Muscle guarding during Kt-1000 testing as measured by electromyography

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MUSCLE GUARDING DURING KT-1000 TESTING
AS MEASURED BY ELECTROMYOGRAPHY

by

Tedd J. Girouard
Bachelor of Science
University of Nevada, Las Vegas
1995

A thesis submitted in partial fulfillment
of the requirements for the degree of

Masters of Science

in

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Muscle Guarding During KT-1000 Testing As Measured
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ABSTRACT

Muscle Guarding During KT-1000 Testing as Measured by Electromyography

by

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Twelve anterior cruciate deficient ACL-D participants volunteered for the study to compare muscular activity before and during two different protocols of KT-1000 knee arthrometer testing (KT-1000). Muscular activity was measured by the amount of electrical activity in specific muscles which cross the injured knee by an electromyogram (EMG). The muscles being tested are the Semimembranosus (SM), The Rectus femoris (RF) the Biceps femoris (BF) the lateral head of the Gastrocnemius (LG) and the medial head of the Gastrocnemius. The resting test (Zero Newtons) involved placing the KT-1000 on a participant but not applying any force. The 89 Newton (89N) test involved pulling the KT-1000 anteriorly with 89 Newtons of pressure. The Manual Maximal (MM) test involves the examiner applying a maximal anterior force to the posterior calf. KT-1000 testing was performed at 206 - 306 of knee flexion. EMG recordings were taken 100 times per second. An analysis of variance was performed for each muscle providing information as to which muscles if any are active during testing. Initial results indicate there is evidence that there is no increase in muscular activity during KT-1000 testing on subjects that are ACL-D.
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CHAPTER 1

INTRODUCTION

A constant goal of researchers in the sports medicine community is to increase the objectivity of orthopedic joint testing. Joint testing is commonplace in orthopedics, as it is used several times from diagnosis to resolution of an injury. Medical practitioners frequently use joint testing to assist in determining injured joint structures. Based on the final diagnosis, a decision can be made regarding treatment and subsequent rehabilitation. As the injury heals, joint testing may be used to determine efficacy or needed changes in the rate of the treatment regimen (Ballantyne et al., 1995). According to Daniel and Stone (1990) measuring joint motion consists of: (a) Positioning the limb in a specified manner: (b) applying a displacing force; and (c) measuring the resultant joint motion. Joint testing can be accomplished by many methods including: manual joint testing, instrumented joint testing, radiography, magnetic resonance imaging, and surgery, either arthroscopic, or open. Due to the inherent costs of other investigations, clinical testing is usually limited to manual or instrumented testing.

Traditionally, tests for joint stability have been limited to manual testing. However, manual testing requires the practitioner to maneuver a patient's joint with a myriad of forces in a variety of directions. When these tests are compared bilaterally.
experienced examiners can produce subjective determinations regarding joint stability (Magee, 1992). Authors have reported on the subjectivity of manually diagnosing knee ligament injuries in the clinical setting (Clancy, 1983). Until the 1980s this was the most common type of testing available to practitioners. However, many of these manual tests provided practitioners with marginal rates of reliability. Katz and Fingeroth (1986) reported that the three most common manual tests of the knee were 22.2% - 88.8% reliable.

In order to add objectivity to joint testing, instrumented joint measuring devices were developed. They are collectively known as arthrometers. An arthrometer is a device that measures joint displacement in a specific direction. Joint displacement is the amount of movement a joint has in a particular direction with the application of a force. This type of displacement is commonly known as joint laxity. The disruption of a ligament may result in an increase in joint laxity, which can be quantified using an arthrometer type instrument for testing (Daniel, Malcom, et al., 1985).

Arthrometers are currently commercially available for testing the integrity of the knee joint. Currently there are several different knee arthrometers on the market. These instruments as a whole have been reported to produce the correct diagnosis of cruciate ligament integrity 70% to 75% of the time (Anderson & Lipscomb, 1989). The KT-1000 (MEDmetrics Corporation) was chosen for this study because it has been the most widely accepted and documented arthrometer in previous studies.

In the human knee joint a commonly disrupted ligament is the anterior cruciate (ACL). The ACL is responsible for resisting an average of 86% of anterior tibial displacement (Butler, Noyes, & Grood, 1980). With its disruption, there is an increase
in anterior excursion of the tibia in relation to the femur (Daniel, Stone, Sachs, & Malcom, 1985). It is this movement for which the KT-1000 is designed to measure.

Statement of the Problem

With increased numbers of practitioners utilizing the KT-1000, research has been produced regarding its validity (Anderson & Lipscomb, 1989; Daniel, Malcom, et al., 1985; Daniel, Stone, et al., 1985), reliability (Ballantyne, 1995; Daniel, Stone et al., 1985; Robnett, 1995), and other inherent testing variables. These variables include examiner experience (Ballantyne et al., 1995), experimenter gender (Ballantyne et al.), leg positioning (Fiebert, 1994; Torzilli, 1981; Torzilli, 1984), race of patient (Hang, Fung, & Hang, 1993), KT-1000 positioning (Kowalk, Wojtys, Disher, & Loubert, 1993), direction of force applied (Kowalk et al., 1993), degree of knee flexion (Emery, 1989; Markolf, 1978; McLaughlin & Perrin, 1991), and neuromuscular activity (Markolf, 1978; Markolf, 1981; Wojtys, 1994).

