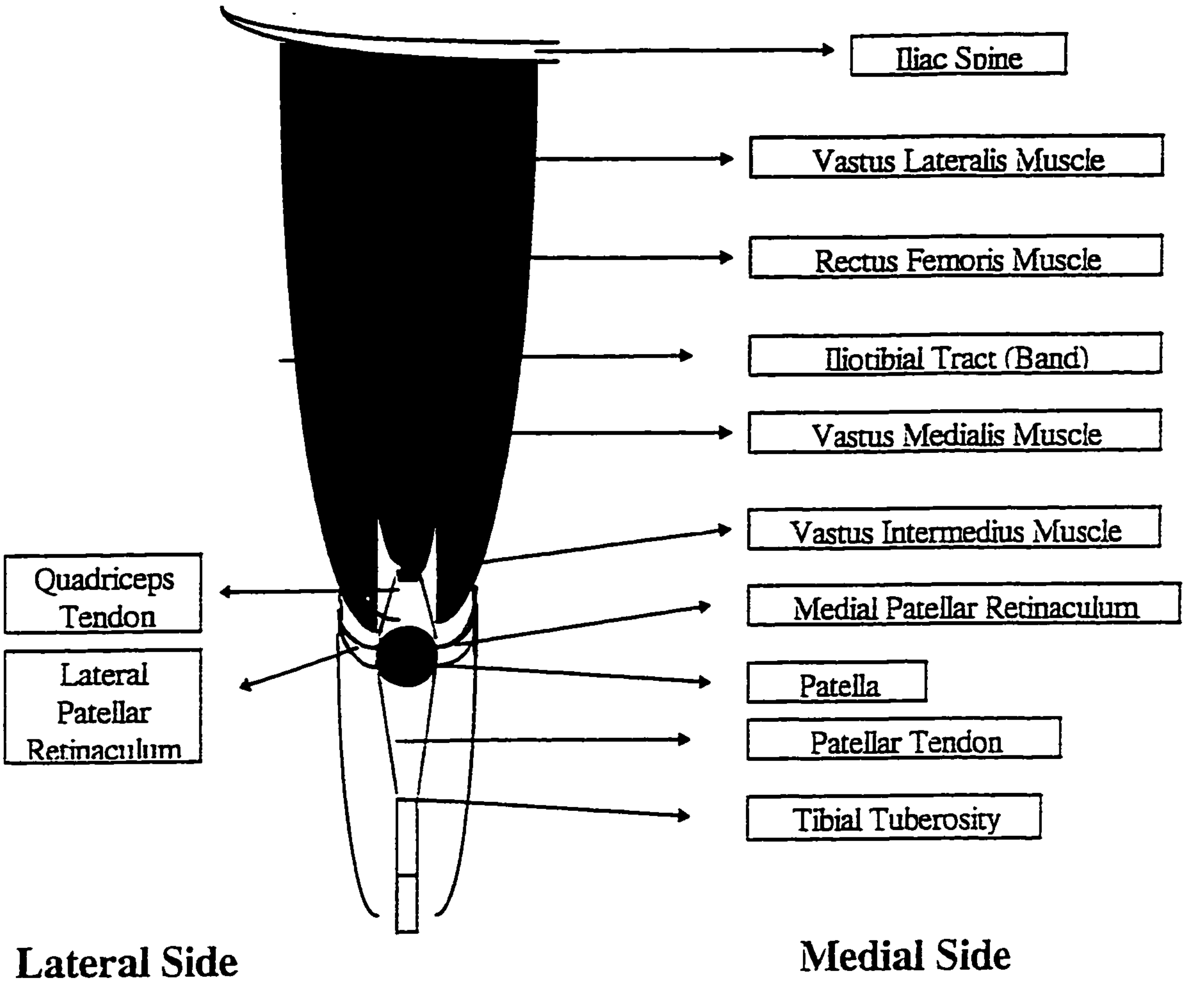


One theory of pain origin in PFPS is the 'maltracking' of the patella. During extended physical activity, walking up or down stairs and/or prolonged flexion, the pressure between the patella and the femur increase, which may cause irritation at the joint. This irritation leads to swelling and the end result is pain.

STATISTICS ON PATELLOFEMORAL PAIN SYNDROME

Sport Medicine Centre's report that up to 40% of all their patients are diagnosed with Anterior Knee Pain (Malek et al., 1981) and the Calgary area revealed 3.7% of patients seeing general physicians were diagnosed with knee problems (Cutbill et al., 1992). Patellofemoral Pain Syndrome is the most common knee complaint and was found to be diagnosed in 30% of patients at sport medicine centres (Derscheid et al., 1987). PFPS is seen in various populations ranging from adolescent females to elite athletes to military recruits. There are two treatment plans available for PFPS patients: a) conservative management, or b)surgical intervention.

