THE UNIVERSITY OF MANITOBA

THE EFFECT OF ELECTRICAL MUSCLE STIMULATION ON QUADRICEPS STRENGTH, PATELLOFEMORAL PAIN AND PATELLAR ALIGNMENT

by

Glen Bergeron

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THE EFFECT OF ELECTRICAL MUSCLE STIMULATION ON QUADRICEPS STRENGTH, PATELLOFEMORAL PAIN AND PATELLAR ALIGNMENT

BY

GLEN BERGERON

A Thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

ABSTRACT

Patellofemoral pain syndrome is described as an overuse injury involving the articulation between the patella and the trochlear surface of the femur. Malalignment of the patella has been implicated as the principal cause and treatment has attempted to promote realignment either surgically or through conservative management.

Electrical muscle stimulation (EMS) of the quadriceps and in particular the vastus medialis is said to offset lateral patellar shift and or rotation. The objectives of this study were to evaluate the effects of electrical muscle stimulation of the quadriceps muscles on isometric strength of the quadriceps, patellar position and patellofemoral pain.

Patients suffering from patellofemoral pain were randomly assigned to nontreatment and treatment groups. Pre-test measurements for both groups included the McGill pain questionnaire, isometric strength of knee extensors at 5º flexion, and patellar position within the trochlear groove of the femur (medial/lateral shift or rotation) using computed tomography (CT-Scan).

Subjects in the nontreatment group were advised to refrain from any treatment other than symptomatic relief of pain such as previously prescribed medication or the application of ice or heat. The treatment group was treated with electrical muscle stimulation superimposed on a maximal voluntary isometric contraction (MVIC) of the quadriceps femoris. The treatment consisted of 18 sessions over a six week period with 10 electrically induced isometric contractions per session. Following the six week treatment period, the nontreatment and treatment groups were tested using the same testing protocol as in the pre-test. Isometric strength, pain and patellar position were compared between pre- and post-test data to determine any significant changes in each parameter.

A sub group of four subjects who participated in both the nontreatment and treatment groups was analyzed as part of a cross over design protocol.

The treatment group demonstrated a significant decrease between pre- and post-test measures of affective and total pain categories but these did not significantly differ from the nontreatment group. Following the treatmnent period, there was a significant medial patellar rotation in the treatment group compared to the nontreatment group when the quadriceps was contracted as measured using patellar tilt angle (PTA 0ºC). The treatment group also demonstrated a significant

increase in isometric strength compared to the nontreatment group. The cumulative workload performed by the treatment group over eighteen sessions significantly correlated to the increase in isometric strength.

Total pain decreased within both the treatment (81.6% of subjects) and nontreatment groups (62.5% of subjects). Although no significant difference between groups was evident, only the treatment group demonstrated a significant decrease in affective and total pain while the nontreatment group did not. A similar result was evident in the cross over study. The cause for the decreased pain may be simply rest in the nontreatment group and due to the effect of training in the treatment group.

The literature suggests that patellofemoral pain is a result of patellofemoral malalignment either due to lateral deviation or lateral rotation of the patella. More subjects in the treatment than nontreament group demonstrated a medial realignment of the patella when the quadriceps were contracted. This would suggest that an increase in quadriceps strength might promote a medial patellar realignment.

Increased quadriceps strength may promote medial patellar rotation as measured using patellar tilt angle measurements on CT scan images. When the quadriceps were contracted, the treatment group demonstrated a significant change in medial rotation of the patella as measured using patellar tilt angle with the knee at zero degrees and the quadriceps contracted (PTA 0º C). This would suggest that the training effect was instrumental in promoting strength gains which in turn affected patellar rotation.

Based on the results of this study, it was concluded , that patients with anterior knee pain can tolerate treatment consisting of EMS of the quadriceps with a maximal voluntary isometric contraction superimposed and that this treatment increases strength of the quadriceps, reduces pain, and may increase the likelihood of patients being able to maintain proper patellar alignment.

ACKNOWLEDGEMENTS

I have a coffee cup that I use every morning. It has "YES WE CAN" written on it. It served as a daily reminder that this degree was possible. More importantly, it reminded me that I could not do this alone. This study was the product of the time, expertise and commitment of many people.

Special thanks to Dr. Wendy Dahlgren who has been an inspiration to me from the time she taught me my first anatomy course twenty-one years ago.

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Last but certainly not least, thankyou to the subjects who committed the time and drive expected of them for the duration of the treatment period.

DEDICATION

To my Wife Val whose love and belief in me has been a constant source of support and understanding.

To my daughter Erin and my son Bryan who were born at the beginning of this process and who are now guiding me through my most important education - Fatherhood.

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INTRODUCTION

Pain experienced about the anterior aspect of the knee joint is often a source of frustration for the physician or therapist trying to determine an appropriate treatment. This is because, while anterior knee pain is one of the most common complaints associated with knee injuries, it remains one of the least understood (Dye & Boll, 1985).

Anterior knee pain in patients reporting with various types of knee injuries has been referred to as the number one type of knee pain (Mehrdad & Mangine, 1981) with reported incidence varying from 11% (Garrick, 1989) to 25 to 40% (Rubin & Collins, 1980) to 58% (Taunton, Clement, Smart & McNichol, 1987). Further, Villar (1985) reported that as many as 25% of military recruits complained of anterior knee pain and that the problem was a significant cause for medical discharge.

Although the etiology and progression of anterior knee pain are poorly understood, the patient's complaints are not. Most complain of pain diffusely felt over the anterior knee. Patients report a gradual onset usually with a history of overuse, although sometimes following a traumatic incident. Characteristically there is pain when the person is going up and down stairs, more typically going down than up (Wise, Fiebert, & Kates, 1984). In addition, some patients complain of increased pain during long periods of sitting, such as in a theatre or a car. The pain usually subsides shortly after the person begins to move about again.

Palpation of the undersurface of the patella usually elicits pain, as does manually compressing the patella on the femur. Unlike knee injuries involving such structures as the cruciate and collateral ligaments, menisci, or muscle, swelling is an infrequent correlate of patellofemoral pain (Arnoldi, 1991).

The patella and its relationship to this anterior knee pain has received a great deal of attention. As Dugdale noted, "It seems likely that more has been written about the patella, relative to its size, than about any other bone in the human body" (Dugdale & Barnett, 1986, pg. 211). Mehrdad & Mangine (1981) cited some 400 scientific articles addressing patellar pain or anterior knee joint pain. Since that review, the literature continues to be replete with articles seeking answers for this poorly understood problem (Armstrong, Mow, & Wirth, 1985; Brunet & Stewart, 1989; Butterwick, 1982; Caillet, 1983; Carson, 1985; Chrisman, 1986; Conteducia, Ferreti, Mariani, Puddu, & Perugia 1991; Eisele, 1991; Fisher, 1986; Fulkerson, 1982; Fulkerson, 1989; Fulkerson & Hungerford, 1990; Garrick, 1989; Huberti & Hayes, 1982; Jacobson & Flandry, 1989; Johnson, 1989; Kramer, Lindsay, Magee, & Mendryk, 1984; McConnell, 1987; O'Donoghue, 1981; Percy & Strother, 1985; Pickett & Radin, 1983; Villar, 1985; Whitelaw, Rullo, Markowitz, Marandola, & DeWaele 1987; Wild, Franklin & Woods, 1982).

As noted, the cause of the pain has long been associated with patellar pathology. Budinger (1906) is credited with being the first to describe softened and fibrillated cartilage on the undersurface of the patella. Dugdale & Barnett (1986), in an historical review of patellofemoral pain, found that the term Chondromalacia Patellae first appeared in published form in 1924 and the term was introduced into the English literature in 1933. The term "chondromalacia patellae" literally refers to a visible deterioration of the articular cartilage on the undersurface of the patella. A direct link between chondromalacia and anterior knee pain has not, however, been clearly demonstrated. Thus, while Ficat, Phillippe, & Hungerford, (1979) reported that 63% of all internal derangements of the knee involved degeneration of the undersurface of the patella, Pickett (1979) observed that nearly every individual may show degenerative changes in the knee joint, first apparent under the patella, after the age of 15. Obviously not all of these cases are accompanied by symptoms. Finally, arthroscopic investigations of the knee have failed to demonstrate a consistent relationship between anterior knee pain and chondromalacic findings (Fulkerson, 1989).

Several terms have been used to describe pain about the patellofemoral joint, including patellalgia (Percy, & Strother, 1985), patellofemoral arthralgia, patellofemoral pain (Fisher, 1986; Radin, 1979), retropatellar pain, anterior knee pain (Jacobson, & Flandry, 1989), patellar malalignment syndrome (Kramer, 1986), lateral facet syndrome (Johnson, 1989), and extensor mechanism disorders (Grana, & Kriegshauser, 1985).

The most recent literature refers to the syndrome as patellofemoral pain and reserves the commonly used term chondromalacia patellae for gross morphological changes to the articular cartilage of the patella, that is, a pathological diagnosis would be made rather than the diagnosis of common overuse patellofemoral pain syndrome (Schutzer, Ramsby, & Fulkerson, 1986a).

Garrick (1989), however, advocated the use of the term chondromalacia patellae because it is the term most familiar to practitioners. Schutzer et al (1986a), argued that CMP, an acronym for chondromalacia patella could come to mean "Could be - May be - Possibly be" in much the same way as the acronym IDK (Internal Derangement of the Knee) used to describe any nondescriptive knee pain but has since come to mean "I Don't Know".

The treatment of patellofemoral pain has usually followed one of two distinct approaches: conservative rehabilitation or more radical surgical intervention. Conservative management usually incorporates some combination of medication, rest, exercise, thermotherapy, cryotherapy, electrical modalities, external braces, orthotics or, in the more severe cases, immobilization. Generally, surgery is reserved for those cases that have not responded to conservative treatment.

Both conservative and surgical treatments are now often based on the premise that an anatomical or mechanical malalignment of the patella exists and is in need of realignment. Hunter & Funk (1984), for example, found that of 844 knee cases, 346 (41%) were due to subluxation or malalignment of the patella.

Some of the more common surgical procedures include lateral retinacular releases, proximal realignment of the vastus medialis on the patella, and repositioning of the tibial tubercle and its patellar tendon attachment. In some cases relief has been sought by the trephining or shaving of the fibrillated articular cartilage of the patella on the basis that the crepitation was assumed to be the root of the pain. Radical surgical removal of the patella is used as a last alternative and is considered only when there is a seriously deteriorated patellofemoral joint that is severely debilitating to the patient.

Whitelaw et al. (1987) reported an 87% success rate using a conservative treatment approach which included non steroidal anti-inflammatory medication, stretching exercises, quadriceps electrical muscle stimulation (EMS), isometric quadriceps sets, progressive straight leg raising and short arc quadriceps sets. McConnell (1987) reported that 90% of patients responded favourably to re-education of the surrounding musculature. Like the surgical approach, the basis for these treatments was the premise that malalignment was at the root of the problem. The treatment concentrates on regaining full range of motion of the knee and patellofemoral joint, promoting normal muscle flexibility and addressing any muscle strength imbalance that may exist, particularly between the vastus medialis and lateralis. Thus, "The principal goal of a conservative program is to develop excellent quadriceps femoris muscle strength, especially of the vastus medialis oblique (VMO) muscle" (Paulos, Ruschek, Johnson, & Noyes, 1980, pg 1627).

Although there are numerous research reports on the effect of EMS on muscle strength in general (Bohannon, 1983; Cox, Mendryk, Kramer, & Hunka, 1986; Currier, & Mann, 1983; Eriksson, & Haggmark, 1979; Eriksson, 1981; Godfrey, Jayawardena, Quance, & Welsh, 1979; Halbach, & Straus, 1980; Hartsell, 1986; Hintz, Chi, Fell, Ivy, Kaiser, Lowry & Lowry, 1982; Houghston, 1983; Hudlicka, Dodd, Renkin, & Gray, 1982; Johnson, Thurston, & Ashcroft, 1977; Kotz, 1971; Kramer, Lindsay, Magee, Mendryk, & Wall, 1984; Kramer, 1983; Laughman, 1983; Salmons, & Henriksson, 1981; Selkowitz, 1985; Selkowitz, 1989), few studies have evaluated the influence of EMS on patellofemoral alignment (Johnson et al, 1977; Bohannon, 1983). From the general studies, then, information has been extrapolated and implied as an effective treatment modality for patellofemoral pain. It is on this basis that EMS is traditionally incorporated into conservative treatment regimes. In particular, stimulation of the vastus medialis is used to counteract the strength of the vastus lateralis, thought to cause the lateral excursion of the patella (Johnson, 1989). Garrick (1989) noted however, that although EMS enhanced the exercise program, there was a lack of scientific evidence documenting its effectiveness.

In summary, although patellofemoral pain is one of the most common complaints associated with knee injuries, its cause is not known and the most common conservative treatment is based only on the assumption that patellar malalignment due to an imbalance in pull and/or strength between the vastus medialis and vastus lateralis may be the cause of the pain. Any study which can provide some links between anterior knee pain, malignment of the patella, and strength in the quadriceps may provide a rationale for the choice of one conservative treatment over another.

PURPOSE OF THE STUDY

The purpose of this study was to determine the effect of EMS on the strength of the quadriceps femoris, patellofemoral pain, and patellar alignment and to determine the relationship, if any, between strength of the quadriceps femoris, patellofemoral pain, and patellar alignment.

NULL HYPOTHESIS

Electrical muscle stimulation of the quadriceps muscle will have no effect on isometric strength, patellofemoral pain or patellar position and there is no relationship between strength, patellofemoral pain, and patellar position in subjects who present with patellofemoral pain syndrome.

SIGNIFICANCE OF THE STUDY

Patellofemoral pain is an enigmatic syndrome for which a standard therapeutic approach has yet to be determined. EMS is used extensively clinically to correct muscular imbalance of the quadriceps based on the generally accepted assumption that malalignment due to muscle imbalance is the precursor to the onset of symptoms of patellofemoral pain.

The results of this study may contribute to the understanding of the efficacy of electrical stimulation in subjects suffering from patellofemoral pain and provide the clinician with a protocol for effective patient care.

LIMITATIONS

The sample population was limited to subjects between the ages of 15 and 40 years of age suffering from patellofemoral pain and did not include a comparison group of normal subjects. The rationale and inclusion/exclusion criteria are outlined in chapter III.

DEFINITION OF TERMS

Quadriceps. As used in this study, quadriceps refers to the four muscles making up the quadriceps femoris.

Strength. As used in this study, strength refers to isometric strength (isometric torque for knee extension at 5º flexion) as measured by the Kin Com Isokinetic Dynamometer.

Chapter II

REVIEW OF LITERATURE

Anatomy of the Patella and its Relationships

Embryology of the Patella

Walmsley (1939) provided a detailed account of the embryological development of the patella. This report is still widely quoted and is the only referrence on the subject cited in a recent text by Fulkerson & Hungerford (1990).

The patella begins to be visible histologically in a 23.4 mm fetus and is located in the substance of the quadriceps close to its relation with the distal end of the developing femur. The position of the knee joint during development approximates 90 degrees flexion, therefore the patella develops in association with "the lower surface and lower part of the anterior surface of the femur" (Walmsley, 1939, pg. 361).

The supracondylar surface of the femur which articulates with the patella attains its shape in association with the developing suprapatellar pouch, rather than with the patella. As early as the 24 mm embryo (8 weeks) the lateral supracondylar surface has a greater anterior projection, larger transverse width and more proximal extension, as compared to the medial supracondylar surface. The larger lateral ridge is considered to serve as a buttress against lateral displacement of the patella during weight bearing (Walmsley, 1939). This larger lateral supracondylar ridge precedes the development of the patello-condylar and condylar-meniscal joints. Thus, it would appear that the form of the trochlea is primary and genetically determined (Walmsley, 1939). This primary development of the supracondylar surface would seem to fulfill a perceived need for lateral stability which will only arise after birth. Development of the lateral trochlea can however continue through to adulthood (Paulos, et al., 1980).

Because of the flexed position of the knee joint in utero, the patella develops adjacent to the femoral condylar surfaces rather than adjacent to the femoral patellar surface. In the 8 week embryo, the medial and lateral patellar facets are essentially equal in size (Walmsley, 1939). It is not until the patella becomes mobile that it develops a characteristic adult shape where the lateral facet is larger than the medial facet. It appears that the change in patellar shape is associated with the development of the femur's supracondylar surface (Walmsley, 1939). During this time, the supracondylar surface of the femur is still covered by perichondrium and is non-articular (Walmsley, 1939). Refinement of the undersurface of the patella, such as the secondary ridge between the medial and odd facets, appears to be secondary characteristics that develop in response to forces and constraints early on in life (Ficat, & Hungerford, 1977; Walmsley, 1939).

It is worth noting that, although the embryonic development of the lateral supracondylar ridge and the lateral patellar facet are independent, the stability of the patellofemoral joint is dependent upon their interelationship.

Gross Anatomy

The anatomical relationships of the patellofemoral joint are complex. Through the evolution of bipedal gait, the patella has become an integral part of the extensor mechanism with all of the characteristics of a "true joint" (Paulos, et al., 1980).

The patella transmits the contractile force generated by the quadriceps muscle to the tibia, thereby promoting knee extension. It is also responsible for maintaining proper alignment of the quadriceps tendon in the trochlear groove and, to some extent, providing some protection to the anterior aspect of the knee.

The patella, as described by Terry (1989), is the center pole of a tent- like system. It is sesamoid by definition, incorporated in the quadriceps tendon and serves as the centre point of attachment (tent pole) for the surrounding dynamic and static structures.

The Patella

The patella is triangular in shape with the apex pointing distally and a wide proximal base (Ficat & Hungerford, 1977). Its anterior surface is characteristically rough in appearance where the quadriceps tendon inserts on the proximal border and where the patellar tendon inserts distally. The most superficial fibers of the quadriceps tendon are adherent to the anterior surface between these two attachment sites.

The posterior surface of the patella is complex in its topographical profile, reflecting its functional significance. Ficat & Hungerford (1977) divided the posterior of the patellar surface into two parts. The inferior 25% is the nonarticulating surface and is porous in appearance due to its vascular foramina. The proximal 75% of the undersurface of the patella is the articulating surface and is covered in hyaline cartilage. The articular surface is oval in shape and includes distinct medial and lateral surfaces, referred to as the medial and lateral articular facets of the patella. The articular facets are divided by a median ridge which runs proximal to distal. In transverse section, the patella is triangular in shape with the apex formed by the median ridge.

Ficat & Hungerford (1977) described the angle created by the medial and lateral facet as the patellar facet angle. This angle may vary between 120º and 140º and averages 130º . The patellar facet angle corresponds with the shape of the femoral trochlear groove, although the patellar facet angle may be 5º to 10º more obtuse owing to the thicker articular cartilage covering the median ridge and odd facet (Ficat & Hungerford, 1977).

The size and shape of the medial and lateral patellar facets can vary. The lateral facet is usually longer than the medial facet: the ratio being said to approximate 1.4 : 1 (Minkoff & Fein, 1989). Ficat & Hungerford (1977), reported a ratio approaching 2 with a range from 1 to 3. The medial facet is generally flat or slightly convex in shape while the lateral facet is concave. The concave shape of the lateral facet is conducive to joint stability, while the convex shape of the medial facet is not (Grana & Kreigshauser, 1985). Cross and Waldrop (1975) reported that, of 1004 radiographs, the area of the medial patellar facet was significantly smaller in patients with patellofemoral instability, even though the difference in overall width of the patella was not significant. Also, the median ridge was more medially placed in relation to the overall width of the patella. Cross, and Waldrop (1975) surmised that a more medially aligned median ridge allowed greater lateral excursion of the patella which could potentially increase lateral patellofemoral compression.

The medial patellar facet is divided further by a secondary ridge into a medial facet "proper" and a more medial vertical or "odd" facet (Ficat & Hungerford, 1977). Walmsley (1939) felt that the development of the secondary ridge and the odd facet was an adaptive change in response to biomechanical stresses imposed after birth.

Wiberg, in 1941, described three main types of patellar shapes; type1, type 2, and type 3.

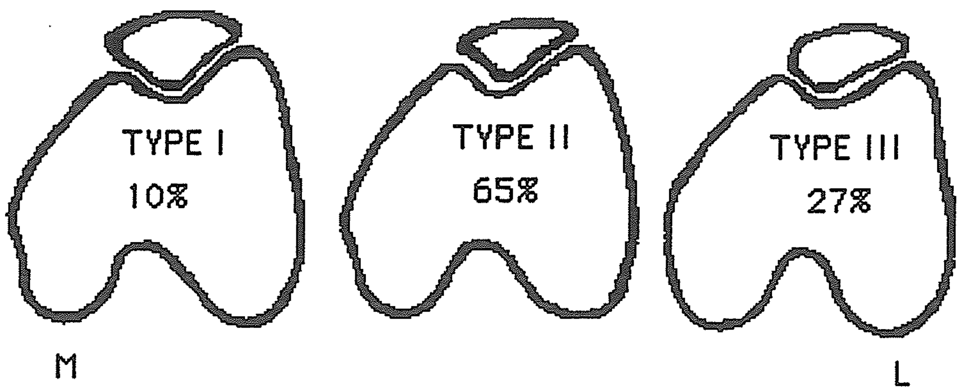

Figure 1. Patellofemoral configurations classified by Wiberg and redrawn according to Mehrdad & Mangine (1981).

Ficat & Hungerford (1977) described the Wiberg patellar classification as follows:

"Type I. In type I patellae both facets are gently concave, symmetrical and roughly the same size, although a slight lateral predominance is common. Theoretically, this would appear to be the ideal patellar form. It is, however, the least common, contributing only 10% of the patellae examined.

Type II. There is a subtle flow from type I to type II where the medial facet is distinctly smaller than the lateral. The lateral facet remains concave while the medial is either flat or slightly convex. The relatively larger lateral facet predominance corresponds with the general lateral prominence of the patellofemoral joint as a whole. This is the most common patellar shape, accounting for 65% of patellae observed.

Type III. In a type III patella the medial facet is considerably smaller with marked lateral predominance."

In his original classification, Wiberg (1941) did not specifically indicate that the medial subchondral outline was convex. However, examples he showed were convex, and subsequent authors have included medial facet convexity as a criterion for type III patellae. Type III patellae were found in 27% of Ficat & Hungerford's (1977) observations.

Ficat & Hungerford (1977) also classified patellar shape according to patellar facet angle measured radiographically. Normal patellar facet angles ranged between 120º and 140º. Angles that were more acute were described as hemipatellar or lacking two distinct facets and were associated with lateral instabilities. Patellar facet angles greater than 140º were described as the so called pebble-shaped patellae which have a characteristically flattened undersurface. In these cases, the patella and femur are poorly related, which leads to an unstable joint. Minkoff and Fein (1989) stated that measuring the patellar angle could be useful in determining whether surgery could improve joint stability.

Other variations in patellar shape which may affect joint stability as reported by Ficat and Hungerford (1977) include large patella (patella magna) or small patella (patella parva) .

Hyaline cartilage covers the articular surfaces of the patella and the trochlear surface of the femur. Ficat & Hungerford (1977) reported that the articular cartilage of the patella is the thickest cartilage in the body - 4 to 5 mm. The articular cartilage is said to be thickest on the the median ridge, where it can be as thick as 6.4 mm (Minkoff et al, 1989).

The Femoral Trochlea

The distal surface of the femur which articulates with the patella is referred to as the trochlear surface; generically termed the patellar surface of the femur. It is located proximal to the femoral condyles on the anterior femoral surface and has well-defined medial and lateral facets. The groove between the trochlear facets is referred to as the femoral sulcus. The sulcus angle describes the depth of this articular surface (Stanford, Phelan, Kathol, Rooholamini, El-Khoury, Palutsis & Albright, 1988). Ficat & Hungerford (1977) reported measures of the sulcus angle to be as great as 143º. Normal measures were between 125º and 130º. Too acute or too flat an angle could lead to an unstable patellofemoral joint.

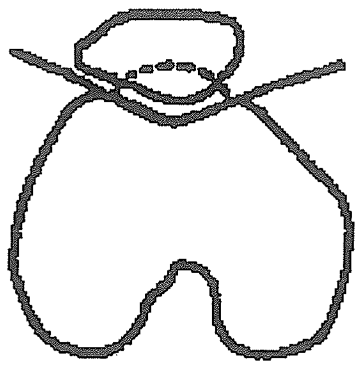

Figure 2. Anterior intercondylar angle (sulcus angle).

A skyline view of the patellofemoral joint is a radiographic technique which portrays the joint in a coronal plane. This image provides a good view of the congruency of the patella in the femoral sulcus. From this, it can be seen that the lateral trochlear facet of the femur is larger in its transverse width, extends further proximally and protrudes further anteriorly than the medial trochlear facet. Also, the lateral supracondylar ridge can be seen to project further anteriorly than the medial ridge. This lateral buttress effect is often considered a major contributor to the stability of the patellofemoral joint. Ficat & Hungerford, (1977) measured this anterior projection, termed the trochlear angle of inclination, and reported it to vary between 3.5º and 6.4º (Ficat & Hungerford, 1977). It should be noted, though, that a clinically reliable procedure that minimizes measurement error due to femoral rotation has yet to be developed.

The articular cartilage covering the trochlear facets extends distally and is continuous with the articulating surfaces of the femoral condyles. It is an average of 2-3 mm thick: thinner than that of the patella. Further, the cartilage on the medial trochlear facet is thinner than that on the lateral trochlear facet (Ficat & Hungerford, 1977). Bose, Kanagasuntheram, & Osman (1980) reported that the articular cartilage on the lateral femoral trochlea is raised (presumably because of its increased thickness) to stabilize the patella. The proximal border of the lateral trochlear facet ends subtly, while the proximal edge of the medial trochlear facet ends abruptly as a noticeable ridge, referred to as the Outerbridge ridge. It has been implicated in medial patellar pain syndromes (Outerbridge, & Dunlop, 1975). During flexion, the patella is forced over this ridge. If the ridge is large, the compression between the patella and the femur is thought to be momentarily magnified as the patella contacts this area (Outerbridge & Dunlop, 1975).

Ficat & Hungerford (1977) postulated that the patella normally entered the trochlea from the lateral side during flexion and that it was this constant motion between the lateral patellar facet and the lateral condylar ridge of the femur that gave it its characteristically smooth transition.

Synovial Capsule

"The synovial capsule of the knee joint is more extensive than that of any other joint; thus, the synovial cavity of the knee joint is the largest in the body" (Clemente, 1985 pg 405). In the embryo, the capsule of the knee is divided into patellar, medial, and lateral compartments by septal folds. During embryonic development the septal folds dividing these three compartments disappear, leaving vestigial folds called plicae. The plicae allow for communication and flow of synovial fluid between the three compartments. The synovial capsule of the knee joint proper, is, therefore, continuous with that of the patellofemoral joint and it extends superiorly beneath the quadriceps muscle to form the suprapatellar pouch.

Patellofemoral Stabilizers

The patellofemoral joint does not rely on its surrounding capsular structure for stability. The synovial capsule which incorporates the patellofemoral joint must allow synovial fluid to invest the synovial capsule and its extensive expansions without obstruction (Ficat & Hungerford, 1977). Patellar alignment, therefore, is dependent on the surrounding muscles, ligaments, retinacula, and aponeuroses. The stabilizing system has been described as a "tent pole effect" with the patella situated as the centre pole (Terry, 1989). It has also been described as a cruciform system where a convergence of active and passive soft tissues act on the patella to provide stability and function (Ficat & Hungerford, 1977). Although all stabilizers must work in synergy, this discussion will examine the influence of the static and dynamic stabilizers separately.

Static Stabilizers

Static stabilizers are noncontractile supporting structures for patellofemoral alignment. Bony static stabilization is provided by the congruent fit of the patella within the femoral trochlea and the buttress effect of the anteriorly projected lateral trochlear facet.

The connective tissue surrounding and attached to the patella is referred to as the retinaculum. It centres the patella in the trochlea and restricts the proximal and distal excursion of the patella. The retinaculum is a fascial expansion of the quadriceps muscle and can be divided into superior/inferior and medial/lateral structures. It is comprised of tendinous expansions from the quadriceps group of muscles (inserting on the proximal patella) and the ligamentum patellae (from the tibial tubercle) which attaches to the apex of the patella. The patellar ligament is particularly important because it determines the height of the patella in relation to the femoral trochlea, as will be discussed below.

The medial and lateral ligaments include the patellofemoral ligaments, patellotibial ligaments, patellomeniscal ligaments and lateral retinaculum. The medial and lateral patellofemoral ligaments attach to their respective proximal borders of the patella and the medial and lateral femoral epicondyles (Fig. 3). These two ligaments act as 'guy wires' to support the patella from above (Ficat & Hungerford, 1977; James, 1979).

Inferiorly, the patellotibial ligaments counter balance the patellofemoral ligaments (Terry, 1989). The patellomeniscal ligaments originate from the anterior aspect of the menisci and insert on the distal aspect of the patella (Ficat & Hungerford, 1977).

Laterally, superficial oblique fibers and deep transverse fibers of the lateral retinaculum provide lateral support (Fulkerson, 1989, Johnson, 1989). The superficial oblique fibers run from the iliotibial band and blend with the quadriceps expansion over the patella (Fulkerson, 1989). These fibers are not thought to provide any important patellar support, but they do overlie a deeper transversely oriented lateral retinaculum. The transverse retinaculum can be divided into a proximal epicondylopatellar band and a deep transverse band. The deep transverse band runs from the iliotibial tract to the mid portion of the patella and is said to be more important than the proximal epicondylopatellar band. This component of the lateral retinaculum provides considerable lateral support to the patella (Fulkerson, 1989). Terry (1989) referred to this structure as the iliopatellar band.

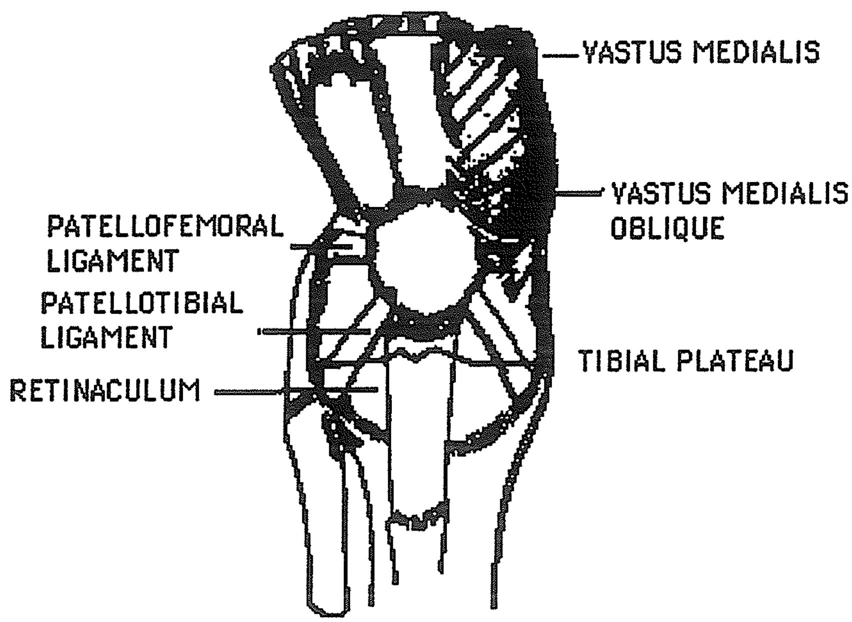

Figure 3. Static stabilizers of the patellofemoral joint redrawn according to Terry (1989).

The lateral fascia is generally thicker than that on the medial side (Lieb & Perry, 1968). In dissections of eight fresh and three embalmed specimens, measurements of the fascia revealed that the lateral fascia was twice as thick over the vastus lateralis and four times as thick over the iliotibial band as compared to the medial fascia (Lieb & Perry, 1968). This is thought to increase the relative lateral fascial tension (Micheli & Stanitski, 1981).

On the medial side, static restraint is provided by the medial patellofemoral ligament. It is a tough fibrous tissue that inserts into the medial two thirds of the patella and represents a much larger structure than its counterpart on the lateral side (Ficat & Hungerford, 1977). Terry (1989) however, described the medial and lateral patellofemoral ligaments as often thin structures and therefore of limited functional importance in the normal knee. He postulated that a normal knee relies more on the surrounding muscles for dynamic stability and the fascia is therefore subjected to minimal stress. He noted that in atrophy (wasting) of the vastus medialis oblique, the patellofemoral ligaments become thicker, likely in response to their added role as stabilizers. The patellotibial ligaments, on the other hand, are normally thick because of their function as the principal stabilizers inferiorly (Terry, 1989).

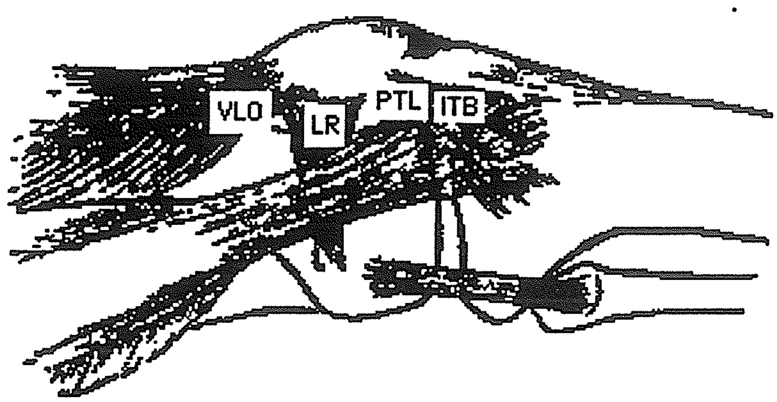

Figure 4. This semidiagramatic drawing of the lateral side of the knee redrawn according to Johnson (1989) shows the Vastus Lateralis Oblique (VLO) , so-called because the oblique distal portion has its own separate attachment into the patella. The Lateral Retinaculum (LR) is shown here as a single restraint on the lateral side of the knee. PTL is the patellar tibial ligament, which is usually in the lateral corpus of the fat pad. This was much more consistent than the patellofemoral ligament, which is not shown here. The anterior fibers of the iliotibial band (ITB) usually attach to the inferior pole of the patella and along the lateral margin of the patellar ligament.

Although the medial patellofemoral ligament is larger than its lateral counterpart, the combined effects of the lateral patellofemoral ligaments, the lateral patellomeniscal ligament, the lateral patellotibial ligament and the lateral retinacular expansion from the iliotibial band (Figure 4) provide stronger lateral support than do the medial restraints (Ficat & Hungerford, 1977). This structural imbalance is thought to cause lateral patellar tilting and excessive compressive force between the lateral patellar facet and the lateral trochlea (Paulos, et al., 1980).

The Arciform layer is a superficial layer of connective tissue that spans the anterior patella to connect the medial and lateral retinacula but does not appear to influence patellofemoral alignment (Terry, 1989).

Dynamic Stabilizers

Although the static stabilizers are the target tissues in surgical correction, the role of the dynamic stabilizers is of major interest in the conservative management of patellofemoral pain. Dynamic patellofemoral stability is dependent on active contraction of the surrounding musculature. The quadriceps muscles are primary dynamic stabilizers of the patellofemoral joint.

The vastus medialis and vastus lateralis insert along the medial and lateral borders of the patella respectively. Although their prime function is to produce extension of the knee, they also play a significant role in centering the patella in the trochlear groove (Lieb & Perry, 1968). Lieb and Perry (1968) calculated the angle of pull for the various components of the quadriceps muscle (Fig 5). They reported the pull of the rectus femoris to be oriented 7º to 10º degrees medial to the midline of the trochlear groove in the frontal plane and 3º to 5º anteriorly in the sagittal plane. The line of pull of the vastus intermedius is parallel to that of the femur while that of the vastus lateralis is 12º to 15º laterally.

Due to its unique structure, the line of pull of vastus medialis is somewhat more complicated than that of the other quadriceps bellies. The muscle is divided into upper and lower fibers. On the basis of the examination of ten preserved cadavers, Bose (1985) reported that the vastus medialis oblique originates from the tendon of the adductor magnus and its fibres travel obliquely or transversely to the medial margin of the patella. The larger, upper group of fibers are aligned 15º to 18º degrees medially (relative to the femur) while the fibers of the vastus medialis oblique (VMO) are oriented 50º to 55º degrees medially (Lieb & Perry, 1968). This origin is unique to the human species and is said to be a developmental adaptation to bipedal gait (Lieb & Perry, 1968). Because of the line of pull on the patella, the vastus medialis oblique is considered to be the chief active medial stabilizer of the patella (Paulos, et al., 1980). Indeed, its primary function has been considered to be patellar alignment (Lieb & Perry, 1968).

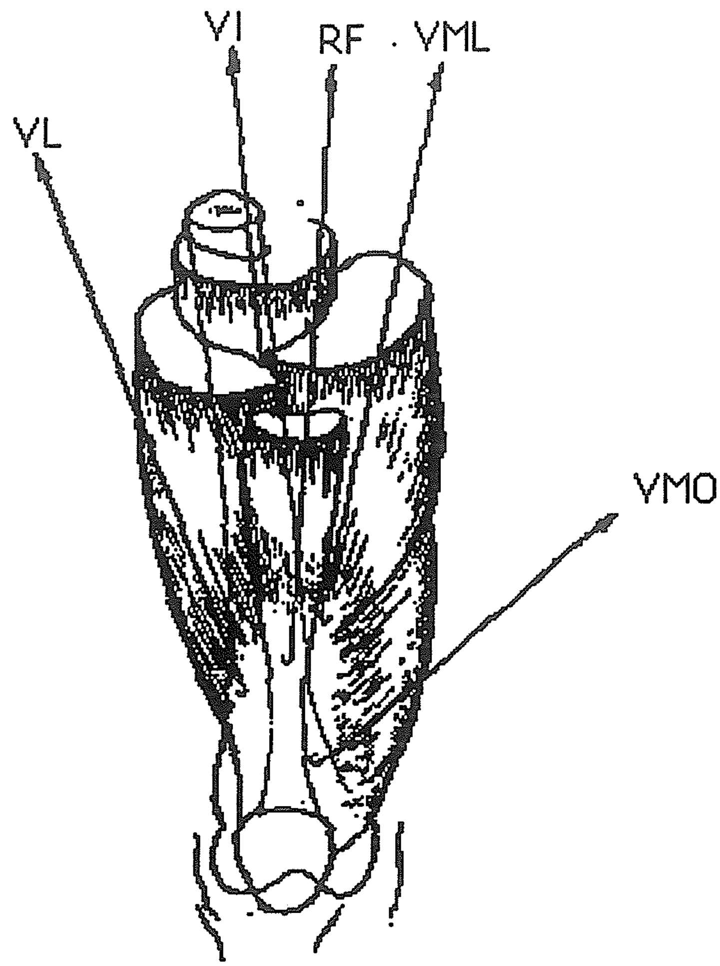

Figure 5. Cable muscle attacments were fastened to the tendons with fishhooks oversewn with NO. 2 silk, or paired serrated discs bolted together. Arrows indicate cable aligned along fibre-axes of the different heads of the quadriceps (Lieb, et al., 1968). VL= Vastus Lateralis, VI = Vastus Intermedius, RF = Rectus Femoris, VML = Vastus Medialis Longus, VMO = Vastus Medialis Oblique.

The vastus lateralis has also been described as having an oblique component known as the vastus lateralis oblique (VLO). The proximal two thirds of the vastus lateralis is said to insert into the central quadriceps tendon while the lower third is a laterally oriented strip that inserts on the patella. Fulkerson, Hallisey & Schutzer (1985) dissected the vastus lateralis in 41 knees, consistently defined a vastus lateralis oblique, and reported that the mean angle of fibre inclination was 45º for males and 39º for females. Fulkerson et al., (1985) reported that the male/female difference was not statistically significant but that fibre inclination was more variable in males. Johnson (1989) studied the effects of the lateral restraining structures and also described the vastus lateralis as similar to the vastus medialis. Johnson (1989) performed surgery on 34 patients diagnosed as having lateral facet syndrome. The vastus lateralis, the lateral retinaculum and the iliotibial band were sequentially cut. The fibres of the so-called vastus lateralis oblique (VLO), were found to provide the primary restraint in one half of the 38 knees examined. Additionally, Johnson (1989) reported that the three structures contributed equally in one third of the knees; the iliotibial band was the primary restraint in six other subjects (18%) while only two subjects depended on the lateral retinaculum for primary restraint. Surgical resection of vastus lateralis oblique, the lateral retinaculum and the iliotibial band resulted in a return to normal activity in 87% of the cases.

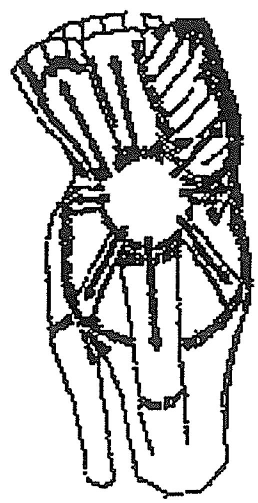

Figure 6. Resolution of the dynamic and static forces provides patellofemoral stability and allows function (Terry, 1989).

The vastus medialis attaches lower on the medial aspect of the patella than does the vastus lateralis on the lateral patellar border (Ficat & Hungerford, 1977). This more distal muscle attachment is thought to provide greater mechanical advantage and more effective stabilization (Ficat & Hungerford, 1977). Outerbridge & Dunlop (1975) believed that a high insertion of the vastus medialis on the patella was a common cause of patellar subluxation in females.

Terry (1989) summarized the action of joint stabilizers by emphasizing the importance of balance between the dynamic and static, medial and lateral stabilizers. "All of these structures are interrelated so that the dynamic medial (vastus medialis obliquus) forces are balanced by the lateral static restraints, and the dynamic lateral (vastus lateralis obliquus) forces are balanced by the medial static restraints" (Terry, 1989, pg 174) (Fig. 6).

The hamstring muscles may also play a role in patellofemoral pain. Any imbalance in strength or flexibility between the extensor quadriceps and the flexor hamstrings can result in increased patellofemoral compressive stress (Grana & Kreigshauser, 1985). Also, the biceps femoris is closely associated with both the iliotibial tract and the iliopatellar band and thus can act as an additional dynamic lateral stabilizer (Terry, 1989).

Vascular Supply (Figure 7)

The patellofemoral joint has a rich vascular supply (Clemente, 1985; Ficat & Hungerford, 1977). The arterial supply is described as an anastomotic peripatellar system comprised of six blood vessels that converge around the patella. The lateral superior genicular artery, a branch of the popliteal artery derived from the femoral artery, supplies the superolateral border of the patella. It anastomoses superomedially with the supreme genicular artery, a branch of the descending genicular artery, and with the medial superior genicular artery, which is also derived from the popliteal artery (Fulkerson & Hungerford, 1990). These two vessels nourish the superomedial aspect of the patella. The medial and lateral inferior genicular arteries, branches of the popliteal artery, supply the inferior aspect of the patella and anastomose with the superomedial and superolateral genicular arteries, respectively. To complete the circle around the patella, a sixth artery, the anterior tibial recurrent artery, a branch of the anterior tibial artery, supplies the inferior pole of the patella. The arterial supply enters the patella through the vascular orifices found on the middle one third of the anterior surface and, posteriorly, through the distal nonarticulating surface. A deeper anastomosis made up of deeper vascular branches from these same genicular arteries supplies the posterior aspect of the patellofemoral joint, including the synovium, femur and tibia.

The venous drainage mirrors the arterial system in that there is a venous loop. Veins from the patella are principally drained by the popliteal vein and, to some extent, the saphenous veins (Fulkerson & Hungerford, 1990). It is thought that the patellar apex is the "vascular hilus" or focal point of the venous drainage (Ficat & Hungerford, 1977). Poor venous drainage, resulting in patellar engorgement, has been implicated as a possible cause of patellofemoral pain (Arnoldi, 1991; Waisbrod, & Noam, 1980,).

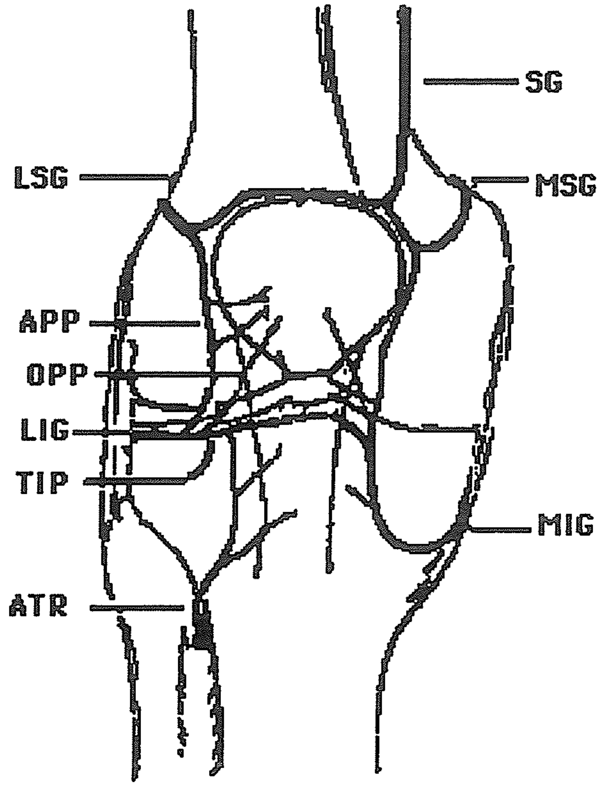

Figure 7. The blood supply to the patella. An anastomotic ring of vessels enters the anterior surface obliquely and provides the main blood supply to the proximal part of the patella. Apical or polar arteries enter the inferior part of the patella and run superiorly, supplying the inferior portion of the patella. SG = articular branch of the descending genicular artery (formerly called the supreme genicular artery), MSG = medial superior genicular artery, MIG = medial inferior genicular artery, LSG = lateral superior genicular artery, ATP = ascending parapetellar artery, OPP = oblique parapatellar artery, LIG = lateral inferior genicular artery, TIP = transverse infrapatellar artery, and ATR = anterior tibial recurrent artery (As redrawn according to LaPrade et al. ,1990)

Innervation

The tibial nerve supplies articular branches that travel with the superior and inferior genicular arteries to supply the entire knee joint. The cutaneous nerves about the knee are referred to as the patellar plexus and are derived from branches of the lateral femoral cutaneous nerve (L2 - L3), anterior femoral cutaneous nerve and the infrapatellar branch of the saphenous nerve originating from the femoral nerve (L2-3-4). Articular cartilage is aneural (Moore, 1983).

Motor control of the quadriceps femoris muscle group is from the femoral nerve (L 2-3-4). Innervation of the adductors, except for the hamstring portion of the adductor magnus, is provided by the obturator nerve (L2-3-4). The hamstring muscle group and the hamstring portion of the adductor magnus are supplied by the tibial division of the sciatic nerve (L4-5, S1-2-3) (Moore, 1983).

It is also important to note the innervation of gluteus maximus and the tensor fascia lata because of their insertion into the iliotibial band. The gluteus maximus is the larger of the two muscles and is innervated by the inferior gluteal nerve (L5- S1-2). The tensor fascia latae is innervated by the superior gluteal nerve (L4-5 -S1) (Clemente, 1985).

Articular Cartilage

Histology

Hungerford and Barry (1979) reported that "The hyaline articular cartilage on the undersurface of the patella provides an insensitive (aneural), avascular tissue which is specifically adapted to bearing high compressive loads. It also allows the force of the quadriceps to be transmitted around an angle during knee flexion without loss due to friction" (pg 9). Whereas hyaline cartilage in other parts of the body is approximately 2-4 mm thick, the thickness of the cartilage in the knee averages about 5 mm (Arnoczky & Torzilli, 1984).

James (1979) described three distinct layers within hyaline cartilage (Fig. 8)

1. Tangential layer. A smooth layer of collagen fiber that lie parallel to the surface creating a relatively smooth surface minimizing patellofemoral frictional forces.

2. Intermediate zone. A zone of randomly oriented collagen fiber that appear in a somewhat coiled arrangement with large open spaces between the fibers. This area is said to act as an area of deformability and energy storage.