The manufacturers of the KT-1000 emphasize that the musculature around the knee must be relaxed in order to obtain reliable results. However, even though the manufacturers provide instructions for relaxing the muscles surrounding the knee joint, there are some researchers that believe patients may not sufficiently relax the associated musculature during testing (Anderson, 1989; Anderson, 1992; Daniel, Malcom, et al., 1985; Daniel, Stone, et al., 1985; Daniel, 1988; Edixhoven, 1987; Shino, 1987). A number of researchers have cited muscular activity as the most significant variable in the limiting motion in joints (Daniel, 1988; Edixhoven, 1987; Markolf, 1978; Shino, 1987). Markolf, Graff-Radford, and Amstutz (1978) reported that when patients were
asked to tense their knee musculature during anterior posterior knee testing laxity measurements decreased by 20% - 50%.

Human's naturally possess afferent protective mechanisms that sense unsafe translation of joints which provide subsequent muscle contraction to protect joints when stressed. These mechanisms are found throughout the musculo-skelital system. However, until 1986 it was unclear which anatomic structures are responsible for initiating this afferent information in ligaments (Zimny, Schutte, & Dabezies, 1986). In 1986 Zimny et al. identified two distinct mechanoreceptors, in the human ACL, these are Ruffini end organs and Pacinian corpuscles. Zimney et al. (1986) further reported that in the ACL these mechanoreceptors are in highest concentration at the ends of the ligament. Regardless of where the afferent input originates, a timely protective response is initiated and is the key to knee joint protection in the injury situation (Wojtys & Huston, 1994). Wojtys and Huston (1994) reported significantly different EMG levels between ACL deficient (ACL-D) and ACL intact individuals when the tibia was translated anteriorly while their feet were planted. These differences were reported in recruitment patterns, and time of response. However, it remains unclear if translation by the KT-1000 will cause similar increases in neuromuscular activity during KT-1000 testing with ACL-D participants.

**Purpose of the Study**

The present study is designed to determine the effect of KT-1000 testing on neuromuscular activity in unilateral ACL-D participants. Electromyographic measurements will be recorded for five muscles: (a) Biceps femoris; (b)
Semimembranosus; (c) Rectus femoris; (d) Lateral head of the Gastrocnemius; and (e) Medial head of the Gastrocnemius in three situations: (a) before testing; (b) during normal KT-1000 testing; and (c) during maximal KT-1000 testing. If substantial differences are noted in the three testing situations this may provide evidence that participants are muscle guarding during KT-1000 testing. However, if no substantial differences are observed this would provide evidence to the contrary and another factor may be causing the KT-1000 to produce some degree of false negative test results.

**Statement of Hypothesis**

*Null* - There is no difference in neuromuscular activity around the knee joint of ACL-D participants; before testing, during normal KT-1000 testing, and during maximal KT-1000 testing in five selected muscles.

*Alternate* - There is a difference in neuromuscular activity around the knee joint of ACL-D participants; before testing, during normal KT-1000 testing, and during maximal KT-1000 testing in five selected muscles.

**Limitations of the Study**

1. Because the force applied during the 89N testing may be greater than 89N the actual force applied is an approximation. As a result there may be variation in displacements, which in turn, may affect EMG levels.

2. Because the force applied during maximal testing is dependent on the experimenter’s strength the actual force applied is an approximation. As a result there may be variation in displacements, which in turn, may affect the EMG levels.
3. Due to the fact that EMG recordings can only be compared with recordings of the same muscle, magnitude differences between the different muscles may not be compared.

4. Since this investigation was conducted on people ranging in age from 18 - 40, the results are limited to this particular age range.

5. The results of this study are limited to the five muscles being tested. Applications of the results are limited to the lateral head of the Medial and Lateral Gastrocnemius, the Biceps femoris, the Rectus femoris and the Semimembranosus.

6. The results of this study are limited to testing displacement in only an anterior direction.

7. The results of this study are limited to the use of a single arthrometer, the KT-1000.
CHAPTER 2

REVIEW OF LITERATURE

Anatomy

Bony Anatomy

The knee joint is a modified ginglymus joint, ginglymus meaning a synovial joint having only forward and backward motion, modified meaning that during flexion there is an aspect of medial and lateral rotation about the knee. The joint is formed by the articulation of three bones: the femur, the tibia, and the patella. The normal knee joint range of motion for flexion is approximately 135°, for extension is approximately 15°, for medial rotation is between 20° and 30°, and for lateral rotation is between 30° and 40° (Magee, 1992).

The femur, the longest bone in the body articulates proximally with the acetabulum of the pelvis forming the hip. The distal femur articulates, via the medial and lateral condyles, with the tibia and the patella to form the knee joint. When the knee is extended the condyles articulate, with the tibia via the medial and lateral menisci (fibrocartilage discs). In this position the anterior portion of the femoral condyles articulate with the posterior patella. When the knee is flexed, the posterior surface of the condyles articulate with the tibia via the menisci. In this position the distal portion of the condyles articulate with the posterior patella.
The tibia, classified as a long bone, articulates distally with the talus to form the ankle joint and proximally with the femur to form the knee joint. On the proximal tibia there are two surfaces, the medial and lateral tibial condyles. Sitting on these condyles are the medial and lateral menisci. The ACL originates between these two condyles on the intercondylar eminence. The tibial tuberosity, which is a measuring point for the KT-1000 is also located on the tibia. It is found on the proximal anterior surface of the tibia and is the insertion point of the patellar tendon.