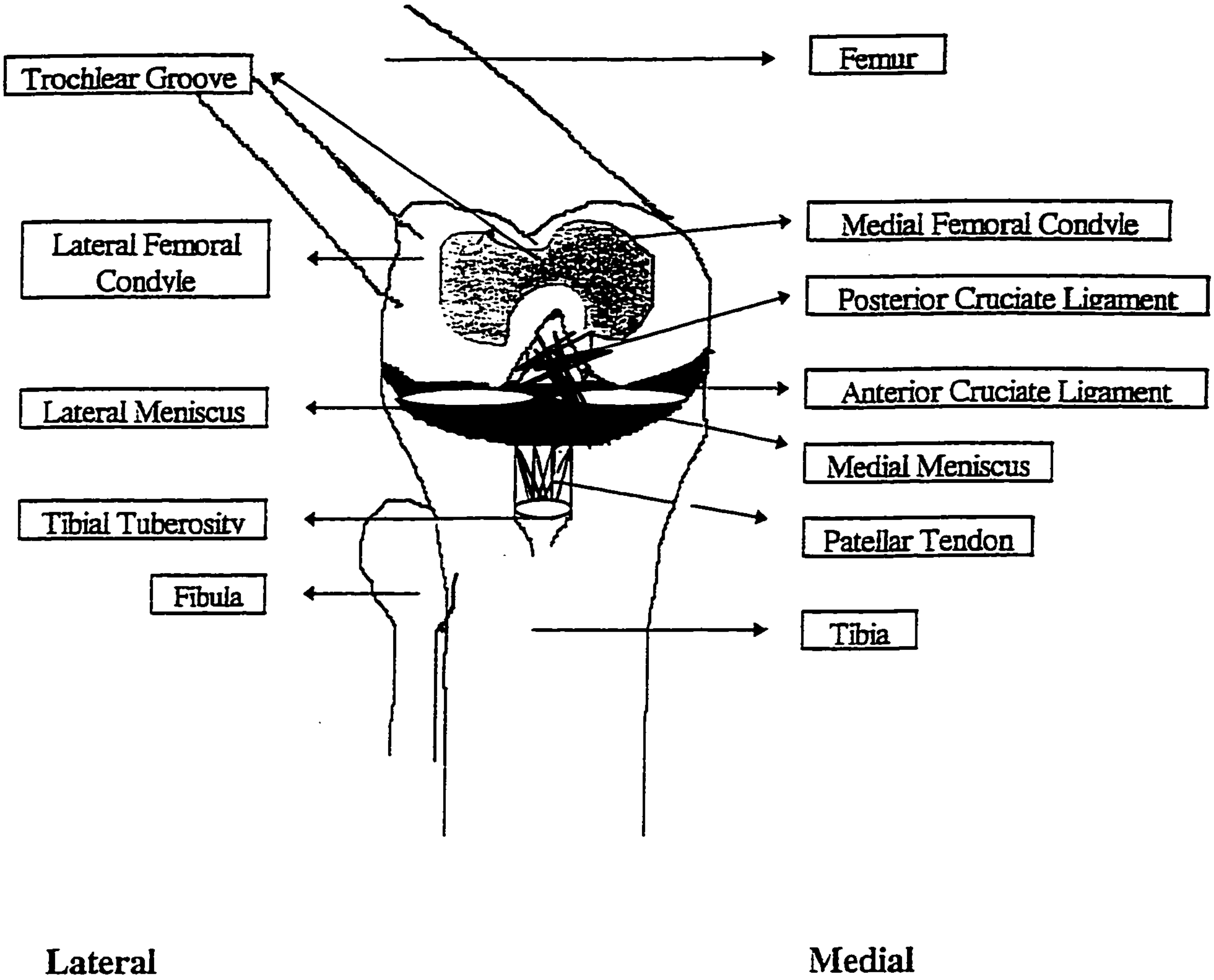
Surgery for this disorder is rare and often the last attempt to help stop pain. Conservative programs are the most common routes advocated by a physician. These programs usually incorporate education, strengthening, stretching, modifying one's activities and application of ice. This booklet will incorporate each of the above topics into your rehabilitative process.



Gross Musculature and Connective Tissue of the Patellofemoral Joint

Anterior View

FIGURE #1



Deep Connective Tissue and Bone of the Patellofemoral Joint

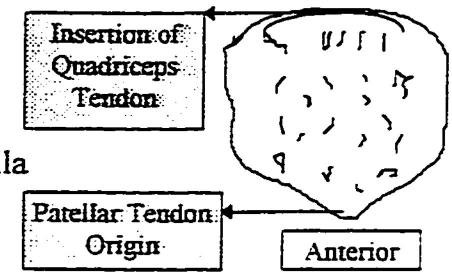
Anterior View of a bent knee

FIGURE #2

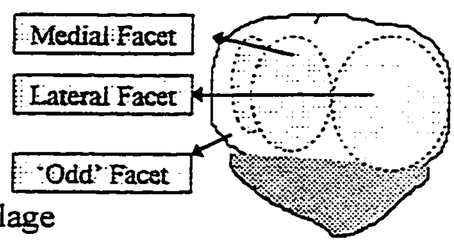
SKELETAL SYSTEM:

The knee joint is the largest and one of the most complex joints in the human body. It combines bone, musculature and connective tissue to aid in moving the lower limb. The knee joint has three areas of contact: the first two are between the bumps at the end of the femur (condyles) and the corresponding bumps (condyles) of the tibia (the tibiofemoral joints) and the third is between the patella and the femur (the patellofemoral joint). It is this last area of contact that will be of interest for you.