3. Deep zone. A zone also called the calcified zone in which the collagen fiber are perpendicularly oriented to the articular surface, with a tighter mesh-like arrangement which functions to bind the articular cartilage to the underlying subchondral bone.

Arnoczky & Torzilli (1984) subdivided the intermediate zone into two zones (transitional and radial) but they did not detail any specific differences between the two zones. They described a thin line between the deep and intermediate zone called the "tidemark", which is not seen in immature animals. The function of the tidemark is unclear but it is thought to form an anchor and spacer between the two zones (Arnoczky & Torzilli, 1984).

Chondrocytes make up the cellular component of articular cartilage while mucopolysaccharides and water make up the ground substance. The general chemical composition of articular cartilage is: 10-15% collagen, 10-15% proteoglycans and 70-80% water (Arnoczky & Torzilli, 1984). Mow, Myers & Wirth, (1982) reported that patellar cartilage is comprised of 20-40% collagen, 10-25% proteoglycans, 5-10% chondrocytes, glycoproteins and lipids, and 60-80% water.

Chondrocytes appear to have a different morphology in the three zones, suggesting they may have different functions (Arnoczky & Torzilli, 1984). In immature cartilage, the cells in the superficial and basal layer seem to be mitotically active, whereas in mature cartilage, chondrocytes in all three layers are either absent or dormant. This could imply that mature chondrocytes do not have the capacity to replicate. Aging, however, does not seem to decrease the overall cell count, suggesting that there is some form of maintenance or replication: a process which, according to Arnoczky and Torzilli (1984), remains a mystery.

Collagen fiber accounts for over 50% of the dry weight and approximately 90% of the protein content of articular cartilage. The diameter of individual collagen fiber ranges from 30nm in the superficial zone to more than 100nm in the deep calcified zone (Arnoczky & Torzilli, 1984).

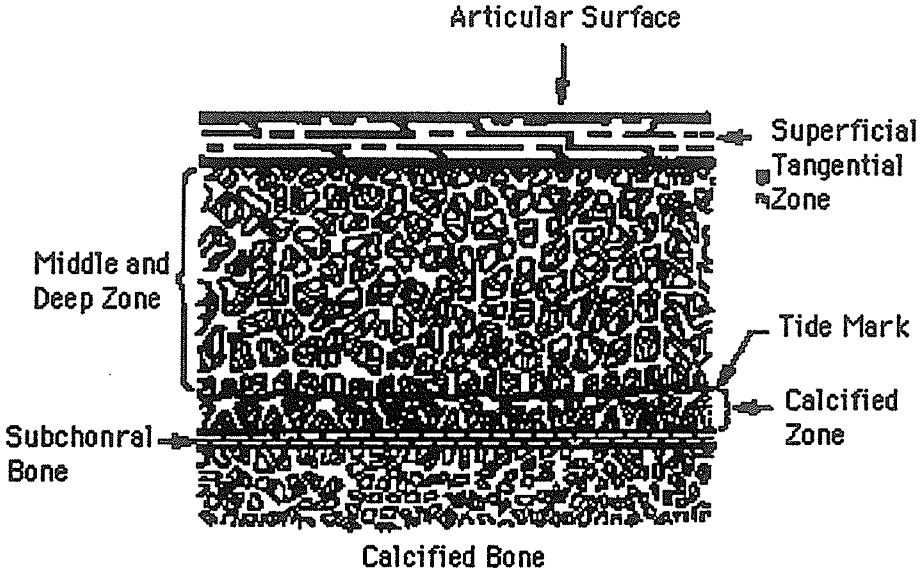

Figure 8. Schematic representation of collagen fibril ultrastructural orientation, as seen from the scanning electron microscope, depicting the three salient zones of articular cartilage (Mow, Myers, & Wirth, 1982).

Proteoglycan molecules represent as much as 50% of the dry weight of articular cartilage. These molecules are comprised of a chain-like protein core with glycosaminoglycans (GAG's) attached at right angles. The GAG's have a repelling charge that makes them project at a 90º angle from the protein core (Fig. 9). This configuration allows the proteoglycans to occupy a large space and makes articular cartilage resistant to compression (Arnoczky & Torzilli, 1984). The repelling nature of the densely packed proteoglycans also causes the cartilage to swell, the extent of which is limited only by the surrounding collagenous network (Mow, Meyers & Wirth, 1982). Therefore, there is a constant tension imposed on the cartilage to maintain its shape when unloaded.

The water content of cartilage, the majority of which is extracellular, amounts to 70% or 80% of the total weight, (Arnoczky & Torzilli, 1984). To some extent, this water is exchangeable with synovial fluid. This exchange of fluid plays a vital role in the lubrication of the joint surface as well as in the importation and exportation of nutrients and cellular waste by-products (Mow et al., 1982).

Nutrition of cartilage is primarily by diffusion of metabolites from the joint synovial fluid. At one time it was thought that some nutrition may be derived from the subchondral bone but it appears that the tidemark, referred to earlier, inhibits this source of supply (Arnoczky & Torzilli, 1984).

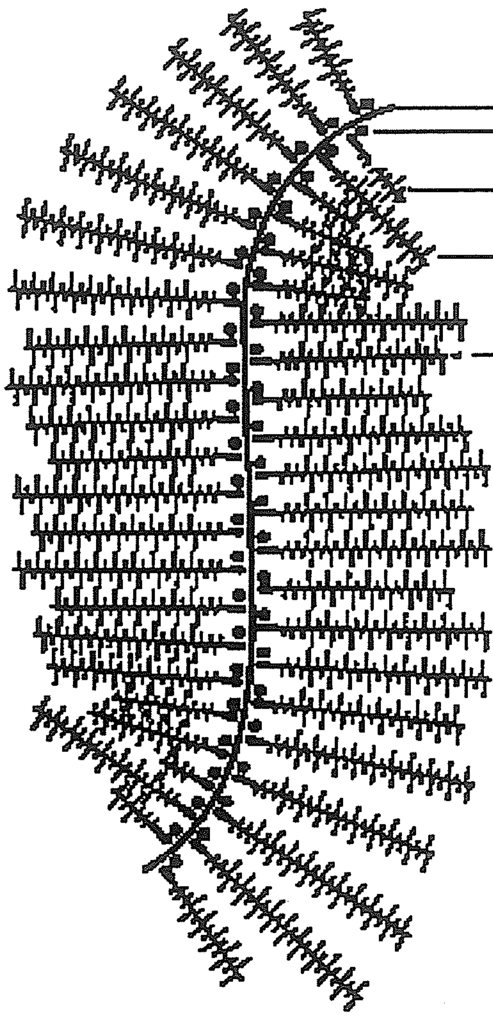

Figure 9. Schematic representation of proteoglycan aggregate as redrawn according to Hunter and Funk (1984).

Articular cartilage is not anchored to or continuous with the underlying bone, rather, it is attached to the bone by the interlocking of the irregularly shaped surfaces much like a jigsaw puzzle (Arnoczky & Torzilli 1984). The progressive calcification of the deep zone is an important feature because it creates a zone of increasing mechanical stiffness to withstand shearing forces (Mow et al., 1982).

Mechanical Properties

Articular cartilage is designed to withstand both compressive and tension forces. Mow et al., (1982) postulated that "the main mechanical function of collagen is to resist tension" (pg 58). They reported that significant tensile stresses and strains exist at the surface of articular cartilage of the patella and that this stress is sustained by the tough collagen fiber found in the superficial zone. Arnoczky & Torzilli (1984) also noted that the superficial collagen fiber are most resistant to tension stresses while fibers in the deeper layers are decreasingly less resistant to tension and more resistant to compressive loads. Further, the superficial layer is more resistant to tension applied parallel to its fiber orientation (shear) than to tension applied perpendicular to its surface. In essence, it can better withstand the stress of an opposing surface traversing parallel to its articular surface (ie. joint motion).

The manner in which hyaline cartilage functions under compressive load is unique to this tissue (Mow, et al., 1982). When a compressive load is applied to articular cartilage, the force is dissipated slowly. This is governed by the composition of the tissue and the rate of exudation of fluid from within (Mow et al., 1982) (Fig. 11).

A compressive load applied to articular cartilage typically causes tissue compression as fluid is extruded and the cellular matrix becomes more dense. The repelling charges of the glycosaminoglycan molecules (GAG's) in the articular cartilage resist this compaction. In effect, the GAG's push back against the compressive force (Mow et al., 1982).

The response of cartilage to a compressive load is described as biphasic in that there is an initial and immediate compression of tissue as the load is applied, followed by a secondary "creep" or controlled change in shape (Mow et al., 1982). The fluid mechanics within articular cartilage are thought to be responsible for this creep phenomenon. As previously mentioned, interstitial fluid is freely exchangeable with the synovial fluid. Under normal loads, as much as 60% of the total tissue fluid can be squeezed out of articular cartilage (Arnoczky & Torzilli, 1984). The rate and amount of fluid exchange, however, is controlled by the permeability of the tissue matrix and is based on the degree of compression. The superficial layer is the least permeable layer and its permeability decreases even more under compression. As a compressive load is applied, the collagen fibers become more densely packed and less permeable to fluid loss. This restricts the free exudation of fluid from within. It is this controlled release of fluid content as a means of force dissipation that is described as the creep phenomenon (Mow et al., 1982). Dissipation of force in the superficial layer protects the deeper layers of the cartilage and, ultimately, the subchondral bone.

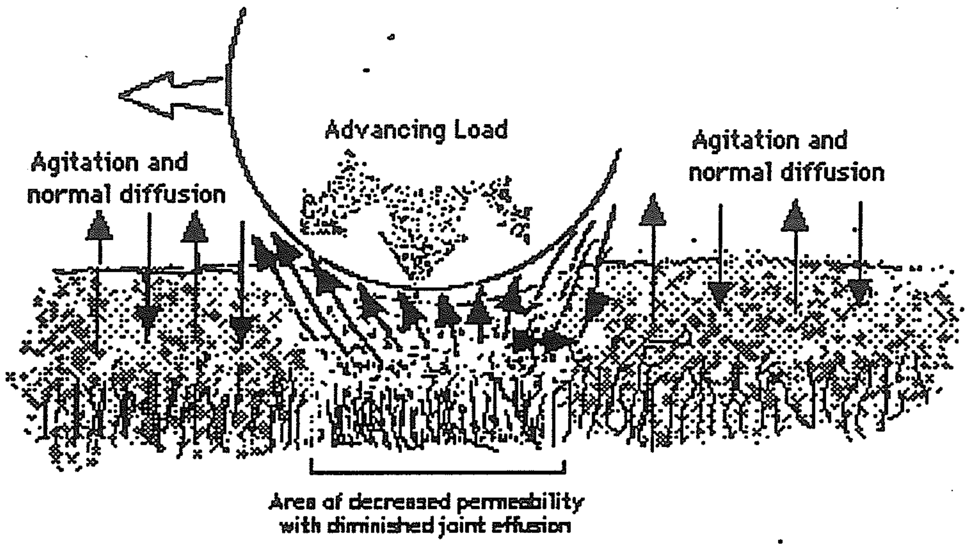

Figure 10. Effect of loading on articular cartilage permeability. An advancing load causes expulsion of fluid from compressed articular cartilage. An area of decreased permeability is created in the area of compression with return of normal permeability behind the advancing load (James, 1979).

Cartilage, therefore, resists damaging tension forces largely through the tensile strength of its superficial fibers and withstands compressive forces through a regulated permeability to interstitial fluid, also largely controlled by the superficial fibers. Both mechanisms function to limit the transmission of excessive stress to the deeper, more vulnerable layers of articular cartilage and the even deeper subchondral bone. It is evident, then, that an intact superficial layer is crucial to the health of the joint's entire articular surface.

Joint Lubrication

Although the articular surface is generally thought to be a smooth surface, the hyaline cartilage is reported to be rough in texture (Mow et al., 1982). Cartilage identations range is size from 0.5mm to 1mm in diameter (Mow et al., 1982). As cartilage ages, these irregularities become more prominent and are thought to be the precursor to degenerative changes (Mow et al., 1982). Lubrication of the joint is therefore important to minimize wear.

Mow et al., (1982) described three types of fluid that lubricate a joint. Lubricating glycoprotein fraction (LGF) is a lubricant molecule with a high affinity for articular cartilage. It forms a monolayer on the articular surface which is not easily rubbed off and is quickly replaced if lost through attrition (Mow et al., 1982). Synovial fluid is also an important lubricant, particularly under light, fast joint movement where it is said to be the lubricant of choice. With heavier loads and slower joint movement, however, interstitial fluid is extruded from articular cartilage and interfaces between the two joint surfaces to allow motion with minimal friction. This exudation of interstitial fluid from articular cartilage is the major mechanism for joint lubrication (Mow et al., 1982). Articular cartilage contains between 100 and 200 times the water content required to lubricate the joint (Mow et al., 1982). As the load on the joint increases beyond the load bearing capacity of the synovial fluid, the interstitial fluid is extruded from the cartilage creating a lubricating film at the point where the two opposing joint surfaces contact. As the compressive load moves to an adjacent area, the now unloaded area imbibes fluid and swells to regain its shape in preparation for further compression, as occurs in the case of cyclic loading (Mow et al., 1982) (see fig 10).

Exchanging fluid between the articular cartilage and the synovial fluid is therefore important to a) reduce the stress and strain on the joint and articular surfaces, b) provide joint motion with minimal resistance and c) allow adequate nutrition. These functions are dependent on the integrity of the superficial layer of cartilage. If the integrity of the superficial layer is disrupted in any way as a result of acute trauma or overuse, lubrication of the articular surface is impaired, adequate nutrition is lost and excessive stress is delivered to the more fragile deeper layers. This may ultimately lead to the degradation of the cartilage and, eventually, the underlying bone (Arnoczky & Torzilli, 1984).

Patellofemoral Biomechanics

A delicate balance between the static and dynamic stabilizers allows for optimal function of the patellofemoral joint. That balance is so critical that any minor disruption can precipitate the degenerative process (Terry, 1989). All of the structures surrounding a normal patellofemoral joint interrelate biomechanically to provide for optimal function and to ensure that no single structure assumes undue destructive stress.

The biomechanical function of the patella is four-fold:

1. To increase the biomechanical lever arm of the extensor mechanism,
2. To centralize the converging fibers of the quadriceps muscle,
3. To bear the compressive forces imposed on the patellofemoral joint, and
4. To allow for the transmission of force around an angle during knee flexion without loss due to friction.

(Hungerford & Barry, 1979)

Normal Biomechanics

With the knee in full extension, an isometric quadriceps contraction causes the patella to move proximally as much as 8 to 10 mm (Ficat & Hungerford, 1977). During 0º to 20º knee flexion, the patella is proximal to the femoral trochlea and is dependent on its static and dynamic stabilizers for stability. The patella enters the trochlea from a supero-lateral position over a smooth transition between the bony lateral supracondyle and the hyaline covered trochlea (Ficat & Hungerford, 1977). At 20º knee flexion, the patella migrates medially and begins to engage within the trochlea. From this point it becomes increasingly more dependent on its congruency with the femoral trochlea for stability. Between 30º and 70º knee flexion, the patella projects anteriorly in the frontal plane as it follows the anterior curve of the lateral femoral condyle (Hungerford & Perry, 1979). This serves to lengthen the moment arm between the patella and the fulcrum of the knee creating the extra force required to offset the increased resistance encountered during weight bearing knee flexion. The patella is responsible for as much as 30% of the quadriceps moment arm (James, 1979). After 90º flexion, the patella, which is now well entrenched in the trochlea, follows a more lateral course along the contour of the lateral femoral condyle. Its function as a lever arm decreases because it is pulled into the intercondylar notch and it now contributes as little as 10% to the quadriceps moment arm (James, 1979). At 135º knee flexion, the patella continues to move along the lateral aspect of the femoral trochlea. At this point it also rotates medially on its long axis and the medial patellar facet to engages in the intercondylar groove. In full flexion, patellar rotation is complete and the odd facet articulates with the lateral surface of the medial femoral condyle. The normal line of patellar excursion is described as a gentle "C" opened laterally (Hungerford & Perry, 1979).

Q-Angle (Figure 11)

The Q-angle is thought to be a critical component of patellofemoral biomechanics. Cruveilhier first described the Q-angle in 1840 (Paulos et al., 1980), observing that a contracting muscle seeks the shortest route between origin and insertion. He noted that "the tendon of the triceps femoris (quadriceps) is directed downward and slightly inward and the ligamentum patellae downward and slightly outward, so that the tendon and the ligamentum patellae form an obtuse angle open laterally" (Paulos, et al., 1980 pg 1625).

With the knee fully extended, the Q-angle is defined as the angle created by a line extending down the anterior aspect of the thigh from the anterior superior iliac spine bisecting the anterior surface of the patella in the saggital plane. This is intersected by a second line drawn from the tibial tubercle extending through that same point on the patella (Percy & Strother, 1985) (Fig. 11). The average Q-angle for men is 14º: for women it is 17º(Percy & Strother, 1985). Angles greater than 20º are considered abnormal (Levine, 1979).

Because the origin and insertion of the quadriceps can be lateral to the patella, abnormally high Q-angles can result in lateralization of the patella when the quadriceps muscle contracts. Thus, the quadriceps, in following its shortest course, creates a lateral vector force and pulls the patella laterally. This lateralization is thought to be the precursor to malalignment syndromes of the patella. Insall, Falvo, & Wise, (1976) reported that 40 of 83 patients (48%) with chondromalacia patellae had an abnormal Q-angle (greater than 20º). Grana and Kreigshauser (1985) reported that 49 of 88 (56%) recurrent dislocating knees had abnormal Q-angles (greater than 10 to 12 degrees in males and 15 to 18 degrees in females).

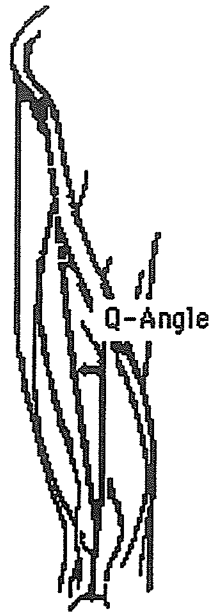

Figure 11. The Q-angle, which may indicate patellar tracking problems, is formed by two lines, one drawn from the anterior superior iliac spine through the center of the patella, and the second from the tibial tubercle through the center of the patella (As redrawn according to Huberti & Hayes, 1982).

Minkoff & Fein (1989) did not agree with generalizing the effect of an increased Q-angle, arguing that the Q-angle, as traditionally defined, might only reflect an alignment deviation of the extended knee and not a pathological anomaly. They stated that a pathological Q-angle was too often diagnosed when, in fact, a simple muscle contraction could realign the patella.

A smaller than normal Q-angle has been considered to be just as harmful as one that is too large (Huberti & Hayes, 1982). Changes in the Q-angle could occur with contraction of the hamstrings because they medially and laterally rotate the tibia, thereby increasing or decreasing the Q-angle (James, 1979). During the first 20º of flexion, the tibia medially derotates from its extended position and effectively reduces the Q-angle (Ficat et al., 1979.) Terry (1989) felt that before changes in the Q-angle can be labeled pathognomonic, the angle must be measured in 45º flexion and lateral patellar hypermobility must also be demonstrated. Minkoff & Fein (1989) cautioned that the Q-angle should be considered a causal factor in patellar deviation only when associated with other signs of lateral instability.

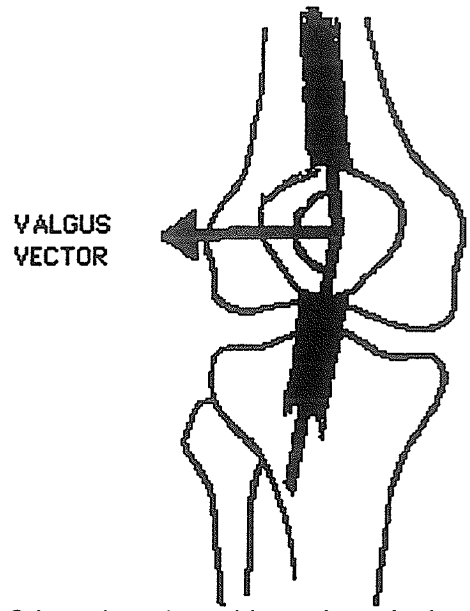

Figure 12. Orientation of quadriceps force in the coronal plane. Valgus vector determines patellofemoral joint pathology (Hungerford & Barry, 1979).

Ficat et al., (1979) felt that the Q-angle was so important that they referred to it as "the Law of Valgus". The lower extremities of bipeds are angulated towards the midline. In humans, the quadriceps follow the longitudinal axis of the femur. This valgus position of the femur and quadriceps alignment is represented by the socalled q-angle open laterally (Figure 12). They put forth morphological evidence to substantiate that this angulation was not a "twist of fate" but, in fact, a deliberate evolutionary change unique to the bipedal animal and refined in the human species. As evidence, they noted that the lateral trochlear prominence is greater than the medial trochlea, both in size and anterior projection, and that a type II Wiberg patella (with its larger lateral facet) is the most common patellar shape. Rather than regard these alterations as dysplastic, they postulated that they should be accepted as normal structural adaptations in response to the Q-angle and bipedal locomotion.

Minns, Birnie, & Abernathy, (1979) measured the patellofemoral forces with changing Q-angles and found that the angle decreased normally from 15º to 5º with flexion and that this significantly reduced the patellofemoral forces. They noted that if the Q-angle did not decrease normally, the compressive loads could be pathologically significant. The Q-angle was therefore considered to be "the most important factor in the production of high tensile stresses on the medial and, in particular the odd facets" (Minns et al., 1979, pg 709).

Patellofemoral Joint Reaction Forces (Figure 13)

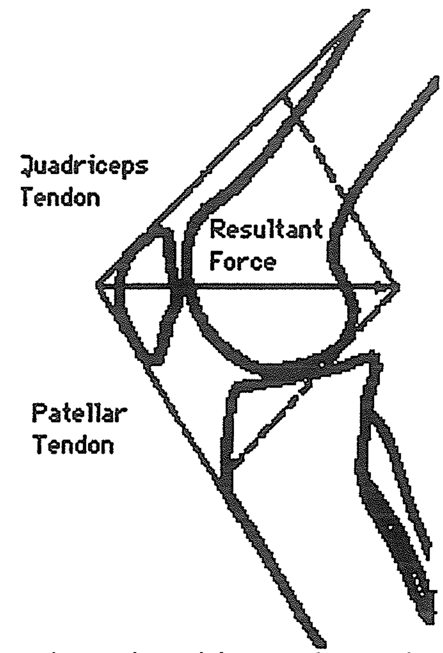

Figure 13. Patellar forces on femoral condyles are the result of quadriceps tension acting perpendicular to the articular surfaces (Percy & Strother, 1985).

In addition to the vector force pulling the patella laterally, a resultant force compresses the patella against the underlying femur. This causes a compressive force referred to as the patellofemoral joint reaction force (PFJR).

Reilly & Martens (1972) have been widely quoted for their work in calculating these forces. They reported that, during walking the compressive force through the patella is equal to 0.5 times body weight; climbing and descending stairs generates a compressive force equal to 3.3 times body weight and deep knee bends create a force 7.6 times body weight. Huberti & Hayes (1982) reported that at 90º flexion the contact pressures were almost twice those calculated by Reilly and Martens (1972), further emphasizing the magnitude of the stress on the patellofemoral joint. These figures may provide some insights into the activities that precipitate anterior knee pain. Activities that require repetitive strong quadriceps muscle contractions and knee flexion could result in microtrauma to the patellofemoral joint. Reilly and Martens (1972) reported that active leg extension exercises using a weight boot created a peak joint reaction force of 1.4 times body weight at 36º flexion. On the other hand, straight leg raises provided minimal joint compressive forces (0.5 times body weight) and were therefore a more appropriate quadriceps exercise for patients with anterior knee pain.

Patellofemoral Contact Areas (Figure 14)

In full extension, the patella lies proximal to the trochlea over the suprapatellar fat pad. Assuming that the line of force generated by the quadriceps with the knee at 0º flexion is parallel to the femur, little or no joint reaction force occurs as a consequence of muscle contraction (Reilly & Martens, 1972).

During knee flexion, the contact area on the patella moves from distal to proximal whereas the femoral contact areas move from proximal to distal (Fig. 14). At 20º flexion, patellar contact area encompasses the full breadth of the lateral and medial facets of the patella exclusive of the odd facet. Between 20º and 90º degrees flexion, the contact area migrates proximally and remains relatively unchanged in its breadth but does increase in its total surface contact area. Hungerford & Barry (1979) studied four cadavers and reported average contact surface areas of the patella to be 2.0 cm^2 at 30º, 3.1cm^2 at 60º, and 4.7cm^2 at 90º. Increased contact area presumably compensates for increased joint reaction forces with increased flexion, however, the increased contact area is not enough to maintain an absolute constant relative to the forces being generated (Hungerford & Barry, 1979). In a study of twelve fresh-frozen human joints with visibly intact articular cartilage, the average contact area increased 60% while the average pressures doubled between 20º and 90º of knee flexion (Huberti & Hayes, 1982). This results in an increase in compressive load per unit area with flexion (Hungerford & Barry, 1979). During extension the opposite occurs: quadriceps force increases while the patellofemoral contact area decreases.

At 90º knee flexion, the patellar contact area involves the proximal articular limits of both patellar facets. The patella is now in contact with the femoral condyles rather than with the trochlear surface (Hungerford & Barry, 1979). Beyond 90º flexion, the patella rotates medially on its longitudinal axis and the contact surfaces on the medial and lateral surfaces of the patella are clearly distinct. The medial facet is no longer in contact with the medial femoral condyle. Contact has shifted from the median ridge to the secondary ridge, which divides the odd facet from the medial facet. This is thought to be a point where high compressive forces are generated and is a common site for degenerative changes (James, 1979). At 135º flexion, the odd facet, for the first time, engages with the articular surface of the femur on the lateral aspect of the medial femoral condyle. This contact point on the medial femoral condyle is the same point where the femur articulates with the intercondylar eminence of the tibia in full knee extension and is an area where osteochondritis dissecans is often noted to occur (Ficat, et al., 1979).

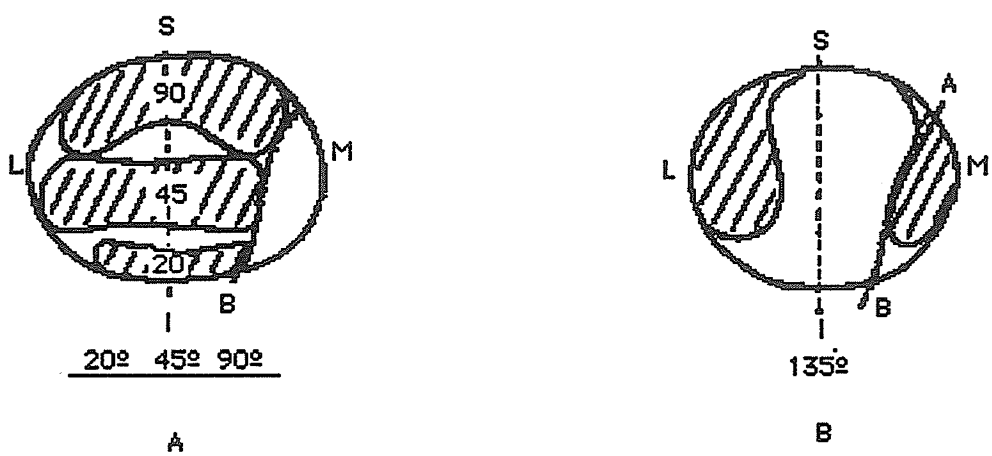

Figure 14. Diagramatic representation of contact areas on the patella in varying degrees of flexion S= superior, m=medial, l= lateral. Line AB represents the secondary ridge between the medial and odd facet. (Goodfellow, 1983).

The quadriceps tendon contacts the femoral trochlea at 90º flexion and absorbs some of the compressive force. Also at this point, the tendon presents a more extensive surface area for articulation than does the proximal patella (James, 1979). However, at 120º flexion the tendofemoral component absorbs only about 45% of the patellofemoral pressures (Huberti & Hayes., 1982). This indicates that the patellofemoral joint must assume the largest proportion of the compressive forces. Huberti & Hayes (1982) measured contact pressures at four different degrees of flexion and three different Q-angles and noted that an increased or decreased Q-angle markedly distorted the contact areas. Obviously, any deviations from normal may cause abnormal contact pressures beyond the physiological capacity of the articular cartilage.

Patellar Position

Abnormal alignment of the patella has been implicated as a cause of patellofemoral pain syndrome. The patella can deviate from the so called ideal position in either a proximal/distal direction, a medial/lateral direction or in a rotary fashion about the long axis of the patella.

Patella alta refers to a high riding patella in which the initial position with the knee fully extended is higher than normal above the trochlear facet. In the normal joint, the patella becomes seated in the trochlea as the knee approaches 30º flexion. With patella alta, seating of the patella within the stable confines of the trochlear groove occurs later in flexion. This means that the joint is unstable for a longer period of time in the early stages of flexion. The result can be excessive contact pressures applied to parts of the articular cartilage ill-equipped to withstand the stress. The reason for this is that abnormal patellar tracking does not allow increasing patellofemoral contact area to occur in synchrony with increasing patellofemoral load. Patella alta is thought to interfere with normal tendofemoral contact and thus limit load bearing capacity of the quadriceps tendon (Huberti & Hayes, 1982). Patella alta is vulnerable to lateral tracking because the patella is allowed to ride over the lateral femoral condyle instead of moving within the confines of the trochlea. This increases the patellofemoral compressive force on the lateral patellar facet (Grana & Kreigshauser, 1985). Hungerford (1979) stated that the degree of knee flexion when the patella becomes stabilized within the trochlea depends solely on patellar tendon length.

Patella baja, on the other hand, refers to a low riding patella and is caused by a relatively short patellar tendon. Although it is relatively stable and prevents dislocations or subluxations, patella baja may be associated with excessive patellar compression because the patella tends to be pulled into the trochlear groove earlier and with greater compressive force. Patella baja is not noted as being a common cause of patellofemoral pain. Insall & Salvati (1971) referred to it only with respect to an overagressive surgical repair for patella alta when the patellar tendon was relocated too far distally.

Measurement of the Patella

There are a number of ways to measure the relative height of the patella radiographically. Bluemensaat's line, which is the earliest described technique, is derived from a lateral view of the knee with the knee flexed 30º (Carson, 1985). A line is drawn along the dome of the intercondylar fossa (seen on a lateral x-ray as a dense line) and extrapolated anteriorly to meet the patella. If the patella lies above this line, the patella is said to be high riding. This technique relies on accurate positioning of the knee at 30º. Carson (1985) noted the angle created by Bluemensaat's line and the longitudinal axis of the femur, as measured on x-ray, can vary between 27º and 60º degrees, thus raising suspicion about the reliability of Bluemensaat's line in estimating the height of the patella.

Another measurement technique was developed with the knee flexed 90º (Carson, 1985). A line is drawn along the anterior femoral shaft towards the patella. Normally the line should intersect with the superior pole of the patella. If the patella lies above this line, it is referred to as patella alta: if below, as patella infera (baja). No method of deriving a statistical measurement was described for this technique.

Insall and Salvati (1971) proposed an easier and apparently more accurate measurement by quantifying the length of the patella relative to the length of the patellar tendon (Fig. 15). A normal ratio (P:PT) approaches one and a deviation greater than 20% was said to be abnormal. A ratio less than 0.80 was referred to as patella alta and a ratio greater than 1.20 as patella infera (baja).

Many researchers reported that the root of anterior knee pain was malalignment of the patella, either medially or laterally relative to the midline of the trochlear groove (Fisher, 1986; Fulkerson, 1989; Johnson, 1989; Kramer, 1986; Ober, 1939; Outerbridge & Dunlop, 1975; Paulos, et al., 1980). Any deviation medially or laterally can mean increased contact pressures applied to a part of the patella and/or trochlear surface which would otherwise be ill-equipped to withstand such pressures.

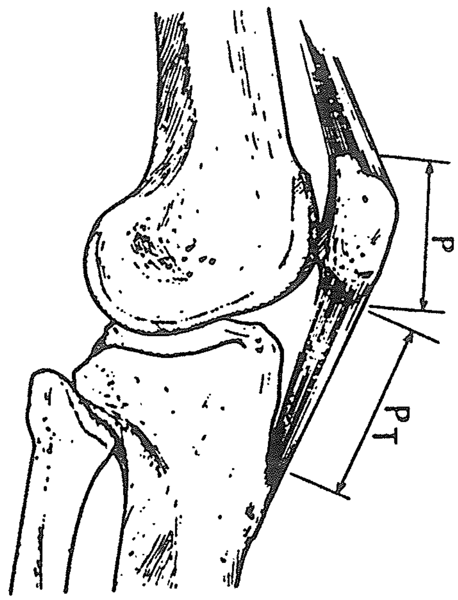

Figure 15. Lateral view of the knee at 30º of flexion will allow for measurement of patellar height. Insall and Salvati measured P (patellar length) vs. PT (patellar tendon), with the normal ratio to be 1 to 1. An increase greater than 20% of PT suggests abnormal patellar height (Mehrdad, M. M. & Mangine, R. E., 1981).

A deviation can also mean that the patellar and femoral surfaces may be receiving too little compression. The health and action of articular cartilage is dependent on effusion of synovial fluid from compression as well as diffusion. Inadequate compression can also lead to eventual deterioration.

The relationship of the patella and the underlying trochlear surface was best evaluated radiographically with a tangential or skyline view of the joint. This axial perspective provides information related to patellofemoral congruence, patellofemoral contact and patellar displacement (Minkoff & Fein, 1989). Congruence of the patellofemoral joint refered to the relationship between the shape of the patella and the femoral trochlea. Dysplasias that altered the shape of the undersurface of the patella or the trochlear surface of the femur would adversely affect the stability of the patellofemoral joint. It was measured by determining the relationship between the angle created by the patellar facets (the patellar facet angle) and the angle of the trochlear groove of the femur (trochlear or sulcus angle).

Tangent offset and bisect offset

Stanford et al., (1988) described tangent offset (Fig. 16A) and bisect offset (Fig. 16B) measurements for lateral patellar displacement. These measurements established reference lines using a predetermined femoral landmark from which other lines were drawn to intersect the patella. The portion of the patella lateral to the intersecting lines was expressed as a percentage of the total patellar width. The main advantage of these measures was that the reference lines were not influenced by rotation of the limb. Stanford et al., (1988) reported that, although there was some difficulty in using bisect offset measurements in full extension, there was a statistically significant correlation between measures at zero and 45 degrees of flexion. Tangent offset measures were also reported to be difficult to determine in full extension because the lateral aspect of the femur, which serves as the marker for the reference line, became more rounded proximally (Stanford et al., 1988).

Lateral patellar displacement was a measure of patellar deviation in relation to the mid point of the trochlear groove. It has been found to be a reasonable indicator for patients suffering from recurrent dislocation of the patella, but a poor indicator of so-called chondromalacia patellae (Laurin, 1983). Sasaki & Yagi (1986) modified Laurin's technique and quantified lateral patellar shift as a percentage of the overall width of the patella. They used computed tomography (CT) scans to compare 24 knees with subluxations of the patella to an asymptomatic control group. The results demonstrated significantly greater measures of lateral patellar shift in the experimental group (Sasaki, & Yagi, 1986).

A number of researchers (Fulkerson, 1989; Kujala, Osterman, Kormano, Komu & Schlenzka, 1989; Schutzer et al., 1986b; Stanford et al., 1988;) have used the congruence angle as described by Merchant, Mercer, & Jacobsen (1974) to determine lateral patellar displacement. A zero reference line was established to bisect the femoral trochlea. A second line was drawn from this point through the most dorsal portion of the patella. The angle created by the two lines described patellar displacement either medially or laterally (Fig. 16D). Because of the difficulty in determining the centre of the posterior projection of the patella, Stanford et al., (1988) did not recommend using this technique with the knee in full extension.

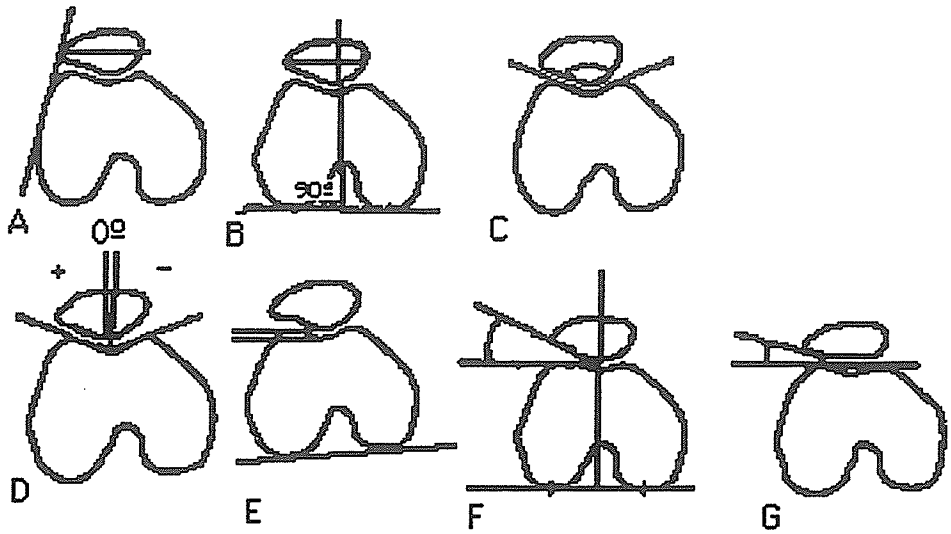

Figure 16. Meaurements of patellofemoral alignment. A Tangent offset, B. Bisect offset, C. Sulcus angle, D. Congruence angle, E. Sulcus depth, F. Patellar tilt angle, G. Lateral patellofemoral angle (Stanford et al., 1988).

Axial views also allowed for evaluation of rotational malalignments of the patella in relation to its long axis. Lateral patellofemoral angle, as described by Laurin, Dussault, & Levesque, (1979) was created by a line tangent to the highest points of the medial and lateral anterior femoral condyles and a second line tangent to the lateral patellar facet (Fig. 16G). This angle was said to open laterally in asymptomatic subjects and parallel or medially open in symptomatic patients. While patellofemoral angle has been accurate in detecting patients with subluxating patellae, it was reported to be not sensitive enough to diagnose patients suffering from patellofemoral chondromalacia (Laurin et al., 1979).

Laurin (1983) described the patellofemoral index as the relative height of the medial patellofemoral compartment to that of the lateral side. The measurement was described as a ratio of the medial distance over the lateral distance, which is one or less in normal individuals. This was thought to be a measure of a "minitilt" for which lateral patellofemoral angle was not sensitive enough to detect. Laurin (1983) reported that this measurement was 93% accurate in detecting the subtle deviations in patients suffering from chondromalacia patellae. This measurement, however, depends heavily on determining the shortest distances within the medial and lateral compartments of the patellofemoral joint, measures that involved considerable estimation.

Fulkerson, Schutzer, Ramsby, & Bernstein (1987) modified the technique for determining lateral patellofemoral angle (Fig. 16F). A horizontal reference line was drawn by connecting the posterior projections of the femoral condyles rather than the anterior reference line used by Laurin (1983). The posterior femoral profile was considered to be less variable than the anterior condylar shape. An accurate measure of changes in lateral patellofemoral angle (patellar rotation) was important because lateral patellar rotation increased the tensile stress (or stretch) on the odd facet medially and shifted the contact area on the lateral patellar facet (Minns et al., 1979).

The sulcus depth was a measure which determined the stability provided by the bony architecture of the femoral trochlea (Stanford, Phelan, Kathol, Rooholamini, El-Khoury, Palutis, & Albright, 1988) (Fig. 16E). It was determined by measuring the distance between a line drawn through the deepest part of the trochlear groove and a second parallel line drawn tangent to the most anterior projection of the lateral femoral condyle. This measurement was not possible with the knee in full extension because the patella migrated cephalad above the levels of the condyles (Stanford et al., 1988).

Problems with Radiological Measurement

Conventional radiography is a poor technique for imaging the patellofemoral joint because the knee must be in at least 20º degrees flexion and malalignment due to soft tissue influences is most evident in the first 30º of flexion (Delgado-Martins, 1979; Minkoff & Fein, 1989 Hungerford & Barry, 1979). Many of the pathologically significant malalignments are therefore reduced in ranges beyond 30º flexion and can go undetected (Schutzer, et al., 1986b). Proper imaging of the patellofemoral joint, therefore, must be captured between 0º and 30º flexion where malalignment is most likely to occur (Schutzer et al., 1986b).

In addition, patellar position with the knee in a static position may be very different from what occurs during active motion. Sasaki & Yagi (1986) examined the change in patellar position during an isometric muscular contraction at 0º flexion. Their study of 24 control and experimental subjects reported a significant increase in lateral shift of the patella (+27.7%) in subjects with subluxating patella compared to the normal control group (+14.0%). Stanford et al., (1988) studied the influence of muscle contraction and dynamic motion on patellar position using ultrafast computed tomography on 18 male and female patients. A series of images was taken at various points throughout the whole range of motion as the patient moved from 90º flexion to full extension. The images were reconstituted as a dynamic cine-playback. Two patterns of patellar movement were observed. In the first instance the patella would centre in the trochlear groove at 90º and remain centered through to full extension. In other patients, the patella would be centered until the last 20º of extension when it would then move laterally (Stanford et al., 1988). It was not indicated if there was a pattern which was more prevalent within the groups or if there were any significant gender differences. One potential problem with dynamic imaging may be that the images do not represent real-time depiction of knee motion (Conway et al., 1991). It is yet to be determined whether or not this is of any clinical significance

Magnetic resonance imaging (MRI) is a new imaging technique in which the greatest advantage over other imaging techniques is the absence of any risks from radiation (as in CT scan and x-ray) to the patient (Conway et al., 1991). Conway et al., (1991) reported that many of the measurements using MRI are also possible through CT Scanning, including images within the 0º to 30º range of motion. MRI, however, can also clearly show articular cartilage (Conway et al., 1991).

Pathomechanics

Injury to the patellofemoral joint can result through a number of mechanisms. Direct trauma is an obvious cause but is not always indicated as the primary cause of injury (MInns et al., 1979). Thus, although direct trauma has been implicated as a possible cause of cartilage destruction, it is thought to be of more importance as an aggravating factor rather than as a primary cause (Minns, et al., 1979; Donohue, Thompson, & Oegema, 1982). Insall et al., (1976), however, found that 40 of 105 patients with patellofemoral pain reported that a direct blow preceded their symptoms. When trauma is the injurious factor, it sometimes involves the static restraints. Thus, a laterally dislocating or subluxating patella could stretch the medial restraining structures causing patellar instability and lateral deviation and eventually predisposing the articular surface of the patella to chronic stress and eventual breakdown (Grana & Kreigshauser, 1985).

Patellar subluxations and dislocations can also cause acute damage to the articular cartilage as the patella is dragged over the lateral femoral condyle (Insall et al., 1976). The articular cartilage can be acutely injured due to direct impact which then initiates a cascading degenerative process.

In most instances, overuse is said to be the primary mechanism of injury to the patellofemoral joint (James, 1979). Paulos et al., (1980) listed three causes of patellofemoral pain, including patellofemoral configuration, supportive structure deficiencies, and malalignment of the lower extremities

Patellofemoral Configuration

With normal patellofemoral configuration, the patella and the patellar surface of the femur are closely associated and interrelate to provide a stable, efficient joint. Dysplastic shapes of either osseous contributor, as previously described, will promote improper patellar tracking and consequent abnormal compressive forces on the articular surface.

Supportive Structure Deficiencies

Malalignment of the patella is generally in a lateral direction due to a relative imbalance in muscle strength between the vastus lateralis and the vastus medialis (Paulos et al., 1980). An effused knee is thought to cause a reflexive inhibition of the surrounding musculature, in particular the vastus medialis (Grana & Kreigshauser, 1985). This can be the precursor to overuse of the patellofemoral joint (Grana & Kreigshauser, 1985). Relative muscle imbalances can also be due to adolescent growth spurts. Rapid skeletal development without an accompanying increase in muscular length can cause lateral tracking of the patella or transient dysplasia (Grana & Kreigshauser, 1985). Finally, rehabilitating a previously injured knee must progress with caution so as not to induce undue patellar stress until the surrounding musculature is sufficiently strengthened to maintain proper patellar alignment.

Deficiencies in the static stabilizers can occur as a result of a previous traumatic event. In addition to acute subluxations and dislocations, medial parapatellar incisions at surgery can destroy or weaken the medial restraining tissues, causing iatrogenically induced patellofemoral pain (Insall et al., 1976; Ober, 1939). Patella alta may increase stress to the articular cartilage, because, as previously described, the patella is late in entering the trochlear groove during flexion, and therefore unstable for a longer period of time. This can result in an erratic excursion of the patella on the articular surfaces of the femur. Changing the normal tracking of the patella may also excessively stress its articular surface. Perhaps more importantly, patella alta limits the function of the quadriceps tendon as a load bearing structure such that the patella is required to bear a load far exceeding its physiological capacity (Huberti & Hayes, 1982).

Patella alta may also affect the mechanical advantage of the vastus medialis oblique. With the patella positioned more proximally, the vastus medialis is shortened and this may limit its force generating capacity and promote a muscular imbalance (Huberti, & Hayes, 1982).

Malalignment of the Extremities

Malalignment of the extremities can include an accentuated Q-angle, genu varum or valgum, tibial varum or valgum, femoral or tibial rotations and foot pronation or supination (Insall et al., 1976). Because the lower limb, including the patellofemoral joint, is part of a closed kinetic chain, any one or combination of these structural deviations can affect normal tracking of the patella. Biomechanically induced malalignments will therefore change the weight bearing surface of the patella, possibly concentrating the stresses on smaller or weaker portions of the articular surface.

Mechanical Stressors

Patellofemoral malalignment is most often cited for initiating anterior knee pain because of the resultant abnormal contact pressures applied to the articular cartilage (Insall et al., 1976). In some cases, the pressure may be too much and, in other cases, it may too little. Incongruous patellofemoral joint motion or increased compressive load on the articular surfaces may result in localized stress and be the first step in articular cartilage damage (Grana & Kreigshauser, 1985).

Disuse, rather than overuse, has also been postulated as an etiology of patellofemoral pain. In this case, malalignment of the patella may deprive the medial facet of vital contact pressures which provide the mechanism for adequate nutrition. By comparison, and even though the biomechanics of the hip joint are completely different from those of the knee, chondromalacia of the articular cartilage of the hip joint has been reported to be predominantly on the non-weight bearing articular surface (Insall et al., 1976).

Similarly, lesions on the medial patellar facet might be explained as a consequence of suboptimal loading because the articular cartilage receives inadequate compression and is deprived of its nutritional requirements (Jacobson & Flandry, 1989). The medial facet can be deprived of adequate nutrition due to hypopressure between the medial patella and the femur (Laurin et al., 1979; Jacobson & Flandry, 1989). The resultant cartilage degradation causes fissuring, edema and the release of degradative enzymes (Laurin et al., 1979). The lysosomal activity of these enzymes causes further deterioration of the cartilaginous matrix and, over time, affects the articular surface of the lateral facet. The lateral facet, exposed to greater compressive forces, is then likely to incur further damage which may progress to the subchondral bone and lead to eventual osteoarthritis (Laurin et al., 1979).

The consensus seems to be that excessive compressive load to the undersurface of the patella is the mechanism most responsible for anterior knee pain (Ficat & Hungerford, 1977). Maquet (1984) stated that patellofemoral arthrosis will result when pressure is either unevenly distributed or exceeds normal tissue resistance.

Patellar malalignment may stress patellofemoral structures in addition to the articular surfaces, therefore evaluation of the peripatellar soft tissue is important in the differential diagnosis of patellofemoral pain (Fulkerson, 1989). A tight lateral retinaculum, for example, will be under considerable stress as the patella centers into the trochlea (Fulkerson, 1989). Similarly, the medial retinaculum can be stretched in the case of a laterally deviated, subluxating or dislocating patella. Fulkerson (1989) cited the cases of two patients with hemangioma of the quadriceps insertion on the patella, manifested as anterior knee pain, to illustrate that the quadriceps can also be the source of pain.