The patella, commonly known as the kneecap, is classified as a sesamoid bone. A sesamoid bone is an oval nodule of bone or fibrocartilage in a tendon playing over a bony surface (Thomas, 1993). The patella is held in place superiorly by the quadriceps tendon, and inferiorly by the patellar ligament. The patella’s only articulation is posteriorly with the femoral condyles. In knee flexion the spine of the posterior patella fits between the two condyles of the femur known as the trochlear groove.

**Muscular Anatomy**

The muscles that cross the knee joint include: the muscles of the quadriceps consisting of the Rectus femoris, the Vastus lateralis, the Vastus medialis, and the Vastus intermedius; the muscles of the hamstrings, consisting of the Biceps femoris, the Semitendinosus, and the Semimembranosus; the Gastrocnemius (medial and lateral heads), the Sartorius, the Plantaris, the Tensor fasciae latae via Iliotibial band, the Popliteus, and the Gracilis.

The five muscles being investigated in this study are the Rectus femoris, the Biceps femoris, the Semimembranosus, the lateral head of the Gastrocnemius, and the
medial head of the Gastrocnemius. These muscles were selected for examination because of the relatively superficial position of each muscle and their larger size relative to adjacent muscles, both of which allow for the good conduction of EMG signals. One muscle, the Semimembranosus was chosen specifically because it directly resists anterior tibial translation (Magee, 1992). The other muscles being examined do not fall into this category but have substantial involvement in and around the knee joint itself.

The Rectus femoris is a muscle of the quadriceps group. It has a dual origin on the anterior inferior spine of the ilium and the lip of the acetabulum. It shares a common insertion with all of the quadriceps on the tibial tuberosity via the patella, which is suspended in its tendon. Neuromuscular innervation is provided by the femoral nerve. This muscle extends the knee and flexes the hip (Van De Graff, 1988).

The Biceps femoris is a muscle of the hamstring group. It is comprised of two heads with the long head originating on the ischial tuberosity of the ischium and the short head originating on the linea aspera of the femur. It has a dual insertion on the head of the fibula and the lateral condyle of the tibia. Neuromuscular innervation is provided by the tibial nerve. This muscle flexes the knee, extends the hip, and laterally rotates the thigh at the hip (Van De Graff, 1988).

The Gastrocnemius consists of two heads. For this study we will isolate the lateral and medial heads. The lateral head originates on the lateral condyle of the femur. The medial head originates on the medial condyle of the femur. Both heads inserts on the posterior surface of the calcaneus via the Achilles tendon. Neuromuscular innervation is provided by the tibial nerve. This muscle flexes the knee and plantar flexes the foot (Van De Graff, 1988).
The Semimembranosus is a muscle on the posterior side thigh. It originates on the ischial tuberosity and inserts on the medial condyle of the tibia. Neuromuscular innervation is provided by the tibial nerve. This muscle has the actions of extending and medially rotating the hip and flexing the knee (Van De Graff, 1988).

The Anterior Cruciate Ligament

The ACL is an intracapsular, extrasynovial ligament. This means that this ligament is located inside the joint capsule, but unlike other intracapsular structures it is not bathed in synovial fluid. The ACL, like other ligaments is non-contractile, meaning that it does not shorten upon innervation, therefore, it is said to be a passive restraint for excessive movements. The anterior cruciate ligament lies most anteriorly on the intercondylar notch, originating in the depression anterior to the medial tibial eminence (Gould, 1990). It extends superiorly, posteriorly, and laterally, twisting itself as it extends from the tibia to the femur (Magee, 1992). From this position the ACL inserts on the lateral femoral condyle in a semicircular pattern, thus providing its convoluted appearance (Gould, 1990).

The ACL is the primary ligament responsible for resisting anterior displacement of the tibia on the femur (Magee, 1992). During testing the ACL provides upwards of 86% of the total restraining force in anterior displacement at 30 degrees of knee flexion (Butler et al., 1980). The ACL also plays several secondary roles. It is responsible for preventing extensive external rotation of the tibia while the knee is in flexion and prevents hyperextension of the knee (Magee).
The ACL is comprised of two separate anatomical structures, the posterior band and the anteromedial band. These two structures prevent anterior displacement in differing ranges of knee flexion. The posterior band resists anterior displacement when the knee is close to full extension (Furman, Marshall, & Grigis, 1976). Whereas, the anteromedial band resists anterior displacement when the knee joint is in partial flexion (Furman et al., 1976). It has been reported that lesions to the anteromedial band alone cannot be distinguished from a rupture of the ACL as a whole (Furman, et al.). Therefore, if the anteromedial band is ruptured it appears under non-invasive testing that the entire ACL is ruptured. In turn if this structure is not injured and only the posterior band is involved a negative test for ACL disruption will be expected.