Patella: (Knee Cap)

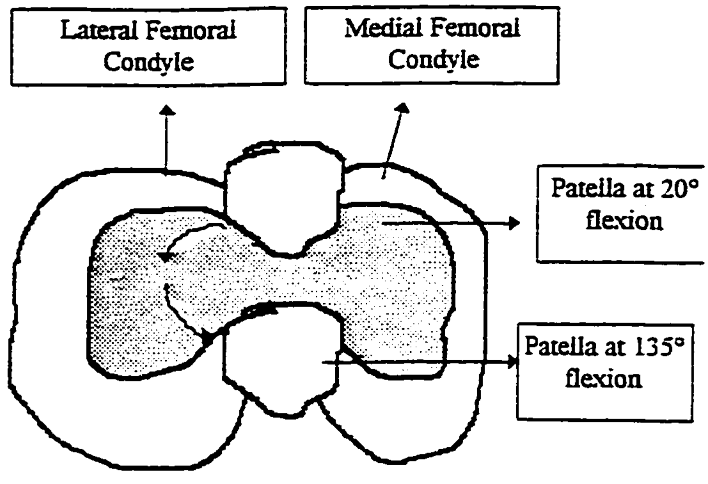


The patella is a somewhat round bone that is located in the front of the knee joint. The patella acts similar to a lever as it helps generate force when straightening the leg.



The front of the knee cap is covered by the quadriceps tendon and the back of the patella is covered with articular cartilage. Articular cartilage is a rubber-like substance that helps reduce friction. The cartilage on the patella is the thickest in the human body and experiences the highest forces of any joint - up to seven times your body weight during a deep squat!! The back surface of the patella has facets (flattened surfaces on the bone) that make contact with the femur. During flexion and extension of the lower limb, these facets contact the two condyles of the femur.

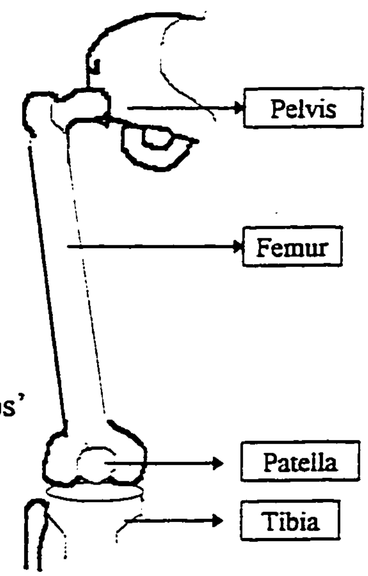
During slight knee flexion (approximately 20° knee bend) the lateral (outside) facet of the patella contacts the lateral (outside) condyle of the femur. As the knee undergoes further flexion (e.g. 135° knee bend) the patella moves into the femoral groove and contacts both condyles of the femur. The overall motion of the patella from full straightening to full flexing is a gentle lateral 'C' in between the condyles of the femur (see above right diagram). A common problem for people diagnosed with PFPS is a lateral tracking of the patella. This means that the patella tends to drift further to the outside of the knee than what may be considered 'normal.'



Anterior View of 90° Bent Knee

Femur

The femur is the longest bone in the body and extends from the hip to the knee. The top of the bone meets the pelvis and the bottom of the femur meets with the tibia. As previously mentioned, the patella contacts the surface of both the medial and lateral 'bumps' of the femur. Wide set hips, knock knees or flat feet are three conditions that can increase some of the forces being transferred through the knee joint.



MUSCLES AND CONNECTIVE TISSUES:

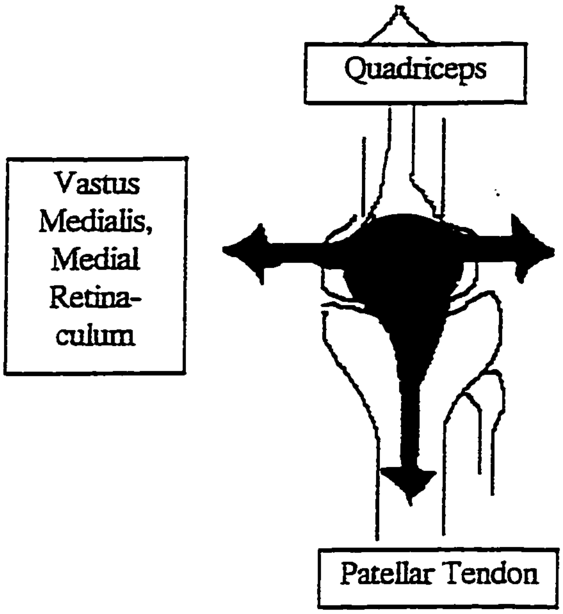
Quadriceps

The quadriceps are comprised of four muscles: the rectus femoris, vastus medialis, vastus intermedius and vastus lateralis (See Figure #1). The major role of these muscles is to extend and stabilize the leg. People diagnosed with PFPS often reveal dysfunction or imbalances in the quadriceps. One muscle of primary focus in PFPS is the vastus medialis oblique (VMO). It's primary function is to pull the patella toward the body's midline. PFPS patients often reveal a weakness or an imbalance of the VMO as compared to the outside (lateral) structures of the thigh. For example, the vastus lateralis runs along the outside of the thigh and pulls the patella away from the body's midline. If the vastus lateralis provides a stronger pull than the VMO, the patella may drift towards the outside of the leg. This is a common problem of patients diagnosed with PFPS and may be the cause of pain at the joint. **Rehabilitation aims to equalize these forces around the knee joint.**

Connective Tissue:

There are many structures at the patellofemoral joint that help provide stability and movement to the leg. Two very important structures will be highlighted in this program, these are the lateral retinaculum and the iliotibial band. Dysfunction in these connective tissues influence the patella's movement in the joint.