Minns et al., (1979) studied 28 cross-sectioned patellar specimens and 28 sky line radiographs using a stress analysis model. They described two stressors which were thought to excessively load the patellofemoral joint:

compressive and tensile stress. They reported that lateral tracking of the patella caused increased compressive forces on the lateral facet and increased tensile stress on the medial side. Increased tensile stress fatigued the collagen matrix due to excessive cyclic action and resulted in eventual cartilage breakdown. This may provide an explanation for lesions involving the medial and odd facet. Injuries to this area of the medial patella are otherwise difficult to explain using the excessive compression model because the areas are seldom in contact with the femur, except during full flexion. It should be noted that resistance to cyclic tensile stress is greater in young cartilage but decreases rapidly with age (Weightman et al., 1978).

Articular cartilage also appears to be vulnerable to injury immediately following immobilization in a long leg cast and following a few postoperative weeks after any arthrotomy (Outerbridge & Dunlop, 1975). This period of vulnerability is said to be a result of disuse and poor nutrition secondary to immobilization (Outerbridge & Dunlop, 1975).

Ultimately it is subchondral bone that is exposed to stress and is the eventual source of pain. "In the final analysis, the causes of all arthrosis can be reduced in one way or another to the phenomenon of excessive pressure" (Ficat & Hungerford, 1977). Even the hypopressure model of Laurin et al., (1979) concedes that it is the hyperpressure on the lateral facet rather than the hypopressure on the medial facet that leads to eventual osteoarthritis. Deterioration of the lateral patellar facet has been termed "Excessive Lateral Pressure Syndrome" (Hungerford, 1983).

Patellofemoral Pain

The exact source of the patellofemoral pain remains somewhat of a mystery. Given that articular cartilage is both avascular and aneural, it cannot be the source of pain (Grana & Kreigshauser, 1985; Mankin, 1974). In addition, arthroscopic assessment indicates that visible cartilage degeneration is poorly correlated to anterior knee pain (Fulkerson, 1989).

Two tissues which are richly innervated with pain fibers are the synovium and subchondral bone. Synovial irritation can be induced by debris within the joint, usually deteriorating articular cartilage, but this is not a characteristic sign of patients with patellofemoral pain (Grana & Kreigshauser, 1985; Insall, et al., 1976; Micheli & Stanitski, 1981).

The subchondral bone is thought to be the most likely source of the pain because it is richly innervated by pain fibres (Minns et al., 1979). Compressive loads transmitted through the articular cartilage to the underlying bone are thought to trigger a painful osseous reaction (Lemperg, 1983). Sclerotic changes as visualized on X-ray, are further evidence of subchondral bone reaction in its later stages (Minns et al., 1979). Subchondral pain may also result from increased venous pressure within the patella (Waisbrod & NOam, 1980; Arnoldi, 1991).

The lateral retinaculum may be also be a source of pain (Fulkerson, 1989). Histological examination has shown neuromatous degeneration of the lateral retinaculum from chronic stress (Fulkerson, 1989). Small nerves in the lateral retinaculum that resemble those found in Morton's neuroma have been identified histologically (Fulkerson, 1989).

A number of other conditions about the patellofemoral joint can present with pain referral patterns that confuse the diagnosis including (Eisele, 1991):

Intra-articular

a) synovitis of the knee

b) rheumatoid arthritis

c) inflammation of the supra patellar plica

Extra-articular

a) Osgood-Schlatter's Disease

b) Larsen-Johansson Disease

c) Bipartite patella

Treatment of Patellofemoral Pain

Strengthening of the Quadriceps

Whether anterior knee pain is the result of hypopressure, hyperpressure, venous engorgement or is secondary to an acute injury, it is generally agreed that the precipitating factor is lateral malalignment of the patellofemoral joint. The vastus medialis oblique is acknowledged to be instrumental in controlling normal alignment. "Whatever the pre-existing structure of the limb, a properly functioning VMO is able to compensate for these imbalances and provide adequate patellofemoral tracking" (Beck & Wildermuth, 1985 pg 348) .

Selectively rehabilitating the vastus medialis is, however, very difficult because it is part of the quadriceps muscle group and thus does not function in isolation from other muscles. If the problem is a strength imbalance between the vastus medialis and lateralis, regaining this balance with voluntary muscle contractions may be difficult. The task would be even more difficult if the objective was to focus specifically on the vastus medialis oblique.

In addition, traditional programs used to increase quadriceps strength require active flexion and extension of the knee, which may cause painful patellofemoral compression. Knee extension utilizing an isokinetic machine increases the patellar tendon and tibiofemoral compressive forces by nine times body weight at slow speeds (30º/sec) and five times body weight at fast speeds (180º/sec) (Brunet & Stewart, 1989). It therefore becomes a "catch-22" that does not offer an easy solution. Nonetheless, the strength of the vastus medialis and vastus medialis oblique need to be developed in preference to strength development of the vastus lateralis if realignment of the patella is to be achieved.

The vastus medialis has shown greater electromyographic activity during "quad sets" (isometric quadriceps contraction) than during straight leg raises, while the rectus femoris has been shown to be most involved during straight leg exercises (Soderberg, Minor, Arnold, henry, Chatterson, Pope & Wall, 1987). Brunet and Stewart (1989) advocated that patients be instructed to do both straight leg raises and quad sets because "when setting the quads before and during the straight leg raises, all of the involved musculature is exercised to its potential" (Brunet & Stewart, 1989 pg 324).

Short arc extension exercises, that is in the last 20º of extension, are employed to strengthen the quadriceps muscles in the range of greatest need for patellar stability and to minimize patellofemoral compression (Brunet & Stewart, 1989). Although short arc exercises have traditionally been used to isolate the vastus medialis, these exercises still involve the whole quadriceps muscle (Packard, 1980). The quadriceps, as a group, are active throughout the whole range of motion and the action of the vastus medialis is not exclusive to terminal extension (Lieb & Perry., 1968). Also important therapeutically is that the quadriceps force required to produce the last 15º of extension is almost twice the force required to move the knee from 90º to 30º extension (Hunter & Funk, 1984). This is because of the sharp decline in biomechanical leverage and is the chief factor in the so called quads lag (inability to actively complete the last 15º of extension). Therefore short arc exercises may not be possible voluntarily if the muscle is too weak to generate the added force required near the end range of motion.

Vigorous isometric exercises have been used to increase vastus medialis strength and improve patellar tracking in the femoral trochlea (Levine, 1979). There is no indication, however, that the vastus medialis can be selectively strengthened with isometric exercises. Garrick (1989) promoted isometric exercises and identified the vastus medialis as the target muscle, but again, did not provide evidence to show how or even if this muscle was strengthened to a greater extent than the rest of the quadriceps muscle. Beck & Wildermuth (1985) advocated that rehabilitation of the extensor mechanism in patellofemoral pain is of little use without first addressing the problem of strengthening the vastus medialis.

McConnell (1987) developed a protocol that involved passive realignment of the patella using specific adhesive taping procedures followed by active exercises to re-educate the firing pattern of the vastus medialis in patients with anterior knee pain. Ninety-two percent of the subjects reported no pain (83%) or decreased pain (8.5%) following treatment.

Electrical Muscle Stimulation (EMS)

Muscle stimulation has been used as a therapeutic adjunct to stimulate quadriceps strength. Garrick (1989) noted that electrical muscle stimulation could be used on the vastus medialis directly, but advocated it as an educational tool to provide biofeedback to patients unable or unwilling to accomplish the task themselves. Fisher (1986) stated that electrical muscle stimulation could be of benefit if the patient was not improving with other strength development techniques. Finally, although a number of authors have mentioned muscle stimulation as part of the therapeutic protocol for anterior knee pain, specific protocols have not been outlined (Outerbridge & Dunlop, 1975; Beck & Wildermuth 1985; James, 1979).

There are a number of studies that have looked at electrical muscle stimulation and its therapeutic effect. Only Johnson et al.,(1977), however, looked at the use of electrical muscle stimulation specifically with reference to the patellofemoral joint. They used the classic Russian 10/50/10 duty cycle protocol (see below) electrical muscle stimulation on the quadriceps muscle and reported strength increases of 25.3% in patients classified with mild patellofemoral pain and a minimum of 200% strength increase in patients classified as suffering severe patellofemoral pain. They did not report maximum strength increases. Bohannon (1983) reported a case study on the efficacy of electrical muscle stimulation on a patient with chronically dislocating patellae. A 29 year old male with a history of dislocating patellae (as often as 30 times per day) with every maximal contraction of the quadriceps, used electrical muscle stimulation of the vastus medialis over a six week period. Lateral dislocation of the patella during a maximal muscle contraction was prevented when combined with electrical muscle stimulation. Unfortunately, the effects were not maintained when contractions were performed without electrical assistance. This study, did, however, demonstrate that strong contraction of the vastus medialis could prevent excessive lateral deviation of the patella. It could be surmised that this patient's instability was too great to be compensated for with an increase in muscle strength alone or that a longer treatment period may have demonstrated some positive effects.

Since the presentation by Kotz (1977) on the Soviet technique of electrical muscle stimulation during a symposium at Concordia University, many studies have tried to replicate or substantiate his claims. Kotz (1977) reported that muscle stimulation could elicit strength gains of as much as 30-40 percent in normal muscle. The most effective duty cycle (on/off/repetition) was reported to be a ten second maximally tolerable muscle contraction followed by a 50 second rest period which was repeated for ten contractions on alternate days (10/50/10) for a total of 20 sessions (Cummings, 1980).

A number of review articles on EMS indicated that comparisons between studies are very difficult because of the wide range of treatment parameters used or left unreported (Lloyd et al., 1986).

Appendix A lists a summary of the research in this area. As noted, comparisons between studies are difficult because of the considerable variability in treatment parameters and differences in study design, stimulator characteristics and training regimes. Other factors that make comparisons difficult include whether the stimulation was of normal or atrophied muscle, the placement of the electrode, motivational factors, testing techniques and comparative exercise groups (Lloyd et al., 1986).

Effectiveness of Electrical Muscle Stimulation (EMS)

A number of studies conducted on normal subjects have reported that strength gains following electrical muscle stimulation alone were significantly better than for controls who did not exercise (Currier, Lehman & Lightfoot, 1979; Currier, & Mann, 1983; Halbach & Straus, 1980; Kramer,Lindsay, Magee, Mendryk & Wall, 1984; Kramer, 1983; Laughman, 1983). However, these same studies reported that strength gains after EMS were not significantly better than gains in subjects who used isometric exercise alone or those who used EMS superimposed on isometric exercise. Selkowitz (1985) reported that subjects training with EMS showed significant improvement compared to subjects training with isometric knee extensions. Gould, Donnermeyer, Pope & Ashikaga, (1982) reported significant strength increases in plantar and dorsi flexors but not in hamstrings or quadriceps.

Few researchers have studied patient populations and the effect of EMS on atrophied or injured muscles. As mentioned earlier, Johnson et al., (1977) and Bohannon (1983) studied patients with patellofemoral pain. Other researchers studied subjects with pathologies about the knee other than patellofemoral pain. Eriksson and Haggmark (1979), for example, studied the effect of EMS on patients recovering from anterior cruciate ligament reconstruction. They reported decreased atrophy and higher succinate dehydrogenase (SDH) activity in patients treated with EMS and thought this to be an indicator of an increase in the muscle's oxidative activity. Curwin, Stanish & Valiant (1980) found similar results in patients who demonstrated an increase in ATPase as compared to a control group after surgery for anterior cruciate repair. Godfrey, Jayawardena, Quance & Welsh, (1979), reported that EMS was as effective as isometric exercise but did not compare the results to control subjects. Morrissey, Brewster, Shields & Brown, (1985) reported that EMS limited the loss of strength to 60% in knee immobilized patients while the control group lost 80% of their pre-immoblization strength. Singer (1986) found significant strength increases (22%) in the stimulated leg as well as in the contralateral non-stimulated quadriceps (14%) .

Other researchers have reported no significant difference between EMS and voluntary contraction in strength development. Plevney and Nutter (1982) used a random cross over design testing 16 females and introduced two exercise bouts of 15 contractions which included a pre and post test. The first session involved maximal voluntary isometric contractions (MVIC) and the second session utilized electrical muscle stimulation (EMS), both at 60º of knee flexion (Plevney & Nutter, 1982). The results showed that, although the EMS group showed increasing torque measures during the 15 exercise sessions and the voluntary contraction group actually decreased in measurable torque from repetition one to fifteen (fatigue), the voluntary contraction group demonstrated significantly greater cumulative training torque for all repetitions. Lainey, Walmsley, and Andrew (1983) reported no significant difference between EMS and isometric exercise but did note that, in their double cross over design, the EMS group showed a greater mean increase (39.5%) than the exercise group (7.4%) during weeks 3 to 6 of training. A further study reported that the overall increase in strength using the combined training methods (exercise alone/stimulation alone/stimulation with exercise) over a six week period produced significant strength gains of 191.3 percent (Lainey et al., 1983). McMiken, Todd-Smith, and Thompson (1983) did not demonstrate any significant difference between EMS and isometrics. Mohr, Carlson, Sulentic, and Landry (1985) compared the use of High Voltage Galvanic Stimulation

(HVGS) to produce isometric contraction with maximal voluntary contractions over 15 exercise sessions. The results showed that EMS was not as effective as MVC. DeDomenico and Strauss, (1986) also reported that EMS could not produce quadriceps torque measures greater than maximal voluntary contraction.

Variations in EMS Applications

Duty Cycle

The duty cycle, or stimulation/rest time, and the number of contractions per sessions varies from study to study. Many studies used the (10/50/10) protocol advocated by Kotz (1977); a ten second contraction interspersed by a 50 second rest period and ten contractions per session (Cox et al., 1986; Godfrey et al., 1979; Halbach & Strauss., 1980; Hartsell, 1986; Johnson, Thurston & Ashcroft, 1977; Kramer, 1983; Lainey et al., 1983; McMiken et al., 1983; Soo, Currier, & Threlkeld, 1988; Stefanovska & Vodovnik, 1985). Other researchers used slightly longer stimulation times (15 seconds) while maintaining the same rest time and number of contractions (15/50/10) (Currier & Mann, 1983; Godfrey et al., 1979; Laughman, 1983; Plevney & Nutter, 1982). Still others used even shorter stimulation times, ranging from 2 to 10 seconds (Currier et al., 1979; Eriksson et al., 1979; Kramer et al., 1984; Romero, Stanford et al., 1982). Cox et al., (1986) measured the effect of electrical muscle stimulation on quadriceps torque using three different rest intervals (35, 50 and 60 seconds). The results showed that 50 and 60 second rest intervals produced similar fatigue levels whereas a 35 second rest interval was associated with significantly greater fatique. Selkowitz (1985) and Walmsley, Letts & Vodis, (1984) used a two minute rest period as opposed to 50 seconds. Selkowitz (1985), who reported significantly better strength increases using EMS as opposed to isometrics, concluded that the results may have been due to a two minute rest time and consequently better recovery between contractions.

Sessions Per Week

The number of sessions per week reported in the literature ranged from 2 to 5 and the number of weeks ranged from 2 to 8.5 (Appendix 1). Gould et al., (1982) stimulated his subjects at a rate of 25 contractions per hour for 16 hours per day for two weeks. No consensus on the ideal number of days per week or number of weeks of training has been established.

Pulse Frequencies

Pulse frequencies used to stimulate muscle also vary widely in the literature. Frequencies as low as 5 Hz and as high as 4100 Hz have been reported (see Appendix A). Cummings (1980) reported that Kotz used 2500 Hz modulated to 50 Hz. Frequency was based on work with animals which showed that maximum tension of the slow twitch muscle fibres was achieved at a rate of 5 -10 Hz while fast twitch muscle fibres had a maximum firing frequency of up to 150 cycles per second (Cummings, 1980). Medium twitch (fast oxidative glycolytic) fibres have a firing range of 30 to 50 Hz.

Low frequency stimulators presently on the market are generally in the range of 10 to 100 Hz while medium frequency stimulators are 2500 Hz. The so-called medium frequency stimulators are, in fact, modulated into packets of pulses which ultimately deliver bursts in the range of 50 Hz (Lloyd et al., 1986). Therefore, there may not be much difference between the low and medium frequencies (Lloyd et al., 1986). Medium frequency stimulators are said to provide for greater patient comfort in that the higher frequencies overcome pain sensitive skin resistance. Electrical current which is less painful is said to allow greater stimulus intensity and maximize motor unit recruitment (Cummings, 1980). Many of the studies (see Appendix A) have used stimulation frequencies ranging between 25 and 100 Hz (Cox et al., 1986; Currier et al., 1979; DeDomenico & Strauss, 1986; Godfrey et al., 1979; Gould et al., 1982; Hartsell, 1986; Johnson et al., 1977; Kramer et al., 1984; McMiken et al., 1983; Mohr et al., 1985; Morrissey et al., 1985; Singer, 1986; Soo et al., 1988; Walmsley et al., 1984). Others have used a stimulation frequency of 2500 Hz modulated to 50 Hz (Currier & Mann, 1983; Garrett et al., 1980; Laughman, 1983; Plevney & Nutter, 1982; Selkowitz, 1985 ; Soo et al., 1988).

Lainey et al.,(1983) and Walmsley et al., (1984) used interferrential current stimulators which utilized two generators. One generator delivered a 4000 Hz frequency crossed by a second frequency of 4100 Hz. At the point of intersection (interference) the currents were said to cancel each other out except for a resultant current of 100 Hz (Lainey, et al., 1983; Walmsley, et al., 1984). Strauss & Domenico (1986) used a similar machine but varied the frequency differential to create a pulse frequency which varied between 50 and 80 Hz. Stefanovska and Vodovnik (1985) used two stimulators to compare a high frequency sinusoidal waveform (2500 Hz/25 pps) to a low frequency rectangular waveform (25Hz). The results demonstrated that isometric torque increased 25% in the low frequency stimulated group as opposed to only 13% in the high frequency stimulated group. It was surmised that an increased fatigue factor was encountered with high frequency stimulation because it selectively stimulated the type II, fast twitch, easily fatigueable muscle fibers (Stefanovska & Vodovnik, 1985).

Other studies have used varying frequencies, including 5 Hz (Halbach & Strauss, 1980), 200 Hz (Eriksson & Haggmark, 1979) and 2000 Hz (Romero, Sanford, Schroeder & Fahey, 1982). A study to determine the mean firing rate of a supramaximal stimulation superimposed on a maximum voluntary contraction produced rates of 31.1 Hz, 29.9 Hz and 10.7 Hz for the biceps brachii, adductor pollicis longus and soleus muscles respectively (Lloyd et al., 1986). This suggests that the maximum firing frequency during a maximum voluntary contraction could be less than 100 Hz. In addition, there is little rationale for using larger frequencies (Lloyd et al., 1986). It is generally accepted that gradually fusing tetany occurs at frequencies greater than 20 Hz but that the optimal frequency is still undetermined and probably differs between muscle groups (Lloyd et al., 1986).

Electrode Placement

Literature reports regarding electrode placements are also varied. Generally, bipolar or monopolar electrode placement techniques have been used. Bipolar electrode placement involves the placement of electrodes over the proximal and distal ends of the muscle belly. The stimulus depolarizes the muscle membrane directly, bypassing the nerve and motor end plate. In monopolar electrode placement the anode (indifferent electrode) is placed over the nerve innervating the muscle and the cathode (active electrode) over the motor point of the muscle.

Stimulating the quadriceps muscle using the bipolar technique calls for the electrodes to be placed on the proximal and distal ends of the quadriceps. The monopolar technique places one electrode over the femoral trunk in the area of the femoral triangle and the distal electrode over the motor point of the vastus medialis (in the case where selective stimulation of this muscle is desired). Benton, Baker, Bowman & Waters, (1981) stated that the monopolar technique is preferred because the excitation threshold of nerve is lower than that of muscle, allowing for greater motor unit recruitment. The monopolar technique is said to innervate deeper muscle fibers as compared to the bipolar technique (Cummings, 1980).

Hartsell (1986) compared monopolar and bipolar electrode placements with a stimulation frequency of 65 HZ. The results indicated that the monopolar technique was more specific to the muscle for which the motor point was being stimulated. The monopolar technique was positively associated with increases in power while the bipolar technique was positively associated with increased endurance.

For vastus medialis, the bipolar technique places the electrodes at the proximal and distal ends of the muscle. However, the proximal end of the vastus medialis is very difficult to access owing to its extensive origin along the medial portion of the linea aspera on the posterior aspect of the femur. Presumably, the electrodes were placed on the proximal portion of the vastus medialis at the point where it becomes prominent on the anterior aspect of the thigh. This would therefore stimulate only a portion of the vastus medialis. Cox et al., (1986) reported that a monopolar electrode technique, placing the anode over the lumbosacral plexus and the cathode over the femoral nerve in the femoral triangle combined with a 50 second rest interval was the most clinically viable protocol in terms of developing high intensity contractions with low torque decrement (fatigue). This technique presumably stimulated the entire quadriceps equally because the motor nerve is the target for stimulation (rather than individual muscle groups). The monopolar technique, as described by Hartsell (1986), would also presumably stimulate the motor nerve for the whole quardiceps muscle (femoral nerve). At the same time, the active electrode over the motor point of vastus medialis would selectively stimulate the vastus medialis.

In summary, patellofemoral pain syndrome appears to be a consequence of malalignment of the patella and that a strength imbalance between the vastus medialis and vastus lateralis is the cause for this malalignment. Electrical muscle stimulation has been used therapeutically to regain muscle balance. The purpose of this study is to measure the effect of electrical muscle stimulation on isometric strength of the quadriceps, patellar position and patlellofemoral pain.

Chapter III

METHODOLOGY

Call For Subjects

A call for subjects was sent to orthopedic surgeons in the Winnipeg area requesting their cooperation in referring patients according to the inclusion criteria (Tables 1 and 2 and Appendix B). Physicians were provided with a referral form (Appendix C) to be returned with the patient. The criteria and referral form were reviewed and approved by the Faculty Committee on the Use of Human Subjects in Research, Faculty of Medicine, University of Manitoba.

INCLUSION:

To be eligible the subject must be between 16 and 35 years of age and diagnosed by the referring orthopedic surgeon with patellofemoral pain exhibiting at least two of the following:

1. Pain on direct compression followed by proximal to distal mobilization against the femoral condyles with the knee in full extension.
2. Tenderness on palpation of the medial retinaculum or undersurface surface of the patella.
3. Pain on resisted knee extension with the knee in 20 degrees flexion.
4. Retropatellar pain with quadriceps contraction against manually applied suprapatellar resistance with the knee in slight flexion (Clarke's Sign)
5, Positive Movie Sign ie. retropatellar pain upon rising after long periods of sitting.
6. Retropatellar pain when using stairs especially going down.
7. Signed consent form.

Table 1 Inclusion criteria for subjects

Exclusion:

Subjects with any of the following history will be excluded:

1. History of acute patellar trauma as the cause of the present signs and symptoms.
2. History of subluxating or dislocating patella.
3. Confirmation of ligamentous, meniscal or fat pad damage as a source of the present signs and symptoms.
4. Evidence of referred pain from the back or hip.
6. Osteochondral or chondral fractures.
7. Radiological evidence of degenerative disease.
8. Postural disorders as observed by the referring physician such as genu recurvatum, genu valgum, foot pronation, femoral anteversion / retroversion.
9. Upper or lower motor neuron lesion.
10. Previous or pending knee surgery for this injury.

Table 2 Exclusion criteria for subjects

Subjects

A total of 19 subjects between the ages of 16 and 37 years of age participated in the study. The treatment group consisted of 11 subjects (8 females and 3 males) and the non treatment group 8 subjects.Four subjects participated in a cross-over design (see below). Wise, Fiebert & Kates, (1984) reported that patellofemoral pain occured equally in males and females between the ages of 15 and 25. The limb which gave the greatest pain was used as the experimental limb in patients with bilateral patellofemoral pain. Although daily activity was not strictly monitored, subjects were asked to refrain from any other form of therapy or exercise related to their knee pain other than medications provided by their physician and ice or heat to control pain and swelling.

Experimental Design

As noted previously, all subjects in this study were included on the basis of their knee pain. Asymptomatic ("normal") subjects were purposefully not included. The reasons for not including mormal subjects in the design are:

1) Sasaki and Yagi (1986) reported that 22% of their asymptomatic subjects presnted with malalignment of the patella. It may not be ethically appropriate to render this treatment to asymptomatic subjects.

2) Although there is minimal risk of injury or harm from any of the procedures, two procedures (EMS and CT Scan) are in fact invasive. There is, therefore, the ethical question of subjecting normal individuals to invasive procedures.

3) The data from normal subjects would be of limited significance, as comparisons/relationships to pain would not be available and also because EMS is of limited value in strengthening normal muscle.

Subjects who qualifyied for the study according to the inclusion and exclusion guidelines outlined in Tables 1 and 2 were randomly assigned to a treatment and non treatment group. The non treatment group was evaluated using Kin Com isokinetic testing, McGill pain questionnaire, and CT scan imaging. After the pretest, the nontreatment subjects were instructed to continue with their normal daily activity but to refrain from any activity or treatment related to their knee pain other than application of ice packs. No subjects were on medications for their patellofemoral pain. These non treatment subjects were offered the option of receiving treatment after the six week non treatment period. Following the six-week non treatment period, four of these subjects began treatment.

The treatment group received the same pretest protocol as the non treatment group, but this group received electrical muscle stimulation of the vastus medialis superimposed over a maximal voluntary contraction three times per week for six weeks. Both groups were tested as in the pre-test six weeks following the pre-test. Data from the four subjects who participated in both groups were extracted and analyzed separately in a cross over design format (Hassard, 1991).

Procedures

Consent Form

A consent form which explained the testing and treatment procedures to be implemented in the study was signed by each subject (APPENDIX C). The consent form was approved by the Faculty Committee on the Use of Human Subjects in Research, Faculty of Medicine, University of Manitoba in 1991.

Random Assignment

After completing the consent form acknowledging their understanding of the procedures and voluntary willingness to participate in the study, subjects were randomly assigned to the treatment group or the non treatment group using a table of random numbers. Subjects assigned to the non treatment group were informed that they could access the treatment protocol after the six week period of no treatment if they so desired.

Pain Questionnaire

The McGill Pain Questionnaire (Appendix D) was administered during the initial interview and also during the post test evaluation. This questionnaire is said to provide "quantitative information that can be tested statistically, and is sufficiently sensitive to detect differences among different methods to relieve pain." (Melzack, 1975). This technique was used instead of the visual analogue scale because of its ability to classify pain into subcategories which may provide some new insights of patellofemoral pain. In accordance with the procedures established by Melzack (1975), the investigator read the instructions to the subject to ensure that they were fully understood. The subject was instructed to select only those words that described the pain at the time the questionnaire was administered.

The questionnaire includes twenty groups of 2 to 6 words classified in four categories. Sensory qualities (groups 1 to 10) described pain in terms of temporal, spatial, pressure, thermal, and other properties. Affective qualities (groups 11 to15) describe pain in terms of tension, fear, and autonomic properties. Evaluative words (group 16) describe the subjective overall intensity of pain. A fourth category (groups 17 to 20), termed a miscellaneous or supplementary group, is purported to provide a well-rounded perspective of the pain experience (Melzack, 1975). Words within each group are rank ordered in perception of increasing intensity of pain.

The values for the chosen words selected from each group of words were added to give a discriminating description of pain (sensory, affective, evaluative, miscellaneous). The total of all four groups was calculated to describe an overall score of pain. The difference in pre- and post- treatment scores in all categories was calculated to determine change in pain.

Patient Assessment Form

A patient assessment and questionnaire form (Appendix E) was used to assess the subjects' complaints and rule out any other obvious contributory factors that might require a different course of treatment (example: obvious biomechanical dysfunctions or ligamentous injuries).

Measurement

Isometric Strength

Isometric torque of knee extensors (quadriceps femoris muscle) strength was determined using a Kin-Com isokinetic dynamometer (Med-Ex Diagnostics of Canada Inc., Vancouver, British Columbia) connected to a Z-8oA microprocessor. The Kin-Com was calibrated before each use according to the manufacturer's procedures. Calibration included a correction factor for gravity. All subjects participated in the pre-test procedure to determine maximum voluntary isometric contraction (MVIC).

Subjects were positioned on the Kin-Com stabilization table with restraining supports across the pelvis and over the thigh. For additional stabilization, the subjects gripped the sides of the chair and leaned back against the backrest, which was inclined posteriorly to an angle of 70 degrees above horizontal. The axis of the Kin-Com lever arm was aligned with the axis of the knee joint. The distal end of the lever arm was firmly attached to the subject's leg proximal to the ankle and the length of the lever arm (lever radius) was set at 270 for all subjects for all tests. The subject was instructed to extend the knee to full extension: the angular position was noted and the limb was positioned and fixed at 5º degrees flexion (start and return angles). The minimum force was set at 20N. Each file contained one repetition of six seconds duration (stop duration = 600) .

Subjects were allowed two submaximal contractions to familiarize themselves with the machine and to allow for warm-up. This was followed by a two minute rest. Testing was performed by asking the subject to extend the knee against the immovable lever arm with as much force as possible and to maintain the contraction until instructed to relax (6 seconds). Subjects were given minimal but consistent verbal encouragement to maximize their effort. Three repetitions were performed, interspersed with a 50 second rest interval, in accordance with the 10/50/10 duty cycle as first described by Kotz (1977). The results for each repetition were recorded separately. The Kin Com collected data every tenth of a second (60 data points per six second repetition). The mean torque rather than peak torque for each repetition was calculated to avoid any overshoot measurements due to sudden kicking movements. The mean torque of the three trials was used as a measure of maximal voluntary contraction (MVIC).

Computed Tomography

Computed tomographic measures were performed pre- and post-treatment using a Siemens Sonaris/2 Somatom Plus CT Scanner (Siemens Electric Limited, Mississauga, Ontario). Two technologists were trained to perform the protocol. Subjects were placed on the gantry in the supine, feet first position, and appropriately draped with a gonadal shield. The level of exposure was well within acceptable limits with minimal scattering due to a collimated beam. The unaffected limb was positioned at approximately 45º hip flexion and 90º degree knee flexion to ensure unimpeded imaging of the test patellofemoral joint.

With the patient positioned on the gantry as previously described, a lateral topogram (scout) was performed to establish the mid-point of the patella as a standardized reference point. The distance between the proximal and distal margins of the patella was determined and divided in half to define the midpoint of the patella. If the cutline did not intersect with the posterior condylar projection, the position of the cutline on the patella was adjusted. In this study all required adjustments were made distal to the centre of the patella. Adjustments were noted and repeated in post-test measurements. Images were exposed using a bone algorithm and a negative exposure setting. Images were enlarged so that one image per exposure was developed.

Images of the treatment knee were captured under three conditions: 0º degrees relaxed, 0º degrees contracted, and 20º degrees relaxed. For measures at 0º, the subject's leg was placed on the gantry in a neutral with the toes pointing up. A styrofoam wedge was used to position the knee in 20º degrees flexion.

Four measures of patellar position (as described by Stanford et al, 1988) were evaluated: Tangent Offset (TO); Bisect Offset (BO); Patellar Tilt Angle (PTA); and Lateral Patellofemoral Angle (LPFA). Pre- and post- test measures were recorded on the CT Scanner measurement form (Appendix G).

Tangent Offset (Appendix M a). This measure was made by drawing a line tangent to the lateral aspect of the femur through the estimated centre of the cortex. This line intersected with a second line drawn through the widest part of the patella. The portion of the patellar width line lateral to the point of intersection was measured and expressed as a percentage of the overall width of the patella. If the patella was entirely medial to the tangent line, the patellar width line was extended to meet the tangent line. The length between the lateral edge of the patella and the tangent line was measured and expressed as a negative measurement.

Bisect Offset (Appendix M b). This measure of lateral patellar shift was measured by first drawing a line tangent to the dorsal convexities of the medial and lateral femoral condyles. The width of the posterior intercondylar space was measured and bisected. From this bisect point, a perpendicular line was projected anteriorly through the patella. This line intersected with the patellar width line described in the previous measurement. The portion of the patella lateral to the bisect line was expressed as a percentage of the overall patellar width.

Lateral Patellofemoral Angle (Appendix M c). This measurement determined the extent of patellar rotation about its long axis. A line was drawn tangent to the most anterior points of the anterior femoral condyles. A second line was drawn tangent to the lateral patellar facet. The angle that was created by the convergence of these two lines was measured.

Patellar Tilt Angle (Appendix M d). This is another measurement of patellar rotation. A line is drawn parallel to the posterior femoral condyllar line through the deepest portion of the trochlear fossa. The angle created by this line and the line previously drawn tangent to the lateral patellar facet was measured.

Stimulation Parameters

A Medtronic Respond (Medtronic Inc., Toronto, Ontario) electrical muscle stimulator was used to stimulate the vastus medialis. The Respond stimulator utilized an asymmetrical alternating current with a pulse width of 225 microseconds with a visible pulse rate adjustment from 0-50 HZ. The rise and fall time were set to two and one second(s) respectively. Electrodes were 5x10cm carbon fibre rubber pads manufactured by Medtronic (Medtronic Inc., Toronto, Ontario). To ensure that the stimulation intensity was reproducible, AAA batteries used to power the stimulator were recharged daily.

The subject was positioned on the Kin Com isokinetic dynanomometer as in the pre-test with the knee fixed at 5º degrees flexion. The Kin Com settings remained the same as in the pre-test except that the duration of exercise was set at twelve seconds (duration = 1200).

The skin was appropriately prepared with shaving (where necessary) and cleansed with alcohol. Carbon fibre electrodes were coated with an electrode gel and placed over the motor point (mid belly) of the vastus medialis distally and over the femoral nerve in the femoral triangle proximally (Hartsell, 1986). The electrodes were large enough to provide current distribution over an area sufficient to ensure that the target tissue was innervated. Where nescessary, the position of the electrodes was adjusted until a maximum observable muscular contraction could be elicited.

Each session included ten repetitions of a twelve second electrical muscle stimulation of the vastus medialis (including a two second rise time) superimposed on a maximal voluntary muscle contraction (knee extension) The stimulator was set at a frequency of 50 (Hz) in accordance with previously reported literature research. The intensity was adjusted by the investigator for each contraction in increasing increments between 0 and 10 to each subject's maximum tolerance. Each subject was asked to record the intensity for each contraction. (Appendix I) A 50 second rest period was interspersed between contractions (Cummings, 1980). Because the Kin Com and the stimulator could not be synchronized, an external timer was used to determine the rest period following each contraction. The stimulator was disconnected from the patient by removing one electrode plug from the stimulator during the rest period. At the end of each session, the subject was asked to indicate whether or not he/she felt he/she had achieved his/her maximum tolerable setting. Subjects performed ten repetitions per session three days per week for six weeks (Hartsell, 1986, Johnson et al., 1977, Morissey et al., 1985,).

Post-Treatment Measurements

The effectiveness of electrical muscle stimulation was determined by calculating the post-test to pre-test changes in isometric strength, patellar position using CT imaging and perceived pain as measured by the McGill pain questionnaire in the same fashion as the pre test protocol. Subjects were not informed of pre-test scores for any of the measures.

Statistical Analysis

In consultation with the Statistical Advisory Service, University of Manitoba, analysis used parametric statistical techniques including ANOVA, correlation coefficients and t-Tests. In all cases the alpha level was set at 0.05.

Chapter IV

RESULTS

Subjects

Table 3 describes the subject profiles for the treatment and nontreatment groups. Eight subjects, all female, were randomly assigned to the nontreatment group. The mean age was 21.38 (15-28), mean height was 164.10 cm (157.5-174.5), and mean weight was 59.91 kg (44.1-74.5). The left knee was the "treatment" knee in 6 of the eight subjects.

Eleven subjects were assigned to the treatment group, as follows. From the original 15 subjects, 7 were randomly assigned to the treatment group. In addition, 4 subjects from the nontreatment group were assigned to the treatment group following the nontreatment (six weeks) period (see below). The data for the treatment group were analyzed including these "cross-over subjects". In addition, the data from the cross-over subjects were analyzed separately.

Mean age ot the total treatment group was 22.82 (18-37), mean height 167.75 cm (160-180), and mean weight was 61.99 kg (49.5-93). The left knee was the treatment knee in 7 of the eleven subjects.

Statistical analysis using independent t-Tests failed to demonstrate any significant differences between the nontreatment, treatment and cross over groups in any of these indices.

NON TREATMENT GROUP N= 8	GENDER	AGE	HEIGHT (CM)	WEIGHT(KG)	TX KNEE
CO	F	28	165	59.4	LEFT
DA	F	21	169	74.5	LEFT
DG	F	21	160	63	LEFT
HR	F	28	162.5	53.5	LEFT
LC	F	15	174.5	74	RIGHT
MS	F	21	162.5	56.25	LEFT
RR	F	17	157.5	44.1	LEFT
TM	F	20	161.8	54.5	RIGHT
Total/Mean	8 F	21.38	164.10	59.91	7 L/2R
TREATMENT GROUP N= 11	GENDER	AGE	HEIGHT (CM)	WEIGHT (KG)	TX KNEE
AH	M	18	186	93	RIGHT
DG	F	21	160	63	LEFT
DO	M	37	175	64	LEFT
EB	F	22	170	59	LEFT
GK	F	20	162.5	58.5	LEFT
HR	F	28	162.5	53.5	LEFT
JN	M	25	180	78	RIGHT
LR	F	21	165	52.6	RIGHT
MS	F	21	162.5	56.25	LEFT
SD	F	18	160	49.5	LEFT
TM	F	20	161.8	54.5	RIGHT
Total/Mean	8F/3M	22.82	167.75	61.99	7L/4R
CROSS OVER	GENDER	AGE	HEIGHT (CM)	WEIGHT (KG)	TX KNEE
SUBJECTS N= 4					
DG	F	21	160	63	LEFT
HR	F	28	162.5	53.5	LEFT
MS	F	21	162.5	56.25	LEFT
TM	F	20	161.8	54.5	RIGHT
Total/Mean	4F	22.5	161.7	56.8125	3L/1R

Table 3 Subject profiles for nontreatment, treatment groups and cross over subjects

Isometric Strength

Isometric strength (isometric torque for knee extension at 5º knee flexion) was measured using the Kin Com Isokinetic Dynamometer. Paired t-

Tests on between subject pre and post test data demonstrated a significant increase in isometric strength in both the nontreatment and treatment groups (Table 4). An independent t-Test demonstrated that the change in isometric strength in the treatment group was significantly greater than that in the nontreatment group (t value = -3.26; P=.0046).

Measurement	Pre-test Mean	SD	Post-test Mean	SD	Mean Change	t- Value	P- Value
X Torque -NTX	20.34	5.8	29.52	8.61	9.18	-3.03	.0192*
X Torque -TX	25.58	12.73	62.08	28.77	36.50	-5.4	.0003*

* t significant at P< .05 level

Table 4. paired t-Tests for torque measurements in treatment and nonttreatment groups.

In addition, torque measures generated by subjects in the treatment group were collected for the 10 contractions as Total Work (measured as the unit area under the torque vs angle curve) in each session and totalled for all 18 sessions (see Table 6). The average torque for the 18 sessions was calculated and correlated with the change in pre- and post-test torque measurements. Average torque measures generated throughout the treatment period significantly correlated with increases in torque measured between pre- and post-tests (r = .83; P<.01).

SUBJECT	PRT TORQUE	PT TORQUE	%PT/PRT TORQUE
	NM	NM	
CO	13.4	38.4	187.2
DA	22.9	37.2	62.5
DG	29.4	38.5	31.2
HR	16.4	13.8	-15.6
LC	19.8	31.03	56.7
MS	13.8	23.7	71.4
RR	20.4	26.9	32.2
TM	26.7	26.5	-0.6
Mean	20.3	29.5	53.1
SD	5.8	8.6	

Table 5. Kin Com torque measures for the nontreatment group. PRT Torque=Pre- test torque; PT Torque=Post- test torque. %PT/PRT Torque = the percent change in torque of the post- test torque compared to the pre- test torque.

SUBJECT	TOTAL WORK	MEAN TORQUE /18NM	PRT TORQUE NM	PT TORQUE NM	%PT/PRT TORQUE
AH	102049.2	74.3	30.4	117.1	285.6
DG	89996.5	60.5	38.5	61.0	58.2
DO	56095.9	51.3	13.0	66.6	410.7
EB	33619.0	25.3	15.4	33.8	119.7
GK	43067.4	29.9	9.3	34.8	273.9
HR	40210.4	31.9	13.8	26.5	91.8
JN	94732.4	72.5	50.6	103.4	104.4
LR	66953.1	46.7	36.9	61.1	65.3
MS	45350.4	40.4	23.7	47.4	100.2
SD	40393.6	26.7	23.1	50.2	117.1
TM	70606.1	65.2	26.5	80.9	204.9
Mean	62097.6	47.7	25.5	62.1	166.5
SD			12.7	28.8	

Table 6. Kin Com torque measures for the treatment group. Total work is the cumulative measure of work performed by the subject for all repetitions (180) measured as the unit area under the torque vs angle curve. Mean Torque /18 is a measure of the mean torque performed by the subject for 18 sets of 10 repetitions. PRT Torque=Pre-test torque; PT Torque=Post-test torque. %PT/PRT Torque = the percent change in torque of the post-test torque compared to the pre- test torque.

Stimulation Intensity

The treatment group received maximally tolerated muscle stimulation 3 times per week for 6 weeks for a total of 18 sessions. During each session, the subject performed 10 maximal voluntary quadriceps contractions superimposed with maximum tolerable electrical muscle stimulation (EMS). The subjects were encouraged to accept increasingly higher stimulation intensities with each contraction. The dial setting on the stimulator was recorded (Appendix F) by the subject after each contraction to motivate him/her to accept increasingly higher intensities from one repetition to the next and from one session to the next. The number of repetitions at which the subject was able to regularly accept the full intensity of the stimulator ranged from the second repetition (first session) to the 124th repetition (13th session), with an average at the 35th repetition (4th session) (Table 7). The correlation between the number of repetitions required to reach the maximum stimulation capacity of the stimulator and the change in patellofemoral pain was not significant.

Subject	Session	# Of Repetitions	Change in Pain (Total)	% Change in Strength
AH	4	34	11	285.61
DG	1	2	-4	58.24
DO	1	5	-4	410.66
EB	3	24	-5	119.7
GK	5	47	8	273.93
HR	1	7	-14	91.83
JN	1	5	-13	104.45
LR	7	70	-6	65.33
MS	13	124	-23	100.25
SD	4	38	-20	117.08
TM	3	25	-15	204.86
MEAN	3.91	34.64		
RANGE	1 - 13	2 - 124	(+8) - (-23)	

Table 7. Time to maximum maximum output of muscle stimulator and changes in pain and strength measures.

Patellofemoral Pain

The McGill Pain Questionniare was administered pre- and post-treatment for the treatment group and 6 weeks apart for the nontreatment group. The questionnaire is comprised of word groupings divided into 4 subclasses: sensory, affective, evaluative, and miscellaneous (Appendix D). Total pain is a score derived by adding the rank score of all words chosen.

Pain Category	Pre-test Mean	SD	Post-test Mean	SD	t-Value	P- Value
Affective	12.12	4.97	12.75	6.45	-00.28	.7856
Sensory	1.62	1.77	1.75	1.669	-00.22	.8357
Evaluative	1.25	1.4	0	0	2.55	.0383*
Misc	4.25	3.37	3.75	3.10	-00.28	.7872
Total	19.25	8.24	18.25	9.78	00.30	.7711

* t significant at $P < .05$

Table 8. Paired t-Tests for changes in pain perception using the McGill Pain Questionnaire for the Nontreatment group.

Pain Category	Pre-test Mean	SD	Post-test Mean	SD	t-Value	P- Value
Affective	14.45	7.23	9.73	7.27	2.54	.0292*
Sensory	2.45	2.77	0.91	1.81	1.70	.1196
Evaluative	0.64	1.21	0.45	.82	.52	.6168
MIsc	2.91	3.11	1.64	3.23	1.24	.2438
Total	20.45	11.80	12.73	11.61	2.40	.0373*

* t significant at P< .05

Table 9. Paired t-Tests for changes in pain perception using the McGill Pain Questionnaire for the Treatment group.

Pain DIFF	Non TX Mean	SD	TX Mean	SD	t-Value	P- Value
Affective	.62	6.25	-4.73	6.2	1.86	.0807
Sensory	.125	1.64	-1.54	3.01	1.42	.1749
Evaluative	-1.25	1.39	-.182	1.17	-1.82	.0865
Misc	-.5	5.04	-1.27	3.40	.4	.6943
Total	-1	9.35	-7.73	10.68	1.43	.172

* t significant at the .05 level

Table 10 Means, standard deviations and Independent t-Test analysis of the change in pain (pre- and Post- test) between the nontreatment and treatment group.

The affective subclass uses word groupings to describe pain in terms of tension, fear, and autonomic senses.There was no significant change in affective pain in the nontreatment group (Table 8). Four subjects in the nontreatment group reported an increase in affective pain, 3 reported a decrease, and one reported no change, indicating a wide variability in this group of subjects (Figure 17). In addition, one subject (DA) reported complete resolution of pain according to these criteria while another (MS) reported a 90% increase in pain. Affective pain significantly decreased in the treatment group (Figure 18). Two subjects reported an increase in pain, 8 reported a decrease, and one reported no change. Because of the degree of variation within the groups, an independent t-Test showed no significant difference in the change in affective pain between the treatment and nontreatment groups (Table 10).

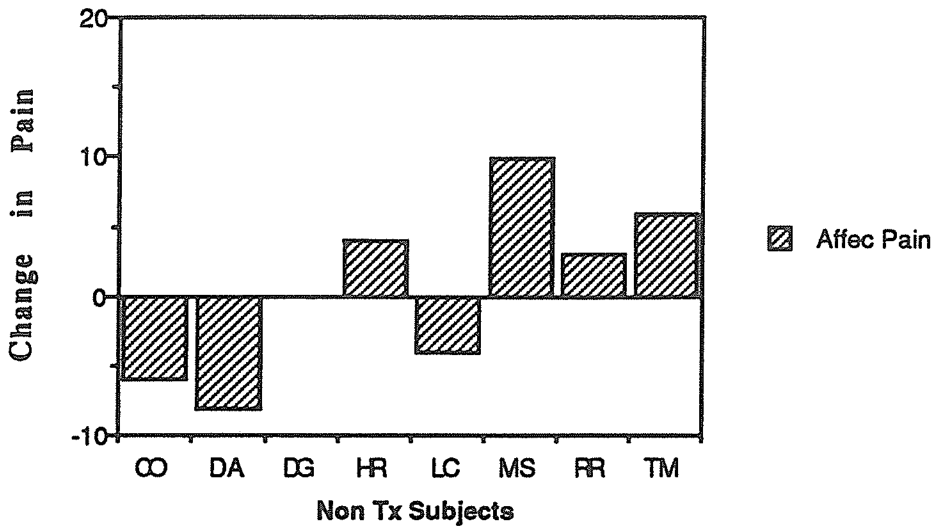

Figure 17. Changes in Affective Pain in the nontreatment group. Negative scores represent a decrease in pain. Positive scores represent an increase in pain. Subjects with no bar on the graph did not report a change in pain. Three subjects decreased in pain, 4 increased in pain and one did not change.