Non-contractile Structures

There are several other non-contractile structures acting upon the knee, aside from the ACL that prevent anterior displacement from occurring. These structures are the joint capsule, the collateral ligaments, and the Iliotibial band. However, the resistance provided by these structures is somewhat tertiary (Butler et al., 1980). This is because deficits in these structures only increase anterior displacement in cases where the anterior cruciate ligament is already disrupted (Furman et al., 1976).

The joint capsule surrounding the knee provides added strength to the knee in all planes and directions as it encompasses the knee as a whole. The mid-medial capsule provides 22.3%, and the mid lateral capsule provides 20.8% of anterior resistance when the ACL is ruptured (Butler et al., 1980). There are particular knee positions in which the joint capsule does provide increased support against anterior displacement. However.
in this study participant testing will be performed in a consistent position this should not have an effect on the outcome. Previous research in this area has provided evidence that an injury to the joint capsule should have no effect on anterior displacement if the ACL is intact (Furman et al., 1976).

The medial and lateral collateral ligaments account for 16.3% and 12.4% respectively of secondary resistance to anterior displacement (Butler et al., 1980). These percentages indicate the amount of resistance the structures provide when the ACL is ruptured.

The Iliotibial band provides 24.8% of the resistance when the ACL is not intact (Butler et al., 1980). The Iliotibial band is the structure with the greatest secondary resistance to anterior displacement. This band is the tendon of the Tensor fasciae latae muscle. However, this should not effect the KT-1000 test because this muscle has no involvement on movement of the knee.

**History of Arthrometers**

As previously mentioned, the protocol for measurement of joint motion consists of limb positioning, application of a force, and a measurement of the subsequent displacement of the tibia via the force. The first instrumented measures of this kind were accomplished by positioning the limb, applying a force, and comparing photographs of the knee in a stressed and in an unstressed position (Sprague & Asprey, 1965). A similar technique to this involved the comparison of radiographs, the first of which was developed by Kennedy and Fowler (1971). They used a clinical stress machine to stress the joint and made in vivo laxity measures via serial radiographs.
Insall (1981) improved on Kennedy and Fowler's (1971) work by modifying the stress machine to correct for tibial rotation. These techniques gained popularity but due to fear of excess radiation and inherent cost they were never used on a large scale.

Markolf et al. (1978) developed an instrumented system that documented anterior-posterior displacement of the tibia on the femur. This system essentially required patients to sit in a modified dental chair while forces were applied to the tibia. This study initially was performed on normal subjects, then on cadavers, and was subsequently repeated by Torzilli, Greenberg, Hood, Pavlov, and Insall in 1984 on patients with a documented absence of their ACL. This system, like others that followed (Daniel, Stone, et al., 1985; Edixhoven, 1987; Shino, 1987) measured this displacement by tracking the tibial tubercle and its position relative to the patella. The first of these systems were extremely bulky and were considered stationary.

Portable testing devices were later developed. The first two were developed by Stryker Corporation, Kalamazoo, Michigan (Stryker Knee Ligament Tester) and the MEDmetric Corporation, San Diego, California (KT-1000). These two machines are limited to testing only in the anterior - posterior plane.

The next evolution was the development of devices that could measure motion in a variety of directions. These devices are the Genucom Knee Analysis System, FARO Medical Technologies Inc., Montreal, Canada and the Knee Signature System (KSS), Acufex Microsurgical Inc., Norwood, Massachusetts.

Each of these measurement devices perform the necessary tasks that an arthrometer must to make it useful for the evaluation of knee ligament integrity. The joint is positioned, a force is applied via one of the machines, and a measurement of tibial
displacement caused by that force is being observed and subsequently recorded. There are slight variations for each device but essentially they measure the anterior excursion of the tibia in relation to the femur.

In order to be of use, the recorded displacement measures are compared to previously measured displacements as when a patient is going through a rehabilitation protocol, or a pre-operative / post-operative comparison. These measures may be compared to excursion through greater forces, or to the displacement of the opposite knee, which is used to determine the patient’s normal laxity for a particular force.

**KT-1000**

**How the KT-1000 Works**

The KT-1000 works by quantifying the magnitude of anterior-posterior translation of the tibia on the femur. The KT-1000 is positioned on the anterior aspect of the tibia where the distal portion of the apparatus rests on the distal tibia as shown in Figure 1. There are two sensor pads, which are positioned on the tibial tuberosity and the anterior aspect of the patella as shown in Figure 2. The Patella Sensor Pad is pushed in a downward direction by the examiner’s hand to position the patella in the intercondylar space. The Tibia Sensor Pad sits on the tibial tuberosity and moves with the tibia as it is distracted.
Figure 1. KT-1000 Placement and components (Adapted from Daniel & Stone, 1990).

Figure 2. KT-1000 Sensor Pad locations (Adapted from Daniel & Stone, 1990).
The KT-1000 is actually measuring the difference between the starting position and the ending or testing position of the two aforementioned measuring pads. When the examiner applies the force in an anterior direction, the integrity of the ACL is being examined. If the force is applied in a posterior direction, the integrity the PCL is being examined.