The lateral retinaculum and iliotibial band are broad sheaths that extend along the outside of the thigh and stop at the lower leg (tibia). A common problem in PFPS patients is tightness in these structures which may cause an increase in pressure at the joint. This program will attempt to reduce this pressure by stretching these components.



Direction of Forces at the Patellofemoral Joint
(Muscles and Connective Tissue)

The above diagram illustrates the forces being applied in each direction at the patellofemoral joint. The medial and lateral direction of pull is most important to the rehabilitation process of patients with PFPS. There are more structures along the lateral side of the thigh that affect patellar tracking than there are medially. This anatomic imbalance may allow for a laterally tracking patella. The rehabilitation process for PFPS aims to restore the balance between the structures of the thigh so that the patella glides smoothly within the femoral condyles. This will be done through a strengthening program targeted at the quadriceps and gluteals and a stretching program for the outside structures of the thigh.

Strengthening Exercise for Patellofemoral Pain

The focus of many rehabilitation programs for PFPS is to restore the tracking and function of the patella in the femoral groove. Since the patella's movement is directly affected by the quadriceps, the treatment program targets these muscles. As mentioned previously, weakness of the inside structures of the thigh can predispose the patella to a lateral drift. Strengthening the vastus medialis oblique will counteract the pull of the stronger outside components of the thigh. This will help restore normal tracking at the knee joint.

A second group of muscles that are targeted in rehabilitation of PFPS are the gluteals. This group of muscles are responsible for keeping the hips stable during both stance and activity. Weak gluteal muscles may allow the hip to fall to either side of the body which may increase the angle along your thigh. An increase in this angle may cause increased forces at the joint which may also be a factor in causing pain.

A primary exercise given in rehabilitation is the Drop Squat. It is more effective than many other exercises because it is a familiar pattern of movement, such as walking up/down stairs, squatting down, kneeling, etc... It is a unique exercise because the strengthening process is occurring during the 'drop' or eccentric part of the activity. You will be allowing your body to drop freely to a 45° angle where contraction of the quadriceps will stop the downward movement. It is important to follow the exact procedure outlined below.

Drop Squat:

Position, Speed and Progression are three important components of the drop squat that you should keep in mind throughout the exercise.

Position:

Correct body positioning will ensure that the quadriceps and gluteals are being strengthened properly.

- **Start with your knees and feet shoulder width apart and equal weight being distributed through each leg**
- **Your knee caps will be facing forward and directly above the second toe throughout the entire activity. Prevent the knees from falling outside the feet or becoming 'knock-kneed.' (See picture on page 15)**

Speed:

- This program is divided into weight and speed progressions. Your daily log sheets will outline the changes that occur from day to day.

  - initial stages of the program (1 - 3 days) are a 'slow-drop' squat. The down phase of the squat is slow and comfortable and should take approximately three seconds to reach a 45° angle at the knee. The up phase of the squat should take five seconds to reach the starting stance.

- After the initial three days, you will move onto a fast drop squat.
  - the descent phase is much shorter in duration - less than one second to reach the 45° knee angle. It will feel as though your knees have collapsed and your quadriceps are stopping the downward forces. Once again, make certain that your knees follow the second toe throughout the entire exercise.

Progression:

- As with any strengthening program, there will be continual increases in weight. The first week of the program will focus on technique and using your own body weight. After the first week, increases in weight will be seen through the addition of hand weights or bleach bottles filled with sand. This weight addition will range from 2.5 lbs in each hand at the second week to 10lbs in each hand at the fourth week.
- The fifth and sixth week of the program will shift from a two legged drop squat to a one legged drop squat. You will have to monitor your body positioning closely during the one legged squat as it is easy to allow your hip to fall to the outside of your body and the knee to become 'knock-kneed.'

The daily activity logs will further outline the body position, the weight progression and the repetitions required for each day.

Front View of the Drop Squat

Side View of the Drop Squat (knees bent to a 45° angle)

Illustration of the Progressive Drop Squat

Make sure to keep the knees in line with the second toe and the hips falling backwards - not to one side

Stretching Exercises for Patellofemoral Pain

Stretching is a very important component to any rehabilitation program. It helps increase the elasticity of the muscle and increases the blood flow to the surrounding area. Patellofemoral pain patients usually reveal tight structures along the outside of the leg. This program will provide three stretching exercises targeting these structures. It is important to hold each stretch for approximately 1 - 3 minutes without jerky or bouncy movements. Deep breathing throughout the stretch is also important to the relaxation of the muscle.