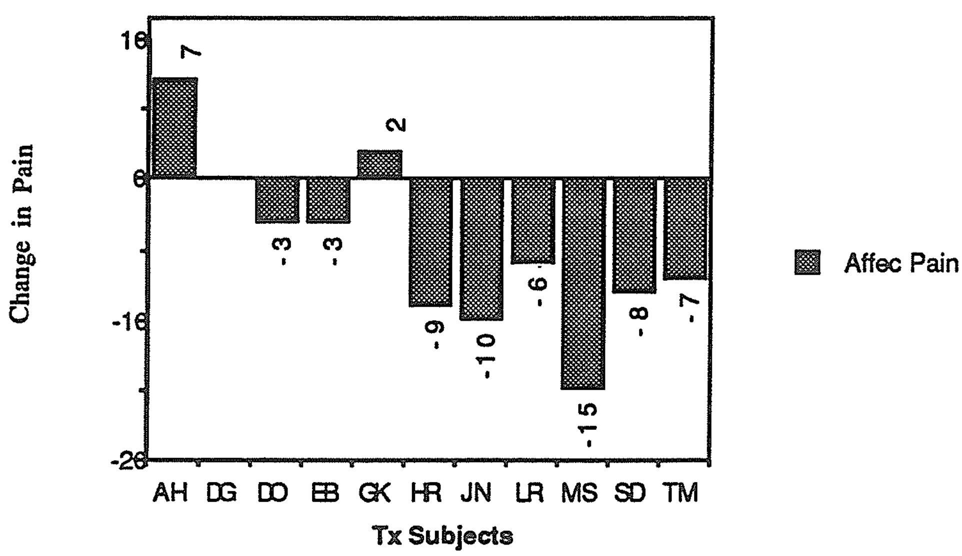

Figure 18. Changes in Affective Pain in the treatment group. Negative scores represent a decrease in pain. Positive scores represent an increase in pain. Subjects with no bar on the graph did not report a change in pain. Eight decreased in pain, 2 increased in pain and one did not change.

The sensory subclass uses word groupings to describe pain in a temporal, spatial, pressure, and thermal sense. Scores in the nontreatment group (n = 8) showed that 2 subjects reported an increase in pain and one subject experienced a decrease in pain. There was no reported change in 5 subjects (Figure 19). In the treatment group (N = 11) one subject reported an increase in pain, 6 reported a decrease in pain, and 4 reported no change (Figure 20). There was no significant difference between the treatment and nontreatment group as determined using an independent t-Test (Table 10).

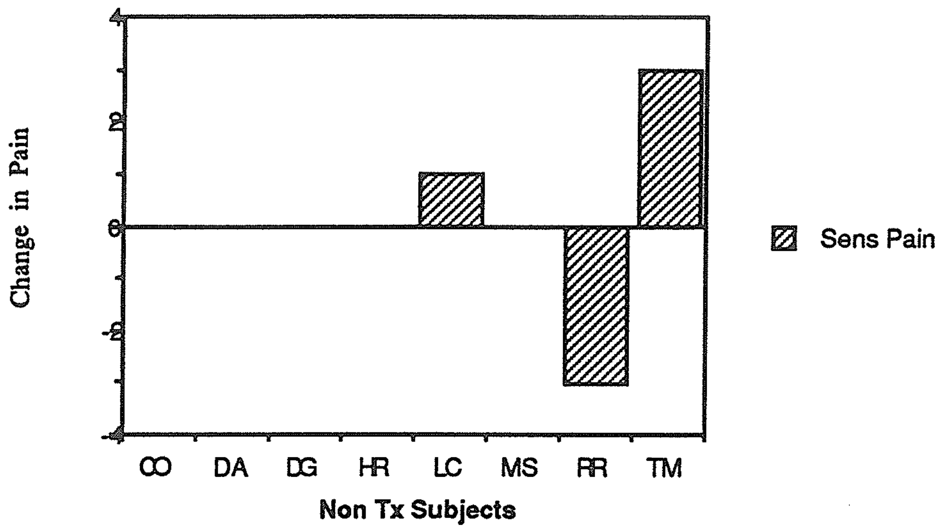

Figure 19. Changes in Sensory Pain in the nontreatment group. Negative scores represent a decrease in pain. Positive scores represent an increase in pain. Subjects with no bar on the graph did not report a change in pain.
Two decreased in pain, 1 increased inpain and 5 did not change.

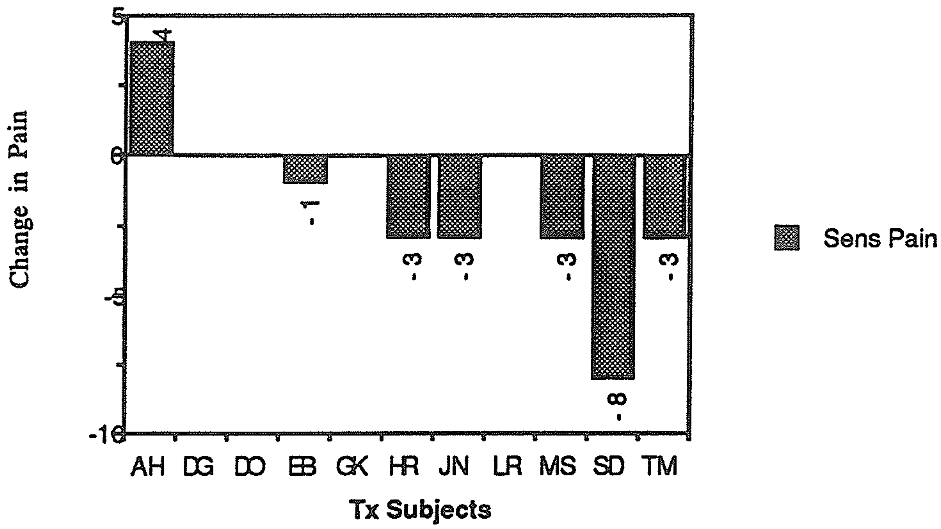

Figure 20. Changes in Sensory Pain in the treatment group. Negative scores represent a decrease in pain. Positive scores represent an increase in pain. Subjects with no bar on the graph did not report a change in pain.
Six decreased in pain, 1 increased in pain and 4 did not change.

Evaluative pain, which measures the overall intensity of pain, was measured using only one group of 4 words. In the nontreatment group, 4 subjects reported a decrease in evaluative pain and 4 reported no change (Figure 21). In the treatment group, 2 reported a decrease in evaluative pain, one reported an increase, and 8 reported no change (Figure 22). In many instances, subjects did not select any of the words in this group in either the pre- or post-test. This was the case for 4 subjects in the nontreatment group and 7 in the treatment group. In addition, in the post-test administration of the questionnaire, none of the nontreatment group subjects selected any of the evaluative words. There was a significant difference in pain pre- and post-test in the nontreatment (P=.0383) (Table 8), but this may be spurious given the fact that so many subjects selected no words from this category. There was no significant difference in changes in evaluative pain between the nontreatment and treatment groups (P=.0796) (Table 10).

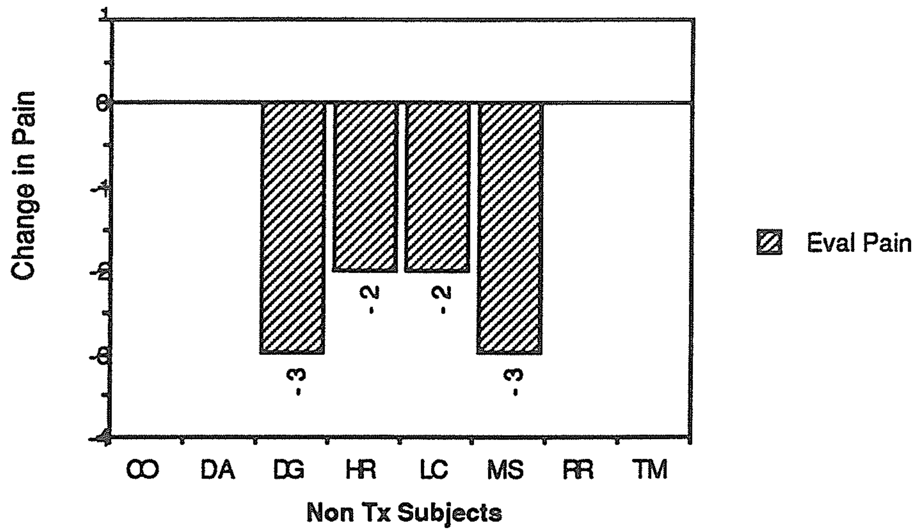

Figure 21. Changes in Evaluative Pain in the nontreatment group. Negative scores represent a decrease in pain. Positive scores represent an increase in pain. Subjects with no bar on the graph did not report a change in pain. Four decreased in pain, and 4 did not change.

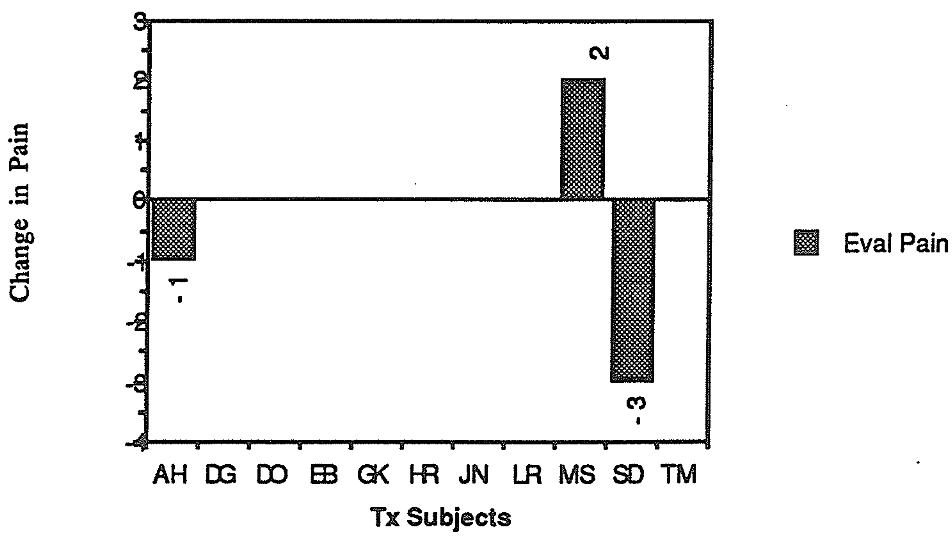

Figure 22. Changes in Evaluative Pain in the treatment group. Negative scores represent a decrease in pain. Positive scores represent an increase in pain. Subjects with no bar on the graph did not report a change in pain. Two decreased in pain, 1 an increase in pain and 8 did not change.

Scores from the word groupings categorized as miscellaneous are used to complete the overall perspective of pain (Melzack, 1975). In the nontreatment group, 2 subjects reported an increase in pain, 3 reported a decrease, and 3 reported no change (Figure 23). In the treatment group, 2 subjects reported an increase in pain, 7 a decrease, and 2 no change (Figure 24). The range in the nontreatment group was from a 90% decrease (in subject CO) to a 400% increase (in subject MS). In the treatment group, reported change in pain ranged from a 120% increase (subject GK) to a 70% decrease (subject MS). There was no significant difference pre- and post- test or between the treatment and nontreatment groups.

In the nontreatment group, affective and miscellaneous pain significantly correlated with total pain whereas sensory and evaluative pain did not (Table 11). In the treatment group, affective, sensory and miscellaneous scores significantly correlated with total pain while evaluative pain did not (Table 12). Generally, subjects who reported an increase (or decrease) in pain according to the word groupings in one subclass also reported an increase (or decrease) or no change in pain according to the word groupings in another subclass (Figures 25 & 26). The variability in the questionnaire results then, appear not to be within subjects but rather between subjects in the same group.

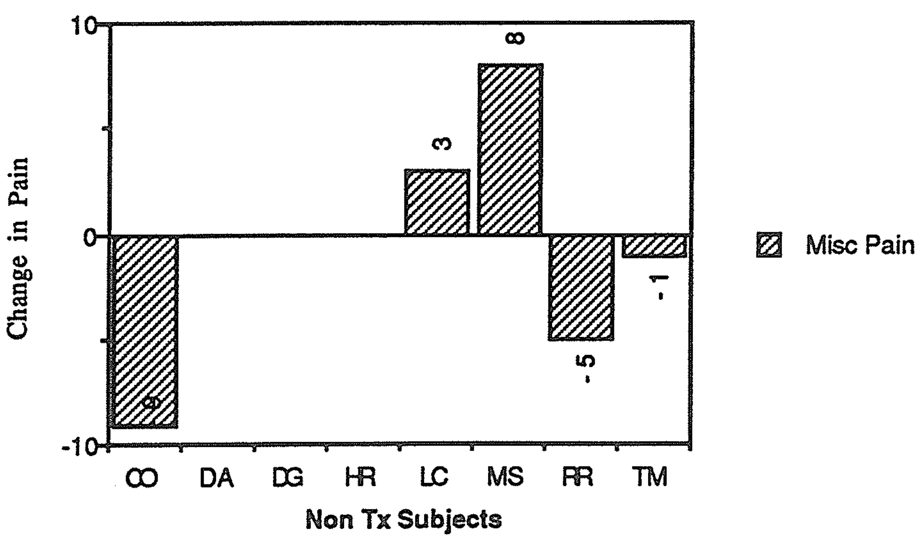

Figure 23. Changes in Miscellaneous Pain in the nontreatment group. Negative scores represent a decrease in pain. Positive scores represent an increase in pain. Subjects with no bar on the graph did not report a change in pain. Three decreased in pain, 2 an increase in pain and 3 did not change.

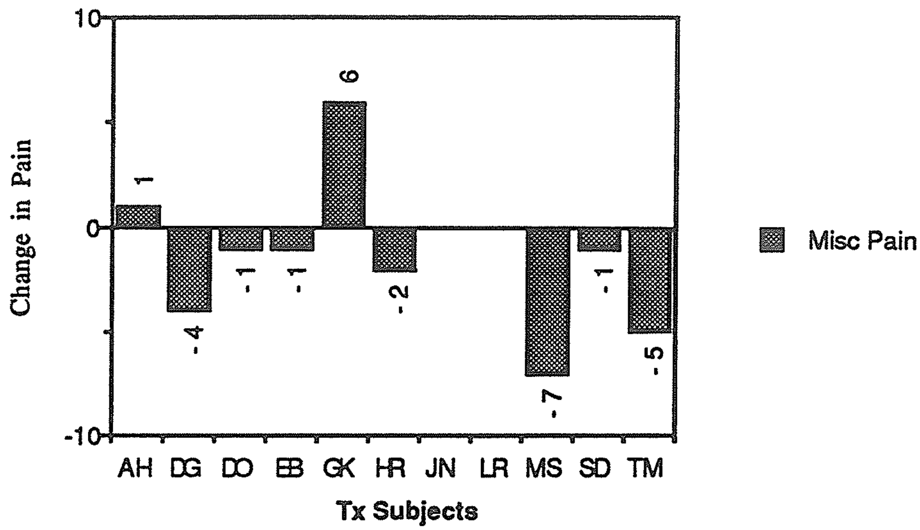

Figure 24. Changes in Miscellaneous Pain in the treatment group. Negative scores represent a decrease in pain. Positive scores represent an increase in pain. Subjects with no bar on the graph did not report a change in pain. Seven decreased in pain, 2 an increase in pain and 2 did not change.

	C - Affec	C - SENS	C - EVAL	C - MISC	C - TOT
C- Affec	1				
C - SENS	.06	1			
C - EVAL	-.39	-.05	1		
C- MISC	.47	.27	-.71	1	
C - TOT	.87*	.35	-.51	.79*	1

*Significant at P<.05 (df=5)

Table 11 Correlation matrix comparing the correlation of responses to the pain categories by the nontreatment group using the McGill Pain Questionnaire. (C= Nontreatment group, AFFEC= Affective pain, SENS = Sensory pain, EVAL= Evaluative pain, MISC = Miscellaneous pain, TOT= Total pain)

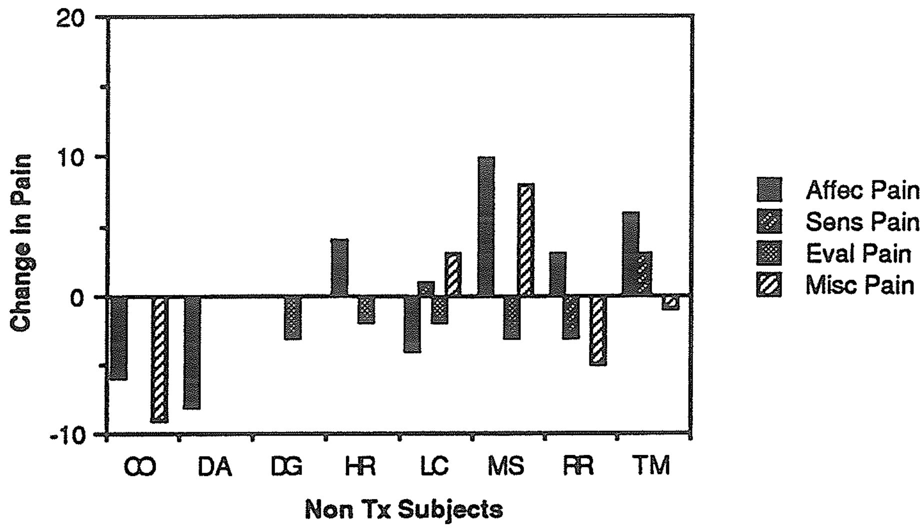

Figure 25. Comparison of responses for all four word groupings for the nontreatment group. Positive scores represent an increase in pain. Subjects with no bar on the graph did not report a change in pain.

	E - Affec	E - SENS	E - EVAL	E - MISC	E - TOT
E - Affec	1				
E - SENS	.74*	1			
E - EVAL	-.31	.31	1		
E - MISC	.59	.32	-.37	1	
E - TOT	.94*	.85*	-.1	.71*	1

*Significant at P<.05 (df=9)

Table 12 Correlation matrix comparing the correlation of responses to the pain categories by the treatment group using the McGill Pain Questionnaire. (E= Treatment group, AFFEC= Affective pain, SENS = Sensory pain, EVAL= Evaluative pain, MISC = Miscellaneous pain, TOT= Total pain.

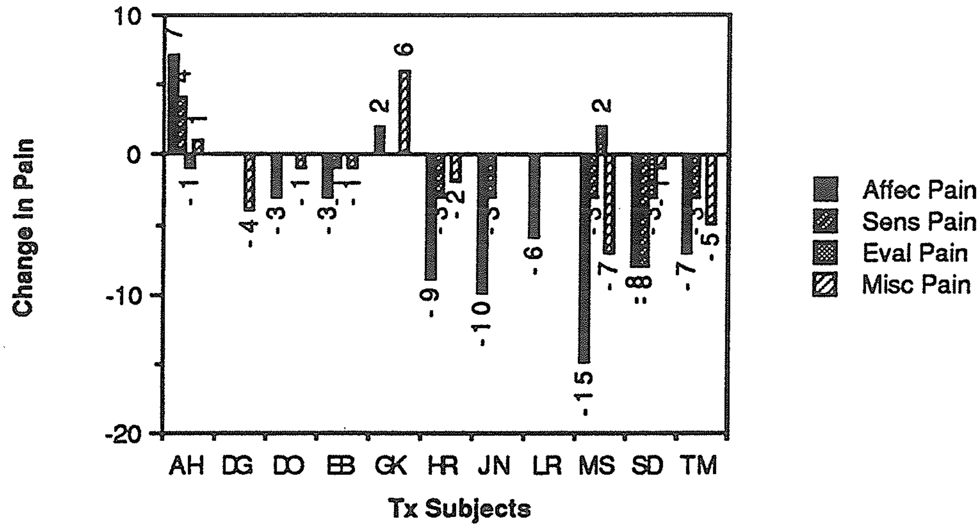

Figure 26. Comparison of responses for all four word groupings for the treatment group. Positive scores represent an increase in pain. Subjects with no bar on the graph did not report a change in pain.

Total pain measured the change in pain as determined by the rank score for words chosen from all groups. There was no significant change in pre- and post-test scores for total pain in the nontreatment group. Five subjects reported a decrease in overall pain while 3 subjects reported an increase (Figure 27).

There was a significant change in total pain in the treatment group (Table 9; P=.0373) where 2 subjects reported an increase in total pain and 9 reported a decrease in total pain (Figure 28). Again, because of the variability in scores within groups, there was no significant difference between the treatment and nontreatment groups (Table 10).

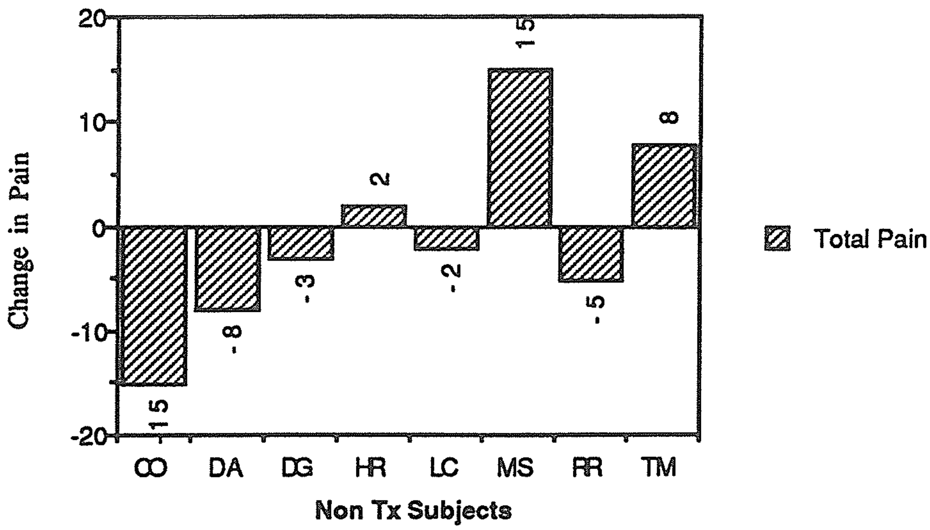

Figure 27. Changes in Total Pain in the nontreatment group. Negative scores represent a decrease in pain. Positive scores represent an increase in pain. Subjects with no bar on the graph did not report a change in pain. Five decreased in pain, and 3 an increase in pain.

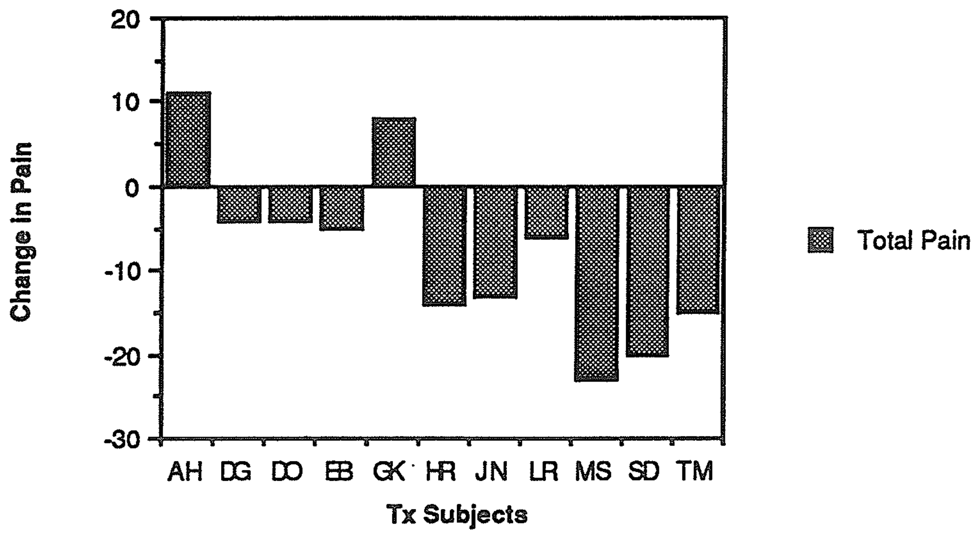

Figure 28. Changes in Total Pain in the treatment group. Negative scores represent a decrease in pain. Positive scores represent an increase in pain. Subjects with no bar on the graph did not report a change in pain. Nine decreased in pain, and 2 an increase in pain.

Computer Tomography - Patellar Position

Paired t-Tests demonstrated a significant change in two measures; LPFA 0ºR and PTA 0º C in the treatment group (Table 14). The nontreatment group did not significantly change in any category (Table 13).

An independent t-Test demonstrated a significant difference in the change of patellar position between the treatment and nontreatment groups as measured using patellar tilt angle with the quadriceps contracted (PTA 0ºC) (t-value = -2.52, p = .0228). There were no significant differences between groups in any other measures of patellar position.

Measurement	Pre-test Mean	SD	Post-test Mean	SD	t Value	P Value
TO 0º R	10.75	6.61	10.11	7.01	.21	.8409
TO 0ºC	12.58	14.12	12.71	11.25	-.06	.9548
TO 20º	2.08	10.21	4.77	9.52	-1.39	.2084
B O 0ºR	73.01	6.68	75.29	10.27	-.83	.4320
B O 0ºC	22.25	47.47	13.03	54.85	.58	.5816
B O 20º	58.90	10.01	64.20	8.60	-1.9	.0993
LPFA 0ºR	5.44	11.80	3.81	7.68	.85	.4247
LPFA 0ºC	3.50	7.40	3.43	6.04	.04	.9716
LPFA 20º	10.69	9.32	9.81	6.92	.59	.5710
PTA 0ºR	12.56	12.15	10.19	8.31	1.12	.2979
PTA 0ºC	10.12	7.30	7.44	6.79	1.67	.1382
PTA 20º–	17.25	4.18	15.87	2.50	1.33	.2253

Table 13. Means, standard deviation, and paired t-Tests for Pre- and Post- test scores of Patellofemoral Alignment (CT Scan measurements) in Nontreatment group subjects. (N=11)

Measurement	Pre-test Mean	SD	Post-test Mean	SD	t Value	P Value
Tang off 0º R	13.12	6.24	13.56	7.53	-.34	.7423
Tang off 0ºC	20.15	10.46	20.64	11.46	-.27	.8410
Tang off 20º	5.53	12.74	4.84	14.80	.25	.8055
B O 0ºR	73.31	10.44	71.68	10.63	.81	.4373
B O 0ºC	44.56	56.38	33.01	57.05	1.18	.2665
B O 20º	57.50	21.33	58.76	20.91	-.28	.7817
LPFA 0ºR	2.50	5.62	0.77	5.93	2.64	.0248*
LPFA 0ºC	1.41	9.11	1.91	8.96	-.46	.6578
LPFA 20º	7.36	6.52	8.09	5.78	-.63	.5402
PTA 0ºR	9.18	6.20	9.09	7.82	.1	.9210
PTA 0ºC	7.50	8.11	10.09	8.42	-2.86	.0170*
PTA 20º–	14.86	9.58	14.64	7.87	.19	.2263

* t significant at P< .05

Table 14. Means, standard deviation, and paired t-Tests for Pre- and Post- test scores of Patellofemoral Alignment (CT Scan measurements) in Treatment group subjects. (N=11)

Tangent Offset

Tangent offset is a measure of patellar position in a medial/lateral orientation (Figure 29). Scores are expressed as a percentage of the total width of the patella, with positive scores indicating a lateral position of the patella and negative scores indicating a medial position. If excessive lateral pressure (or lateral positioning of the patella) has a direct relationship to patellofemoral pain, then a lateral shift of the patella would presumably increase the pain. Conversely, a medial shift in the patella after treatment should be associated with a decrease in pain.

Tangent Offset (0º Relaxed)

Following the six week period, 6 subjects (75%) in the nontreatment group demonstrated a lateral shift of the patella and 2 demonstrated a medial shift (Figure 30). Of the 6 subjects who demonstrated a lateral shift, 3 (50%) also reported increased pain (Figure 31). The remaining 3 subjects reported a decrease in pain. Interestingly, one of the subjects (CO) who reported a decrease in pain was also one of the subjects showing the greatest degree of lateral shift. Subject MS, however, also experienced a lateral shift of the patella (6.97%) and reported an increase in pain. Both subjects who demonstrated a medial shift in the patella reported a decrease in pain. Subject DA reported complete resolution of pain and MS reported a decrease in pain.

Overall there was more of a tendency for medial shifting of the patella to occur in the treatment group (54.5%) than in the nontreatment group (25%). In the treatment group a medially shifted patella was usually associated with a decrease in pain (Figure 33). A lateral shift was associated with an increase in pain. However, due to the within group variability, an independent t-Test failed to identify any significant differences between the two groups.

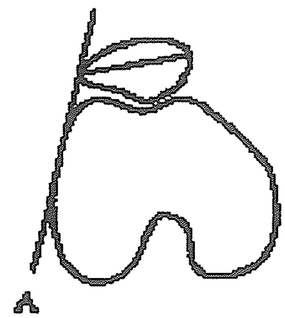

Figure 29. Measuring Tangent Offset to determine the medial/lateral alignment of the patella in relation to the femoral trochlea.

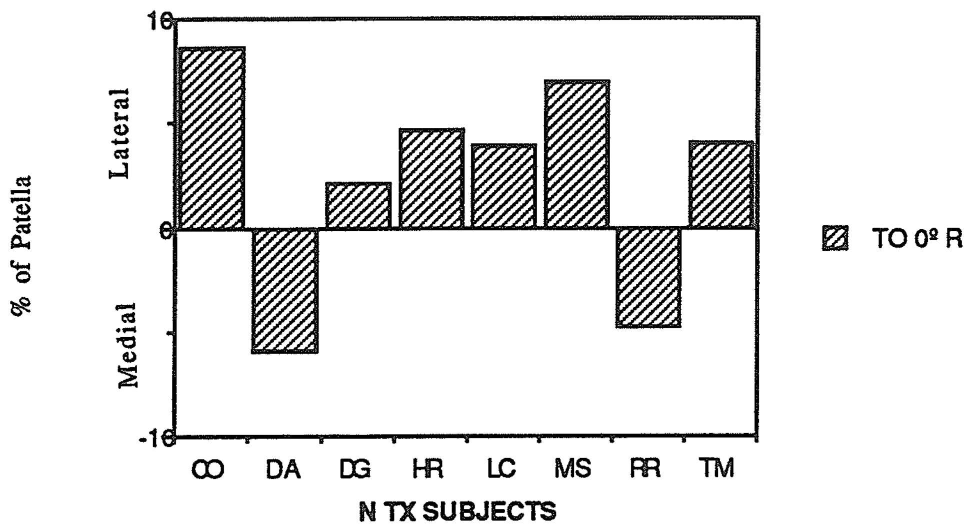

Figure 30. Changes in Tangent Offset at 0º relaxed in the nontreatment group. Scores are calculated as a percent of the overall patellar width that lies lateral to the tangent offset line. Negative scores represent a medial patellar shift. Positive scores represent a lateral shift. Subjects with no bar on the graph did not demonstrate a change in patellar position. Six demonstrated a lateral shift, and 2 subjects medially shift.

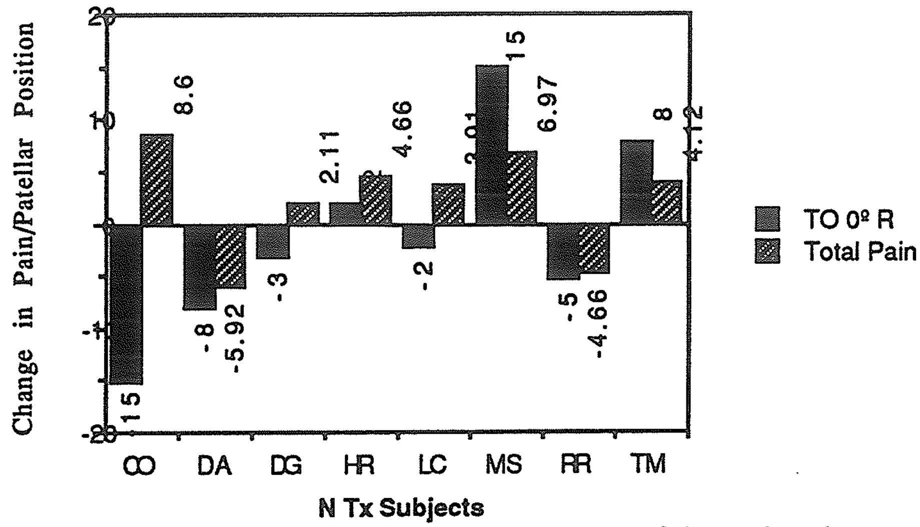

Figure 31. Comparison of changes in Tangent Offset relaxed compared to changes in pain in the nontreatment group. Generally subjects who medially shifted had a decrease in pain whereas subjects who had a laterally shifted patella had an increase in pain. Negative scores represent a Medial patellar shift and increase in pain. Positive scores represent a lateral shift and decrease in pain. Subjects with no bar on the graph did not demonstrate a change patellar position.

The 11 subjects in the treatment group were almost equally divided with regard to patellar shift: 5 demonstrated a lateral shift of the patella and 6 demonstrated a medial shift after treatment (Figure 32). Of the five subjects who demonstrated a lateral shift, 3 reported a decrease in total pain and the other two reported an increase in total pain (Figure 33). All 6 subjects who reported a medial shift of the patella also reported a decrease in total pain.

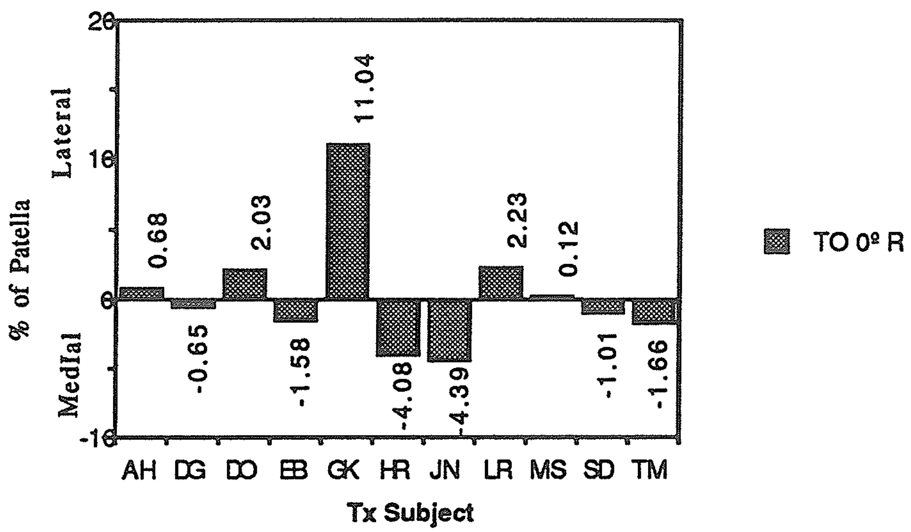

Figure 32. Changes in Tangent Offset at 0º relaxed in the treatment group. Scores are calculated as a percent of the overall patellar width that lies lateral to the tangent offset line. Negative scores represent a medial patellar shift. Positive scores represent a lateral shift. Subjects with no bar on the graph did not demonstrate a change in patellar position. Five demonstrated a lateral shift, and 6 subjects a medial shift.

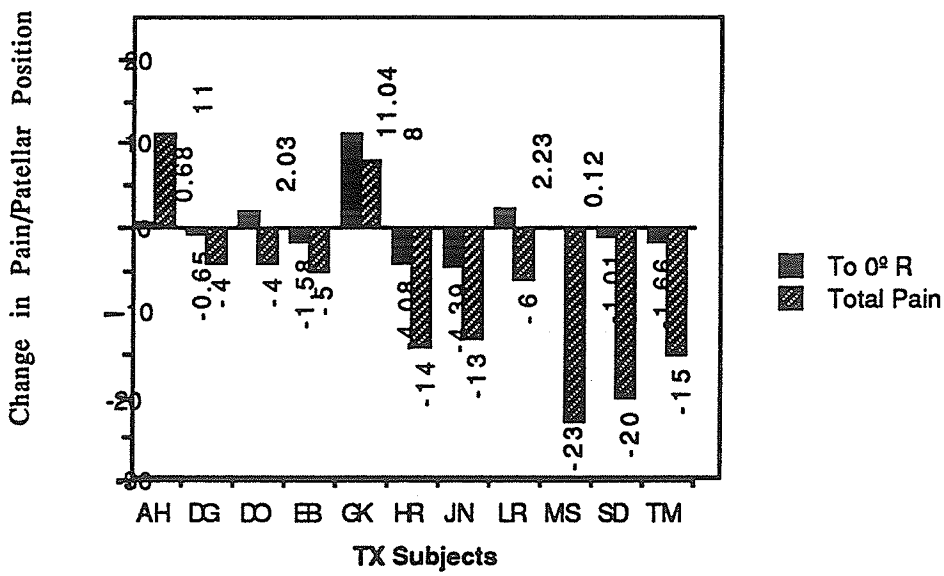

Figure 33. Comparison of changes in Tangent Offset relaxed compared to changes in pain in the treatment group. Generally subjects who medially shifted had a decrease in pain whereas subjects who had a laterally shifted patella had an increase in pain. Negative scores represent a Medial patellar shift and increase in pain. Positive scores represent a lateral shift and decrease in pain. Subjects with no bar on the graph did not demonstrate a change patellar position.

Tangent Offset (0º Contracted)

Tangent offset was measured with the quadriceps maximally contracted at 0º flexion. An independent t-Test did not demonstrate any significant difference between the nontreatment and treatment groups.

In the nontreatment group, 4 subjects demonstrated a lateral shift of the patella over the 6-week period while 3 demonstrated a slight medial shift. One subject showed no change in patellar position (Figure 34).

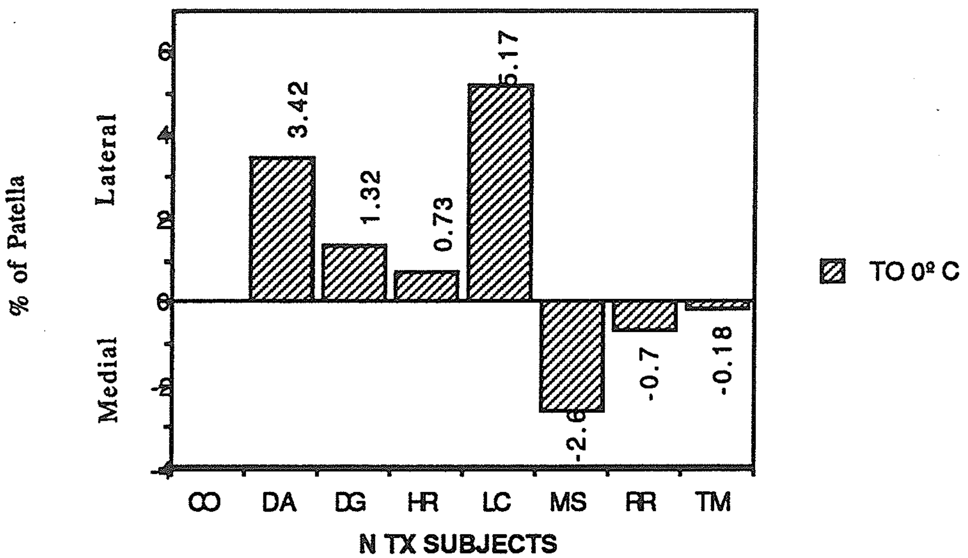

Figure 34. Changes in Tangent Offset at 0º contracted in the nontreatment group. Scores are calculated as a percent of the overall patellar width that lies lateral to the tangent offset line. Negative scores represent a medial patellar shift. Positive scores represent a lateral shift. Subjects with no bar on the graph did not demonstrate a change in patellar position. Four subjects demonstrated a lateral shift, 3 subjects medially shift and one subject did not change.

When comparing the effect of muscular contraction relative to patellar position in the relaxed state in the nontreatment group, one subject (DA) who medially shifted in the relaxed state demonstrated a lateral shift with quadriceps contraction. Three subjects (DG, HR, and LC) laterally shifted in both situations and two subjects (MS & TM) who laterally shifted in the relaxed state medially shifted with quadriceps contraction. One subject (CO) laterally shifted in the relaxed state and did not demonstrate any change when the quadriceps contracted. (Figure 35).

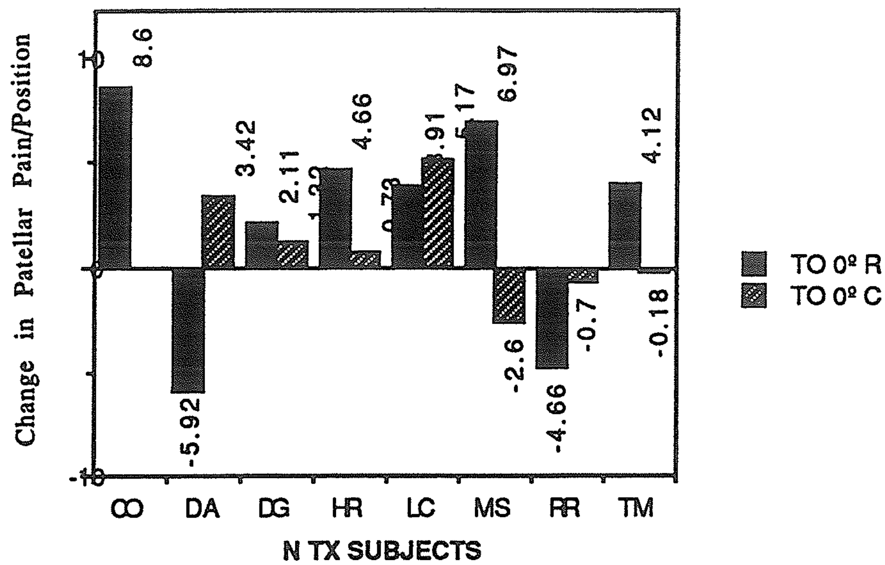

Figure 35. Comparison of changes in patellar position in TO 0º R relaxed compared to that with muscular contraction in the nontreatment group. One subject (DA) who medially shifted in the relaxed state demonstrated a lateral shift with quadriceps contraction. Three subjects (DG, HR, and LC) laterally shifted in both situations and two subjects (MS & TM) who laterally shifted in the relaxed state medially shifted with quadriceps contraction. one subject (CO) laterally shifted in the relaxed state and did not demonstrate any change when the quadriceps contracted.

In the treatment group, 3 subjects demonstrated a lateral shift at 0º in the contracted state while the remaining 7 subjects demonstrated a medial shift of the patella (Figure 36). Data for one subject was not captured due to technical difficulties. Two treatment subjects (JN and HR) both demonstrated comparatively large medial patellar shifts of 17.92% and 8.06% respectively.

The effect of muscle contraction on tangent offset compared to the same measure in the relaxed position for subjects in the treatment group indicated that 2 of 11 subjects (AH & DO) who laterally shifted in the relaxed state were also laterally shifted with muscle contraction. Three subjects (DG, LR, MS) medially shifted when measured in the relaxed state and laterally shifted with quadriceps contraction. Five subjects (EB, HR, JN, SD, TM) were medially shifted in both the relaxed and contracted states (Figure 37). Of particular note is the comparatively large change in patellar position demonstrated by subject GK. In the relaxed state this subject demonstrated the largest lateral shift. In the contracted state, however, the patella shifted more medially. Also of note is the marked medial shift (17.92%) demonstrated by subject JN in the contracted state as compared to the relaxed state (4.39%).

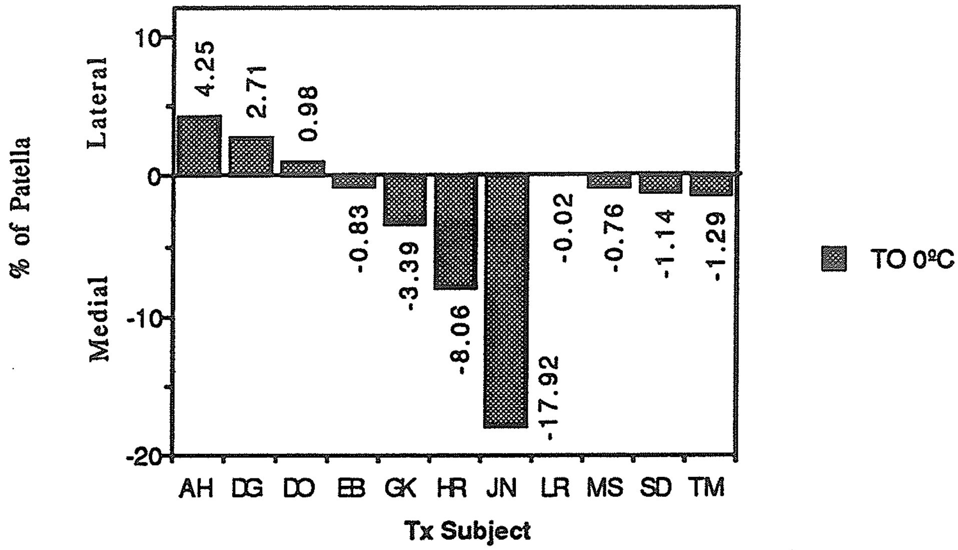

Figure 36. Changes in Tangent Offset at 0º contracted in the treatment group. Scores are calculated as a percent of the overall patellar width that lies lateral to the tangent offset line. Negative scores represent a medial patellar shift. Positive scores represent a lateral shift. Subjects with no bar on the graph did not demonstrate a change in patellar position. Three subjects demonstrated a lateral shift, 7 subjects medially shift. Data for one subject was not captured.

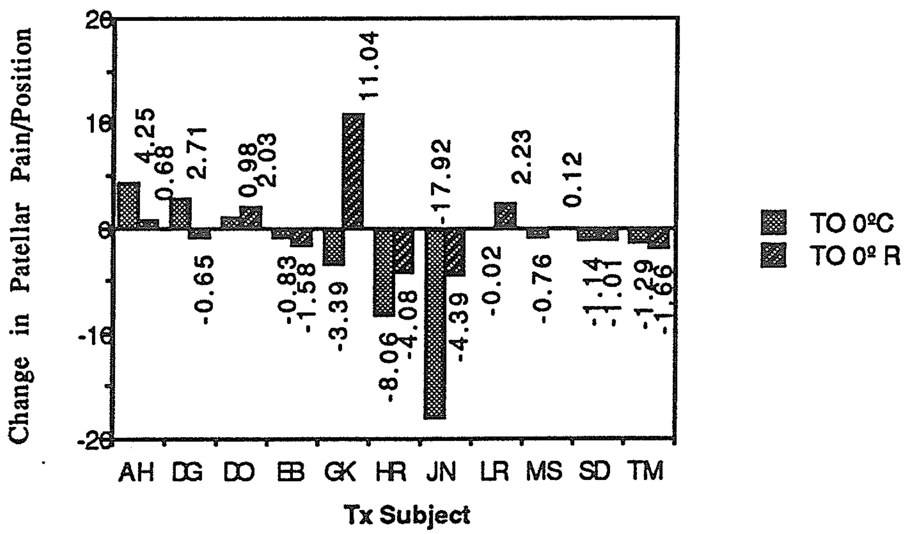

Figure 37. Comparison of changes in patellar position in TO 0º R relaxed compared to that with muscular contraction. Negative scores represent a medial patellar shift. Positive scores represent a lateral shift. Three subjects who were laterally shifted in the relaxed state continued to laterally shift. Two of 11 subjects (AH & DO) who laterally shifted in the relaxed state also laterally shift with muscle contraction. Three subjects (DG, LR, MS) medially shifted when measured in the relaxed state and latterally shifted with quadriceps contraction. One subject (GK) who was laterally shifted in the relaxed state medially shifted with muscle contraction. Five subjects (EB, HR, JN, SD, TM) medially shift in both the relaxed and contracted states .

Tangent Offset (20º Relaxed)

Tangent offset was measured with the quadriceps relaxed and at 20º knee flexion. Independent t-Tests did not demonstrate any significant difference between the treatment and nontreatment groups.

In the nontreatment group, 4 of the subjects demonstrated a medial shift and 4 demonstrated a lateral shift (Figure 38). The degree of shifting ranged between a 2.17% lateral shift and a 3.49% medial shift.

In the treatment group, 7 subjects demonstrated a medial shift while 4 demonstrated a lateral shift of the patella (Figure 39).