The literature supports the notion that the ACL is the main stabilizer of the knee joint with respect to preventing anterior displacement (Butler et al., 1980). Therefore, disruption of the ACL should allow enhanced anterior displacement of the tibia on the femur. Cadaver studies have provided documented reports of greater knee joint laxity resulting from ACL disruptions (Daniel, Malcom et al., 1985; Fukubayashi, 1982; Markolf, 1976). Similar results were reported with in vivo ACL-D studies (Daniel, Malcom, et al., 1985; Daniel, Stone, et al., 1985; Kennedy & Fowler, 1971; Malcom, 1985; Markolf, 1984).

Placement of the KT-1000

The correct placement of the KT-1000 is essential for obtaining accurate and reliable results (Kowalk et al., 1993). Kowalk et al. reported that for in vivo testing, the effect of malposition of the KT-1000 along the joint line changes the displacement significantly, which in turn, may change results. Kowalk et al. also noted that if the device was incorrectly positioned 1 cm proximal to the joint line a larger translation measurement was yielded than when positioned at the joint line (5.8 mm versus 5.4 mm). If the device is positioned 1 cm distal, smaller measurements are obtained (4.4 mm vs. 5.4 mm). These results could be explained because the KT-1000 measures displacement...
of the tibial tuberosity with respect to patella. When the device is moved further away from the joint axis, the lever is lengthened and forces directed to the joint should increase. According to Highgenboten, Jackson, Jansson, and Meske (1992), when anterior forces are increased knee joint displacements expand. Conversely, if the lever is shortened by placing the KT-1000 closer to the joint axis (posterior to the joint line) forces acting on the joint will decrease and resultant joint displacements may decline (Kowalk et al.). Therefore, care must be taken to correctly align the KT-1000 on the joint line so proper measurement of knee displacement may occur.

**Body Positioning**

Body positioning plays an important role in KT-1000 testing. Control and correct positioning of variables such as the trunk and knee positions are vital to record accurate and consistent KT-1000 results. These variables have a direct correlation with the amount of anterior displacement achieved with the KT-1000.

Trunk positioning has been under some debate as of late. The original recommendations by the MEDmetric Corporation instruct the patient to lie supine (Malcom, Daniel, Stone, & Sachs. 1985). Therefore, the trunk flexion angle will increase as the knee flexion angle increases, as shown in Figure 3. Adler, Hoekman, and Beach (1995) compared Lachman testing on injured knees with two different trunk positions and concluded that positioning the hip in full extension and slight abduction results in increased knee laxity measures. In the same study Alder et al. (1995) compared uninjured knees and found only a 0.5 mm difference in positioning leading the authors to suggest that trunk positioning has no effect on ACL testing. This conclusion is supported
by Webright, Perrin, and Gansneder (1997) whom compared three different trunk positions (15, 45, and 90 hip flexion) and reported that changing the trunk in these positions also had no significant affect on knee laxity measured by the KT-1000.

![Diagram of knee and hip joint angles]

**Figure 3.** The relationship of the knee flexion angle and the hip flexion angle.

The knee is positioned according to flexion and rotation. The manufacturer recommends that the thigh be placed on the support provided. This would position the knee in 25 degrees of flexion (+/- 5) degrees depending on leg length. Markolf, Kochan, and Amstutz (1984) reported that the greatest amount of anterior posterior movement occurs when the knee is positioned in 20 degrees of flexion. Others researchers have reported high correlation coefficients for the KT-1000 when the knee is between the standard 20 and 30 degrees of flexion (Daniel, Malcom et al., 1985; Hanten & Pace,
When comparing the KT-1000 at 20, 45 and 90 degrees of flexion, McLaughlin and Perrin (1991), reported that testing at 90 degrees of flexion provided less anterior displacement than the 20 and the 45-degree trials.

Past research (Torg, Conrad, & Kalen, 1976) indicates that if the knee is excessively flexed, as is done during the anterior drawer test, there may be additional anatomical structures other than the ACL limiting anterior displacement. In this position the posterior horn of the medial meniscus becomes buttressed against the posterior most margin of the medial femoral condyle, thus preventing further anterior tibial displacement (Torg et al., 1976).

For rotation of the knee, the manufacturers suggest placing the patient's heels in the provided foot support device, the knee will subsequently be positioned in external rotation between 15 and 25 degrees of symmetrical rotation. Markolf et al. (1984) reported that the greatest amount of anterior laxity was observed when the knee was prepositioned at approximately 15 degrees of external rotation. Fiebert, Gresley, Hoffman, and Kunkel, (1994) reported that when comparing internal, external, and neutral starting position there was significantly less anterior displacement when the starting position was in internal rotation, as compared to external or neutral rotation. Fiebert et al. (1994) also reported that there was no significant difference between the neutral position and 30 degrees of external rotation. When the tibia translates anteriorly there is some aspect of this movement that is attributed to internal rotation (Neuschwander, Drez, Paine, & Young, 1990). The anterior motion of the tibia on the femur is known to be a coupled motion of both anterior translation and internal rotation of the tibia (Neuschwander et al., 1990). Therefore, if testing is started in internal rotation it should be expected that there
would be a limited amount of anterior displacement measured. If the tibia is not allowed to medially (internally) rotate freely, anterior tibial displacement is decreased by 30% at all flexion angles (Fukubayashi, Torzilli, Sherman, & Warren, 1982).