Seated Spinal Rotation (Spinal Rotations):

- **This stretch will start from a seated position with both legs extended straight out in front of you. -Make sure you are upright on the bones of your buttocks. -Flex one leg at the knee and bring it over the extended leg and across the body into the chest.**
- **Take the arm opposite to the flexed leg and apply gentle pressure on the outside of the thigh while bringing the leg into your chest. -Your head and trunk will be rotated in the direction of the flexed leg. -Hold this stretch while gradually applying more pressure. -Repeat with opposite leg.**

Seated Spinal Rotation

Supine Hip External Rotation (Hip Rotations):

- This exercise is done while lying flat on your back with legs extended. Bend one leg to an angle of 90° and bring the bent leg towards the chest.
- Gently pull the bent leg across the body over top of the extended leg. Try to keep your shoulders and back flat on the ground while you feel the stretch extend along the outside of the bent leg and into the buttocks. Hold this stretch and then repeat with the other leg (see illustration below).

Hip Rotations

Standing Quadriceps Stretch:

- You will need the assistance of a wall or high backed chair for this stretch. While standing with your legs straight and feet together. flex one knee behind you and raise your heel into the buttocks. Hold the bent leg at the laces of your shoes (see picture below) and raise the other arm to shoulder level using the wall or chair for support.
- To increase the stretch along the front of the thigh. push the hips forward into the wall or chair. You should feel this stretch extend from the pelvis down to the knee. Hold for one to three minutes and then repeat with the other leg.

Quadriceps Stretch

Post-Exercise Icing

Icing is has been used for centuries. Ice helps to reduce pain and inflammation. It will be used at the completion of the exercises when the knee joint may be somewhat irritated. It is also recommended that you apply ice to the knee after activity or prolonged flexion (such as sitting in a car for a long period of time).

The best method for icing is to use a frozen bag of vegetables (peas, carrots, etc.) wrapped in a towel and placed directly over and/or around the knee cap. Be careful not to apply ice directly onto the skin as this may hurt. Icing can be done anywhere from 10 - 30 minutes for the best effect.

Activity Modification

It is important that you modify the time and intensity of the exercises that cause pain at the patellofemoral joint. If an activity elicits constant pain, you will need to discontinue the activity until you are further along in your rehabilitation process. For example, if long distance running brings about painful symptoms then you will need to reduce the time and intensity of your runs.

You will need to rely on your own judgment and awareness throughout any rehabilitation program. If an exercise brings extreme pain at the knee joint... STOP!! If thirty minutes of activity brings you pain later that day, you should try only fifteen minutes the next day. You can always be progressive with your activities throughout your rehabilitation program.

Listen to your physician. If he/she recommends discontinuing a sport or exercise program when you were diagnosed with Patellofemoral Pain Syndrome, then consult him/her when you want to resume activity.

How to Use the Daily Schedule:

The Home Exercise Rehabilitation Scheduler will allow you to record your daily tasks and exercises into each day. Try to plan a time period every day over the next six weeks to practice these exercises. You should spend anywhere from 20- 30 minutes performing the squats and stretches and then icing should take approximately 10 - 20 minutes. In total, this program will require only 30 - 50 minutes of your time each day to complete the prescribed activities.

The schedule is very user friendly with spaces for the date, your daily goals and the day's events/activities. Page 21 gives an example of how to use the daily schedule.

-The headline of each page is a motivational saying that may help with keeping your focus over the six week period.

-Below the motivational saying is a **pain scale** to be completed at the end of each exercise session. It provides a continuous line that ranges from **no pain** to **severe pain** and you should place a perpendicular line on this scale where you would best describe your level of pain. This will give a comparison basis upon how you are feeling throughout the program.

-Below the **pain scale** is a frame of your personal **Goals for the Day.** This is handy to prioritize your day's events, meetings, activities, etc.

-To the right of the schedule is a detailed description of the exercises and stretches to be performed each day. The blank line is to mark the duration of activity or the number of sets performed. Please follow the descriptions carefully.

COMMONLY USED TERMS AND DEFINITIONS: **(see Figure # 1 & # 2)**

ANTERIOR: referring to the front, in front of

CONNECTIVE TISSUE: a form of tissue that helps bind structures together and gives support, protection and stability to the body; common examples are tendons and ligaments

FEMUR: long bone of the thigh that starts from the hip and extends to the knee

INFERIOR: referring to the lower portion, below another structure

ISOKINETIC EXERCISES: the muscle undergoes a change in length but the contraction is performed at a constant speed

ISOMETRIC EXERCISES: performed in a static position where the muscle does not undergo any change in length

ISOTONIC EXERCISES: show a change in the muscle length through two common phases of movement: concentric and eccentric contractions

> CONCENTRIC: the muscle shortens while contracting against resistance, usually working against gravity
>
> ECCENTRIC: the muscle lengthens during contraction against resistance, usually working with gravity

LATERAL: referring to the side, away from the middle

MEDIAL: toward or near the midline

MENISCI: C-shaped plates of cartilage on the superior surface of the tibia.