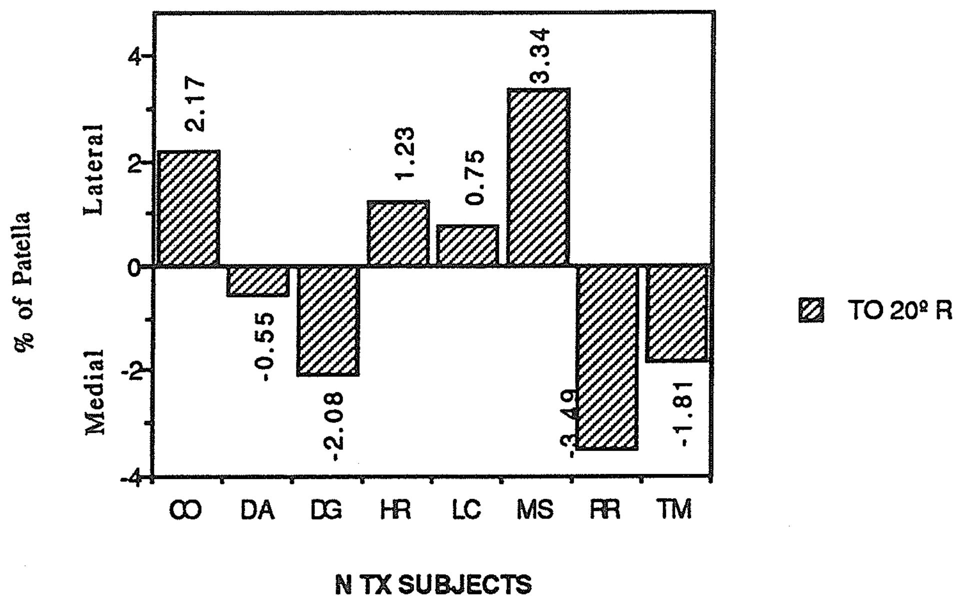

Figure 38 Changes in Tangent Offset at 20º relaxed in the nontreatment group. Scores are calculated as a percent of the overall patellar width that lies lateral to the tangent offset line. Negative scores represent a medial patellar shift. Positive scores represent a lateral shift. Subjects with no bar on the graph did not demonstrate a change in patellar position. Four subjects demonstrated a lateral shift, 4 subjects medially shifted.

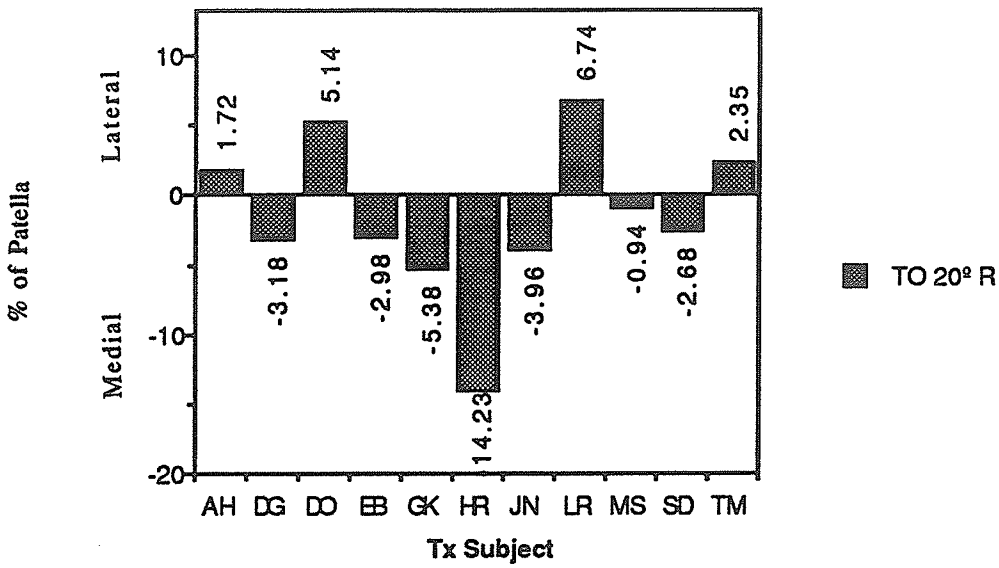

Figure 39. Changes in Tangent Offset at 20º relaxed in the treatment group. Scores are calculated as a percent of the overall patellar width that lies lateral to the tangent offset line. Negative scores represent a medial patellar shift. Positive scores represent a lateral shift. Subjects with no bar on the graph did not demonstrate a change in patellar position. Four subjects demonstrated a lateral shift, 7 subjects medially shifted.

Bisect Offset

A typical example of a bisect offset meaurement is shown in Figure 40. The bisect offset is also used to demonstrate medial and lateral patellar shift. As in tangent offset measurements, a positive difference between the pre- and post-test measurements indicates a lateral shift of the patella whereas a negative change indicates a medial shift of the patella.

Bisect Offset (0º Relaxed)

Subjects in the nontreatment groups were equally divided in that 4 demonstrated a medial shift and 4 demonstrated a lateral shift (Figure 41). Results were similar in the treatment group: 6 subjects demonstrated a lateral shift and 5 a medial shift (Figure 42).

An independent t-Test did not demonstrate any significant difference between the two groups.

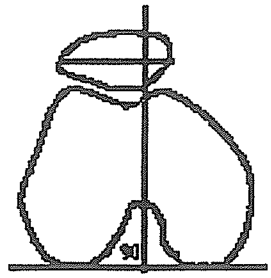

Figure 40. Measuring Bisect Offset to determine the medial/lateral alignment of the patella in relation to the femoral trochlea.

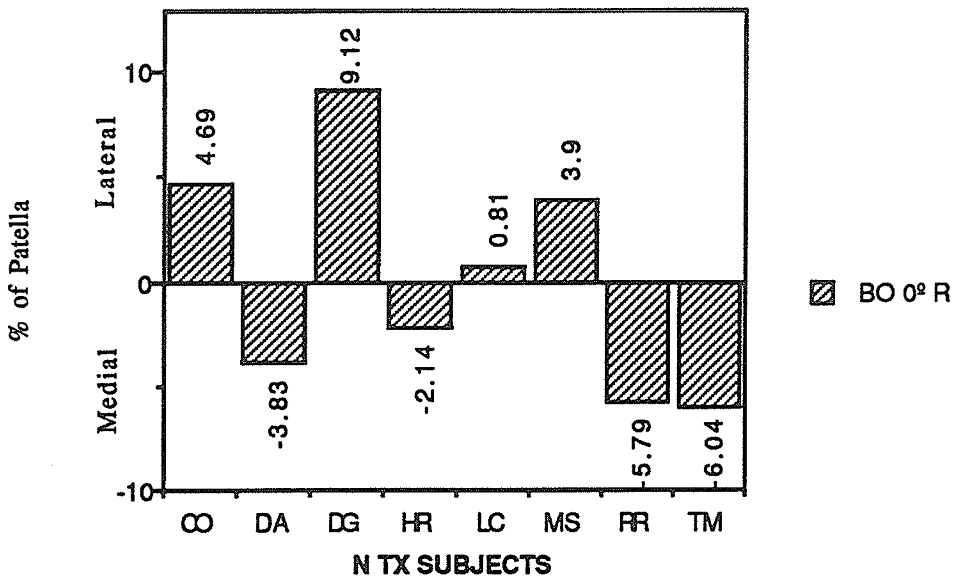

Figure 41. Changes in Bisect Offset 0º relaxed in the nontreatment group. Scores are calculated as a percent of the overall patellar width that lies lateral to the tangent offset line. Negative scores represent a medial patellar shift. Positive scores represent a lateral shift. Subjects with no bar on the graph did not demonstrate a change in patellar position. Four subjects demonstrated a lateral shift, 4 subjects medially shifted.

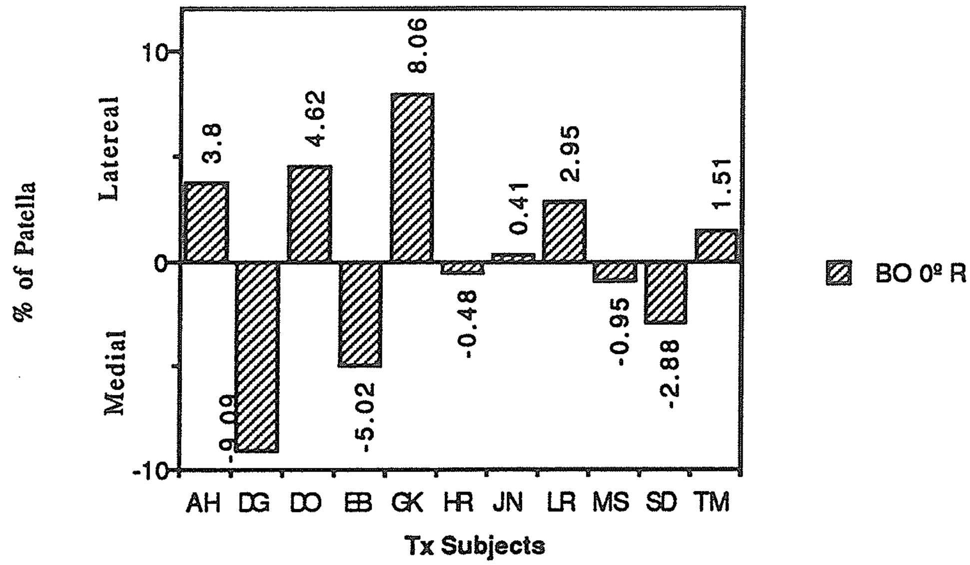

Figure 42. Changes in Bisect Offset 0º relaxed in the treatment group. Scores are calculated as a percent of the overall patellar width that lies lateral to the tangent offset line. Negative scores represent a medial patellar shift. Positive scores represent a lateral shift. Subjects with no bar on the graph did not demonstrate a change in patellar position. Six subjects demonstrated a lateral shift, 5 subjects medially shifted.

Bisect Offset (0º Contracted)

This bisect offset was measured with the quadriceps femoris contracted and the knee at 0º flexion. An Independent t-Test did not demonstrate any significant difference between the nontreatment and treatment groups.

Of the 7 subjects in the nontreatment group whose data were usable, only 2 subjects demonstrated a medial shift of the patella while the other 5 demonstrated a lateral shift (Figure 43). The two subjects who demonstrated the medial shift also demonstrated a medial shift at 0º degrees relaxed (BO 0º R).

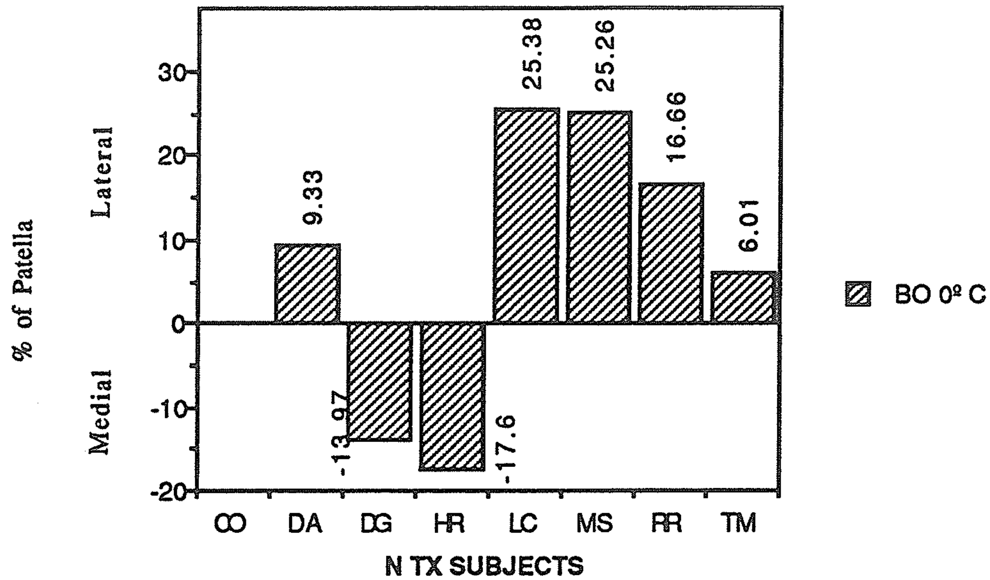

Figure 43. Changes in Bisect Offset 0º contracted in the nontreatment group. Scores are calculated as a percent of the overall patellar width that lies lateral to the tangent offset line. Negative scores represent a medial patellar shift. Positive scores represent a lateral shift. Subjects with no bar on the graph did not demonstrate a change in patellar position. Five subjects demonstrated a lateral shift, 2 subjects medially shifted. One subject's data was not available.

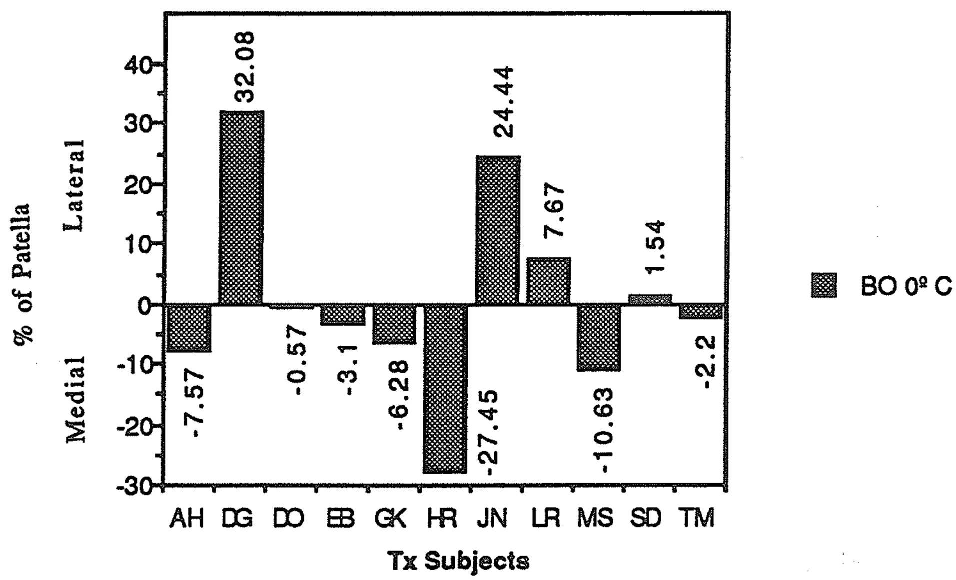

Figure 44. Changes in Bisect Offset 0º contracted in the treatment group. Scores are calculated as a percent of the overall patellar width that lies lateral to the tangent offset line. Negative scores represent a medial patellar shift. Positive scores represent a lateral shift. Subjects with no bar on the graph did not demonstrate a change in patellar position. Four subjects demonstrated a lateral shift, 7 subjects medially shifted. One subject's data was not available.

In the treatment group, 7 subjects demonstrated a medial shift, one, (HR) showed a 27.5% shift (Figure 44). Of the 4 subjects who demonstrated a lateral shift, two were extreme: DG and JN showed increases of 32% and 24.4% respectively.

Bisect Offset (20º Relaxed)

Bisect offset was measured with the quadriceps femoris relaxed and the knee flexed to 20º. An Independent t-Test did not demonstrate any significant difference between the two groups.

Six of the 8 nontreatment group subjects demonstrated a lateral shift in patellar position. The medial patellar shift in the remaining two subjects was 0.49% (TM) and 5.21% (DG) (Figure 45).

In the treatment group, 4 of the 11 subjects demonstrated a medial shift of the patella and 7 demonstrated a lateral shift (Figure 46).

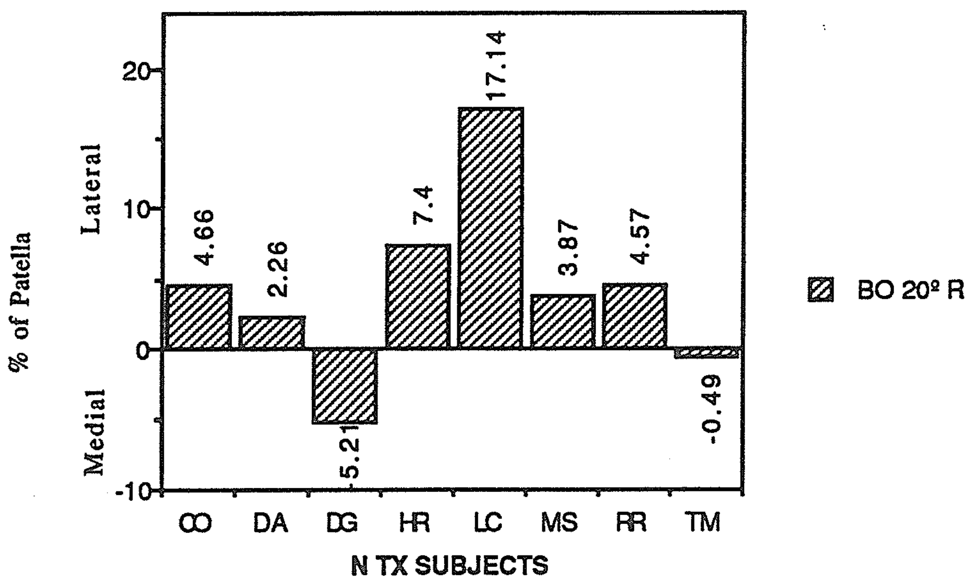

Figure 45. Changes in Bisect Offset 20º relaxed in the nontreatment group. Scores are calculated as a percent of the overall patellar width that lies lateral to the tangent offset line. Negative scores represent a medial patellar shift. Positive scores represent a lateral shift. Subjects with no bar on the graph did not demonstrate a change in patellar position. Six subjects demonstrated a lateral shift, 2 subjects medially shifted.

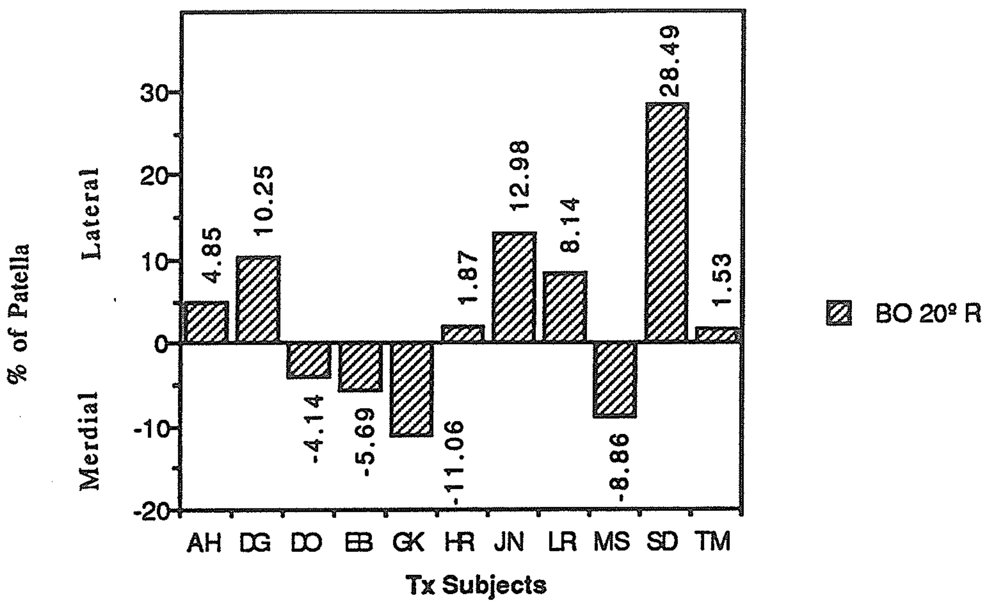

Figure 46. Changes in Bisect Offset 20º relaxed in the treatment group. Scores are calculated as a percent of the overall patellar width that lies lateral to the tangent offset line. Negative scores represent a medial patellar shift. Positive scores represent a lateral shift. Subjects with no bar on the graph did not demonstrate a change in patellar position. Seven subjects demonstrated a lateral shift, 4 subjects medially shifted.

Lateral Patellofemoral Angle

Lateral patellofemoral angle (Figure 47) was measured in degrees and was one of two measures used in this study to determine any change in patellar rotation about its long axis. A positive change in the angle is indicative of a medial rotation of the patella while a negative change is indicative of a lateral rotation of the patella. An increased lateral rotation would presumably approximate the lateral patellar facet and the lateral femoral condyle, thereby increasing patellofemoral compression. Conversely, medial rotation would presumably reduce lateral patellofemoral compression. In none of the three conditions was there any significant difference between the treatment and nontreatment groups.

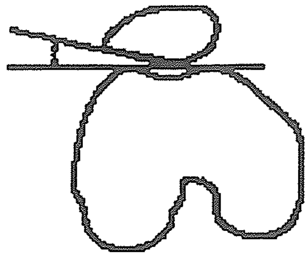

Figure 47. Measuring Lateral Patellofemoral Angle to determine the medial/lateral rotation of the patella in relation to the femoral trochlea.

Lateral Patellofemoral Angle (0º Relaxed)

Lateral patellofemoral angle was measured with the quadriceps femoris relaxed and the knee at 0º flexion. There was no significant difference between the nontreatment and treatment groups as measured using an Independent t-Test.

In the nontreatment group, 3 of the 8 subjects demonstrated a medial rotation of the patella, 3 demonstrated a lateral rotation, and 2 showed no change (Figure 48). The degree of rotation (medial and lateral) ranged between a 4.5º lateral rotation and a 4º medial rotation.

A paired t-Test demonstrated a significant difference in LPFA between pre- and post-test in the treatment group (Table 14). This is indicative of increased lateral rotation of the patella. Two subjects demonstrated a medial rotation of the patella, 7 demonstrated a lateral rotation and 2 did not change (Figure 49).

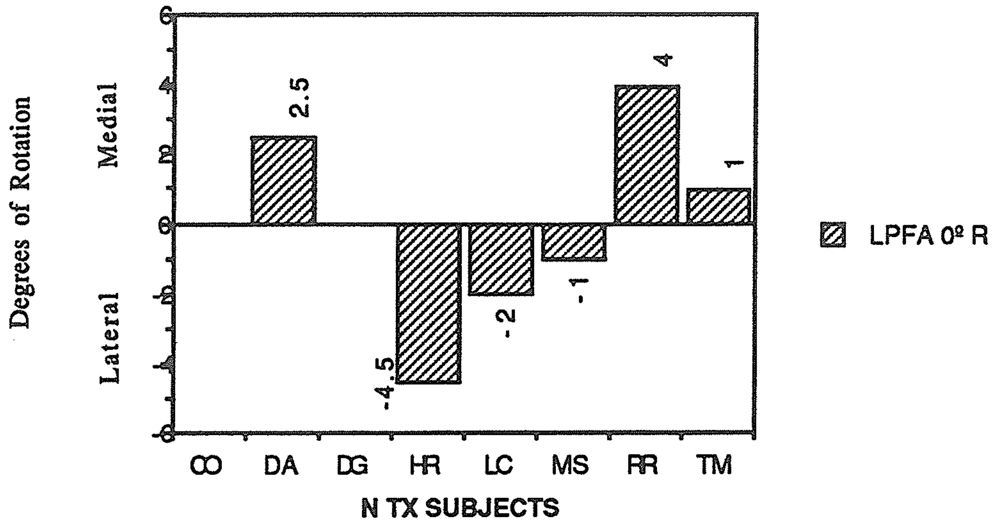

Figure 48 Changes in Lateral Patellofemoral Angle at 0º relaxed in the nontreatment group. Scores represent changes in degrees. Negative scores represent a lateral patellar rotation. Positive scores represent a medial patellar rotation. Subjects with no bar on the graph did not demonstrate a change in patellar position. Three subjects demonstrated a medial rotation, 3 subjects laterally rotated and 2 did not change.

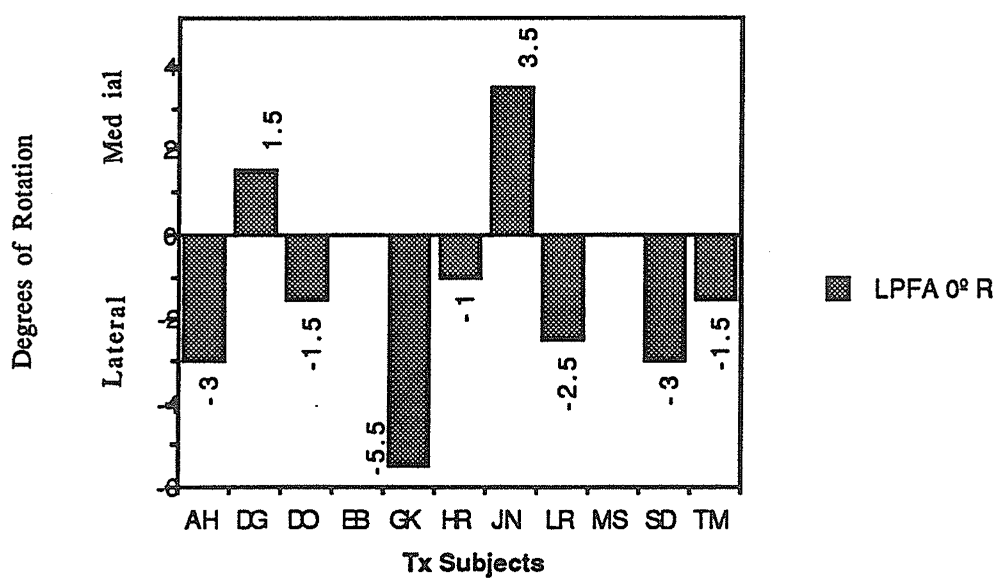

Figure 49 Changes in Lateral Patellofemoral Angle at 0º relaxed in the treatment group. Scores represent changes in degrees. Negative scores represent a lateral patellar rotation. Positive scores represent a medial patellar rotation. Subjects with no bar on the graph did not demonstrate a change in patellar position. Two subjects demonstrated a medial rotation, 7 subjects laterally rotated and 2 did not change.

Lateral Patellofemoral Angle (0º Contracted)

Lateral patellofemoral angle was measured with the quadriceps femoris contracted and the knee at 0º of flexion.

In the nontreatment group, 6 of the 8 subjects demonstrated a lateral rotation of the patella, one subject demonstrated a medial rotation and one did not change (Figure 50). Subject HR demonstrated a much larger (8º) lateral rotation than the other subjects.

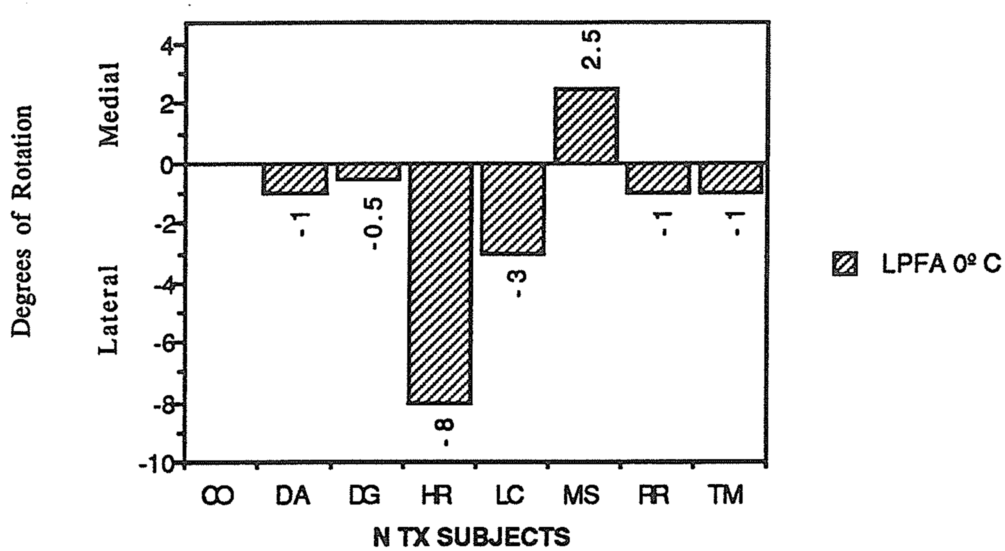

Figure 50 Changes in lateral patellofemoral angle at 0º contracted in the nontreatment group. Scores represent changes in degrees. Negative scores represent a lateral patellar rotation. Positive scores represent a medial patellar rotation. Subjects with no bar on the graph did not demonstrate a change in patellar position. One subject demonstrated a medial rotation, 6 subjects laterally rotated and one did not change.

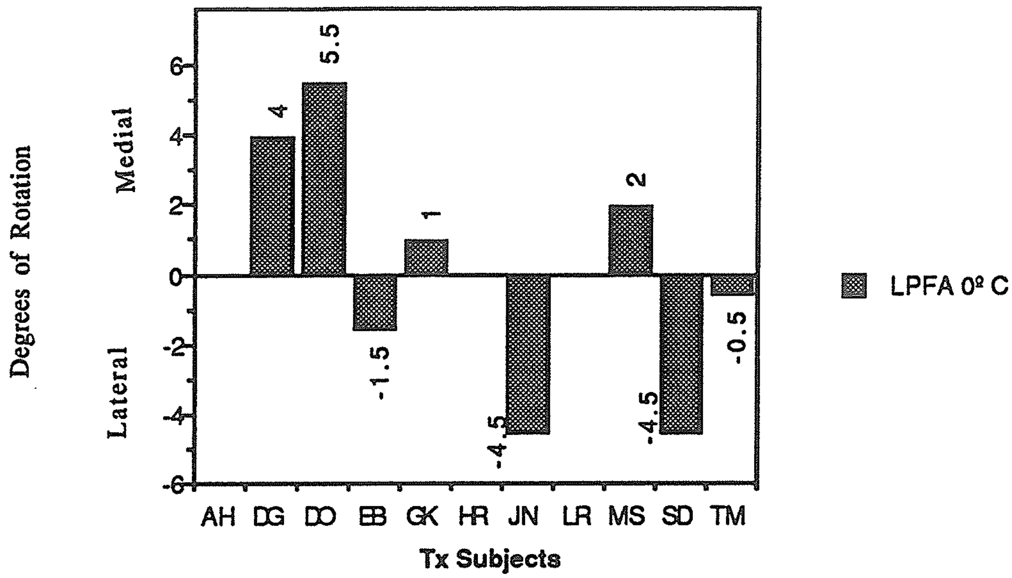

Figure 51 Changes in lateral patellofemoral angle at 0º contracted in the treatment group. Scores represent changes in degrees. Negative scores represent a lateral patellar rotation. Positive scores represent a medial patellar rotation. Subjects with no bar on the graph did not demonstrate a change in patellar position. Four subjects demonstrated a medial rotation, 4 subjects laterally rotated and 3 did not change.

In the treatment group, an equal number (4) demonstrated medial rotation as demonstrated lateral rotation. The remaining 3 subjects showed no change (Figure 51). The degree of rotation ranged from 5.5º medially to 4.5º laterally.

Lateral Patellofemoral Angle (20º Relaxed)

Lateral patellofemoral angle was measured with the quadriceps femoris relaxed and the knee flexed 20 degrees. An independent t-Test did not demonstrate a significant difference between the nontreatment and treatment groups.

In the nontreatment group, 3 of 8 subjects demonstrated a lateral rotation, 4 a medial rotation, and one showed no change (Figure 52). The range was from 5.5º lateral rotation to 4.5º medial.

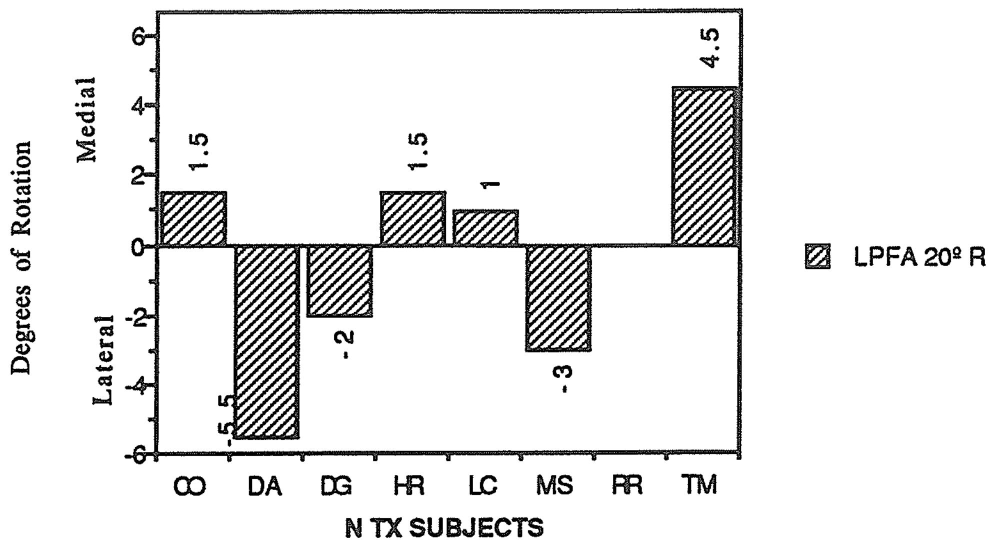

Figure 52 Changes in lateral patellofemoral angle at 20º relaxed in the nontreatment group. Scores represent changes in degrees. Negative scores represent a lateral patellar rotation. Positive scores represent a medial patellar rotation. Subjects with no bar on the graph did not demonstrate a change in patellar position. Four subjects demonstrated a medial rotation, 3 subjects laterally rotated and one did not change.

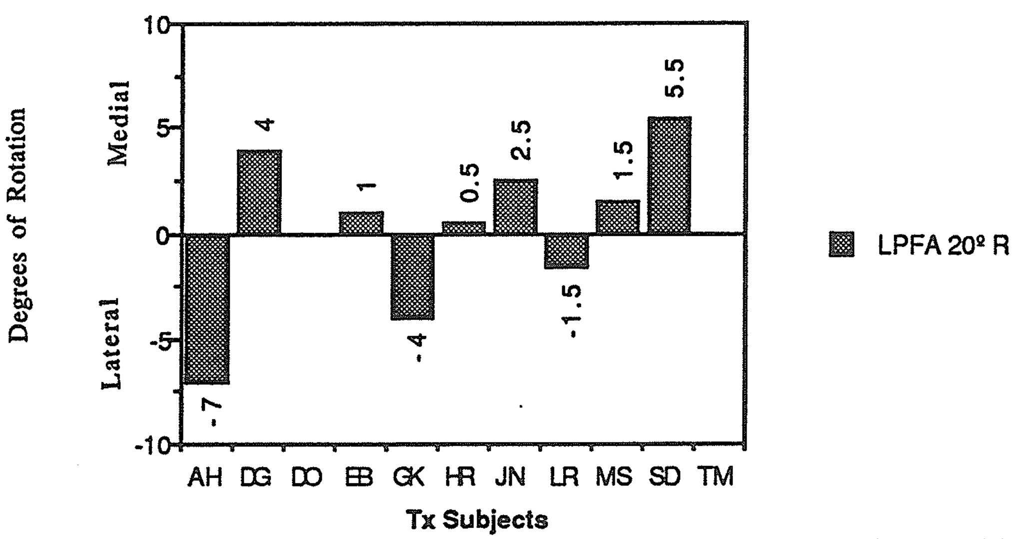

Figure 53 Changes in lateral patellofemoral angle at 20º relaxed in the treatment group. Scores represent changes in degrees. Negative scores represent a lateral patellar rotation. Positive scores represent a medial patellar rotation. Subjects with no bar on the graph did not demonstrate a change in patellar position. Six subjects demonstrated a medial rotation, 3 subjects laterally rotated and two did not change.

In the treatment group, 6 of the 11 subjects demonstrated a medial rotation while only 3 demonstrated lateral rotation and 2 showed no change. It is interesting to note that although there was a signficant lateral rotation at 0º relaxed, this was not evident when the knee was flexed to 20 degrees (Table 14).

Patellar Tilt Angle

As in lateral patellofemoral angle, a positive change indicates a medial rotation of the patella and a negative change indicates a lateral rotation of the patella.

Independent t-Tests did not demonstrate any significant differences between the nontreatment and treatment groups in any of these three measures (Table 14).

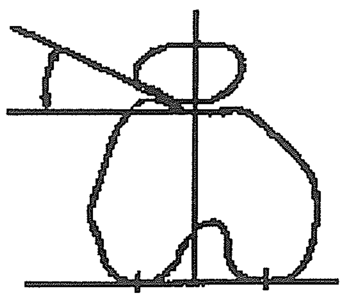

Figure 54. Measuring Patellar Tilt Angle to determine the medial/lateral rotation of the patella in relation to the femoral trochlea.

Patellar Tilt Angle (0º Relaxed)

Figure 54 shows a typical measure of the patellar tilt angle. In the nontreatment group, 2 of 8 subjects demonstrated medial rotation while 5 demonstrated lateral rotation and one did not change.

In the treatment group, 5 subjects demonstrated medial rotation after treatment and 6 demonstrated lateral rotation after treatment (Figure 56).

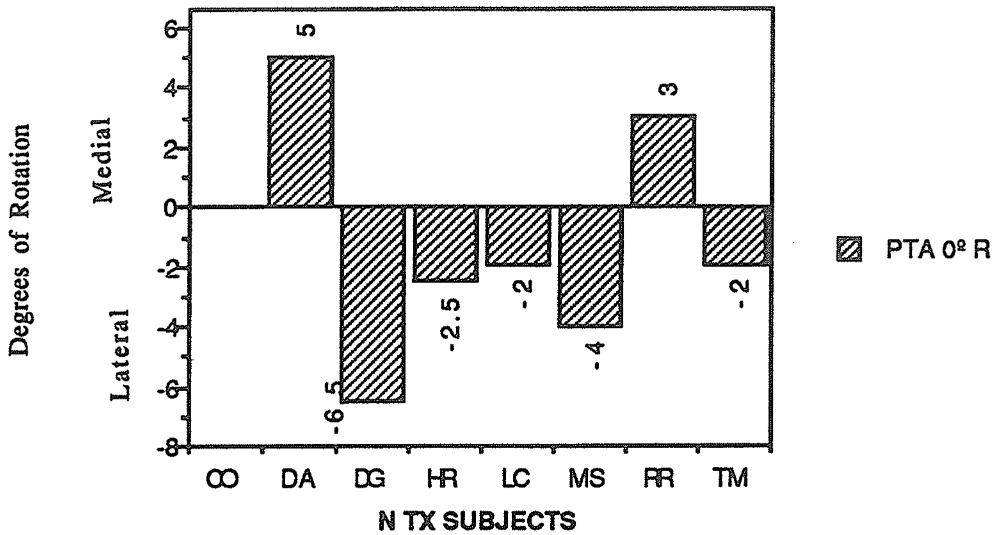

Figure 55 Changes in Patellar Tilt Angle at 0º relaxed in the nontreatment group. Scores represent changes in degrees. Negative scores represent a lateral patellar rotation. Positive scores represent a medial patellar rotation. Subjects with no bar on the graph did not demonstrate a change in patellar position. Two subjects demonstrated a medial rotation, 5 subjects laterally rotated and one did not change.

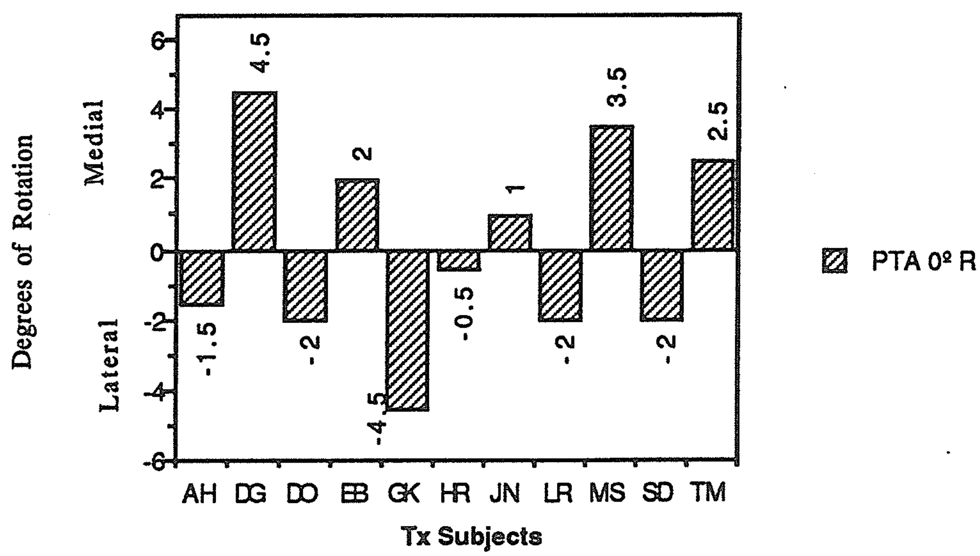

Figure 56 Changes in Patellar Tilt Angle at 0º relaxed in the treatment group. Scores represent changes in degrees. Negative scores represent a lateral patellar rotation. Positive scores represent a medial patellar rotation. Subjects with no bar on the graph did not demonstrate a change in patellar position. Five subjects demonstrated a medial rotation and 6 subjects laterally rotated.

Patellar Tilt Angle (0° Contracted)

Patellar tilt angle was measured with the quadriceps femoris contracted and the knee flexed 0 degrees.

Only one of the nontreatment group subjects demonstrated a medial rotation while half (4 of 8) demonstrated a lateral rotation. The other three subjects in this group showed little or no change (Figure 57). There was no significant change pre- vs post-test (Table 14).

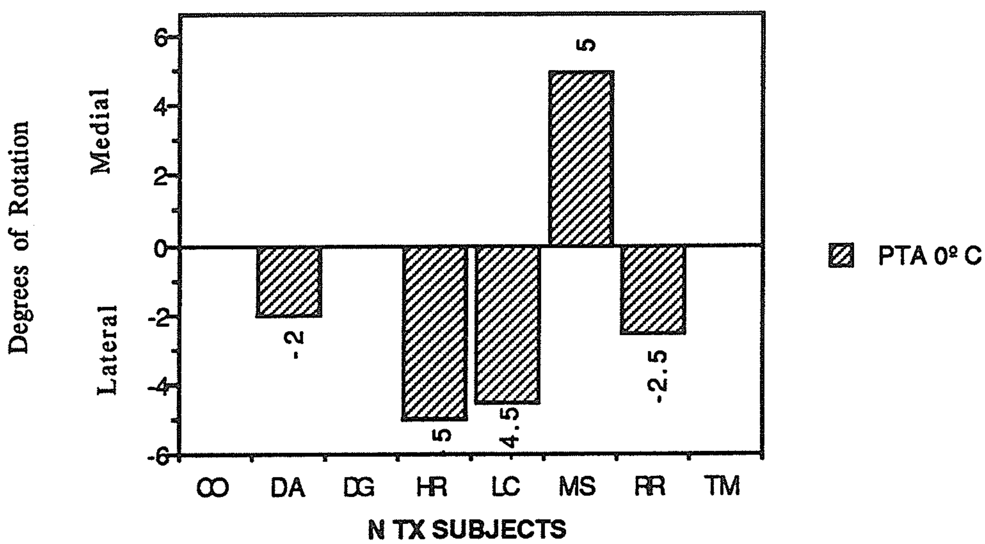

Figure 57 Changes in Patellar Tilt Angle at 0º contracted in the nontreatment group. Scores represent changes in degrees. Negative scores represent a lateral patellar rotation. Positive scores represent a medial patellar rotation. Subjects with no bar on the graph did not demonstrate a change in patellar position. One subject demonstrated a medial rotation, 4 subjects laterally rotated and 3 did not change.

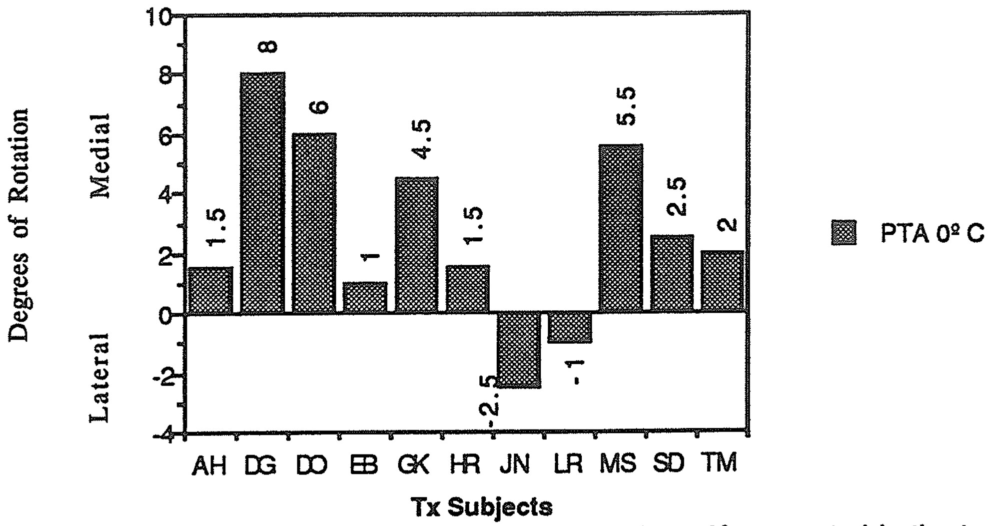

Figure 58 Changes in Patellar Tilt Angle at 0º contracted in the treatment group. Scores represent changes in degrees. Negative scores represent a lateral patellar rotation. Positive scores represent a medial patellar rotation. Subjects with no bar on the graph did not demonstrate a change in patellar position. Nine subject demonstrated a medial rotation, and 2 subjects laterally rotated.

In contrast, there was a significant change pre- and post-test in the treatment group ($P < .05$) (Table 14). Nine of 11 subjects demonstrated a medial rotation while only 2 demonstrated a lateral rotation (Figure 58).

An independent t-Test demonstrated a significant difference in the change in patellar position between nontreatment and treatment groups (t-value = -2.52, P = .0226).

Patellar Tilt Angle (20º Relaxed)

Patellar tilt angle was measured with the quadriceps femoris relaxed and the knee flexed to 20 degrees.

The nontreatment group results were mixed: 4 subjects demonstrated a medial rotation of the patella, 2 demonstrated a lateral rotation, and 2 showed little or no change (Figure 59).

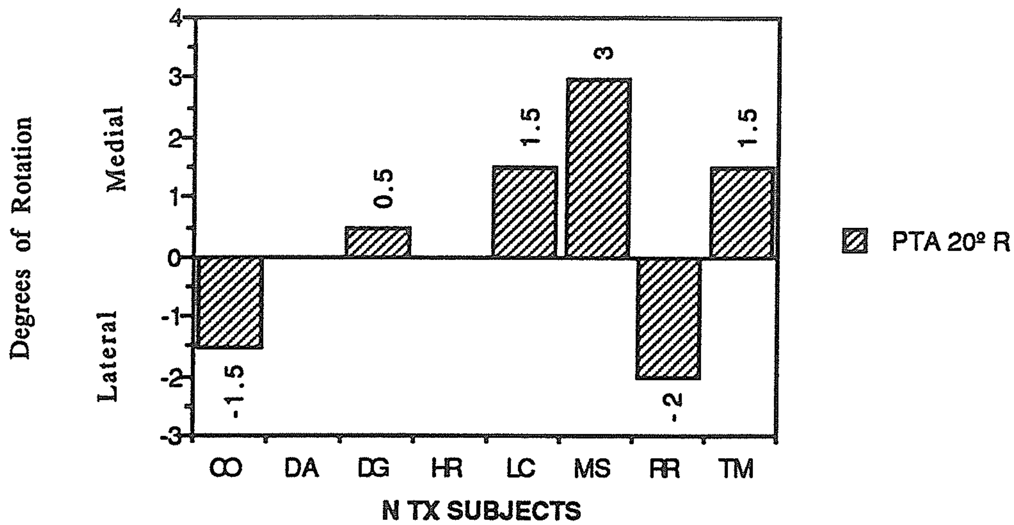

Figure 59 Changes in Patellar Tilt Angle at 20º relaxed in the nontreatment group. Scores represent changes in degrees. Negative scores represent a lateral patellar rotation. Positive scores represent a medial patellar rotation. Subjects with no bar on the graph did not demonstrate a change in patellar position. Four subjects demonstrated a medial rotation, 2 subjects laterally rotated and 2 did not change.