When testing with the knee arthrometer reliability is a factor as testers are often comparing pre and post measurements. To obtain a high degree of reliability correct and consistent placement of the KT-1000 on the participant is important. The position of the participant prior to testing is also important, it is considered that the best position for the knee during testing is 20 - 30 degrees flexion and 15 - 30 degrees of external rotation. These positions, as well as the placement of the arthrometer must remain constant through all tests to give reproducible results as these variables may dramatically influence results.

The Role of the KT-1000

It is known that the KT - 1000 is primarily utilized to test the integrity of two ligaments, they are the Anterior Cruciate Ligament and the Posterior Cruciate Ligament (PCL). For this task, the KT-1000 is utilized by a myriad of health professionals. This group ranges from orthopedic surgeons to athletic trainers to physical therapists. It is utilized to determine the distance the proximal tibia can be displaced on the distal femur in the sagittal plane. In turn, this provides the clinician with information as to the integrity of the ligament being tested. It has been documented that anterior displacement of the tibia on the femur has a positive correlation with an ACL disruption (Bach, 1990; Fukubayashi, 1982; Sherman, 1987).
Instrumented measurement systems that have the ability to objectively determine anterior-posterior displacement by measuring the tibial tuberosity in relation to the patella, have gained recent acceptance in the orthopedic community (Bach, 1990; Daniel, Stone, et al., 1985; Edixhoven, 1987; Malcom, 1985; Markolf, 1976; Steiner, 1990; Wroble, 1990). This past research has primarily focused on using arthrometers such as the KT-1000 to document ACL integrity at different stages of the injury and repair process.

Currently the KT-1000 has two primary roles in the orthopedic community. The first of which is to diagnosis ligament rupture. The second is to determine how a ligament repair and subsequent rehabilitation protocol is performing with respect to ligament laxity. For any diagnostic piece of equipment to be utilized by the medical community the results must be accurate and repeatable. Past in vivo instrumented testing has proven a the KT-1000 to be a reliable, reproducible and objective way to measure laxity in knee joints (Daniel, Stone, 1985; Hanten & Pace, 1987; Highgenboten, 1992; Markolf, 1978; Torzilli, 1981; Torzilli, 1991).

Historically, this instrument and other knee arthrometers have played a role in helping the medical community to better understand the integrity and function of the knee ligaments (Butler, 1985; Kennedy & Fowler, 1971; Markolf, 1976; Markolf, 1978; Markolf, 1981). It has also played a continuing role in procedures used to manage the injuries to ligaments about the knee, primarily those injuries to the ACL.
Types of KT-1000 Testing

There are three generally accepted testing protocols used with the KT-1000 they are the manual maximal test (MMT), the 89N test, and the quadriceps active test.

Manual Maximal Test

The manual maximal test is a test with the KT-1000 that closely resembles the Lachman Maneuver. It is actually the Lachman Maneuver with the KT-1000 on the patient. The advantage of this test over the Lachman Maneuver is that it quantifies the displacement because the practitioner can read the amount of displacement off of the KT-1000's dial. It has been documented that the manual maximal test is the best diagnostic test of an ACL disruption (Bach, 1990; Neuschwander, 1990; Rangger, 1993). This higher level of diagnostic accuracy may be attributed to a higher applied load in a more proximal position (Bach, 1990; Daniel & Stone, 1990).

89 Newton Test.

The 89 Newton test was the test first recommended by the manufacturers of the KT-1000. This test involves positioning the KT-1000 on the patient’s knee, and applying an 89 Newton stress in the anterior direction. The 89N test is the middle test of three tests weights signaled by the KT-1000.

Quadriceps Active Test

The quadriceps active test is a test where by the KT-1000 is placed on the patient’s knee. The patient is then instructed to contract their quadriceps muscle group. The resultant force on the knee joint causes an anterior displacement of the tibia on the
femur (Daniel, Malcom et al., 1985; Daniel & Stone, 1990). This test is also included in the original instructions by the manufacturer.

**Data Interpretation**

When the KT-1000 was developed it was used to document anterior and posterior displacements of the knee. The displacements in the anterior direction correlate with ACL disruption (Bach, 1990; Fukubayashi, 1982; Rangger, 1990; Sherman, 1987). However, due to the inordinate amount of variety in the normal population (Daniel, Malcom et al., 1985), differing ways to disseminate the raw values were determined. There are basically two accepted ways of interpreting the KT-1000 data. One is a compliance indicator, whereby a number is derived by subtracting the displacement values recorded from an 89N test from a 67N test. The other, more effective technique is the injured - non-injured comparison, whereby the resultant displacement of the uninjured knee is subtracted by the displacement of the uninjured knee, and a value is given. A differing displacement value of greater than the 3 mm is considered positive for having a disrupted ACL (Daniel, Stone et al., 1985).