PATELLAR TENDON: the insertion band from the quadriceps that runs from the patella onto the tibial tuberosity

PATELLA: the kneecap

POSTERIOR: referring to the back

QUADRICEPS: the large muscle group at the front of the thigh that is responsible for straightening the leg. It is made of four primary muscles: the rectus femoris, vastus medialis, vastus intermedius and vastus lateralis.

RECTUS FEMORIS: the primary extender of the leg. It runs from the hipbone down the front of the thigh to form a tendon that inserts into the tibia (patellar tendon).

SUPERIOR: above another structure, on top of

TIBIA: the medial bone of the lower leg that extends from the knee to the ankle

VASTUS INTERMEDIUS: this muscle lies under the rectus femoris and between the vastus lateralis and vastus medialis. It runs from the top of the femur to the patella.

VASTUS LATERALIS: the outer thigh muscle that runs from the pelvis to the patella. This muscle helps keep the patella from drifting or tracking towards the midline of the body. Persons with patellofemoral pain often show a more developed vastus lateralis that the inner thigh muscle .

VASTUS MEDIALIS: the inner thigh muscle that runs from the pelvis to the patella. This is the primary muscle targeted in patellofemoral pain because research indicates there are muscle fibres within this muscle bulk that are responsible for keeping the patella stabilized within the joint.

APPENDIX F
(page 168)

____
Date

Success is a Journey... Not a Destination

TODAY'S OBJECTIVES:

I. Drop Squat: Double Leg
   Slow down, Slow up
II. Spinal Rotations (2min.)
III. Hip Rotations (2min.)
IV. Quadriceps Stretch
   (2min.)

Level of Pain at Completion of Exercise:

None ______________________________ Severe

Goals for Today:

____
____
____
____

9:00 AM	
10:00 AM	
11:00 AM	
12:00 PM	
1:00 PM	
2:00 PM	
3:00 PM	
4:00 PM	
5:00 PM	
6:00 PM	

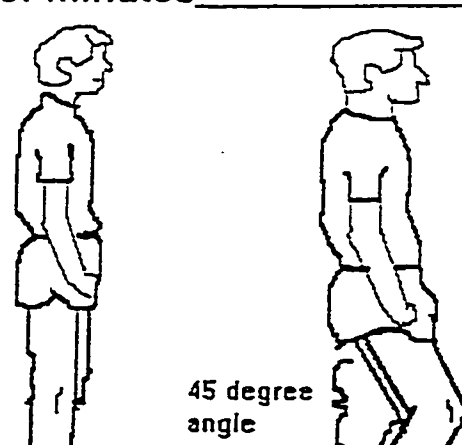
Drop Squat: (double leg, 3 x 20 reps)
_____ _____ _____

Spinal Rotations: (left & right)
   # of minutes______________

Hip Rotations: (left & right)
   # of minutes______________

Quadriceps Stretch:(left & right)
   # of minutes______________

Post-Exercise Icing:
   # of minutes______________



APPENDIX G

Root Mean Square Program

```
double root_mean_square(input,gain,total_data, chan1num)
double input [] [10000],gain;
int total_data, chan1num

double_sum_all, mean_data
int index;

sum_all = 0
/*testing if the gain is 0 */
if(gain==0)
gain = 1;

for(index==0; index<total_data;++index)

sum_all +=SQR(input[chan1num][index]/gain);

mean_data = sqrt(sum_all/total_data);
return (mean_data);
```

APPENDIX H

RAW DATA - Visual Analogue Scale Results of All Subjects

HOME EXERCISE GROUP				PHYSICAL THERAPY GROUP				CONTROL GROUP			
Subject #	Day1	Day 21	Day 42	Subject #	Day 1	Day 21	Day 42	Subject #	Day 1	Day 21	Day 42
1	6.7	6.5	0.5	1	0	0	0	1	0	0	0
2	1.5	1	1.4	2	0	0	0	2	0	0	0
3	0	0	0	3	2.4	0.4	0.8	3	0	0	0
4	0	3.6	1.2	4	0.5	2	0	4	0	0	0
5	0	0	0	5	5	0.4	0.1	5	0.5	0	0.7
6	2.2	3.60	0	6	4	1.6	0.8	6	2	1.8	2
7	1.3	3.00	0.6	7	0	0	0	7	0	0	0
8	1	2.15	1.2	8	0	0	0	8	0	0	0
9	1.2	2.1	0	9	2.8	1	0.6	9	0	0	0
10	0	0.0	0	10	0	0.7	0.1	10	0	0	0
11	2.2	2.0	1	11	1.6	1.0	1	11	0	0	0
12	0	0.0	0	12	1	0.7	0	12	0	0	0
13	2.5	2.3	1.4	13	6	3.1	0	13	0	0	0
14	6.3	7.6	2	14	0.7	0.1	0	14	0	0	0
15	3.5	6.2	0.3	15	1	0	0.5	15	0	0	0
								16	0	0	0
								16	0	0	0
Mean	1.89	2.67	0.64	Mean	1.67	0.733	0.26	Mean	0.1563	0.1125	0.1688
S.D.	2.16	2.475	0.674	S.D.	1.97	0.903	0.368	S.D.	0.5072	0.45	0.5186