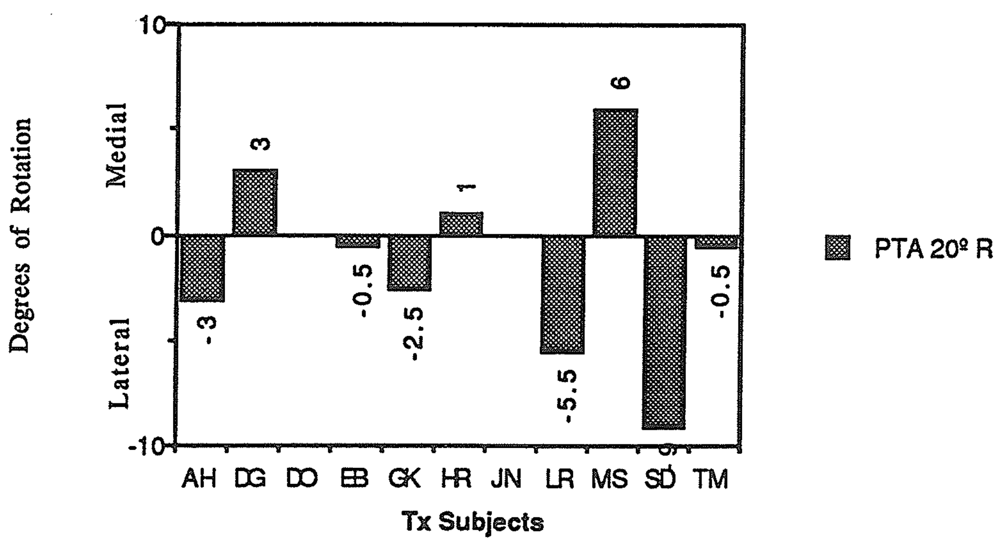

Figure 60 Changes in Patellar Tilt Angle at 20º relaxed in the treatment group. Scores represent changes in degrees. Negative scores represent a lateral patellar rotation. Positive scores represent a medial patellar rotation. Subjects with no bar on the graph did not demonstrate a change in patellar position. Three subjects demonstrated a medial rotation, 6 subjects laterally rotated and 2 did not change.

In the treatment group, 3 subjects demonstrated medial rotation, 6 subjects demonstrated a lateral rotation, and 2 subjects showed little or no change (Figure 60).

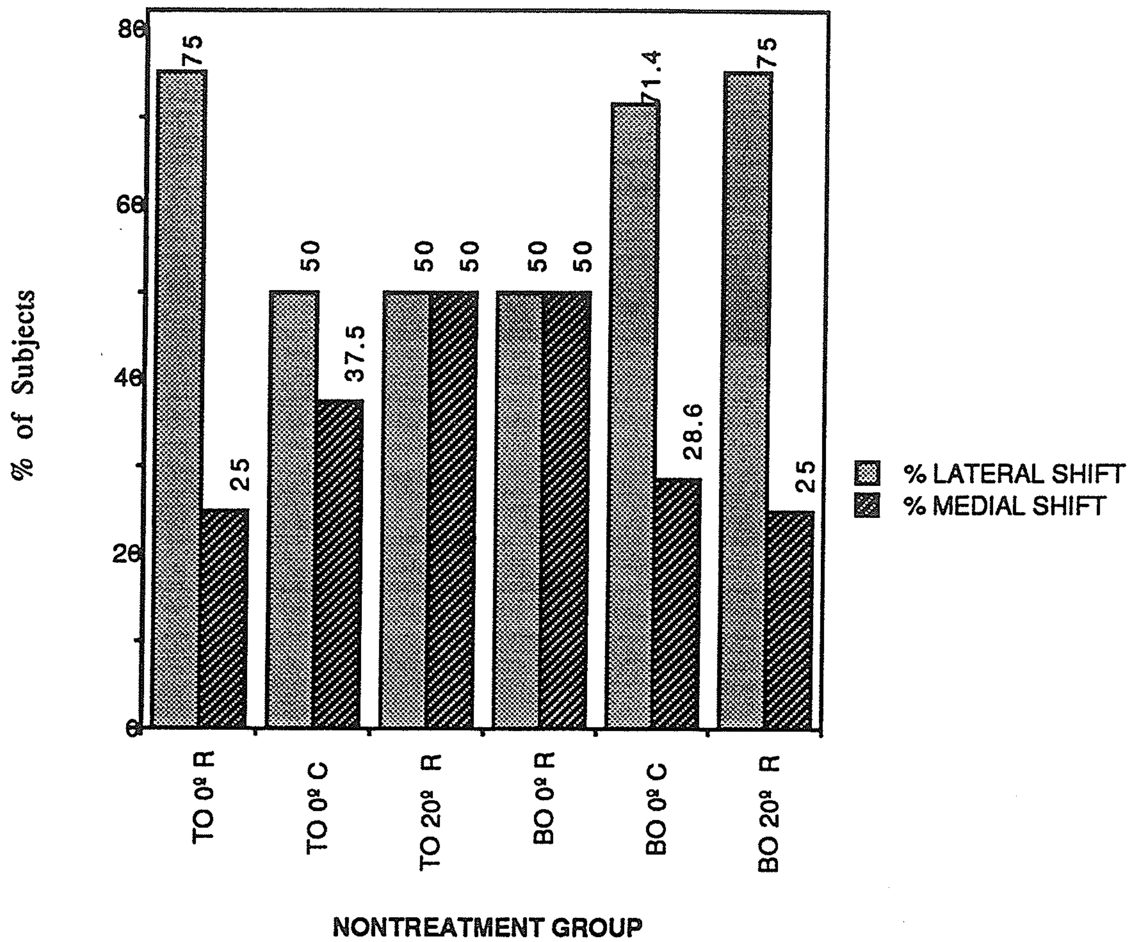

Figure 61. Percentage of nontreatment subjects who demonstrated a medial, lateral or no change in patellar shift of the patella as measured using tangent offset and bisect offset.

DESCRIPTIVE COMPARISONS

It is important to recognize that what may not be statistically significant may be clinically significant. In the case of this study, it may not be the amount of patellar shift that is important but simply that there is a patellar shift.

Table 15 is a report of the percent of subjects in each group demonstrating medial or lateral changes in patellar position regardless of their amount of change.

NTX	TO 0ºR	TO 0ºC	TO 20º	BO 0ºR	BO 0ºC	BO 20º	LPFA 0ºR	LPFA 0ºC	LPFA 20º	PTA 0ºR	PTA 0ºC	PTA 20º
LAT	75	50	50	50	71.4	75	37.5	75	37.5	62.5	50	25
MED	25	37.5	50	50	28.6	25	37.5	12.5	50	25	12.5	50
ø		12.5					25	12.5	12.5	12.5	37.5	25
TX	TO 0ºR	TO 0ºC	TO 20º	BO 0ºR	BO 0ºC	BO 20º	LPFA 0ºR	LPFA 0ºC	LPFA 20º	PTA 0ºR	PTA 0ºC	PTA 20º
LAT	45.5	27.3	36.4	54.5	36.4	63.6	63.6	36.4	27.3	54.5	18.2	54.5
MED	54.5	72.7	63.6	45.5	63.6	36.4	18.2	36.4	54.5	45.5	81.8	27.3
ø							18.2	27.2	18.2			18.2

TABLE 15 The percentage of subjects who demonstrated a change in patellar position as measured on CT Scans. NTX=Nontreatment group (N=8), TX= Treatment group (N=11), LAT=Lateral patellar rotation/shift, MED= Medial patellar rotation/shift, ø=no change in patellar position, TO 0ºR=Tangent offset 0º Relaxed, TOº C= Tangent offset 0º contracted, TO 20º= Tangent offset 20º relaxed, BO 0ºR-Bisect offset 0º relaxed, BO 0º C= Bisect offset 0º contracted, BO 20º= Bisect offset 20º relaxed, LPFA 0ºR=Lateral patellofemoral angle 0º Relaxed, LPFAº C= Lateral patellofemoral angle 0º contracted, LPFA 20º= Lateral patellofemoral angle 20º relaxed.

It is interesting to note that lateral shifting of the patella occured in more nontreatment subjects in four of the six measures and as often as a medial shift in the other two measures (Figure 61).

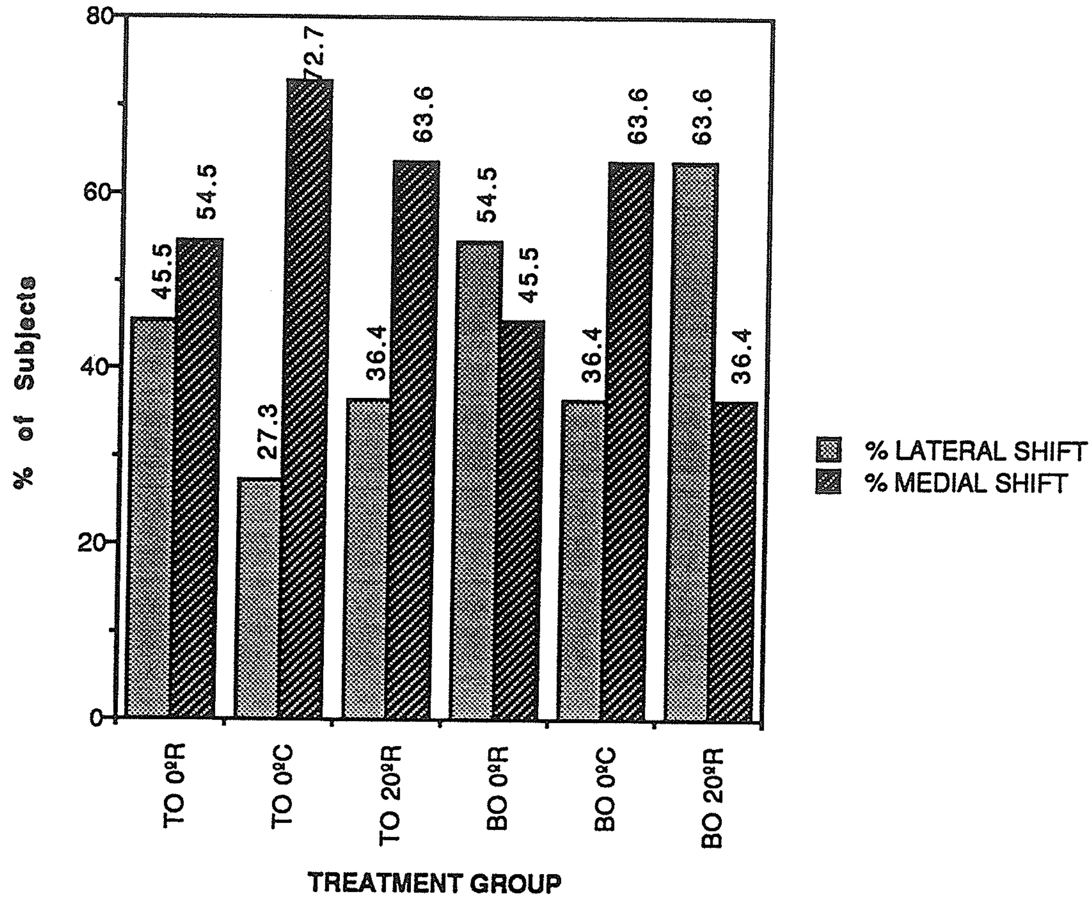

Figure 62. Percentage of treatment group subjects who demonstrated a medial, lateral or no change in patellar shift of the patella as measured using tangent offset and bisect offset.

In the treatment group, more subjects demonstrated a medial shift than a lateral shift in four of the six measures (Figure 62).

Measures of tangent offset in the contracted state indicated that 50% of nontreatment subjects laterally deviated, whereas 72.7% of subjects in the treatment group medially deviated. Bisect offset measurements in the contracted state show that 71.4% of the nontreatment group laterally rotated while 63.6% of the treatment group medially rotated.

Patellar shift can also be compared in the relaxed state versus the contracted state. In the relaxed state 54.5% of the treatment subjects medially rotated whereas 72.7% of the same subjects experienced a medially rotated patella when measured with the quadriceps contracted.

Similar results occurred with bisect offset (45.5% relaxed and 63.6% contracted).

This would suggest that increased quadriceps strength may influence patellar position.

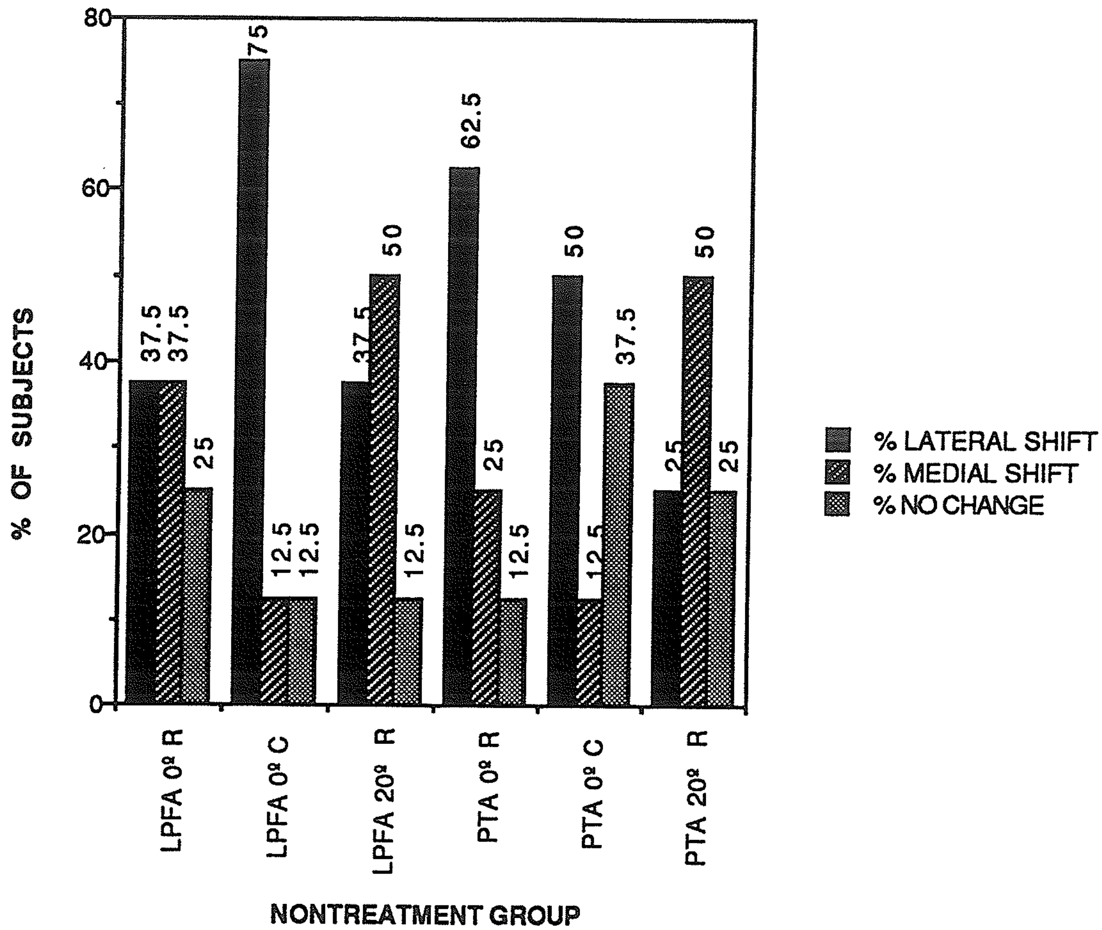

Figure 63. Percentage of nontreatment group subjects who demonstrated a medial, lateral or no change in patellar rotation of the patella as measured using lateral patellofemoral angle and patellar tilt angle.

In the nontreatment group, 75% of the subjects demonstrated a lateral patellar rotation when measured using LPFA 0ºC. Conversely in the treatment group, only 36.4% of the subjects laterally rotated. Only 12.5% of the nontreatment group medially rotated while 36.4% of the treatment group experienced a medial change in patellar position.

Measurements of patellar tilt angle at 0º contracted provided even more evidence as to the effect of increased quadriceps isometric strength. In the nontreatment group 50% of the subjects laterally shifted and 12.5% medially rotated with quadriceps contraction while in the treatment group 81.8% medially rotated and the remainder laterally rotated.

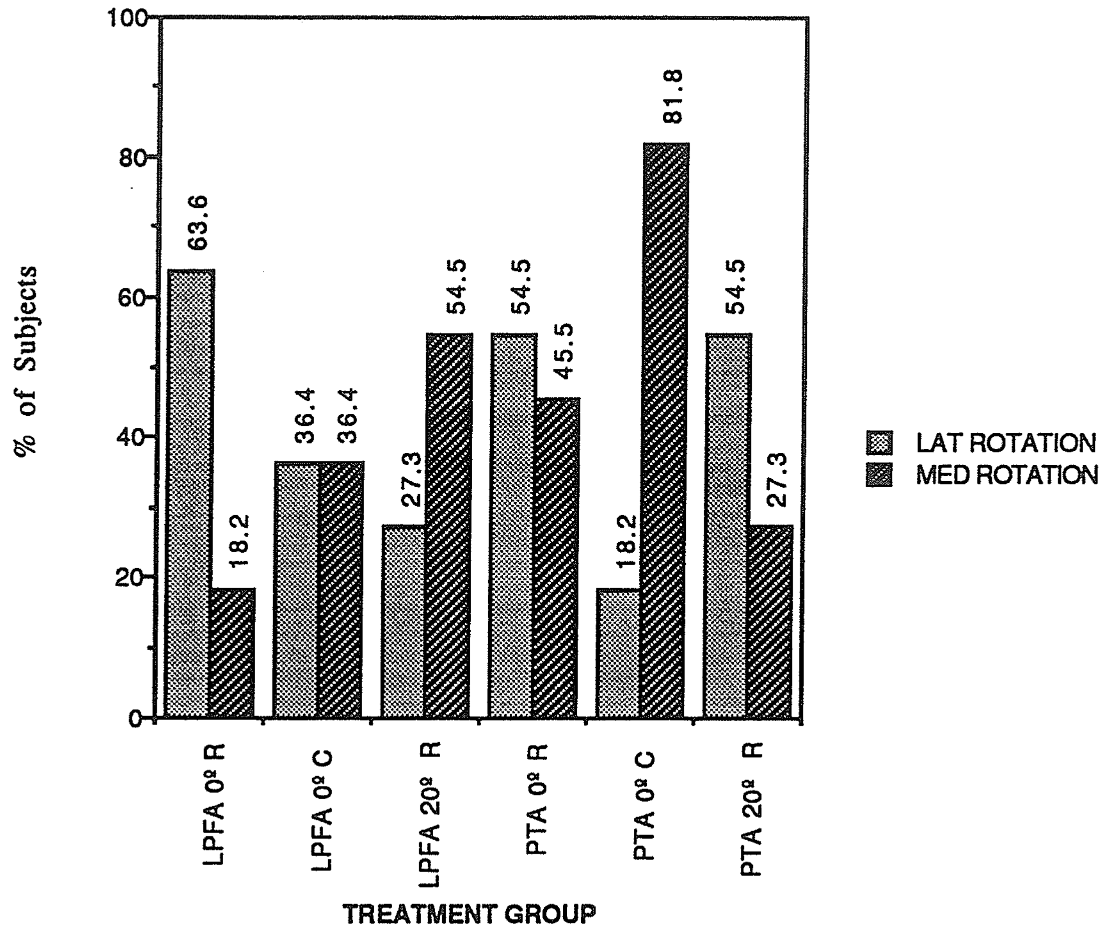

Figure 64. Percentage of treatment group subjects who demonstrated a medial, lateral or no change in patellar rotation of the patella as measured using lateral patellofemoral angle and patellar tilt angle.

Comparison of patellar position in the relaxed and contracted state also suggests that increased quadriceps strength may influence patellar rotation. In the treatment group, most of the subjects laterally rotated in the relaxed state as measured using LPFA. Measurements in the contracted state showed that only 36.4% of the subjects laterally rotated. This was even more evident in measures of patellar tilt angle. In the relaxed sate, 54.5% of treatment subjects were laterally rotated while in the contracted state, 18.8% of subjects laterally rotated and 81.8% of these subjects medially rotated.

Cross Over Experimental Results

As noted, the data for four subjects (DG, HR, MS, TM) who participated in a cross over experimental design were analyzed separately from the treatment group, which also included their results. Following the pre-test, they were assigned to the nontreatment group for a six week period. They were given the same instructions as the other subjects in the nontreatment group, that is, to not participate in any strength training or treatment programs that might affect their present condition. Following the six week period, they were again tested. Subsequently they received the same six week treatment period as did the original seven treatment group subjects and they were then tested a third time.

An analysis of variance demonstrated a significant change in Isometric quadriceps strength (p=.0126) (Table 16). The Scheffe F-Test post hoc analysis (Table 17) showed a significant increase in isometric strength during the treatment period but not during the nontreatment period.

Measurement	M1		M2		M3		P Value
	Mean	SD	Mean	SD	Mean	SD	
Torque	21.57	7.63	25.65	10.18	53.96	22.89	.0126*

* t significant at P< .05

TABLE 16 One factor with repeated measures ANOVA of changes in isometric torque for quadriceps muscle in cross over subjects. M1 = pre-test torque prior to nontreatment period, M2 = isometric torque following a six week nontreatment period, M3 = post-test isometric torque following a six week treatment period.

Comparison:	Mean Difference	Fisher PLSD	Scheffe F-test
M1 torque vs M2 torque	-1.6	18.9	1.42.1
M1 torque vs M3 torque	-30.5	18.9*	7.8*
M2 torque vs M3 torque	-29	18.9*	7*

* t significant at the .05 level

Table 17. Post hoc analysis of isometric strength as reported by subjects who participated in the cross over design. M1 = pre-test torque prior to nontreatment period, M2 = isometric torque following a six week nontreatment period, M3 = post-test isometric torque following a six week treatment period.

As shown in table 18, analysis of variance demonstrated significant changes in the evaluative pain category and in the measure of total pain. None of the other categories of pain changed significantly. The treatment group which included these subjects also showed a significant difference in total pain.

Only following the treatment period did these subjects demonstrate a significant decrease in any of the pain categories. Thus, following the treatment period subjects reported a significant decrease in total pain (Table 19).

Pain	M1		M2		M3		P Value
Category	Mean	SD	Mean	SD	Mean	SD	
Affective	10	1.83	15	5.35	7.25	1.5	.0581
Sensory	1.5	1.73	2.25	1.5	0	0	.0723
Evaluative	2	1.41	0	0	.5	1	.0429*
Misc	4	1.63	5.75	2.99	1.25	1.26	.0785
Total	17.5	2.38	23	8.6	9	1.83	.0144*

* t significant at P< .05

TABLE 18 One factor with repeated measures ANOVA of changes in pain in cross over subjects. M1 = pre-test pain prior to nontreatment period, M2 = pain following six week nontreatment period, M3 = post-test pain following a six week treatment period.

Comparison:	Mean Difference	Fisher PLSD	Scheffe F-test
M1 total vs M2 total	-5.5	8	1.4
M1 Total vs M3 Total	8.5	8*	3.4
M2 Total vs M3 Total	14	8*	9.2*

* t significant at the .05 level

Table 19. Post hoc analysis of pain perception as reported by subjects who participated the cross over design using the McGill Pain Questionnaire. M1 = pre-test torque prior to nontreatment period, M2 = isometric torque following a six week nontreatment period, M3 = post-test isometric torque following a six week treatment period.

As shown in table 20, an anlaysis of variance demonstrated that a significant change in patellar position was found only in a measure of tangent offset in the relaxed state (TO0ºR) (P = .0227). A post hoc analysis using a Scheffe F-test (Table 21) showed a significant lateral shift during the nontreatment period.

	M1		M2		M3		P VALUE
	Mean	SD	Mean	SD	Mean	SD	
TO 0º R	6.7	2.74	11.16	4.98	9.56	6.33	.0227*
TO 0ºC	16.98	4.45	16.8	2.74	13.18	4.88	.4274
TO 20º	-6.33	2.68	-6.16	3.13	-9.98	6.93	.4047
B O 0ºR	78.45	6.58	79.66	12.34	77.14	7.96	.7001
B O 0ºC	114.05	19.46	113.97	23.7	108.95	30.38	.9085
B O 20º	66.76	5.07	68.17	5.37	69.37	8.30	.7409
LPFA 0ºR	3	2.16	1.88	3.33	1.63	3.01	.4943
LPFA 0ºC	3.5	5.12	1.75	4.63	3.12	3.75	.7122
LPFA 20º	9.12	2.59	9.38	2.17	11	2.12	.3939
PTA 0ºR	12.25	3.84	8.5	5.70	11	4.6	.0759
PTA 0ºC	7.12	6.69	7.12	4.97	14	3.87	.1938
PTA 20º–	15.25	2.5	16.5	2.42	18.88	3.45	.1026

* t significant at P< .05

TABLE 20 One factor with repeated measures ANOVA of changes in patellar position in cross over subjects. M1 = pre-test patellar position prior to nontreatment period, M2 = patellar position following six week nontreatment period, M3 = post-test patellar position following a six week treatment period.

Comparison:	Mean Difference	Fisher PLSD	Scheffe F-test
M1 To 0ºR vs M2 To 0ºR	-4.43	2.82*	7.38*
M1 To 0ºRvs M3 To 0ºR	-2.86	2.82*	3.08
M2 To 0ºRvs M3 To 0ºR	1.57	2.82	.925

* t significant at the .05 level

Table 21. Post hoc analysis of patellar position as reported by subjects who participated in the cross over design. M1 = pre-test torque prior to nontreatment period, M2 = isometric torque following a six week nontreatment period, M3 = post-test isometric torque following a six week treatment period.

Chapter V

DISCUSSION

Chapter V

DISCUSSION

Patellofemoral pain has been widely studied with regard to its etiology, signs and symptoms, however little is known as to the efficacy of conservative treatment. Conservative treatment can include rest, exercise, braces and medications while surgery is a more aggressive attempt to realign what is perceived to be an anatomical patellofemoral malalignment. The purpose of this study was to investigate the effect of EMS on strength of the quadriceps and on patellofemoral alignment and pain. The relationships between quadriceps strength following EMS, and patellar position (as measured on computed tomography) and with changes in patellofemoral pain (as reported on the McGill Pain Questionnaire) were also examined.

Isometric Quadriceps Strength

The results of this study indicated that isometric quadriceps strength significantly increased in the treatment group as compared to the nontreatment group. Kotz (1977) reported strength increases of between 30 and 40 percent when normal musculature was trained with electrical stimulation. Johnson et al. (1977) treated patients with patellofemoral pain and reported that the minimum strength increase in his subjects was 200%. He did not report maximum increases. The present study demonstrated strength increases between 58.2% and 410.6% following EMS training coupled with a maximal quadriceps contraction. Johnson et al. (1977) concluded that patients with patellofemoral pain likely reflect a greater potential for strength improvement than do normal subjects. Other studies (Johnson et al., 1977; Currier & Mann, 1983; Selkowitz, 1985) have reported that increase in strength was directly related to the intensity of the stimulation.

It is also important to note, although one might logically assume, that the workload performed throughout the treatment period correlated positively and significantly to increases in isometric strength. Only one other study (Selkowitz, 1985) related the workload to the eventual strength increases. Selkowitz (1985) concluded that training three times per week for four weeks using electrically induced maximal voluntary contraction of the quadriceps femoris muscle group produced significantly greater strength gains than training using isometrics alone. He also reported that improvement in strength was positively and significantly correlated to training contraction intensity and duration using EMS. The findings from this present study agree with Selkowitz's (1985) suggestion that increase in strength using EMS may be determined by the subject's ability and willingness to tolerate longer and more forceful contractions.

Selkowitz (1984) used a high frequency current (2200 Hz) modulated to 50 Hz and a two minute rest period, whereas the present study used a conventional low frequency stimulator (50 Hz) and a 50 second rest period. He reported that the increase in strength gains in his study may have been a consequence of the two minute rest period. This was not substantiated in the present study in view of the significantly positive results obtained with a 50 second rest period. It may also be that LLoyd et al.(1986) were correct in saying that the optimal frequency is as yet to be determined and that there may not be any difference between the present low and medium frequency units which all package the electrical output to ultimately deliver a frequency of 50 Hz to the muscle.

Changes in Patellofemoral Pain

The literature does not report any studies that have measured the effect of increased quadriceps strength on patellofemoral pain. Johnson et al. (1977) developed a grading system from one to four based on the patients subjective evaluation of their ability to return to the preinjury level of function. Wise et al. (1984) studied the effect of biofeedback on patellofemoral pain subjects. The results showed that biofeedback did enhance the selective recruitment of the vastus medialis oblique and a return to pain free activity. The study did not report any pre- and post-test protocol for the measurement of pain; only an end point perception of pain after a three week course of treatment. The McGill Pain Questionnaire was used in the present study to both quantify and standardize pain between subjects.

The traditional precept that pain is expressed in relation to the amount of tissue damage is a notion that is no longer accepted (Melzack, 1989). Pain is a multivariate expression of trauma which is influenced by attention, anxiety, suggestion and other psychological variables (Melzack, 1989). The McGill Pain Questionnaire was developed to capture this multifaceted response to pain.

The results of this study did not provide a clear and decisive answer. The treatment group did demonstrate a significant change in affective and total pain pre- vs post-test but the change was not statistically different between treatment and nontreatment groups in either of these categories. Part of the difficulty seems to be the large within group variability that exists in subject reporting of response to pain. This might suggest that the chronic nature of patellofemoral pain may be difficult to put into words (as required by the McGill Pain Questionnaire) or that patellofemoral pain is highly variable from day to day. It might be more appropriate to allow subjects to report their post-test scores in relation to their pre-test scores. The difficulty in designing a study to look at patellofemoral pain is that the pain can be variable from day to day or even during the course of the day.

Patellofemoral pain is even more variable in response to changes in activity, including exercise such as, climbing stairs. Conversely, it is also variable with inactivity, such as periods of long sitting. Consequently any pain measuring tool which captures the perception of pain at a particular moment in time may not be representative of the pain at all times.

The other problem with studying patellofemoral pain is that, like any other overuse syndrome, activity increases the pain while rest, and cessation of activity, allows time for the pain to subside. Consequently, comparisons of pain levels in a treatment group to a nontreament group cannot control for the "rest" variable, which alone may account for a decrease in pain. Changes in pain between the treatment and nontreatment groups may not be significant simply because pain decreases in both groups but for different reasons.

The McGill Pain Questionnaire was chosen because it allowed for the subclassification of patellofemoral pain. The affective category of pain described pain related to tension, fear, and autonomic properties. The treatment group demonstrated a significant change in affective pain while no significant change was demonstrated in the the nontreatment group. Eight of 11 treatment subjects reported a decrease in affective pain as compared to only 3 of 8 (37.5%) in the nontreatment group. The reason for the decrease in this type of pain in a few subjects in the nontreatment group might simply be a consequence of rest and time. Decreased pain in the treatment group cannot be attributed to rest because of their regular schedule of treatment but may be a consequence of training over time. It is interesting to note that every subject in the study selected words from the affective category of pain. This would indicate that the affective category of pain is identifiable with patellofemoral pain. Affective pain also significantly correlated with total pain.

The sensory pain category measures pain in terms of temporal, spatial, pressure, thermal, and other properties. Five of 8 (62.5%) subjects in the nontreatment group reported no change in sensory pain while 4 of 11 (36.4%) of the treatment group did not experience any change in pain. On the other hand, only 1 of 8 of the nontreatment subjects experienced a decrease in sensory pain while 6 of 11 treatment subjects demonstrated a decrease in sensory pain. Sensory scores were significantly correlated to scores of total pain in the treatment group but not in the nontreatment group. Additionally, words from the sensory category were not chosen by 2 of 8 (25%) of the nontreatment subjects and 3 of 11 (27%) of the treatment subjects. This would suggest that sensory expression of pain is only moderately applicable to patellofemoral pain. Currier and Mann (1984) reported that words from the sensory group were chosen significantly more often than affective and evaluative words in subjects reporting on the pain they experienced during EMS. In the study by Currier and Mann (1984), the measurable pain was that experienced during the simualtion period. The pain measured in the present study was patellofemoral pain during activities of daily living at the time the questionnaire was completed.

Evaluative pain, which is a measure of the subjective overall intensity of pain is comprised of only one group of words. Unfortunately 4 of 8 (50%) of the nontreatment group and 7 of 11 (63.3%) of the treatment group did not select any words from this category in either the pre- or post-test questionnaire. Scores of evaluative pain were not significantly correlated with scores of total pain in either nontreatment or treatment groups. It would appear then that the evaluative category does not adequately describe patellofemoral pain. Any separate comparison of scores in this category related to this study would not be truly representative of patellofemoral pain. To allow for full representation of total pain, scores of evaluative pain were included in the calculation of total pain.

The miscellaneous category is a subclass of the McGill pain questionnaire that was added after initial pilot studies were conducted by Melzack (1989) and subjects noted that the list did not include some words that they would have used to describe their pain. The miscellaneous category is said to complement the initial list to give a complete description of the pain experience. Seven of 11

(63.6%) subjects in the treatment group experienced a decrease in miscellaneous pain whereas only 3 of 8 (32.5%) of the nontreatment experienced a decrease in this area. Two of 8 (25%) nontreatment subjects had an increase in miscellaneous pain while only 2 of 11 (18%) of the treatment subjects reported greater miscellaneous pain after treatment. The remainder of subjects in both groups did not experience any change in this category. Most of the subjects in both groups selected words from this category (87.5% and 81.8% for the treatment and nontreatment groups respectively). Scores for miscellaneous pain were significantly correlated to scores of total pain in both the nontreatment and treatment groups. This would suggest that the miscellaneous category is an appropriate category for the description of patellofemoral pain.

Five of 8 (62.5%) of the nontreatment group experienced a decrease in total pain. Although this was not a significant change, it may confound the results of the study because the decrease in pain may be due to rest which the treatment group did not receive because of the regularly scheduled exercise program. Even though not significant, the slight decrease in pain in the nontreatment group may have been a consequence of time (rest) during which the inflammatory response may have subsided due to natural guarding and rest.

The treatment group reported a significant decrease in total pain (9 of 11) subjects. Although this was not significantly different from the nontreatment group, these subjects vigorously stressed the patellofemoral joint through regular exercise (treatment program) in contrast to the rest followed by the nontreatment group. Any decrease in pain in this case is therefore not likely due to a guarding response and more likely a consequence of the treatment.

When the data from the subjects who participated in the cross over design was analyzed with paired t-Tests, the treatment period again demonstrated a significant change in miscellaneous and total pain. No significant changes in any pain category were found following the nontreatment period. Although not significantly different from that during the nontreatment period (P=.0849) the change in pain approximated significance. This would suggest that a cross over design might be an appropriate methodology for the study of patellofemoral pain. Once again, however, any decrease in pain during the nontreatment period might be due to time and rest while a decrease of pain during the treatment period may be a consequence of the treatment program.

Total pain appears to be the best indicator of changes in patellofemoral pain although scores describing changes in affective and miscellaneous pain in the nontreatment group and scores of affective, sensory and miscellaneous pain in the treatment group were significantly correlated to total pain. Evaluative pain was not significantly correlated to total pain in either the nontreatment or treatment groups. The variability in the questionnaire results appear not to be within subjects but rather between subjects in the same group.

Computer Tomography - Patellar Position

The objective of this study was to determine if there was a statistically significant change in the patellar position as a consequence of increase isometric quadriceps strength. Changes in patellar position in the majority of measures were not statistically significant, but they may have been clinically significant. Statistical significance is dependent on the degree of change and the number of subjects whereas clinical significance may be described as being dependent on the alleviation of pain. The results of this study were therefore examined using both parametric and nonparametric statistics.

Tangent Offset

It is interesting to note that a medial patellar shift occured in a larger percentage of the subjects in the treatment group than in the nontreatment group in all three conditions (0º-relaxed, 0º-contracted and 20º-relaxed). Of particular note is that 75% of the nontreatment group experienced increased lateral patellar shift over the six week period as measured at 0º-relaxed. This might be a consequence of an increasing imbalance between the vastus medialis and the vastus lateralis. When CT scans were taken with the subjects fully contracting the quadriceps muscles, 72.7% of the treatment group experienced a medial change in patellar position pre- vs post-test. Measurements at 20º flexion suggested a similar result, with 63.6% of treatment subjects experiencing a medial shift.

As noted previously, a medial shift of the patella would presumably decrease the pain and would also suggest that the treatment and/or increase in strength was responsible for the shift. Although more subjects in the treatment group did demonstrate a medial shifting of the patella following the treatment, the degree of shift between the two groups was not significantly different. This is due, in part, to the variability within the groups, that is, to the fact that some of the subjects in each group demonstrated a medial shift while others demonstrated a lateral shift.

The observation that muscle contractions in both the treatment and nontreatment group can influence shifting of the patella in either a medial or lateral direction from its relaxed position indicates the importance of imaging the patellofemoral joint in the contracted state to differentiate patellar malalignment due to static or dynamic imbalances.

When the change in patellar position at 0º relaxed is compared to that occuring at 20º relaxed, only 2 subjects (25%) in the nontreatment group who demonstrated a lateral shift of the patella at 0º relaxed, were medially shifted at 20º. The direction of patellar shifting did not differ in the remaining subjects, that is, 4 subjects (50%) demonstrated a lateral shift of the patella at both angles of knee flexion and 2 subjects (25%) demonstrated a medial shift of the patella at both angles.

Similar comparisons in the treatment group revealed that 2 subjects (18%) who were laterally shifted at 0º relaxed were medially shifted at 20 degrees flexion. One subject medially shifted at 0º relaxed and then laterally shifted at 20 degrees relaxed. The remaining 8 subjects (72%) did not change their patellar orientation, that is, if they were medially shifted at 0º relaxed they were also medially shifted at 20 degrees and vice versa. This would suggest that, at least in the treatment group, tangent offset measures of the patellofemoral joint might not differ substantially between 0º of flexion and 20º of flexion.

Bisect Offset

Bisect offset measures at 0º relaxed indicated that the treatment and nontreatment groups were similarly divided in terms of the number of subjects who experienced either a medial or lateral patellar shift. When the subjects were asked to contract, however, 63.6% of the treatment group experienced a medial shift of the patella as compared to a lateral shift of the patella reported in 71.4% of the nontreatment group. This would suggest that increased muscle strength, as demonstrated in the treatment group, did promote medial patellar positioning. At 20º relaxed, the majority of both groups demonstrated a lateral shift of the patella. Because the muscles were relaxed and did not impose a dynamic influence, the static restraining structures may be acting unabetted on the patella as the knee was flexed.

Comparison of bisect offset measures at 0º relaxed to tangent offset measures at 0º relaxed indicated that in the nontreatment group only two subjects (25%) demonstrated conflicting results with the two measurement techniques (i.e. the patella shifted medially in the tangent offset measure while a lateral shift was reported using the bisect offset technique). The remaining 6 subjects (75%) demonstrated shifting of the patella in the same direction using both measurement techniques.

Similarly in the treatment group, 2 subjects (18.2%) demonstrated a medial shift of the patella using the tangent offset technique and a lateral shift using the bisect offset technique. One subject (9%) was laterally shifted using tangent offset and medially shifted with bisect offset. The direction in which the patella was shifted in the remaining 8 subjects (72.7%) was consistent using both tests.

It would appear that the tangent offset and bisect offset measurement techniques provide comparable results and could be used interchangeably. Although, as will be discussed later in the computed tomography section, the femoral landmarks used to define bisect offset can be more variable resulting in a greater potential for error.

Lateral Patellofemoral Angle

Lateral patellofemoral angle (LPFA) is a measure of rotation about the long axis of the patella. An increase in the LPFA indicates a medial rotation presumably decompressing the lateral patellofemoral compartment. The treatment group demonstrated a significant lateral patellar rotation following treatment. At 0º relaxed, 63.6% of the treatment group recorded a lateral rotation of the patella after the treatment program as compared to a similar shift in only 37.5% in the nontreatment group. This is difficult to explain in view of the fact that the muscles were not actively contracting. When the quadriceps were contracted however, the results indicated that the reverse occured: 75% of the nontreatment group demonstrated a lateral rotation of the patella while only 36.4% of the treatment group laterally rotated. This would suggest that increased quadriceps strength may promote medial patellar rotation, or at least control excessive lateral patellar rotation.

Patellar Tilt Angle

Patellar tilt angle is another measure of patellar rotation about the long axis of the patella. Similarly, an increase in the angle is indicative of a medial rotation of the patella, presumably decompressing the lateral patellofemoral compartment. The opposite is true if the patellar tilt angle decreases.

At 0º relaxed the majority of the treatment and nontreatment groups demonstrated a lateral rotation of the patella. When the subjects were measured with the quadriceps contracted however, the treatment group demonstrated a statistically significant increase in medial patellar rotation by patellar tilt angle. This in contrast to 50% of the nontreatment group who demonstrated an increased lateral rotation of the patella (PTA) when the quadriceps muscles were contracted.

Although Sasaki and Yagi (1986) used a different measurement technique, they reported a signifcant increase in lateral patellar rotation when patellofemoral patients were measured with the quadriceps muscle contracted compared to the same measure in the relaxed state. This increase in patellar rotation was also significantly greater than that of a control group (Sasaki and Yagi, 1986). These results would suggest that increased quadriceps strength can provide dynamic control of patellar rotation.

Cross Over Design Group

Four subjects who participated in both the nontreatment and treatment periods were studied as a separate group. Subjects followed a cross over design in that the first six weeks was a nontreatment period followed by a six week period of treatment.

Although isometric strength did not significantly increase during the treatment, the results very closely approached significance (P= .0518), whereas the nontreatment period did not result in any significant change in isometric strength. Following the treatment period there was no significant change in isometric strength nor was there a difference in isometric strength gains between treatment and nontreatment periods.

The cross over group also demonstrated a significant decrease in miscelllaneous and total pain following the treatment period but not following the nontreatment period. A paired t-Test comparison indicated that there was a significant decrease in all parameters of pain during the treatment period as compared to the nontreatment period. This would suggest that this type of design, where the same subjects are tested in both situations may be effective in clinical studies of this type.

Changes in patellar position were significant in one measurement parameter during the nontreatment period and none during the treatment period. Tangent offset at 0º relaxed (TO 0ºR) demonstrated a significant lateral patellar shift during the nontreatment period. The change in patellar position between the nontreatment and treatment periods was significantly different for tangent offset and patellar tilt angle both with the knee at zero degrees and the quadriceps relaxed. This would suggest that the treatment program may influence patellar rotation and lateral patellar shift in the relaxed state and that measures taken with the quadriceps relaxed may still be an important measure when assessing patients with patellofemoral pain.

CT Scan Measurement Problems

CT scan and measurement of the patellofemoral joint is not without problems. The present measurement techniques depended extensively on bony landmarks of the patella and femur. The measures were repeated 3 times by the investigator to ensure reproducibility. Even so, there may have been inter-subject variability introduced by the measurement technique due to the level at which the cross sectional image was captured. Identification of bony landmarks required for placement of lines from which angles are created and patellar position established are also difficult to standardize.

Stanford et al. (1988) reported that congruence angle, patellar tilt angle and lateral patellofemoral angle were not measureable with the knee at zero degrees because the patella would ride proximally out of the sulcus eliminating from view the necessary bony landmarks. His protocol was to image the patellofemoral joint dynamically moving through the range of motion from 90º flexion to full extension using a Cine CT Scanner. This did not allow for adjustment of the cut line position on the patella to ensure that the necessary bony landmarks of the femur were captured in the image. Sasaki and Yagi (1986) used the mid patella as the landmark from which a cross sectional image was captured. Their measurement protocol utilized the anterior condylar projections instead of the posterior condylar margins as the reference points.

Estimation of patellar position depended on a perpendicular line drawn from the highest point of the lateral femoral condyle. This technique is probably open to at least as much estimation as the technique in this study in view of the fact that the sulcus angle becomes less acute proximally and the trochlear ridges are therefore less well defined.

The present study imaged the patellofemoral joint in three static positions which allowed for adjustment of the patellar cut line prior to imaging to capture the posterior condylar convexities of the femur. The cut line is an indicator on the CT scan monitor which identifies the level at which the cross sectional image will be captured. Normally, the total length of the patella is measured and the midpoint is calculated. The mid patella is normally used as the standard level from which the patellofemoral joint is imaged (Sasaki and Yagi 1986). For many measurements, the posterior condylar projections are necessary as landmarks to derive standardized measurements. When the patella is high riding, a cross sectional image taken at the midpoint of the patella would not include the posterior condylar projections of the femur. In this study the cut line was adjusted (where necessary) so that the image would include the posterior condylar projections of the femur. In every case where an adjustment was required, the adjustment was made distally on the patella. Standardization was maintained by recording the adjusted cut line level and reproduced during subsequent tests on the same subject (see Appendix I).

It is interesting to note that at 0º relaxed the mean cut line adjustment was between 1.21mm and 1.75 mm from the mid patella, while after contraction (0º-contracted) the mean cut line adjustment was between 9.11mm and 9.75 mm. There was a significant difference between the adjustment required between the two test conditions at 0 degrees ($P =< 0.05$). Fulkerson and Hungerford (1990) reported that setting the quadriceps normally produces 8 - 10mm of proximal patellar movement. This suggests that contraction of the quadriceps pulls the patella proximally making many of the measurements impossible if the mid patella cut line is used as the landmark. The mean cut line adjustments required when the knee was imaged in 20º flexion were between 4.11mm and 4.38mm. These adjustments were significantly different from the previous two test conditions. This proximal excursion of the patella at 20º flexion could also preclude some measurements if cut line adjustments were not made. There were no significant differences in the cut line adjustments required between the treatment and nontreatment groups. Similarly there were no significant differences in cut line adjustments between pre-test and post-test images for any of the test conditions.

Boven, Bellemans, Guerts and Potvilege, (1982) reported that the shape of the patella changes from slice to slice when CT scan images are captured at regular intervals from proximal to distal. This is why it is important to ensure that repeat measures are taken from the same reference point. Similarly, because this study adusted and standardized the patellar cutline reference points, it is difficult to compare results with other studies.

Because the landmarks are not always clearly defined, establishing consistent reference lines requires some experience to ensure reliability. For this reason the measurements in this study were conducted by one researcher. The tangent offset measure (Appendix M - a) uses a line tangent to the anterolateral aspect of the femur as the reference point. On CT scan, that line is generated by drawing the line through the estimated centre of the femoral cortex. The margin for error in establishing the centre of the cortex is small but the anterolateral line of the femur can take on a rounded shape which can make the generation of a representative straight line more awkward.

The bisect offset and patellar tilt angle measurements depend on a line perpendicular to the posterior condylar line (Appendix M - b & d). The point from where this line is drawn is determined by selecting a point midway between the condyles. Establishing the midpoint is based on some estimation. Stanford et al. (1988) estimated the midpoint of the medial and lateral condyle and the distance between these two points was bisected (Figure 16). The present study measured the width of the posterior intercondylar groove and established a midpoint from which the perpendicular line was drawn (Appendix M - a & d).

To define the patellar tilt angle, a horizontal line is drawn 90º from the bisect line at the point corresponding with the deepest part of the sulcus (Appendix M - d). In some cases the sulcus may not be a well defined groove and therefore the deepest point of the groove can be obscure.

Small angle measurements (one to three degrees) can be difficult to determine when measuring patellar tilt angle and lateral patellofemoral angles because the lines must be extended beyond the confines of the film. Fortunately, each image in this study was developed individually on a large 31 x 31 cm film which provided for good measurements but, even at that, some of the lines needed to be transcribed beyond the edges of the film.

In summary, CT Scan measures are useful in that they allow for measurement of the patellofemoral joint in the first 20º of flexion which is where the joint is least stable. CT Scan also allows for measurement of the patella when the quadriceps is contracted to allow evaluation of the dynamic control of the patella. Because of the lack of a standardized measurement protocol, it is difficult to relate the findings from this study to results of previous reports. The lack of a standardized protocol also makes it important to have the same researcher (technician) perform the measurements in test re-test situations for both research and clinical evaluations. The recent advent of cine CT Scans, which allow for a dynamic imaging of the patellofemoral joint through a range of motion, may provide further insights into the pathomechanics of patellofemoral pain.