**KT-1000 and Other Testing Methods**

**Arthrometers**

The KT-1000 performs as well if not better than all arthrometers currently on the market for determining knee laxity, in normal patients and ACL-D patients. (Anderson, 1992; Anderson & Lipscomb, 1989; Highgenboten, 1992; Neuschwander, 1990; Sherman, 1987; Steiner, 1990) In 1992, Anderson, Snyder, Federspiel, and Lipscomb reported that of five Arthrometers tested the KT-1000 showed no statistical difference in
bilateral comparisons of normal patients. Whereas, when they tested ACL-D subjects they determined that the KT-1000 provided the greatest right knee - left knee differences. The differences reported between the KT-1000 and the Stryker Knee Laxity Tester (Stryker, Kalamazoo, MI) were not statistically significant. A previous study by Anderson & Lipscomb in 1989 concluded that laxity measurements in ACL-D patients were almost identical when comparing the KT-1000 and the Stryker arthrometer. However, they did feel that the KT-1000 was advantageous because with it they could identify the quadriceps neutral position, which allowed them to more accurately determine PCL instability. They also concluded than when comparing arthrometers the Genucom Knee Analysis was more versatile than the KT-1000, but recorded significantly lower laxity measures.

When comparing four arthrometers on normal subjects Steiner et al. (1990) reported that the KT-1000, the Stryker, the Genucom and the Acufex produced similar measurements for anterior displacement at 89N and 133N. In this report Steiner et al. concluded that for normal patients there was no statistically significant difference when comparing normal right and left knees. However, when they tested the difference between normal and ACL-D knees, anterior displacement were significantly higher for all devices. In this test the Acufex, KT-1000, and Stryker arthrometers produced the most reproducible measurements. Whereas, testing with the Genucom device resulted in decreased reproducibility of results.

In 1990, Neuschwander et al. compared the KT-1000 and the Knee Signature System (KSS) (Orthopedic Systems, Inc., Hayward Calif.) They reported that for ACL-D patients there was no statistical difference while performing similar tests. The two
similar tests performed were the 89N test and the manual maximal test, with the manual maximal test producing the most comparable results. In their discussion, Neuschwander et al. (1990) mentioned that for ACL testing their personal preference is the KT-1000 because it is relatively quick to use (only a couple of minutes) compared to the KSS which takes about 20 minutes to complete a bilateral test.

Sherman, Markolf, and Ferkel (1987) compared a new portable model of the University of California at Los Angeles (UCLA) instrumented clinical knee testing apparatus and the KT-1000. Their data suggests that the two devices were very similar with both being 90% - 95% accurate in correctly classifying an ACL-D knee outside the normal range.

Highgenboten, Jackson, and Meske (1989) compared the KT-1000 with the Stryker system and the Genucom measuring devices. They reported each of these measuring devices could provide reproducible quantitative measurements of knee laxity; however they concluded that due to the differences in device sensitivities and functional design, numerical results from one device cannot be generalized to another. This conclusion makes comparison of actually joint displacement between different arthrometers a relatively moot point. This study suggested that the focus should to be shifted to other variables such as comparisons of sensitivity and success rates.

**Arthroscopy**

There are two basic types of inspection for ligament damage, one is direct, where the ligament is actually viewed by the practitioner, the other is indirect where either some type of joint image is obtained or the joint is externally stressed to reveal joint laxity.
The only direct inspection of an ACL injury is by arthroscopic surgery (DeHaven, 1980; Noyes et al., 1983). However, this is an expensive procedure and as with any surgery there are the inherent risks associated with being anesthetized and the risk of subsequent infection. However, in cases of acute hemarthrosis, which is blood within the joint, when clinical exams are negative, arthroscopy may be an acceptable procedure for diagnosing injuries (DeHaven, 1990). In 1980, DeHaven reported that of 113 athletes whom had sustained acute trauma to the knee with immediate disability and early onset of hemarthrosis but did not have demonstrable clinical laxity that surgical significance was found arthroscopically in 90% of cases and ACL tears were present in 79% of those cases.

**Magnetic Resonance Imaging**

Magnetic Resonance Imaging (MRI) has proven itself to be a successful noninvasive method to evaluate knee ligament pathology (Reicher et al., 1985). However, MRI does have its obstacles. These are cost, lack of evidence that MRI imaging is superior to KT-1000 testing (Liu, Osti, Henry & Bucchi, 1995), and the fact that this procedure only documents ligament injury (Liu et al., 1995), but does not measure the amount of tibial translations as other instrumented testing devices (Bach, 1990; Daniel, Malcom, et al., 1985; Daniel, Stone, et al., 1985; Daniel & Stone, 1990; Edixhoven, 1987; Hanten and Pace, 1987; Malcom, 1985; Markolf, 1976; Markolf, 1978; Markolf, 1984; Neuschwander, 1990; Sherman, 1987; Shino, 1987; Steiner, 1990).

In 1995 Liu et al. compared MRI and KT-1000 testing. Their results indicate that in the diagnosis of later proven ACL disruptions that the KT-1000 MMT protocol
performed significantly better than the MRI. They also indicate that the MRI was more expensive and in many cases was more uncomfortable. The MRI performance was significantly less accurate than the 15 lb., and the 20 lb. KT-1000 test.