APPENDIX I

RAW DATA - Functional Knee Score Scale Results of All Patients

Home Exercise Group				**Physical Therapy Group**				**Control Group**			
Subject #	Day 1	Day 21	Day 42	Subject #	Day 1	Day 21	Day 42	Subject #	Day 1	Day 21	Day 42
1	36	38	48	1	29	28	44	1	53	53	53
2	39	39	46	2	35	38	42	2	53	53	51
3	49	44	53	3	25	33	40	3	50	50	50
4	40	43	32	4	49	45	52	4	51	51	51
5	36	23	29	5	41	51	50	5	49	49	49
6	28	40	45	6	41	41	47	6	43	43	43
7	32	37	37	7	35	36	43	7	51	51	51
8	29	45	46	8	43	43	42	8	53	53	53
9	35	47	52	9	21	36	41	9	45	40	40
10	41	44	39	10	42	41	41	10	53	53	53
11	33	34	39	11	34	43	43	11	50	50	50
12	36	35	36	12	37	41	37	12	53	53	53
13	47	32	36	13	24	34	52	13	53	53	53
14	33	34	38	14	41	50	53	14	52	52	52
15	30	30	25	15	20	33	35	15	53	53	53
								16	53	53	53
Mean	36.3	37.67	39.4	Mean	34.5	39.53	44.13	Mean	50.8	50.47	50.33
S.D.	6.26	7.71	8.89	S.D.	8.02	6.34	5.53	S.D.	3.48	3.83	3.87

APPENDIX J

RAW DATA – Maximal Isometric Contraction Condition (Force – Nm) Results of All Subjects

MAXIMAL ISOMETRIC CONTRACTIONS								
HOME EXERCISE PROGRAM			PHYSICAL THERAPY PROGRAM			CONTROL GROUP		
Subject #	Day 1	Day 42	Subject #	Day 1	Day 42	Subject #	Day 1	Day 42
1	61.523	89.370	1	40.182	50.183	1	108.193	111.571
2	73.453	84.901	2	76.679	97.723	2	86.526	76.223
3	90.384	99.456	3	72.401	102.368	3	91.317	91.241
4	78.370	78.878	4	77.152	81.557	4	11.777	20.474
5	50.613	50.709	5	56.235	69.658	5	95.806	85.322
6	45.336	49.380	6	46.454	64.805	6	103.011	100.745
7	75.006	79.584	7	51.742	56.006	7	102.264	102.153
8	30.132	58.923	8	123.707	132.039	8	56.275	56.809
9	87.112	86.410	9	46.144	47.398	9	80.601	75.924
10	76.585	86.435	10	57.889	59.777	10	71.080	75.898
11	62.079	79.382	11	44.227	57.685	11	78.817	83.171
12	85.244	93.766	12	49.714	59.529	12	55.550	73.929
13	100.923	107.735	13	44.094	58.313	13	82.908	79.389
14	44.037	45.072	14	103.742	150.370	14	68.745	64.178
15	68.288	68.447	15	46.903	55.910	15	72.702	77.682
						16	90.008	82.338
Mean	68.606	77.230	Mean	62.484	76.221	Mean	77.705	78.314
S.D.	19.646	18.92	S.D.	24.26	31.058	S.D.	24.27	21.484

APPENDIX K

RAW DATA - VMO:VL Submaximal 60% Contraction Condition Results of All Subjects

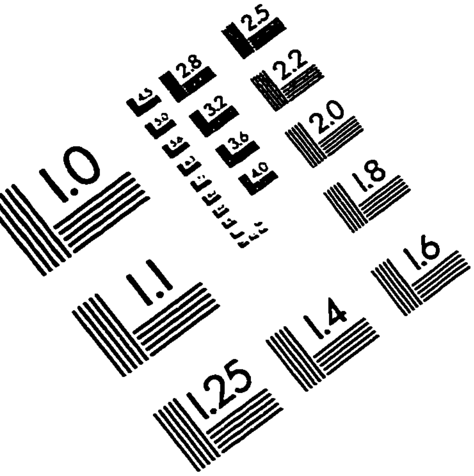
HOME EXERCISE GROUP				PHYSICAL THERAPY				CONTROL GROUP		
	Day 1	Day 42			Day 1	Day 42			Day 1	Day 42
1	1.016	1.116		1	0.795	0.892		1	1.22	0.835
2	0.878	0.903		2	1.247	0.721		2	0.917	0.11
3	0.972	1.102		3	0.884	0.641		3	0.829	0.878
4	0.747	1.161		4	0.616	0.817		4	1.241	0.924
5	0.931	0.955		5	0.884	1.095		5	1.014	0.89
6	1.033	0.397		6	1.23	1.274		6	1.071	0.987
7	0.829	0.83		7	0.928	0.989		7	0.991	0.755
8	1.068	0.938		8	1.012	1.028		8	0.844	0.919
9	0.919	0.833		9	1.23	0.907		9	1.028	0.212
10	1.034	0.786		10	0.901	1.228		10	1.187	0.809
11	1.046	1.002		11	0.878	0.398		11	0.93	1.22
12	0.997	1.02		12	0.843	1.155		12	1.159	0.772
13	0.491	1.236		13	1.083	1.089		13	1.017	1.204
14	0.828	1.588		14	1.183	1.128		14	1.318	0.867
15	0.944	1.061		15	0.842	1.278		15	1.116	0.839
									0.971	1.17
Mean	0.915	0.995		**Mean**	0.97	0.976		**Mean**	1.053	0.899
S.D.	0.15	0.259		**S.D.**	0.187	0.25		**S.D.**	0.265	0.265