Chapter VI

SUMMARY AND CONCLUSIONS

Patients suffering from patellofemoral pain were divided into nontreatment and treatment groups. Pre-test measurements for both groups included the McGill pain questionnaire, isometric strength of knee extension at 5º flexion, and patellar position within the trochlear groove of the femur (medial/lateral shift or rotation) using computed tomography (CT-Scan).

Subjects in the nontreatment group were advised to refrain from any treatment other than symptomatic relief of pain such as previously prescribed medication or the application of ice or heat. The treatment group was treated with electrical muscle stimulation superimposed on a maximal voluntary isometric contraction (MVIC) of the quadriceps femoris. The treatment consisted of 18 sessions over a six week period with 10 electrically induced isometric contractions per session. Following the six week treatment period, the nontreatment and treatment groups were tested using the same protocol as in the pre-test. Changes in isometric strength, pain and patellar position were analyzed to determine any significant changes in each parameter.

A sub group of four subjects who participated in both the nontreatment and treatment groups were analyzed separately as part of a cross over design.

The nontreatment and treatment groups did not significantly differ from each other in changes in pain. This may have been due to the small sample size and the wide variability of responses between subjects in the same group, The treatment group, however demonstrated a significant increase in isometric strength compared to the nontreatment group as measured at 5º flexion on the Kin Com dynamometer. The cumulative workload performed by the treatment group over 18 sessions significantly correlated to the increase in isometric strength. The treatment group also demonstrated a significant decrease in affective and total pain categories as well as changes in patellar tilt angle at 0º contracted.

Total pain decreased in the both treatment (81.6% of subjects) and nontreatment groups (62.5% of subjects). Although no significant difference between groups was evident, the treatment group demonstrated a significant decrease in affective and total pain while the nontreatment group did not. A similar result was evident in the cross over subjects. The cause for the slightly decreased pain in the nontreament group may be simply due to rest and time. The significant decrease in pain in the treatment group may be due to the training effect.

The literature suggests that patellofemoral pain is a result of patellofemoral malalignment either due to lateral deviation or lateral rotation of the patella. More subjects in the treatment group also demonstrated a medial realignment of the patella (although not significant) when the quadriceps were contracted. This would suggest that an increase in quadriceps strength might promote a medial patellar realignment.

Increased quadriceps strength may also promote medial patellar rotation, or at least control increased excessive lateral patellar rotation as measured by patellar tilt angle measurements on CT scan images. When the quadriceps were contracted, the treatment group demonstrated a significant change in medial rotation of the patella ie. post- vs pre-test as measured using PTA 0º C. This would suggest that the training effect may be instrumental in promoting strength gains which in turn affect patellar rotation.

Based on the results of this study, the following conclusions seem justified:

1. Patients with anterior knee pain are able to tolerate treatment consisting of EMS of the quadriceps superimposed with a maximal voluntary isometric contraction .

2. EMS in combination with a maximal voluntary isometric contraction will increase the strength of the quadriceps muscle after a 6-week training period in subjects with anterior knee pain compared to a regimen of no EMS or exercise.

3. Muscle stimulation using a 10/50/10 duty cycle and medium frequency electrical current is effective in developing isometric strength after a 6-week training programme in patients with anterior knee pain compared to a regimen of no EMS or exercise.

4. Gains in isometric strength are significantly correlated to average torque or workload over the course of an 18 session treatment period.

5. EMS of the quadriceps in combination with a maximal voluntary contraction over a 6-week period may reduce pain in a majority of patients with anterior knee pain.

6. EMS of the quadriceps in combination with a maximal voluntary contraction over a 6-week period increases the likelihood of a patient with anterior knee pain being able to maintain or restore a proper patellar alignment.

7. Tangent offset and Bisect offset, as measures of lateral patellar shift, do not produce different results and may be considered as two measures for the same variable.

RECOMMENDATIONS

1. If the McGill pain questionnaire is used to measure changes in patellofemoral pain, the subject should be allowed to amend the pre-test questionnaire to indicate if the pain has increased or decreased post-treatment. Evaluative, affective, and miscellaneous categories may not be sensitive enough to detect changes in patellofemoral pain whereas a measure of total pain does detect these changes.

2. Because patellofemoral pain appears to vary from day to day depending on the level of activity, daily recording of pain and an analysis of change over time may be more appropriate indicators of this pain. A visual analog scale may be more suitable for this type of measurement.

3. It appears that Tangent Offset and Biset Offset measures can be used interchangeably, therefore, Tangent Offset is recommended because the cortex of the lateral femoral condyle (used in Tangent Offset) is a more consistent landmark than the bisected posterior intercondylar notch (used in Bisect Offset) from which to establish a reference line.

4. Further research is necessary to develop standardized patellofemoral measurement techniques using CT-Scans. Cross sectional reference points need to be adjusted from the midpoint of the patella to capture the necessary bony landmarks. Special care must be taken to record and reproduce the point on the patella from where cross sectional images are captured.

5. The roles of Cine CT Scans and MRI need to be explored to determine the feasibility of using dynamic imaging of the patellofemoral joint throughout the range of motion in studies of this type.

6. The cause of patellofemoral pain needs further examination to determine if patellofemoral malalignment is in fact at the root of the problem. The role of increased patellar venous pressure may provide some explanation for effect of EMS and MVIC treatment in reducing patellofemoral pain.

7. Because of the variability between subjects, a cross over design may be the design of choice in determination of the cause and treatrment of patellofemoral pain.

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APPENDIX A

SUMMARY OF ELECTRICAL MUSCLE STIMULATION RESEARCH

Author	Research Question	Design	Stimulator Characteristcs	Training Regimen	Conclusions
Johnson et al 1977	Effective in chondromalacia patients	Before and after 50 subjects	Triang/Rectang wave 65 HZ 60 m amps-110 v	10-50-10 19 Tx/6wks	23-200% increase in quadriceps strength
Erikson and Haggmark 1979	EMS & Isokinetic effective following reconstructive surgery of the Knee	4 subjects per group	wave form? 200 Hz 100v current?	5 sec on/off 1 hour per day 5 days/week 4 weeks	Combined treatment superior Increased levels of SDH
Currier et al 1979	EMS & isometrics EMS effectiveness in strengthening normal quadriceps	3 groups 14 control 11 isometric 12 combined	rectangular wave 25 Hz voltage? Current	6 sec contraction 5/days/week 2 weeks	No difference between isometric training, EMS and isometric combined with stimulation all better than Control
Godfrey et al 1979	EMS vs Isometric exercise effectiveness in stregthening quadriceps muscle in patients with knee pain	EMS - 18 Isometric - 17 double blind no control	wave form? 60Hz voltage? current?	10/50/10 12 treatments 3 weeks	EMS as effective as isometrics
Curwin et al 1980	Effects of EMS in Post surgical patients	Post surgical control Post Surgical EMS	Electro Stim 180 2500Hz (50pps)	10/50/10 5x/week 85 weeks	significant increase in ATPase as compared to control
Halback & Straus 1980	EMS vs Isokinetic exercises-effective in strength training the quadriceps muscle	2 groups 3 subjects/group	Halbwellenstrom wave form 5Hz voltage? current?	10/50/10 5 treatments/week 3 weeks	Isokinetics superior to EMS; 22% increase with EMS; no change in girth measurements
Garrett et al 1980	EMS effective in Strengthening nomal quadriceps compared to control and isokinetics	3 groups 10 subjects per group	High frequency 50 bursts /sec variable voltage and current	? 5 treatments/week 5 weeks	EMS superior to control Isometric superior to control No difference between isometric and EMS
Romero et al 1982	EMS effective in strengthening compared to control	2 groups 9 subjects/group	2000 Hz ?Burst frequency	4 sec on/off for 15 min 2 days per week 5 weeks	EMS superior to control 21%-31% increase in strength
Gould et al 1982	EMS reduce the rate of atrophy in normal individuals? Superior to controls? Superior to Isometrics? Plantar flexors? Dorsi flexors? Quadriceps? Hamstrings?	3 groups 10 subjects/group	Square wave 17 Hz constant current voltage ? 100ma	25 contr/hour 16 hours per day 2 weeks	EMS more effective for plantar and dorsi flexors- no difference for quadriceps and hamstrings
Plevney et al 1982	Effects of voluntary and electrically stimulated exercise on knee torque	16 female subjects randomized cross over test (rct)	Sine wave 2500 hz (50pps)	15/15/50 two sessions 7-12 days apart	Torque increased with EMS and decreased slightly with VC VC provided greater trainig torque overall

Lainey et al 1983	Isometrics and EMS more effective than isometrics alone	cross over 8 subjects	Interferential High 4000-4100 Hz 100Hz voltage ? current ?	10/50/10 5 times/first week 4 x/ next 4 weeks	No significant difference
McMiken et al 1983	Effectiveness of EMS vs Isometrics in normal quadriceps	8 EMS 7 Isometrics	Square wave 75 Hz voltage 100 or less current ?	10/50/10	No difference between groups Training voltage of trength of contraction does not influence strength
Laughman et al 1983	EMS vs Isometrics in normal quadriceps	3 groups control - 20 EMS - 19 Isometrics -19	sine wave 2500Hz 400 volts 70ma	15/50/10 5 /week 5 weeks	EMS and isometrics produced significant strength gains no difference between groups
Currier & Mann 1983	Effectiveness of EMS vs Isometrics vs combined in normal quadriceps	control - 9 EMS - 8 Isometric - 8 combined - 9	Sinusoidal wave 2500 Hz 50 pps voltage ? current ?	15/50/10 3/week 5 weeks	All groups differed significantly from control no significant difference between groups
Walmsley et al 1984	Knee torque using EMS and MVC using different Stimulators	14 males 15 athletes RCT	2200 Hz (50pps) IFC 4000/4100 60 Hz 50 hz	3 sessions 3/6/120	EMS did not exceed values for MVC with any of the stimulators
Selkowitz 1984	Improvement in quadriceps strength with EMS	Control - 12 EMS - 12	sinusoidal wave 2200 Hz/50 pps 28-90ma	10/120/10 3 days/week 4 weeks	EMS significantly better than isometrics Increases correlated to intensity and duration
Kramer and Semple 1983	EMS vs isometric alone and combined	EMS - 10 Isometric - 10 combined - 10 control - 10	asym biphas rectang 100 Hz	10/50/10 10-12 sessions 4-5 weeks	all exercise groups were significantly better than control group but none better than the other
Owen & Malone 1983	Treatment Parameters of High Frequency stimulation	Daily tx - 5 3x/week - 5 control - 5	Electro stim 180 2500Hz (50pps0	15/50/10	No sign gains although gains approached sign stim = 60% of MVC
Kramer et al 1984	Comparison of EMS and voluntary contraction torques	10 subjects voluntary EMS combined	asym biphasic rect asym bipahsic spike sym monoph square	2-5/50/4 2 practise, 1 test	EMS no more effective in developing strength gains than MVC alone in normal muscle
Stefanovska et al 1985	High frequency vs low frequency stimulation on Quadriceps strength	High freq - 5 Med Freq - 5 Control - 5	Square wave 25 Hz Sine 2500 hz(50pps)	3 weeks 10/50/10	Low freq increased 25% Hi Freq increased 13% Hi Freq > Fatique no comparison with MVC
Mohr et al 1985	Isometric exercise vs High voltage Galvanic stimulation	HVG - 6 Isometric - 5 control - 6	Monophasic twin peaks 50 Hz	10/10/10 3 weeks daily treatment	HVG stimulation not as effective as isometric exercise
Morissey et al 1985	EMS on post op Knees(casted)	Stimulation - 8 Control - 7	Respond II 50Hz	10/50/10 8 Hrs/day 6 weeks(during immobilization)	60% decrease Stim 80% decrease control no difference 6 weeks after cast removal

Hartsell 1986	EMS vs Isometric exercise on quadriceps parameters monopolar bipolar EMS and Isometric	3 groups Control - 5 isometric - 4 MI Ems/isom - 6 BI EMS/Isom -6	Square wave 65Hz current ? voltage ?	10/50/10 5 days/week 6 weeks	EMS with Isometric significantly better than control no more effective than isometric alone
Cox et al 1986	Effect of electrode placement and rest duration on quadricep tourque	lumbosacral plexus motor point	Biphasic rectangular 100 Hz	3 sessions 10/35/10 10/50/10 10/65/10	50 and 65 sec rests had similar torque decrements 35 sec rests had greater decrements
De Domenico & Strauss 1986	Max Quad torque using a variety of EMS stimulators	MVC vs 7 types of Stimulators	Monopahsic & biphas 50-80 Hz		none of the stimulators caused a contraction > MVC
Strauss & De Demenico 1986	MVC vz EMS in Quadriceps and Upper arm torques	15 females RCT	IFC 5000Hz (50-80 pps) High volt 65 Hz		EMS produced 65-74% of MVC for quads torque
K Singer 1986	Unilateral EMS on Motor Unit Activity Patterns in Atrophic Quadriceps	15 males	Respond 50 Hz Myocare 50 Hz Biostim 100 Hz	2 s ramp/6 s on/15 m 4 weeks Daily stim x 15 min	Sign increases in force for treated(22%) (14% untreated contralat) no change in cross sectional area ? neuromotor change
Soo et al 1988	Effect of Low dose EMS Qauds strength left leg control	9 males 6 females	electrostim 180 2500Hz (50pps)	10/50/10 2 tx /week 5 weeks 50% MVC	low dose EMS increased Qauds torque in men

APPENDIX B

CALL FOR SUBJECTS

CALL FOR SUBJECTS

Dear Dr.

Re: Subjects for Clinical Research Entitled:

The Effect of Electrical Muscle Stimulation on Quadriceps Strength, Patellofemoral Pain and Patellar Alignment

The above designated research is in partial fulfillment of PhD requirements in the Department of Anatomy, Faculty of Medicine, University of Manitoba.

Subjects suffering from patellofemoral pain are being sought to participate in a research project to assess the efficacy of electrical muscle stimulation over a six week period on patellofemoral alignment. Thrice weekly sessions will involve ten electrically stimulated contractions of the vastus medialis muscle superimposed on the patients maximal voluntary contraction for a ten second duration and interspersed with a 50 second rest period. The subject will be encouraged to accept stimulation to tolerance for each contraction.

Subjects will be randomly assigned to an experimental or control group. The control group will not receive treatment for a six week period but will be offered treatment after that time.

Measurement will include pre and post CT Scan measurements to evaluate changes in patellar position in relation to the patellar surface of the femur. Changes in girth measurement of the vastus medialis and lateralis using the CT scanner will also be examined. Isometric strength measurements at 0º degrees flexion will be recorded using the Kin Com Isokinetic Machine.

Patients to be included in the study must be between the ages of 16 and 35 and conform with the following criteria:

<u>INCLUSION</u>:

To be eligible the subject must exhibit at least **two** of the following criteria:

1. Pain on direct compression followed by proximal to distal mobilization against the femoral condyles with the knee in full extension.
2. Tenderness on palpation of the medial retinaculum or undersurface of the patella.
3. Pain on resisted knee extension with the knee in 20 degrees flexion.

4. Retropatellar pain with quadriceps contraction against manually applied suprapatellar resistance with the knee in slight flexion (Clarke's Sign)
5, Positive Movie Sign ie. retropatellar pain upon rising after long periods of sitting.
6. Retropatellar pain when using stairs especially going down.

Exclusion:

Subjects with any of the following history will be excluded:

1. History of acute patellar trauma as the cause of the present signs and symptoms.
2. History of subluxating or dislocating patellae.
3. Confirmation of ligamentous, meniscal or fat pad damage as source of the present signs and symptoms.
4. Evidence of referred pain from the back or hip.
6. Osteochondral or chondral fractures.
7. Radiological evidence of degenerative disease.
8. Obvious postural disorders such as genu recurvatum, genu valgum, foot pronation, femoral anteversion / retroversion.
9. Upper or lower motor neuron lesion.
10. Previous or pending knee surgery for this injury.

Prospective subjects should referred to:

Glen Bergeron,Director
Athletic Therapy Centre
102 Frank Kennedy Centre
University of Manitoba
Winnipeg, Manitoba
R3T 2N2
Phone 474-8724

Please have the patient indicate they are a potential candidate for the study and not wishing a regular appointment. Assessments and treatments will provided at no cost to the patient.

PLEASE NOTE: In order to best schedule the CT Scan assessments, we will need **two** referrals slips,one for the initial scan and a second referral slip asking for a follow-up assessment seven weeks following. Appointments will be made with the Health Sciences Centre.Radiology Department through my office

Sincerely,

Glen Bergeron

APPENDIX C

SUBJECT CONSENT FORM

CONSENT FORM

Research Title:

The Effect of Electrical Muscle Stimulation on Quadriceps Strength, Patellofemoral Pain and Patellar Alignment

Dear

We would like you to participate in a research program designed to study the effectiveness of therapeutic electrical muscle stimulation on the realignment of the knee cap in relation to the underlying femur (thigh bone). The pain which you have described to your physician has been diagnosed as being a consequence of this malalignment. Imbalances in strength of the muscles on either side of the knee cap have been implicated as a major cause of malalignment.

Electrical Muscle Stimulation is used clinically to increase muscular strength and restore the balance of opposing muscles without imposing pain which occurs in normal strength building exercises.

Subjects will be randomly assigned to either the experimental or control group. The experimental group will be asked to undergo treatments three times a week for a period of six weeks. Treatments will involve ten (10) stimulations of ten seconds duration with a two minute rest between contractions. Intensity of stimulation will always be under the patient's control, but the subject will be encouraged to accept stimulation to tolerance for each contraction. Treatment time will be approximately 30 minutes per session.

Subjects in the control group will receive treatment to control pain and discomfort as required but will not receive muscle stimulation. Patients wishing to follow a course of treatment including muscle stimulation will be offered that service after the six week control period.

Whichever treatment you receive will be decided by chance, as in tossing a coin. There is a 50/50 chance of receiving either treatment. Doctors and therapists don't usually make decisions this way but it is the most reliable method of deciding which treatment is better.

The Muscle Stimulator in this study is commonly used clinically to treat your condition. The only noted reaction in some cases is a mild reddening of the skin at the sites of the surface electrode which subsides within one to two hours. Patients may also experience increased pain beneath the knee cap with the first few sessions.

Changes in the positioning of the knee cap will be measured by CT Scan taken before and after the series of treatments.

Strength measurements will be taken at full extension to minimize any painful reaction.

Subjects can withdraw at any time without prejudicing future care.

Glen Bergeron is involved in the research with Dr. Wendy Dahlgren as supervisor of the research.

All personally identifiable records and information will be held in strictest confidence. You will receive a copy of this signed consent form for your records. There will be no costs incurred for treatments by the subject.

****

I hereby declare that I understand the procedures involved in the research project and willingly agree to participate.

______________________ ______________________

Signed Date

______________________ ______________________

Witness Date

****

You have been scheduled for your first consultation at:

_______pm/am on__________/__________/______,1990

day month date

*Please come to the Athletic Therapy Centre on the ground floor of the Frank Kennedy Centre at the University of Manitoba.

*Parking meters are available in the adjacent ' X ' parking lot.

*Please wear Athletic Shorts

For any further information, please do not hesitate to contact me at: 474-8724

Thankyou

GLEN BERGERON

APPENDIX D

MCGILL PAIN QUESTIONNAIRE

McGill - Melzack
PAIN QUESTIONNAIRE

Patient's Name: ________________ Age: ________________

File No.:_____________ Date: _______________

Diagnosis: ________________________
____
____

Analgesic (if already administered):
1. Type ____________________
2. Dosage ____________________
3. Time given in relation to this test: ________________________

Patient's intelligence: circle number that represents best estimate

1 (low) 2 3 4 5 (high)

****

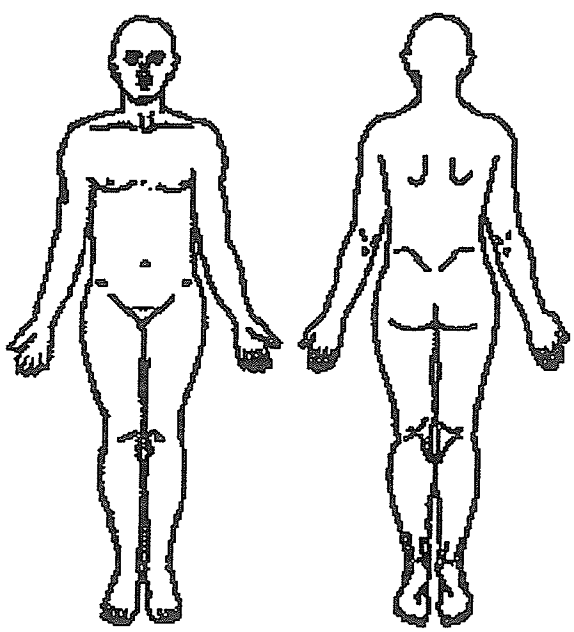
This questionnaire has been designed to tell us more about your pain. Four major questions we ask are :

1. Where is your pain?
2. What does it feel like?
3. How does it change with time?
4. How strong is it?

It is important that you tell us how your pain feels now. Please follow the instructions at the beginning of each part.

Part 1 <u>Where Is Your Pain?</u>

Please mark on the drawings below, the area where you feel pain. Put (E) if external or (I) if internal near the areas which you mark. Put (EI) if both external and internal.



Part 2

What Does your Pain Feel Like?

Some of the words below describe your present pain. Circle ONLY those words that best describe it. Leave out any category that is not suitable. uso only a single word in each appropriate catgory - the one that applies best.

1	2	3	4
Flickering	Jumping	Pricking	Sharp
Quivering	Flashing	Boring	Cutting
Pulsing	Shooting	Drilling	Lacerating
Throbbing		Stabbing	
Beating		Lancinating	
Pounding			

5	6	7	8
Pinching	Tugging	Hot	Tingling
Pressing	Pulling	Burning	Itchy
Gnawing	Wrenching	Scalding	Smarting
Cramping		Searing	Stinging
Crushing			

9	10	11	12
Dull	Tender	Tiring	Sickening
Sore	Taut	Exhausting	Suffocating
Hurting	Rasping		
Aching	Splitting		
Heavy			

13	14	15	16
Fearful	Punishing	Wretched	Annoying
Frightful	Gruelling	Blinding	Miserable
Troublesome	Cruel		Intense
Terrifying	Vicious		Unbearable
	Killing		

17	18	19	20
Spreading	Tight	Cool	Nagging
Radiating	Numb	Cold	Nauseating
Penetrating	Drawing	Freezing	Agonizing
Piercing	Squeezing		Dreadful
	Tearing		Torturing

Part 3 How Does Your Pain Change With Time?

1. Which word or words would you use to describe the pattern of your pain?

1	2	3
Continuous	Rhythmic	Brief
Steady	Periodic	Momentary
Constant	Intermittent	Transient

2. What kind of things relieve your pain?

3. What kind of things increase your pain?

Part 4 How Strong Is Your Pain?

People agree that the following 5 words represent pain of increasing intensity. They are:

1	2	3	4	5
Mild	Discomforting	Distressing	Horrible	Excruciating

To answer each question below, write the number of the most appropriate word in the space beside the question.

1. Which word describes your pain right now? ________
2. Which word describes it as its worst? ________
3. Which word describes it when it is least? ________
4. Which word describes the worst toothache your ever had? ________
5. Which word describes the worst headache you ever had? ________
6. Which word describes the worst stomach-ache you ever had? ________

APPENDIX E

SUBJECT ASSESSMENT FORM

PATELLOFEMORAL PAIN RESEARCH

PATIENT ASSESSMENT FORM and QUESTIONNAIRE

Date: ____________________
Name: _____________________________
Address: __________________________ Postal Code: ________________
Phone: _____________(H)_______________(B) MHSC#_____________
Age:____ M__ F___ Referring Physician:___________________
Handedness: R L Height: _____(Cm) Weight: _______(Kg)

****

Date of Injury: ____________________ Knee: R L Both R><L

3. Activity related to onset of pain:________________________

____

4. Previous Therapy: yes no

Date of previous treatment:____________

Type of Treatment:_________________________________

____

Level of effectiveness:

1 2 3 4 5 6 7 8 9 10

Fully recovered Pain increased

5. Are you on any medication related to this injury? Yes no

If yes, please list the medication and the reason for their prescription____

____

6. Do you have any of the following (please check if yes):

___History of a direct trauma related to your present knee injury

___History of any previous cartilage tear or ligament damage

___History of dislocating knee caps

___History of tendinitis, bursitis or joint swelling related to your present knee injury

___History of referred knee pain from a back injury

___History of fractures of the knee cap

___Scheduled for any surgery related to your present injury

Postural Assessment/Observation:

Pelvic heights: R<>L

Hips: Int/Ext Rotation

Atrophy Vastus Medialis Vastus Lateralis Rectus Femoris

Hamstrings Gluteals Adductors

Swelling Intracapsular Peripatellar other

Genu Varum Valgum

Tibial Varum Valgum

Q-Angle R ____ L ____

Foot Assessment Pronation R/L Supination R/L

Flexibilty:

Hamstrings R<>L Quadriceps R<>L

Range of Motion:

Hip Flex ____ Ext ____ Int Rot ____ Ext Rot ____

Knee Flex ____ Ext ____

Special Tests:

Ligaments MCL ____ LCL ____ ACL ____ PCL ____

Mc Murray's ____ Patellar Grind ____

Pain on Palpation:

R Med/Lat Facet ____ Med/Lat Condylar Ridge ____

L Med/Lat Facet ____ Med /Lat Condylar Ridge ____

COMMENTS: ____

____

____

APPENDIX F

EMS INTENSITY RECORD FORM

NAME:								TREATMENT LIMB R L					
DATE:	SESSION				DIAL SETTING PER CONTRACTION							MAX. TOLERABLE SETTING?	
	1	1	2	3	4	5	6	7	8	9	10	YES	NO
	2												
	3												
	4												
	5												
	6												
	7												
	8												
	9												
	10												
	11												
	12												
	13												
	14												
	15												
	16												
	17												
	18												
		NOTE: It has been shown that increase in muscle strength using electrical muscle stimulation is											
		closely correlated to stimulation levels approaching individual maximum levels											

APPENDIX G

KIN COM TREATMENT DATA SUMMARY

NAME AH			
TRIAL	TOTAL WORK/10	AVG TORQUE/10	SD/10
1	3165.89	40.94	11.97
2	7335.76	60.87	18.4
3	3483.24	51.3	17.03
4	3616.8	62.97	22.01
5	4636.55	63.9	19.92
6	5524.13	67.08	21.34
7	4631.53	56.8	17.53
8	3531.59	47.24	13.16
9	7234.63	92.15	31.46
10	5569.08	72.61	24.64
11	6088.05	87.09	28.25
12	3632.58	60.62	15.02
13	6399.51	84.21	20.25
14	6116.08	99.65	27.5
15	7037.84	101.62	26.94
16	7506.9	98.22	33.83
17	10522.7	97.05	27.75
18	6016.34	92.62	31.42
TOTAL WORK	102049.20		
AVG/18	5669.4	74.27	22.69
PRT	550.72	30.37	10.41
PTC			
PT	2122.62	117.11	
%PTC/PRT			
%PT(C)/PRT	285.43	285.61	

NAME DG			
TRIAL	TOTAL	AVG	SD/10
	WORK/10	TORQUE/10	
1	2360.48	27.24	6.36
2	3460.14	37.35	13.35
3	3173.56	44.66	9.51
4	3800.75	48.87	7.77
5	5290.89	58.08	10.82
6	3506.68	54.05	14.46
7	4033.04	58.69	15.12
8	5648.02	67.84	17.36
9	6271.38	67.81	15.15
10	6571.33	60.62	19
11	5585.02	68.37	13.21
12	4797.68	75.33	27.96
13	4285.16	58.24	22.72
14	7313.56	86.72	24.09
15	5918.64	79.54	24.85
16	8353.93	68.55	16.88
17	4912.96	69.32	18.25
18	4713.33	58.13	23.08
TOTAL WORK	89996.55		
AVG/18	4999.81	60.52	16.66
PRT	532.65	29.39	9.3
PTC	698.95	38.55	5.9
PT	1102.83	61	33.53
%PTC/PRT	31.22	31.17	
%PT(C)/PRT	107.05	107.55	

NAME DO			
TRIAL	TOTAL	AVG	SD/10
	WORK/10	TORQUE/10	
1	1781.29	20.99	6.31
2	2083.87	27.27	8.07
3	2625.1	29.51	8.75
4	2606.84	33.52	9.59
5	2165.78	48.81	16.02
6			
7	1866.12	31.75	9.93
8	3880.22	52.95	12.82
9	4430.19	73.12	21.06
10	3958.67	57.45	18.83
11	3858.55	67.51	22.91
12	7587.44	63.11	20.18
13	5175.4	60.86	17.51
14	4437.54	64.42	21.48
15	4886.47	67.93	23.79
16	4752.51	70.09	21.14
17			
18			
TOTAL WORK	56095.99		
AVG/18	3739.73	51.29	15.89
PRT	235.77	13.04	4.4
PTC			
PT	1203.59	66.59	
%PTC/PRT			
%PT(C)/PRT	410.49	410.66	

NAME EB			
TRIAL	TOTAL	AVG	SD/10
	WORK/10	TORQUE/10	
1	1395.49	23.72	6.09
2	1284.46	20.14	7.68
3	543.01	18.6	4.81
4	1833.58	17.44	5.12
5	700.25	17.66	5.67
6	2420.57	31.87	8.2
7	1612.41	27.85	8.59
8	2372.71	29.42	10.03
9	1852.12	29.45	9.67
10	1583.85	25.42	6.82
11	2098.99	26.66	8.16
12	2668.98	26.9	7.05
13	2404.67	28.47	5.99
14	2161.55	28.29	8.12
15	2003.43	17.73	8.67
16	2098.99	23.99	5.64
17	2461.92	32.83	7.81
18	2122.02	28.81	8.22
TOTAL WORK	33619.00		
AVG/18	1867.72	25.29	7.35
PRT	278.14	15.38	3.34
PTC			
PT	611.81	33.79	
%PTC/PRT			
%PT(C)/PRT	119.96	119.70	

NAME GK			
TRIAL	TOTAL	AVG	SD/10
	WORK/10	TORQUE/10	
1	1638.91	13.62	3.25
2	1410.58	14.65	2.86
3	161.51	22.68	4.18
4	1651.53	24.14	5.37
5	1746.48	25.28	6.89
6	2526.34	20.06	4.49
7	2156.68	31.73	8.05
8	2382.39	22.01	7.69
9			
10	2549.32	23.55	8.14
11	3993.34	52.58	15.56
12	3674.11	33.67	15.27
13	5609.59	46.59	10.7
14	2067.91	34.88	13.48
15	2711.67	41.91	13.48
16	4083.8	37.72	13.89
17	2206.98	34.32	13.53
18	2496.26	30.45	12.06
TOTAL WORK	43067.40		
AVG/18	2533.38	21.77	9.35
PRT	168.27	9.32	4.05
PTC			
PT	630.11	34.85	19.13
%PTC/PRT			
%PT(C)/PRT	274.46	273.93	

NAME HR			
TRIAL	TOTAL WORK/10	AVG TORQUE/10	SD/10
1	2495.85	18.31	4.42
2	1987.89	27.56	8.9
3	2183.47	24.91	6.64
4	2809.48	38.94	11.21
5	1258.47	29.62	13.75
6	3355.14	30.99	9.39
7	2243.97	33.19	11.93
8	2449.13	36.59	13.18
9	2269.02	32.4	11.61
10	2040.24	35.48	12.26
11	1777.14	28.33	10.73
12	2402.73	34.42	12.78
13	2058.47	31.65	11.84
14	2242.03	35.6	13.26
15	2266.88	34.74	14.14
16	2294.65	35.82	13
17	2063.64	33.5	13.75
18	2012.2	33.47	13.82
TOTAL WORK	40210.40		
AVG/18	2233.91	31.97	11.48
PRT	296.18	16.39	4.42
PTC	250.38	13.83	5.36
PT	479	26.53	11.61
%PTC/PRT	-15.46	-15.62	
%PT(C)/PRT	61.73	61.87	

NAME JN			
TRIAL	TOTAL WORK/10	AVG TORQUE/10	SD/10
1	1120.45	23.71	4.97
2	5077.3	46.84	10.65
3	4304.75	64.95	20.99
4	3859.86	75.66	18.68
5	5321.12	78.6	29.87
6	4662.62	66.43	20.2
7	4943.39	79.09	28.35
8	9645.16	88.95	27.34
9	5188.44	88.12	30.28
10	5640.37	83.08	30.93
11	6035.1	82.94	30.42
12	5562.47	82.79	31.37
13	5418.74	71.74	27.11
14	5149.8	71.54	22.2
15	5228.22	70.52	22.62
16	7318.51	67.53	23.53
17	5611.66	89.45	26.42
18	4644.41	72.56	24.99
TOTAL WORK	94732.37		
AVG/18	5262.91	72.47	23.94
PRT	919.65	50.6	14.74
PTC			
PT	1871.53	103.45	46.47
%PTC/PRT			
%PT(C)/PRT	103.50	104.45	

NAME LR			
TRIAL	TOTAL	AVG	SD/10
	WORK/10	TORQUE/10	
1	4001.34	33.2	8.5
2	5011.03	41.63	11.91
3	5440.31	45.19	17.15
4	3009.74	50.93	14.28
5			
6	4268.88	39.42	14.48
7	5028.41	46.43	15.61
8	2614.59	46.78	14.08
9	2939.86	52.57	13.76
10	3278.14	44.68	15.5
11	5424.71	50.06	14.63
12	2660.27	40.99	11.7
13	4467.06	45.37	12.73
14	2559.56	41.5	2.85
15	3304.29	49.25	14.34
16	3982.61	54.16	14.39
17	5541.29	58	14.43
18	3421.02	54.48	15.55
TOTAL WORK	66953.11		
AVG/18	3938.42	46.74	13.29
PRT	670.2	36.95	15.79
PTC			
PT	1106.66	61.09	17.69
%PTC/PRT			
%PT(C)/PRT	65.12	65.33	

NAME MS			
TRIAL	TOTAL	AVG	SD/10
	WORK/10	TORQUE/10	
1	1296.58	18.86	6.98
2	2140.68	26.98	6.57
3	2698	40.12	10.99
4	2634.34	48.28	16.56
5	2220.64	39.42	12.51
6	2226.25	35.7	13.86
7	2584.62	43.42	14.99
8	2373.6	35.34	11.5
9	2399.51	40.04	12.5
10	2017.45	40.5	40.5
11	1990.01	37.64	37.64
12	2709.2	40.4	40.4
13	1510.68	50.13	50.13
14	2831.87	45.68	45.68
15	3375.24	50.21	50.12
16	3348.54	52.05	52.05
17	4060.81	37.48	37.48
18	2932.4	45.32	45.32
TOTAL WORK	45350.42		
AVG/18	2519.47	40.42	28.10
PRT	248.87	13.81	8.71
PTC	428.78	23.67	5.26
PT	859.18	47.4	16.57
%PTC/PRT	72.29	71.40	
%PT(C)/PRT	245.23	243.23	

NAME SD			
TRIAL	TOTAL WORK/10	AVG TORQUE/10	SD/10
1	1082.55	18.21	5.85
2	966.49	11.31	2.92
3	1327.02	15.53	3.68
4	1058.3	10.15	3.17
5	1851.11	14.31	4.49
6	1331.82	18.7	4.12
7	1486.86	19.63	4.07
8	1870.14	23.81	5.79
9	3370.45	31.91	6.68
10	2431.34	31.46	6.48
11	2438.42	33.94	5.67
12	2710.14	30.51	6.73
13	1661.11	31.75	6.81
14	3410.63	41.06	10.56
15	2111.45	33.79	10.26
16	5494.31	46.12	14.46
17	3076.75	38.52	9.48
18	2714.75	29.69	9.05
TOTAL WORK	40393.64		
AVG/18	2244.09	26.69	6.68
PRT	426.98	23.12	2.23
PTC			
PT	892.42	50.19	
%PTC/PRT			
%PT(C)/PRT	109.01	117.08	

NAME TM			
TRIAL	TOTAL	AVG	SD/10
	WORK/10	TORQUE/10	
1	2392.88	39.61	12.96
2	1082.55	44.59	14.91
3	3431	65.57	25.28
4	4010.62	56.84	20.02
5			
6	3955.31	67.01	23.91
7	4187.27	53.39	20.01
8	3569.02	62.09	21.46
9	3740.57	67.39	24.51
10	6685.76	61.7	22.75
11	4589.2	74.96	26.55
12	3182.65	63.99	22.27
13	4025.89	68.06	22.86
14	5017.48	75.84	26.6
15	5715.89	75.06	26.01
16	4573.22	73.82	22.48
17	5064.68	80.68	28.94
18	5382.13	76.99	29.15
TOTAL WORK	70606.12		
AVG/18	4153.30	65.15	22.98
PRT	482.89	26.7	12.45
PTC	480.02	26.54	9.62
PT	1462.3	80.91	48.65
%PTC/PRT	-0.59	-0.60	
%PT(C)/PRT	202.82	203.03	

APPENDIX H

SAMPLE CT SCAN CALCULATION FORM

NAME:						
PRT PAT. WIDTH LINE		%		%		%
PT PAT. WIDTH LINE		CHANGE		CHANGE		CHANGE
TANGENT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT		0º RELXD		0 º CONTRACTED		20º RELAXED
PT		0º RELAXED		0 º CONTRACTED		20º RELAXED
BISECT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT		0º RELXD		0 º CONTRACTED		20º RELAXED
PT		0º RELAXED		0 º CONTRACTED		20º RELAXED
LAT PF ANGLE	0º RELAXED		0 º CONTRACTED		20º RELAXED	
PRT						
PT						
PAT TILT ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT						
PT						

APPENDIX I

CT SCAN CUT LINE ADJUSTMENTS

DA	DATE	0º RELAXED	0º CONTRACTED	20º RELAXED
TEST #1	DEC 4/91	8MM DISTAL	9 MM DISTAL	4MM DISTAL
TEST #2	JAN 30/92	5MM DISTAL	13MM DISTAL	4MM DISTAL
EB				
TEST #1	DEC 4/91	1MM DISTAL	11MM DISTAL	13 MM DISTAL
TEST #2	JAN 22/92	1MM DISTAL	11MM DISTAL	7 MM DISTAL
TEST #3	MAR 17/92	CENTRE	1MM DISTAL	7MM DISTAL
LC				
TEST #1	NOV 11/91	CENTRE	13MM DISTAL	7MM DISTAL
TEST #2	DEC 28/91	CENTRE	13MM DISTAL	7MM DISTAL
SD				
TEST #1	NOV 11/91	CENTRE	12MM DISTAL	7MM DISTAL
TEST #2	DEC 28/91	CENTRE	12MM DISTAL	7MM DISTAL
DG				
TEST #1	DEC 4/91	CENTRE	11MM DISTAL	5MM DISTAL
TEST #2	JAN 22/92	CENTRE	13MM DISTAL	5MM DISTAL
TEST #3	MR 16/92	CENTRE	11MM DISTAL	5MM DISTAL
AH				
TEST #1	MAR 3/92	CENTRE	CENTRE	CENTRE
TEST #2	MAY 6/92	CENTRE	CENTRE	CENTRE
GK				
TEST #1	NOV 11/91	CENTRE	CENTRE	CENTRE
TEST #2	DEC 28/91	CENTRE	CENTRE	CENTRE
TM				
TEST #1	NOV 11/91	CENTER	4MM DISTAL	CENTER
TEST #2	JAN 16/92	CENTER	4MM DISTAL	CENTER
TEST #3	APRIL 6/92	CENTER	4MM DISTAL	CENTER
JN				
TEST #1	JAN 22/92	CENTRE	6MM DISTAL	4MM DISTAL
TEST #2	MAR 16/92	CENTRE	7MM DISTAL	4MM DISTAL
DO				
TEST #1	NOV 11/91	CENTRE	12MM DISTAL	CENTRE
TEST #2	DEC 18/91	CENTRE	12MM DISTAL	CENTRE
CO				
TEST #1	NOV 11/91	CENTRE	6MM DISTAL	CENTRE

TEST #2	DEC 28/91	CENTRE	7MM DISTAL	CENTRE
HR				
TEST #1	DEC 4/91	3MM DISTAL	13MM DISTAL	7MM DISTAL
TEST #2	JAN 22/92	3MM DISTAL	11/8MM DISTAL	7MM DISTAL
TEST #3	MAR 17/92	3/6MM DISTAL	8MM DISATL	7MM DISTAL
RR	FEB 6/92	1MM DISTAL	4MM DISTAL	3MM DISTAL
	MAR 16/92	2MM DISTAL	7/3MM DISTAL	5MM DISTAL
LR				
TEST #1	FEB 6/92	1MM DISTAL	8MM DISTAL	3MM DISTAL
TEST #2	APRIL 6/92	1MM DISTAL	8MM DISTAL	3MM DISTAL
MS				
TEST #1	DEC 4/91	2MM DISTAL	14 MM DISTAL	7MM DISTAL
TEST #2	JAN 22/92	3MM DISTAL	14 MM DISTAL	7MM DISTAL
TEST #3	MAR 17/92	3MM DISTAL	14MM DISTAL	7MM DISTAL

APPENDIX J

CT SCAN RAW DATA SUMMARY

NON TX	PRT TANG	PT TANG	TO 0ºR	PRT TANG	PT TANG	TO 0ºC	PRT TANG	PT TANG	TO 20º	PRT BIS	PT BIS	BO 0ºR
SUBJECTS	OFF OºR	OFF OºR	DIFF	OFF 0ºC	OFF 0ºC	DIFF	OFF 20º	OFF 20º	DIFF	OFF OºR	OFF OºR	DIFF
CO	9.47	18.07	8.6			0	-3.96	-1.79	2.17	61.58	66.27	4.69
DA	20.12	14.2	-5.92	-3.42	0	3.42	0.55	0	-0.55	81.1	77.27	-3.83
DG	8.28	10.39	2.11	13.68	15	1.32	-8.59	-10.67	-2.08	88.28	97.4	9.12
HR	4.3	8.96	4.66	13.85	14.58	0.73	-4.65	-3.42	1.23	75.27	73.13	-2.14
LC	-6.49	-2.58	3.91	-5.17	0	5.17	-22.97	-22.22	0.75	74.03	74.84	0.81
MS	11.36	18.33	6.97	23.19	20.59	-2.6	-8.64	-5.3	3.34	74.43	78.33	3.9
RR	9.15	4.49	-4.66	26.39	25.69	-0.7	-4.94	-8.43	-3.49	66.46	60.67	-5.79
TM	2.86	6.98	4.12	17.2	17.02	-0.18	-3.45	-5.26	-1.81	75.81	69.77	-6.04
TX	PRT TANG	PT TANG	TO 0ºR	PRT TANG	PT TANG	TO 0ºC	PRT TANG	PT TANG	TO 20º	PRT BIS	PT BIS	BO 0ºR
SUBJECTS	OFF OºR	OFF OºR	DIFF	OFF 0ºC	OFF 0ºC	DIFF	OFF 20º	OFF 20º	DIFF	OFF OºR	OFF OºR	DIFF
AH	16.49	17.17	0.68	25	29.25	4.25	10.1	11.82	1.72	61.86	65.66	3.8
DG	10.39	9.74	-0.65	15	17.71	2.71	-10.67	-13.85	-3.18	97.4	88.31	-9.09
DO	5.38	7.41	2.03	14.81	15.79	0.98	-15.48	-10.34	5.14	64.52	69.14	4.62
EB	14.71	13.13	-1.58	22.92	22.09	-0.83	-4.08	-7.06	-2.98	67.65	62.63	-5.02
GK	12.87	23.91	11.04	31.48	28.09	-3.39	14.58	9.2	-5.38	71.29	79.35	8.06
HR	8.82	4.74	-4.08	14.58	6.52	-8.06	-3.42	-17.65	-14.23	72.06	71.58	-0.48
JN	14.29	9.9	-4.39	21.15	3.23	-17.92	-1.3	-5.26	-3.96	64.94	65.35	0.41
LR	25.77	28	2.23	33.87	33.85	-0.02	4.84	11.58	6.74	85.05	88	2.95
MS	18.33	18.45	0.12	13.51	12.75	-0.76	-4.55	-5.49	-0.94	78.33	77.38	-0.95
SD	12.97	11.96	-1.01	35.71	34.57	-1.14	-1.02	-3.7	-2.68	70.27	67.39	-2.88
TM	6.98	5.32	-1.66	17.02	15.73	-1.29	-5.26	-2.91	2.35	69.77	71.28	1.51

PRT BIS	PT BIS	BO 0ºC	PRT BIS	PT BIS	BO 20º	PRT LAT P	PT LAT PF	LPFA 0ºR	PRT LAT P	PT LAT PF	LPFA 0ºC	PRT LAT P
OFF 0ºC	OFF 0ºC	DIFF	OFF 20º	OFF 20º	DIFF	ANG 0ºR	ANG 0ºR	DIFF	ANG 0ºC	ANG 0ºC	DIFF	ANG 20º
		0	46.53	51.19	4.66	0	0	0			0	0
108.85	118.18	9.33	50.55	52.81	2.26	-10.5	-8	2.5	3.5	2.5	-1	8
125.64	111.67	-13.97	71.88	66.67	-5.21	0	0	0	-3.5	-4	-0.5	11
123.85	106.25	-17.6	62.79	70.19	7.4	3	-1.5	-4.5	8	0	-8	6
108.62	134	25.38	52.7	69.84	17.14	20	18	-2	16	13	-3	17.5
121.74	147	25.26	70.37	74.24	3.87	4	3	-1	3	5.5	2.5	11.5
90.28	106.94	16.66	60.49	65.06	4.57	3.5	7.5	4	-7.5	-8.5	-1	9
84.95	90.96	6.01	62.07	61.58	-0.49	5	6	1	6.5	5.5	-1	8

PRT BIS	PT BIS	BO 0ºC	PRT BIS	PT BIS	BO 20º	PRT LAT P	PT LAT PF	LPFA 0ºR	PRT LAT P	PT LAT PF	LPFA 0ºC	PRT LAT P
OFF 0ºC	OFF 0ºC	DIFF	OFF 20º	OFF 20º	DIFF	ANG 0ºR	ANG 0ºR	DIFF	ANG 0ºC	ANG 0ºC	DIFF	ANG 20º
67	59.43	-7.57	56.06	60.91	4.85	8	5	-3	7.5	7.5	0	16
111.67	143.75	32.08	66.67	76.92	10.25	0	1.5	1.5	-4	0	4	9
91.36	90.79	-0.57	53.57	49.43	-4.14	-6	-7.5	-1.5	-2.5	3	5.5	
83.33	80.23	-3.1	55.1	49.41	-5.69	0	0	0	-1	-2.5	-1.5	9
91.67	85.39	-6.28	70.83	59.77	-11.06	8	2.5	-5.5	-6	-5	1	14
106.25	78.8	-27.45	70.19	72.06	1.87	-1.5	-2.5	-1	0	0	0	8
88.46	112.9	24.44	56.49	69.47	12.98	5.5	9	3.5	20	15.5	-4.5	12
133.87	141.54	7.67	63.44	71.58	8.14	-7	-9.5	-2.5	5.5	5.5	0	-3
135.14	124.51	-10.63	74.24	65.38	-8.86	3	3	0	5.5	7.5	2	8.5
75	76.54	1.54	35.71	64.2	28.49	9.5	6.5	-3	-16	-20.5	-4.5	0
90.96	88.76	-2.2	61.58	63.11	1.53	6	4.5	-1.5	5.5	5	-0.5	12.5

PT LAT PF	LPFA 20º	PRT TILT	PT TILT	PTA 0ºR	PRT TILT	PT TILT	PTA 0ºC	PRT TILT	PT TILT	PTA 20º	TO 0º R VS
ANG 20º	DIFF	ANG0ºR	ANG0ºR	DIFF	ANG0ºC	ANG0ºC	DIFF	ANG20º	ANG20º	DIFF	TO 0º C
1.5	1.5	7	7	0			0	13.5	12	-1.5	N/A
2.5	-5.5	0	5	5	14.5	12.5	-2	17	17	0	9.34
9	-2	6.5	0	-6.5	0	0	0	12.5	13	0.5	-0.79
7.5	1.5	14	11.5	-2.5	16	11	-5	18.5	18.5	0	-3.93
18.5	1	27.5	25.5	-2	22.5	18	-4.5	24	25.5	1.5	1.26
8.5	-3	14.5	10.5	-4	5	10	5	14.5	17.5	3	-9.57
9	0	12.5	15.5	3	2.5	0	-2.5	16	14	-2	3.96
12.5	4.5	14	12	-2	7.5	7.5	0	15.5	17	1.5	-4.3

PT LAT PF	LPFA 20º	PRT TILT	PT TILT	PTA 0ºR	PRT TILT	PT TILT	PTA 0ºC	PRT TILT	PT TILT	PTA 20º	TO 0º R VS
ANG 20º	DIFF	ANG0ºR	ANG0ºR	DIFF	ANG0ºC	ANG0ºC	DIFF	ANG20º	ANG20º	DIFF	TO 0º C
9	-7	15	13.5	-1.5	17	18.5	1.5	20	17	-3	3.57
13	4	0	4.5	4.5	0	8	8	13	16	3	3.36
	0	10	8	-2	8	14	6			0	-1.05
10	1	10.5	12.5	2	10.5	11.5	1	19.5	19	-0.5	0.75
10	-4	10	5.5	-4.5	-4.5	0	4.5	17	14.5	-2.5	-14.43
8.5	0.5	11.5	11	-0.5	11	12.5	1.5	18.5	19.5	1	-3.98
14.5	2.5	17.5	18.5	1	26	23.5	-2.5	22.5	22.5	0	-13.53
-4.5	-1.5	-4.5	-6.5	-2	8	7	-1	5.5	0	-5.5	-2.25
10	1.5	10.5	14	3.5	10	15.5	5.5	17.5	23.5	6	-0.88
5.5	5.5	14.5	12.5	-2	-5	-2.5	2.5	19.5	10.5	-9	-0.13
12.5	0	12	14.5	2.5	7.5	9.5	2	17	16.5	-0.5	0.37

APPENDIX K

CT SCAN DATA CALCULATIONS

NONTREATMENT GROUP

SUBJECT: CO						
PRT PAT. WIDTH LINE 9.5	9.50	%	9.20	%	10.1	%
PT PAT. WIDTH LINE	8.30	CHANGE	7.40	CHANGE	8.4	CHANGE
TANGENT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	0.90	0º RELXD		0º CONTRACTED		20º RELAXED
		9.47	N/A	N/A	-0.40	-3.96
PT	1.50	0º RELAXED		0º CONTRACTED		20º RELAXED
		18.07	N/A	N/A	-0.15	-1.79
BISECT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT		0º RELXD		0º CONTRACTED		20º RELAXED
	5.85	61.58	N/A	N/A	4.7	46.53
PT		0º RELAXED		0º CONTRACTED		20º RELAXED
	5.50	66.27	N/A	N/A	4.3	51.19
LAT PF ANGLE	0º RELAXED	0º CONTRCTD	20º RELAXED			
PRT	0.00	N/A	0.00			
PT	0.00	N/A	1.50			
PAT TILT ANGLE	0º RELAXED	0º CONTRCTD	20º RELAXED			
PRT	7.00	N/A	13.50			
PT	7.00	N/A	12.00			

CT SCAN CALCULATION FORM

Patellar Width, Tangent Offset, and Bisect Offset measured in (mm). Lateral Patellofemoral Angle, and Patellar Tilt Angle measured in degrees. Change in Patellar position measured as percentage of post- vs pre- test data.