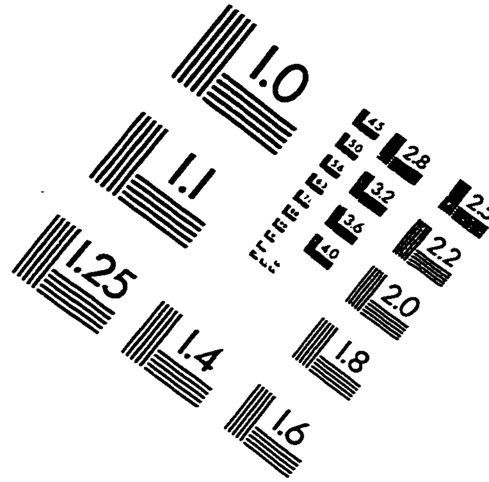
APPENDIX L

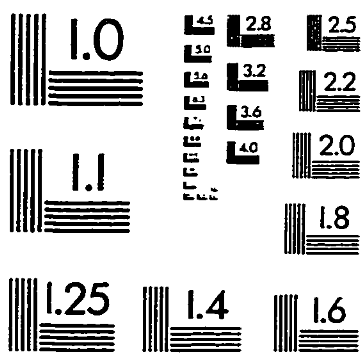
RAW DATA - VMO:VL Submaximal 30% Contraction Condition Results of All Subjects

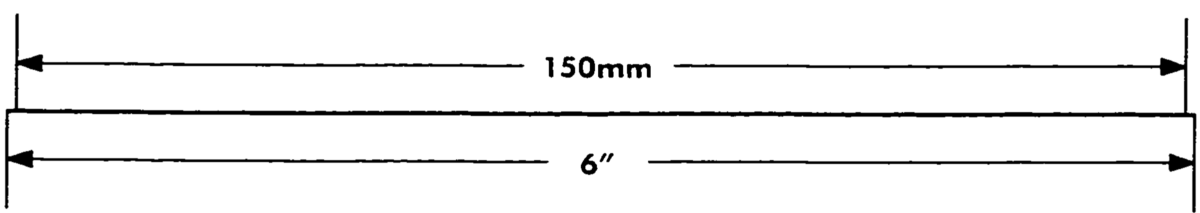
HOME EXERCISE GROUP				PHYSICAL THERAPY				CONTROL GROUP		
	Day 1	Day 42			Day 1	Day 42			Day 1	Day 42
1	1.359	0.878		1	0.763	3.117		1	1.055	0.822
2	0.969	0.918		2	1.217	1.107		2	0.988	0.863
3	1.041	1.095		3	0.765	0.841		3	1.141	1.077
4	0.775	1.07		4	0.823	0.756		4	1.233	0.869
5	0.28	0.771		5	0.652	1.038		5	1.016	0.957
6	0.864	0.932		6	1.241	1.347		6	1.031	1.024
7	0.726	0.215		7	0.916	1.368		7	0.943	0.825
8	0.82	1.099		8	5.037	0.84		8	0.918	1.054
9	0.829	0.905		9	0.939	0.832		9	15.312	1.495
10	0.678	0.566		10	1.158	0.352		10	1.6	0.975
11	1.019	1.096		11	0.722	0.687		11	0.753	0.864
12	0.697	0.994		12	0.647	6.088		12	1.658	0.96
13	0.382	0.539		13	0.944	0.952		13	0.779	0.847
14	0.89	1.584		14	0.277	0.994		14	4.651	1.05
15	0.68	0.886		15	0.643	6.289		15	1.046	1.798
									1.008	0.877
Mean	0.801	0.889		**Mean**	1.12	1.77		**Mean**	2.2	1.02
S.D.	0.261	0.347		**S.D.**	1.11	1.9		**S.D.**	3.61	0.264

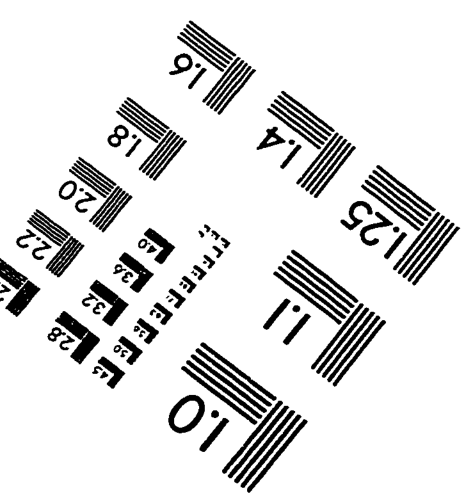
IMAGE EVALUATION TEST TARGET (QA-3)











APPLIED IMAGE . Inc
1653 East Main Street
Rochester, NY 14609 USA
Phone: 716/482-0300
Fax: 716/288-5989