SUBJECT: DA						
PRT PAT. WIDTH LINE	8.20	%	5.85	%	9.1	%
PT PAT. WIDTH LINE	8.80	CHANGE	4.40	CHANGE	8.9	CHANGE
TANGENT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	1.65	0º RELXD	-0.20	0º CONTRACTED	0.05	20º RELAXED
		20.12		-3.42		0.55
PT	1.25	0º RELAXED	0.00	0º CONTRACTED	0	20º RELAXED
		14.20		0.00		0.00
BISECT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	6.65	0º RELXD	5.90	0º CONTRACTED	4.6	20º RELAXED
		81.10		100.85		50.55
PT	6.8	0º RELAXED	5.20	0º CONTRACTED	4.7	20º RELAXED
		77.27		118.18		52.81
LAT PF ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	-10.50		3.50		8	
PT	-8.00		2.50		2.5	
PAT TILT ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	0.00		14.50		17	
PT	5.00		12.50		17	

CT SCAN CALCULATION FORM

Patellar Width, Tangent Offset, and Bisect Offset measured in (mm). Lateral Patellofemoral Angle, and Patellar Tilt Angle measured in degrees. Change in Patellar position measured as percentage of post- vs pre- test data.

SUBJECT: DG						
PRT PAT. WIDTH LINE	7.25	%	5.85	%	6.4	%
PT PAT. WIDTH LINE	7.70	CHANGE	6.00	CHANGE	7.5	CHANGE
TANGENT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	0.60	0º RELXD	0.80	0º CONTRACTED	-0.55	20º RELAXED
		8.28		13.68		-8.59
PT	0.80	0º RELAXED	0.90	0º CONTRACTED	-0.8	20º RELAXED
		10.39		15.00		-10.67
BISECT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	6.4	0º RELXD	7.35	0º CONTRACTED	4.6	20º RELAXED
		88.28		125.64		71.88
PT	7.5	0º RELAXED	6.70	0º CONTRACTED	5	20º RELAXED
		97.40		111.67		66.67
LAT PF ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	0.00		-3.50		11.00	
PT	0.00		-4.00		9.00	
PAT TILT ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	6.50		0.00		12.5	
PT	0.00		0.00		13	

CT SCAN CALCULATION FORM

Patellar Width, Tangent Offset, and Bisect Offset measured in (mm). Lateral Patellofemoral Angle, and Patellar Tilt Angle measured in degrees. Change in Patellar position measured as percentage of post- vs pre- test data.

SUBJECT: HR						
PRT PAT. WIDTH LINE	9.30	%	6.50	%	8.6	%
PT PAT. WIDTH LINE	6.70	CHANGE	4.80	CHANGE	5.85	CHANGE
TANGENT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	0.40	0º RELXD	0.90	0º CONTRACTED	-0.4	20º RELAXED
		4.30		13.85		-4.65
PT	0.60	0º RELAXED	0.70	0º CONTRACTED	-0.2	20º RELAXED
		8.96		14.58		-3.42
BISECT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	7	0º RELXD	8.05	0º CONTRACTED	5.4	20º RELAXED
		75.27		123.85		62.79
PT	4.9	0º RELAXED	5.10	0º CONTRACTED	3.65	20º RELAXED
		73.13		106.25		62.39
LAT PF ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	3.00		8		6.00	
PT	-1.50		0		7.50	
PAT TILT ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	14.00		16		18.50	
			11			
PT	11.50				18.50	

CT SCAN CALCULATION FORM

Patellar Width, Tangent Offset, and Bisect Offset measured in (mm). Lateral Patellofemoral Angle, and Patellar Tilt Angle measured in degrees. Change in Patellar position measured as percentage of post- vs pre- test data.

SUBJECT: LC						
		%		%		%
PRT PAT. WIDTH LINE	7.70	CHANGE	5.80	CHANGE	7.4	CHANGE
PT PAT. WIDTH LINE	7.75		5.00		6.3	
TANGENT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	-0.50	0º RELXD	-0.30	0º CONTRACTED	-1.7	20º RELAXED
		-6.49		-5.17		-22.97
PT	-0.20	0º RELAXED	0.00	0º CONTRACTED	-1.4	20º RELAXED
		-2.58		0.00		-22.22
BISECT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	5.7	0º RELXD	6.30	0º CONTRACTED	3.9	20º RELAXED
		74.03		108.62		52.70
PT	5.8	0º RELAXED	6.70	0º CONTRACTED	4.4	20º RELAXED
		74.84		134.00		69.84
LAT PF ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	20.00		16		17.50	
PT	18.00		13		18.50	
PAT TILT ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	27.50		22.5		24.00	
PT	25.50		18		25.50	

CT SCAN CALCULATION FORM

Patellar Width, Tangent Offset, and Bisect Offset measured in (mm). Lateral Patellofemoral Angle, and Patellar Tilt Angle measured in degrees. Change in Patellar position measured as percentage of post- vs pre- test data.

SUBJECT: MS						
PRT PAT. WIDTH LINE	8.80	%	6.90	%	8.1	%
PT PAT. WIDTH LINE	6.00	CHANGE	3.40	CHANGE	6.6	CHANGE
TANGENT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	1.00	0º RELXD	1.60	0º CONTRACTED	-0.7	20º RELAXED
		11.36		23.19		-8.64
PT	1.10	0º RELAXED	0.70	0º CONTRACTED	-0.3	20º RELAXED
		18.33		20.59		-4.55
BISECT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	6.55	0º RELXD	8.40	0º CONTRACTED	5.7	20º RELAXED
		74.43		121.74		70.37
PT	4.7	0º RELAXED	5.00	0º CONTRACTED	4.9	20º RELAXED
		78.33		147.06		74.24
LAT PF ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	4.00		3.00		11.50	
PT	3.00		5.50		8.50	
PAT TILT ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	14.50		5.00		14.5	
PT	10.50		10.00		17.5	

CT SCAN CALCULATION FORM

Patellar Width, Tangent Offset, and Bisect Offset measured in (mm). Lateral Patellofemoral Angle, and Patellar Tilt Angle measured in degrees. Change in Patellar position measured as percentage of post- vs pre- test data.

SUBJECT: RR						
PRT PAT. WIDTH LINE	8.20	%	7.20	%	8.1	%
PT PAT. WIDTH LINE	8.90	CHANGE	7.20	CHANGE	8.3	CHANGE
TANGENT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	0.75	0º RELXD	1.90	0º CONTRACTED	-0.4	20º RELAXED
		9.15		26.39		-4.94
PT	0.40	0º RELAXED	1.85	0º CONTRACTED	-0.7	20º RELAXED
		4.49		25.69		-8.43
BISECT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	5.45	0º RELXD	6.50	0º CONTRACTED	4.9	20º RELAXED
		66.46		90.28		60.49
PT	5.4	0º RELAXED	7.70	0º CONTRACTED	5.4	20º RELAXED
		60.67		106.94		65.06
LAT PF ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	3.50		-7.5		9.00	
PT	7.50		-8.5		9.00	
PAT TILT ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	12.50		2.50		16	
PT	15.50		0.00		14	

CT SCAN CALCULATION FORM

Patellar Width, Tangent Offset, and Bisect Offset measured in (mm). Lateral Patellofemoral Angle, and Patellar Tilt Angle measured in degrees. Change in Patellar position measured as percentage of post- vs pre- test data.

SUBJECT: TM						
PRT PAT. WIDTH LINE	3.50	%	9.30	%	8.7	%
PT PAT. WIDTH LINE	8.60	CHANGE	9.40	CHANGE	9.5	CHANGE
TANGENT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	0.10	0º RELXD	1.60	0º CONTRACTED	-0.3	20º RELAXED
		2.86		17.20		-3.45
PT	0.60	0º RELAXED		0º CONTRACTED	-0.5	20º RELAXED
		6.98	1.60	17.02		-5.26
BISECT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	2.2	0º RELXD	7.90	0º CONTRACTED	5.4	20º RELAXED
		62.86		84.95		62.07
PT	6	0º RELAXED	8.55	0º CONTRACTED	5.85	20º RELAXED
		69.77		90.96		61.58
LAT PF ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	5.00		6.50		8.00	
PT	6.00		5.50		12.50	
PAT TILT ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	14.00		7.50		15.5	
PT	12.00		7.50		17	

CT SCAN CALCULATION FORM

Patellar Width, Tangent Offset, and Bisect Offset measured in (mm). Lateral Patellofemoral Angle, and Patellar Tilt Angle measured in degrees. Change in Patellar position measured as percentage of post- vs pre- test data.

APPENDIX L

CT SCAN DATA CALCULATIONS

TREATMENT GROUP

SUBJECT: AH						
PRT PAT. WIDTH LINE	9.70	%	10.00	%	9.9	%
PT PAT. WIDTH LINE	9.90	CHANGE	10.60	CHANGE	11	CHANGE
TANGENT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	1.60	0º RELXD	2.50	0º CONTRACTED	1	20º RELAXED
		16.49		25.00		10.10
PT	1.70	0º RELAXED	3.10	0º CONTRACTED	1.3	20º RELAXED
		17.17		29.25		11.82
BISECT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	6	0º RELXD	6.70	0º CONTRACTED	5.55	20º RELAXED
		61.86		67.00		56.06
PT	6.5	0º RELAXED	6.30	0º CONTRACTED	6.7	20º RELAXED
		65.66		59.43		60.91
LAT PF ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	8.00		7.50		16.00	
PT	5.00		7.50		9.00	
PAT TILT ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	15.00		17.00		20	
PT	13.50		18.50		17	

CT SCAN CALCULATION FORM

Patellar Width, Tangent Offset, and Bisect Offset measured in (mm). Lateral Patellofemoral Angle, and Patellar Tilt Angle measured in degrees. Change in Patellar position measured as percentage of post- vs pre- test data.

SUBJECT: DO						
PRT PAT. WIDTH LINE	9.30	%	8.10	%	8.4	%
PT PAT. WIDTH LINE	8.10	CHANGE	7.60	CHANGE	8.7	CHANGE
TANGENT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	0.50	0º RELXD	1.20	0º CONTRACTED	-1.3	20º RELAXED
		5.38		14.81		-15.48
PT	0.60	0º RELAXED	1.20	0º CONTRACTED	-0.9	20º RELAXED
		7.41		15.79		-10.34
BISECT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	6	0º RELXD	7.40	0º CONTRACTED	4.5	20º RELAXED
		64.52		91.36		53.57
PT	5.6	0º RELAXED	6.90	0º CONTRACTED	4.3	20º RELAXED
		69.14		90.79		49.43
LAT PF ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	-5.50		-2.50		N/A	
PT	-7.50		3.00		N/A	
PAT TILT ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	10.00		8.00		N/A	
PT	8.00		14.00		N/A	

CT SCAN CALCULATION FORM

Patellar Width, Tangent Offset, and Bisect Offset measured in (mm). Lateral Patellofemoral Angle, and Patellar Tilt Angle measured in degrees. Change in Patellar position measured as percentage of post- vs pre- test data.

SUBJECT: DG						
PRT PAT. WIDTH LINE	7.70	%	6.00	%	7.5	%
PT PAT. WIDTH LINE	7.70	CHANGE	4.80	CHANGE	6.5	CHANGE
TANGENT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	0.80	0º RELXD	0.90	0º CONTRACTED	-0.8	20º RELAXED
		10.39		15.00		-10.67
PT	0.75	0º RELAXED	0.85	0º CONTRACTED	-0.9	20º RELAXED
		9.74		17.71		-13.85
BISECT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	7.5	0º RELXD	6.70	0º CONTRACTED	5	20º RELAXED
		97.40		111.67		66.67
PT	6.8	0º RELAXED	6.90	0º CONTRACTED	5	20º RELAXED
		88.31		143.75		76.92
LAT PF ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	0.00		-4.00		9.00	
PT	1.50		0.00		13.00	
PAT TILT ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	0.00		0.00		13	
PT	4.50		8.00		16	

CT SCAN CALCULATION FORM

Patellar Width, Tangent Offset, and Bisect Offset measured in (mm). Lateral Patellofemoral Angle, and Patellar Tilt Angle measured in degrees. Change in Patellar position measured as percentage of post- vs pre- test data.

SUBJECT: EB						
PRT PAT. WIDTH LINE	6.80	%	4.80	%	4.9	%
PT PAT. WIDTH LINE	9.90	CHANGE	8.60	CHANGE	8.5	CHANGE
TANGENT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	1.00	0º RELXD	1.00	0º CONTRACTED	-0.2	20º RELAXED
		14.71		20.83		-4.08
PT	1.30	0º RELAXED	1.90	0º CONTRACTED	-0.6	20º RELAXED
		13.13		22.09		-7.06
BISECT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	4.6	0º RELXD	4.00	0º CONTRACTED	2.7	20º RELAXED
		67.65		83.33		55.10
PT	6.2	0º RELAXED	6.90	0º CONTRACTED	4.2	20º RELAXED
		62.63		80.23		49.41
LAT PF ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	0.00		-1.00		9.00	
PT	0.00		-2.50		10.00	
PAT TILT ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	10.50		10.50		19.5	
PT	12.50		11.50		19	

CT SCAN CALCULATION FORM

Patellar Width, Tangent Offset, and Bisect Offset measured in (mm). Lateral Patellofemoral Angle, and Patellar Tilt Angle measured in degrees. Change in Patellar position measured as percentage of post- vs pre- test data.

SUBJECT: GK						
PRT PAT. WIDTH LINE	10.10		10.80		9.6	
PT PAT. WIDTH LINE	9.20		8.90		8.7	
TANGENT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT		0° RELXD		0° CONTRACTED		20° RELAXED
	1.3	12.87	3.40	31.48	1.40	14.58
PT		0° RELAXED		0° CONTRACTED		20° RELAXED
	2.2	23.91	2.50	28.09	0.8	9.20
BISECT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT		0° RELXD		0° CONTRACTED		20° RELAXED
	7.20	71.29	9.90	91.67	6.8	70.83
PT		0° RELAXED		0° CONTRACTED		20° RELAXED
	7.30	79.35	7.60	85.39	5.2	59.77
LAT PF ANGLE	0° RELAXED	0° CONTRCTD	20° RELAXED			
PRT	8.00	-6.00	14.00			
	2.5	-5.00	10.00			
PT						
PAT TILT ANGLE	0° RELAXED	0° CONTRCTD	20° RELAXED			
PRT	10.00	-4.50	17.00			
PT	5.5	0.00	14.50			

CT SCAN CALCULATION FORM

Patellar Width, Tangent Offset, and Bisect Offset measured in (mm). Lateral Patellofemoral Angle, and Patellar Tilt Angle measured in degrees. Change in Patellar position measured as percentage of post- vs pre- test data.

SUBJECT: HR						
PRT PAT. WIDTH LINE	6.80	%	4.80	%	5.2	%
PT PAT. WIDTH LINE	9.50	CHANGE	9.20	CHANGE	6.8	CHANGE
TANGENT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	0.60	0º RELXD		0º CONTRACTED	-0.55	20º RELAXED
		8.82	0.70	14.58		-10.58
PT	0.45	0º RELAXED	0.60	0º CONTRACTED	-1.2	20º RELAXED
		4.74		6.52		-17.65
BISECT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	4.9	0º RELXD	5.10	0º CONTRACTED	3.65	20º RELAXED
		72.06		106.25		70.19
PT	6.8	0º RELAXED	7.25	0º CONTRACTED	4.9	20º RELAXED
		71.58		78.80		72.06
LAT PF ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	-1.50		0		8.00	
PT	-2.50		0		8.50	
PAT TILT ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	11.50		11		18.50	
			12.5			
PT	11.00				19.50	

CT SCAN CALCULATION FORM

Patellar Width, Tangent Offset, and Bisect Offset measured in (mm). Lateral Patellofemoral Angle, and Patellar Tilt Angle measured in degrees. Change in Patellar position measured as percentage of post- vs pre- test data.

SUBJECT: JN						
PRT PAT. WIDTH LINE	7.70	%	5.20	%	7.7	%
PT PAT. WIDTH LINE	10.10	CHANGE	6.20	CHANGE	9.5	CHANGE
TANGENT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	1.10	0º RELXD	1.10	0º CONTRACTED	-0.1	20º RELAXED
		14.29		21.15		-1.30
PT	1.00	0º RELAXED	0.20	0º CONTRACTED	-0.5	20º RELAXED
		9.90		3.23		-5.26
BISECT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	5	0º RELXD	4.60	0º CONTRACTED	4.35	20º RELAXED
		64.94		88.46		56.49
PT	6.6	0º RELAXED	7.00	0º CONTRACTED	6.6	20º RELAXED
		65.35		112.90		69.47
LAT PF ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	5.50		20.00		12.00	
PT	9.00		15.50		14.50	
PAT TILT ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	17.50		26.00		22.5	
PT	18.50		23.50		22.5	

CT SCAN CALCULATION FORM

Patellar Width, Tangent Offset, and Bisect Offset measured in (mm). Lateral Patellofemoral Angle, and Patellar Tilt Angle measured in degrees. Change in Patellar position measured as percentage of post- vs pre- test data.

SUBJECT: LR						
PRT PAT. WIDTH LINE	9.70	%	6.20	%	9.3	%
PT PAT. WIDTH LINE	10.00	CHANGE	6.50	CHANGE	9.5	CHANGE
TANGENT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	2.50	0º RELXD	2.10	0º CONTRACTED	0.45	20º RELAXED
		25.77		33.87		4.84
PT	2.80	0º RELAXED	2.20	0º CONTRACTED	1.1	20º RELAXED
		28.00		33.85		11.58
BISECT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	8.25	0º RELXD	8.30	0º CONTRACTED	5.9	20º RELAXED
		85.05		133.87		63.44
PT	8.8	0º RELAXED	9.20	0º CONTRACTED	6.8	20º RELAXED
		88.00		141.54		71.58
LAT PF ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	-7.00		5.50		-3.00	
PT	-9.50		5.50		-4.50	
PAT TILT ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	-4.50		8.00		5.5	
PT	-6.50		7.00		0	

CT SCAN CALCULATION FORM

Patellar Width, Tangent Offset, and Bisect Offset measured in (mm). Lateral Patellofemoral Angle, and Patellar Tilt Angle measured in degrees. Change in Patellar position measured as percentage of post- vs pre- test data.

SUBJECT: MS						
PRT PAT. WIDTH LINE	6.00	%	3.70	%	6.6	%
PT PAT. WIDTH LINE	8.40	CHANGE	5.10	CHANGE	9.1	CHANGE
TANGENT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	1.10	0º RELXD	0.50	0º CONTRACTED	-0.3	20º RELAXED
		18.33		13.51		-4.55
PT	1.55	0º RELAXED	0.65	0º CONTRACTED	-0.5	20º RELAXED
		18.45		12.75		-5.49
BISECT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	4.7	0º RELXD	5.00	0º CONTRACTED	4.9	20º RELAXED
		78.33		135.14		74.24
PT	6.5	0º RELAXED	6.35	0º CONTRACTED	5.95	20º RELAXED
		77.38		124.51		65.38
LAT PF ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	3.00		5.50		8.50	
PT	3.00		7.50		10.00	
PAT TILT ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	10.50		10.00		17.5	
PT	14.00		15.50		23.5	

CT SCAN CALCULATION FORM

Patellar Width, Tangent Offset, and Bisect Offset measured in (mm). Lateral Patellofemoral Angle, and Patellar Tilt Angle measured in degrees. Change in Patellar position measured as percentage of post- vs pre- test data.

SUBJECT: SD						
PRT PAT. WIDTH LINE	9.25	%	8.40	%	9.8	%
PT PAT. WIDTH LINE	9.20	CHANGE	8.10	CHANGE	8.1	CHANGE
TANGENT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	1.20	0º RELXD	3.00	0º CONTRACTED	-0.1	20º RELAXED
		12.97		35.71		-1.02
PT	1.10	0º RELAXED	2.80	0º CONTRACTED	-0.3	20º RELAXED
		11.96		34.57		-3.70
BISECT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	6.5	0º RELXD	6.30	0º CONTRACTED	3.5	20º RELAXED
		70.27		75.00		35.71
PT	6.2	0º RELAXED	6.20	0º CONTRACTED	5.2	20º RELAXED
		67.39		76.54		64.20
LAT PF ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	9.50		-16.00		0.00	
PT	6.50		-20.50		5.50	
PAT TILT ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	14.50		-5.00		19.5	
PT	12.50		-2.50		10.5	

CT SCAN CALCULATION FORM

Patellar Width, Tangent Offset, and Bisect Offset measured in (mm). Lateral Patellofemoral Angle, and Patellar Tilt Angle measured in degrees. Change in Patellar position measured as percentage of post- vs pre- test data.

SUBJECT: TM						
PRT PAT. WIDTH LINE	8.60	%	9.40	%	9.5	%
PT PAT. WIDTH LINE	9.40	CHANGE	8.90	CHANGE	10.3	CHANGE
TANGENT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	0.60	0º RELXD	1.60	0º CONTRACTED	-0.5	20º RELAXED
		6.98		17.02		-5.26
PT	0.50	0º RELAXED	1.40	0º CONTRACTED	-0.3	20º RELAXED
		5.32		15.73		-2.91
BISECT OFFSET	MEASURMENT		MEASURMENT		MEASURMENT	
PRT	6	0º RELXD	8.55	0º CONTRACTED	5.85	20º RELAXED
		69.77		90.96		61.58
PT	6.7	0º RELAXED	7.90	0º CONTRACTED	6.5	20º RELAXED
		71.28		88.76		63.11
LAT PF ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	6.00		5.50		12.50	
PT	4.50		5.00		12.50	
PAT TILT ANGLE	0º RELAXED		0º CONTRCTD		20º RELAXED	
PRT	12.00		7.50		17	
PT	14.50		9.50		16.5	

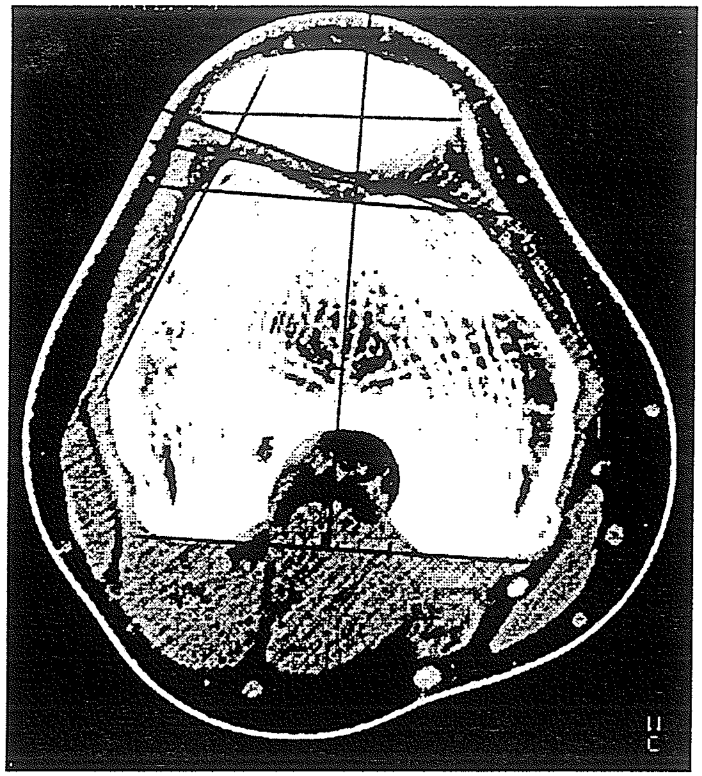
CT SCAN CALCULATION FORM

Patellar Width, Tangent Offset, and Bisect Offset measured in (mm). Lateral Patellofemoral Angle, and Patellar Tilt Angle measured in degrees. Change in Patellar position measured as percentage of post- vs pre- test data.

APPENDIX M

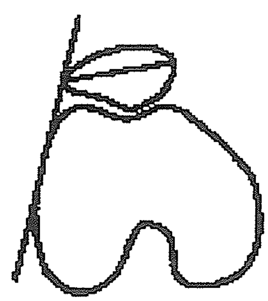
SAMPLE CT SCAN IMAGES

A



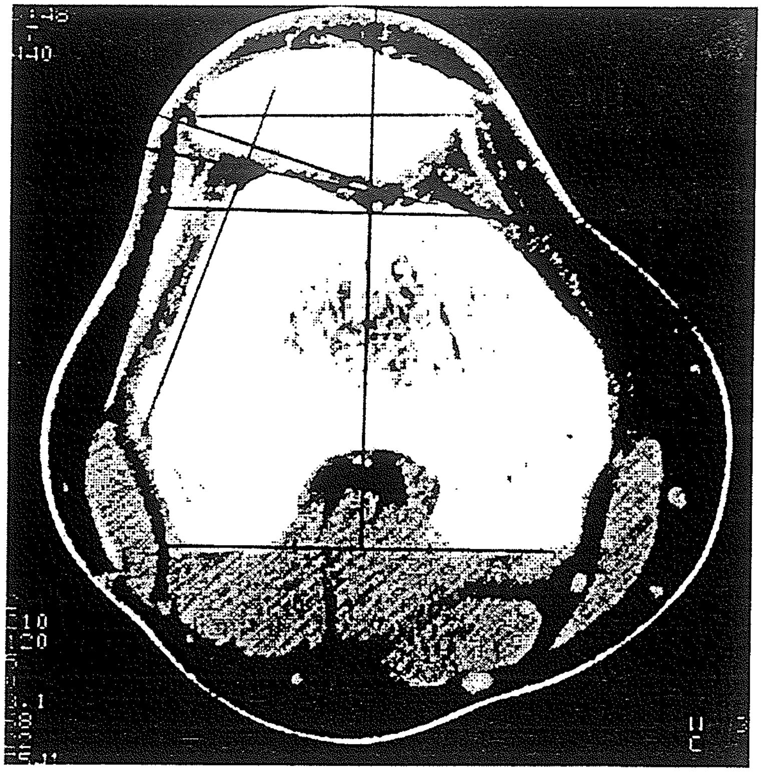
SUBJECT AH: 0º RELAXED

B



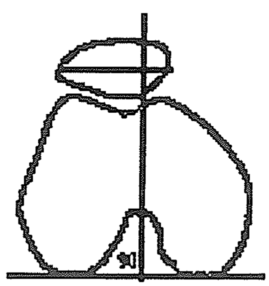
APPENDIX M (a): A. CT Scan of subject AH 20º Relaxed. B. Diagrammatic representation of tangent offset (TO 20º R).

A



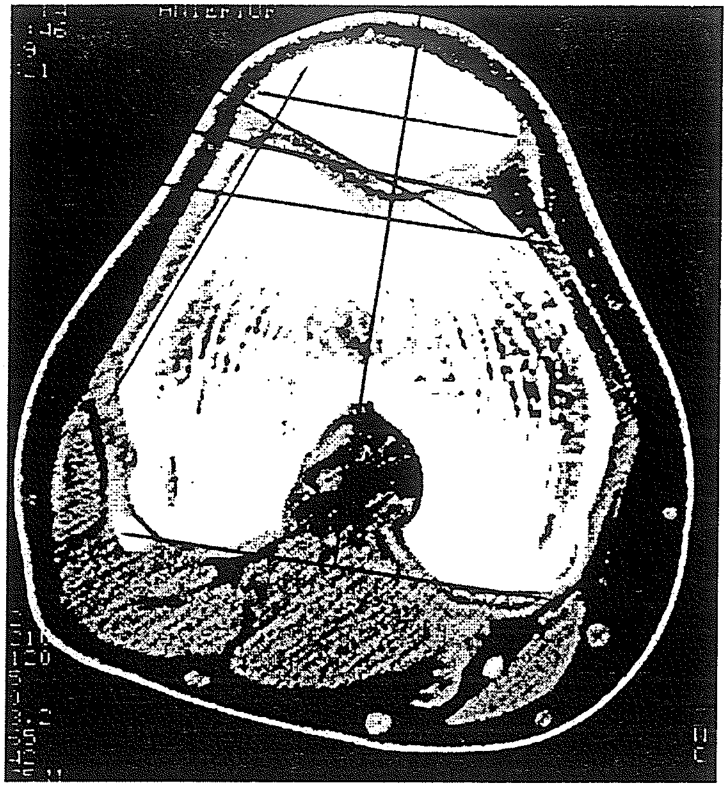
SUBJECT AH 0º CONTRACTED

B



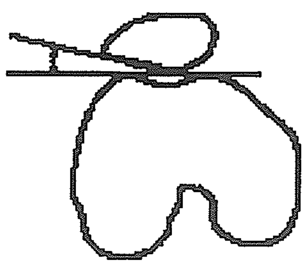
APPENDIX M (b): A. CT Scan of subject AH 0º Contracted.
B. Diagrammatic representation of bisect offset (BO 0º C).

A



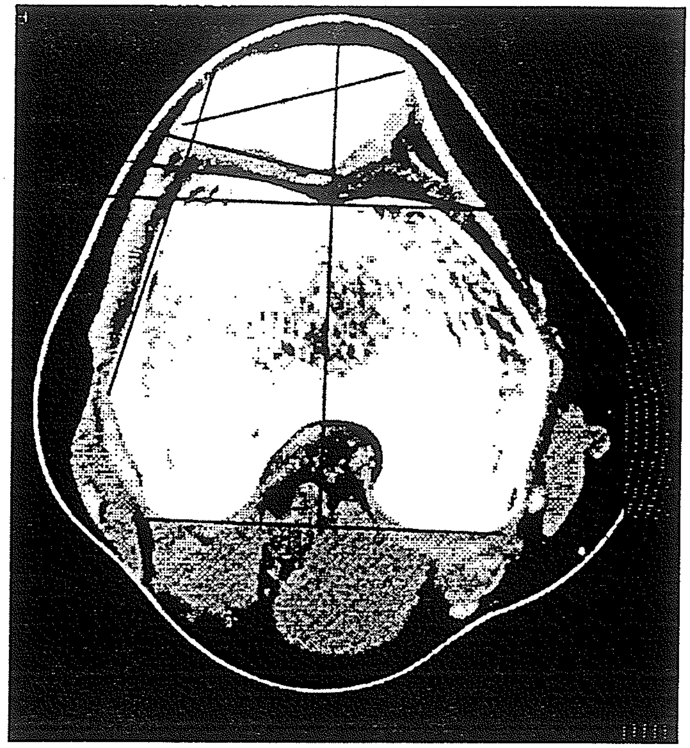
SUBJECT AH: 20º RELAXED

B



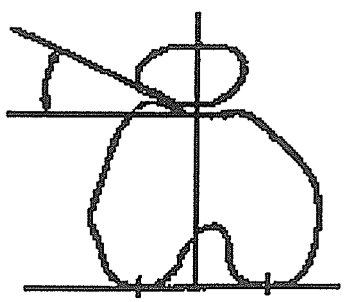
APPENDIX M(c): A.CT Scan of subject AH 20º Relaxed. B. Diagrammatic representation of patellofemoral angle (LPFA 20º R).

A



SUBJECT TM: 0º RELAXED

B



APPENDIX M (d): A. Subject TM 0º Relaxed. B. A diagrammatic Representation of patellar tilt angle (PTA 0º R)

APPENDIX N

PAIN RAW DATA SUMMARY

NON															
TREATMEMT	PRT	PT	AFFEC	PRT	PT	SENS	PRT	PT	EVAL	PRT	PT	MISC	PRT	PT	TOTAL
SUBJECT	AFFEC	AFFEC	DIFF	SENS	SENS	DIFF	EVAL	EVAL	DIFF	M ISC	MISC	DIFF	TOTAL	TOTAL	DIFF
GD	23	17	-6	4	4	0	0	0	0	10	1	-9	37	22	-15
DA	8	0	-8	0	0	0	0	0	0	0	0	0	8	0	-8
DG	8	8	0	0	0	0	3	0	-3	5	5	0	16	13	-3
HR	12	16	4	3	3	0	2	0	-2	3	3	0	20	22	2
LC	15	11	-4	0	1	1	2	0	-2	1	4	3	18	16	-2
MS	11	21	10	3	3	0	3	0	-3	2	10	8	19	34	15
RR	11	14	3	3	0	-3	0	0	0	7	2	-5	21	16	-5
TM	9	15	6	0	3	3	0	0	0	6	5	-1	15	23	8
TREATMEMT	PRT	PT	AFFEC	PRT	PT	SENS	PRT	PT	EVAL	PRT	PT	MISC	PRT	PT	TOTAL
SUBJECT	AFFEC	AFFEC	DIFF	SENS	SENS	DIFF	EVAL	EVAL	DIFF	M ISC	MISC	DIFF	TOTAL	TOTAL	DIFF
AH	5	12	7	0	4	4	3	2	-1	0	1	1	8	19	11
DG	9	9	0	0	0	0	0	0	0	5	1	-4	14	10	-4
DO	8	5	-3	0	0	0	0	0	0	1	0	-1	9	5	-4
EB	13	10	-3	1	0	-1	0	0	0	1	0	-1	15	10	-5
GK	23	25	2	5	5	0	1	1	0	5	11	6	34	42	8
HR	15	6	-9	3	0	-3	0	0	0	3	1	-2	21	7	-14
JN	11	1	-10	3	0	-3	0	0	0	0	0	0	14	1	-13
LR	10	4	-6	0	0	0	0	0	0	0	0	0	10	4	-6
MS	21	6	-15	3	0	-3	0	2	2	10	3	-7	34	11	-23
SD	29	21	-8	9	1	-8	3	0	-3	2	1	-1	43	23	-20
TM	15	8	-7	3	0	-3	0	0	0	5	0	-5	23	8	-15

APPENDIX 0

PAIN DATA
NONTREATMENT GROUP

NAME: RR			NET
	PRETEST	POSTTEST	CHANGE
AFFECTIVE (1-10)	11	14	3
SENSORY (11-15)	3	0	-3
EVALUATIVE (16)	0	0	0
MISCELLANEOUS (17-20)	7	2	-5
TOTAL	21	16	-5
NAME: DG			NET
	PRETEST	POSTTEST	CHANGE
AFFECTIVE (1-10)	8	8	0
SENSORY (11-15)	0	0	0
EVALUATIVE (16)	3	0	-3
MISCELLANEOUS (17-20)	5	5	0
TOTAL	16	13	-3
NAME: HR			NET
	PRETEST	POSTTEST	CHANGE
AFFECTIVE (1-10)	12	16	4
SENSORY (11-15)	3	3	0
EVALUATIVE (16)	2	0	-2
MISCELLANEOUS (17-20)	3	3	0
TOTAL	20	22	2
NAME: DA			NET
	PRETEST	POSTTEST	CHANGE
AFFECTIVE (1-10)	8	0	-8
SENSORY (11-15)	0	0	0
EVALUATIVE (16)	0	0	0
MISCELLANEOUS (17-20)	0	0	0
TOTAL	8	0	-8

NAME: RR			NET
	PRETEST	POSTTEST	CHANGE
AFFECTIVE (1-10)	11	14	3
SENSORY (11-15)	3	0	-3
EVALUATIVE (16)	0	0	0
MISCELLANEOUS (17-20)	7	2	-5
TOTAL	21	16	-5
NAME: DG			NET
	PRETEST	POSTTEST	CHANGE
AFFECTIVE (1-10)	8	8	0
SENSORY (11-15)	0	0	0
EVALUATIVE (16)	3	0	-3
MISCELLANEOUS (17-20)	5	5	0
TOTAL	16	13	-3
NAME: HR			NET
	PRETEST	POSTTEST	CHANGE
AFFECTIVE (1-10)	12	16	4
SENSORY (11-15)	3	3	0
EVALUATIVE (16)	2	0	-2
MISCELLANEOUS (17-20)	3	3	0
TOTAL	20	22	2
NAME: DA			NET
	PRETEST	POSTTEST	CHANGE
AFFECTIVE (1-10)	8	0	-8
SENSORY (11-15)	0	0	0
EVALUATIVE (16)	0	0	0
MISCELLANEOUS (17-20)	0	0	0
TOTAL	8	0	-8

APPENDIX P

PAIN DATA
TREATMENT GROUP

HR			NET
	PRETEST	POSTTEST	CHANGE
AFFECTIVE (1-10)	15	6	-9
SENSORY (11-15)	3	0	-3
EVALUATIVE (16)	0	0	0
MISCELLANEOUS (17-20)	3	1	-2
TOTAL	21	7	-14
NAME: DG			NET
	PRETEST	POSTTEST	CHANGE
AFFECTIVE (1-10)	9	9	0
SENSORY (11-15)	0	0	0
EVALUATIVE (16)	0	0	0
MISCELLANEOUS (17-20)	5	1	-4
TOTAL	14	10	-4
NAME:TM			NET
	PRETEST	POSTTEST	CHANGE
AFFECTIVE (1-10)	15	8	-7
SENSORY (11-15)	3	0	-3
EVALUATIVE (16)	0	0	0
MISCELLANEOUS (17-20)	5	0	-5
TOTAL	23	8	-15
NAME: MS			NET
	PRETEST	POSTTEST	CHANGE
AFFECTIVE (1-10)	21	6	-15
SENSORY (11-15)	3	0	-3
EVALUATIVE (16)	0	2	2
MISCELLANEOUS (17-20)	10	3	-7
TOTAL	34	11	-23

HR			NET
	PRETEST	POSTTEST	CHANGE
AFFECTIVE (1-10)	15	6	-9
SENSORY (11-15)	3	0	-3
EVALUATIVE (16)	0	0	0
MISCELLANEOUS (17-20)	3	1	-2
TOTAL	21	7	-14
NAME: DG			NET
	PRETEST	POSTTEST	CHANGE
AFFECTIVE (1-10)	9	9	0
SENSORY (11-15)	0	0	0
EVALUATIVE (16)	0	0	0
MISCELLANEOUS (17-20)	5	1	-4
TOTAL	14	10	-4
NAME:TM			NET
	PRETEST	POSTTEST	CHANGE
AFFECTIVE (1-10)	15	8	-7
SENSORY (11-15)	3	0	-3
EVALUATIVE (16)	0	0	0
MISCELLANEOUS (17-20)	5	0	-5
TOTAL	23	8	-15
NAME: MS			NET
	PRETEST	POSTTEST	CHANGE
AFFECTIVE (1-10)	21	6	-15
SENSORY (11-15)	3	0	-3
EVALUATIVE (16)	0	2	2
MISCELLANEOUS (17-20)	10	3	-7
TOTAL	34	11	-23

NAME: JN			NET
	PRETEST	POSTTEST	CHANGE %
AFFECTIVE (1-10)	11	1	-10
SENSORY (11-15)	3	0	-3
EVALUATIVE (16)	0	0	0
MISCELLANEOUS (17-20)	0	0	0
TOTAL	14	1	-13
NAME: AH			NET
	PRETEST	POSTTEST	CHANGE %
AFFECTIVE (1-10)	5	12	7
SENSORY (11-15)	0	4	4
EVALUATIVE (16)	3	2	-1
MISCELLANEOUS (17-20)	0	1	1
TOTAL	8	19	11
NAME: LR			NET
	PRETEST	POSTTEST	CHANGE %
AFFECTIVE (1-10)	10	4	-6
SENSORY (11-15)	0	0	0
EVALUATIVE (16)	0	0	0
MISCELLANEOUS (17-20)	0	0	0
TOTAL	10	4	-6

APPENDIX Q

SAMPLE KIN COM RAW DATA

KIN/COM data MED*EX DIAGNOSTICS OF CANADA INC. page 2

sample	mark	angle degree	velocity D/S	force newton	torque N M	power watts
470		164	0	-178	-48.0	0.0
480		164	0	-180	-48.6	0.0
490		164	0	-177	-47.7	0.0
500		164	0	-169	-45.6	0.0
510		164	0	-156	-42.1	0.0
520		164	0	-152	-41.0	0.0
530		164	0	-152	-41.0	0.0
540		164	0	-149	-40.2	0.0
550		164	0	-158	-42.6	0.0
560		164	0	-166	-44.8	0.0
570		164	0	-166	-44.8	0.0
580		164	0	-161	-43.4	0.0
590		164	0	-155	-41.8	0.0
600		164	0	-151	-40.7	0.0
610		164	0	-149	-40.2	0.0
620		164	0	-151	-40.7	0.0
630		164	0	-157	-42.3	0.0
640		164	0	-161	-43.4	0.0
650		164	0	-169	-45.6	0.0
660		164	0	-183	-49.4	0.0
670		164	0	-182	-49.1	0.0
680		164	0	-185	-49.9	0.0
690		164	0	-192	-51.8	0.0
700		164	0	-181	-48.8	0.0
710		164	0	-178	-48.0	0.0
720		164	0	-180	-48.6	0.0
730		164	0	-176	-47.5	0.0
740		164	0	-177	-47.7	0.0
750		164	0	-183	-49.4	0.0
760		164	0	-181	-48.8	0.0
770		164	0	-184	-49.6	0.0
780		164	0	-189	-51.0	0.0
790		164	0	-184	-49.6	0.0
800		164	0	-182	-49.1	0.0
810		164	0	-182	-49.1	0.0
820		164	0	-183	-49.4	0.0
830		164	0	-183	-49.4	0.0
840		164	0	-170	-45.9	0.0
850		164	0	-176	-47.5	0.0
860		164	0	-182	-49.1	0.0
870		164	0	-191	-51.5	0.0
880		164	0	-198	-53.4	0.0
890		164	0	-194	-52.3	0.0
900		164	0	-198	-53.4	0.0
910		164	0	-187	-50.4	0.0
920		164	0	-179	-48.3	0.0
930		164	0	-175	-47.2	0.0
940		164	0	-177	-47.7	0.0
950		164	0	-173	-46.7	0.0
960		164	0	-165	-44.5	0.0
970		164	0	-159	-42.9	0.0
980		164	0	-158	-42.6	0.0

KIN/COM data MED*EX DIAGNOSTICS OF CANADA INC. page 1
EXERCISE MODE ANGLE Disk File F:AH1/1

START ANGLE	165	RETURN ANGLE	165
NUMBER OF STOPS	1	MINIMUM FORCE	20
REPETITIONS	1	STOP DURATION	1200
LEVER RADIUS	270	GRAVITY ANGLE	175
REFERENCE ANGLE	175	GRAVITY FORCE	0

Gravity Compensated YES

sample	mark	angle degree	velocity D/S	force newton	torque N M	power watts
0	bgncyc	164	-1	-22	-5.9	0.1
10		164	0	-19	-5.1	0.0
20		164	0	-28	-7.5	0.0
30		164	0	-42	-11.3	0.0
40		164	0	-39	-10.5	0.0
50		164	0	-48	-12.9	0.0
60		164	0	-48	-12.9	0.0
70		164	0	-61	-16.4	0.0
80		164	0	-70	-18.9	0.0
90		164	0	-77	-20.7	0.0
100		164	0	-75	-20.2	0.0
110		164	0	-77	-20.7	0.0
120		164	0	-90	-24.3	0.0
130		164	0	-95	-25.6	0.0
140		164	0	-89	-24.0	0.0
150		164	0	-92	-24.8	0.0
160		164	0	-103	-27.8	0.0
170		164	0	-113	-30.5	0.0
180		164	0	-112	-30.2	0.0
190		164	0	-120	-32.4	0.0
200		164	0	-140	-37.8	0.0
210		164	0	-145	-39.1	0.0
220		164	0	-160	-43.2	0.0
230		164	0	-154	-41.5	0.0
240		164	0	-138	-37.2	0.0
250		164	0	-123	-33.2	0.0
260		164	0	-124	-33.4	0.0
270		164	0	-155	-41.8	0.0
280		164	0	-169	-45.6	0.0
290		164	0	-173	-46.7	0.0
300		164	0	-187	-50.4	0.0
310		164	0	-188	-50.7	0.0
320		164	0	-195	-52.6	0.0
330		164	0	-202	-54.5	0.9
340		164	0	-199	-53.7	0.0
350		164	0	-218	-58.8	0.0
360		164	0	-220	-59.4	0.0
370		164	0	-235	-63.4	0.0
380		164	0	-246	-66.4	0.0
390		164	0	-248	-66.9	0.0
400		164	0	-241	-65.0	0.0
410		164	0	-230	-62.1	0.0
420		164	0	-217	-58.5	0.0
430		164	0	-196	-52.9	0.0
440		164	0	-186	-50.2	0.0
450		164	0	-183	-49.4	0.0
460		164	0	-181	-48.8	0.0