**Radiographic Stress Testing**

Other health professionals utilize radiographic stress testing. While this is a good diagnostic tool, it provides a limited amount of radiation to the patient for each image, it is relatively expensive, and there needs to be attention to detail when positioning the patient. Stäubli and Jakob (1991) compared the KT-1000 and stress radiography and found the two measuring techniques performed statistically similar. Radiography also presents the risks of excessive radiation with the multiple number of examinations performed from injury to resolution.

**Clinical Tests**

Practitioners also utilize several orthopedic stress tests known as “clinical tests.” These tests are common place in sports medicine ligament testing. These include, but are not limited to, the Anterior Drawer Test, the Lachman Maneuver, and the Pivot Shift Test (Katz & Fingeroth, 1986). The Lachman Maneuver is the most sensitive of the manual tests (Katz & Fingeroth, 1986; Torg, 1976). These tests provide relatively good measures of laxity with the exception of the Anterior Drawer, which has been demonstrated to perform with rather weak sensitivity (Katz & Fingeroth). The major limitation of such tests is that they are subjective measures. In the past, research has provided varying results as to the accuracy of clinical examinations to correctly diagnose
ACL disruptions, these results vary from 7% (Noyes, Mooar, Matthews, & Butler, 1983), to 87% (Kannus & Järvinen, 1987).

Researchers have reported that there are several reasons why KT-1000 testing is superior to the Lachman Maneuver. First, the Lachman Maneuver is a subjective test, whereas, the KT-1000 is objective. The difference in anterior translation between injured and uninjured knees has been reported between 3 mm and 6 mm (Bach, 1990; Daniel, Malcom, et al., 1985; Daniel, Stone, et al., 1985; Highgenboten, 1992; Steiner, 1990). According to Daniel, Malcom, et al. (1985) and the manufactures of the KT-1000 a + 3 mm difference between knees is indicative of an ACL injury. Therefore, if the difference is just 2 mm the test would be negative. When performing a Lachman test only the most experienced practitioner would be able perform a bilateral test and distinguish between a 2 mm and a 3 mm test. Whereas, with the KT-1000 one should be able to perform these measures with a high degree of reliability. (Daniel, Stone, et al., 1985). In comparing the Lachman Maneuver and the KT-1000 Liu et al. (1995) reported that the Lachman Maneuver and a KT-1000 manual maximal test where statistically similar in the diagnosis of acute complete tears of the anterior cruciate ligament. Therefore, because the KT-1000 is an objective measure it may have an objectivity advantage over the Lachman Maneuver.

**KT-1000 Reliability**

**Cadaver Studies**

The MEDmetric Corporation, manufactures and distributors of the KT-1000 report data from Daniel, Malcom, et al. (1985) with regards to accuracy and reproducibility. They report a relatively low mean error of .39 +/- .25 mm when tested
against a displacement transducer, and 0.16 +/- 0.44 mm ($r = 0.979$) when compared with Steinmann pins. A Steinmann pin is a sturdy pin placed in the distal end of a long bone so that a weight may be attached to apply traction.

**Normal Knees**

When comparing the displacement values of knees from uninjured patients with the uninjured knee of either chronic or acutely injured patients Rangger, Daniel, Stone, and Kaufman (1993) reported that there was no significant difference between these groups when tested at 89N. during a manual maximal displacement force, or during the quadriceps contraction leg lift test. Therefore, when testing an uninjured knee the type of KT-1000 test should not have any affect on the accuracy of displacement values.

Daniel, Stone, et al. (1985) reported that when testing 120 normal knees at 20 lb., displacements ranged from 3 mm to 13.5 mm. In comparing the means from a previous report by Daniel, Malcom et al. (1985) the average normal knee displacement changed from 5.6 mm to 7.2 mm. They attributed this change to advances in relaxation techniques, and testing procedures.

In further evaluation of uninjured knees researchers reported laxity measurements of 4.6 mm and 7.1 mm respectively (Highgenboten, 1992; Wroble. 1990). However, because these results and those that proceeded it varied so much no successful benchmark was set. Therefore, it is difficult to ascertain what is normal for one specific knee. Thus providing evidence for the performance of bilateral comparisons.
Comparison of Injured vs. Non-Injured Knees

Researchers have reported fairly good results when using the KT-1000. Several of these researches made comparisons of injured and uninjured knees (Daniel, Stone, et al., 1985; Sherman, 1987; Stäubli & Jakob, 1991; Steiner, 1990) producing laxity levels ranging from 13 mm (Daniel, Stone, et al., 1985), to 7.8 mm (Steiner et al., 1990) for injured knees and laxity values ranging from 6.2 mm (Stäubli & Jakob, 1991) to 3.9 mm (Steiner et al.) for uninjured knees.

Daniel, Stone, et al. (1985) determined that a difference between injured to uninjured knees of greater then 3 mm at 89 N is indicative of a positive test for ACL disruption. This has become the benchmark of further research and testing. Daniel, Stone et al. produced this standard by comparing right leg - left leg differences in normal and ACL disrupted patients. For normal patients the right knee - left knee difference mean was 0.8 mm with either a 89N test or a manual maximal test. They also reported that 88% of normal subjects had a right knee - left knee displacement difference of less then 2 mm. Whereas, when testing participants with unilateral ACL damage they reported that in tests without anesthesia at 89N, 33 out of 53 patients with complete ruptures had a right knee - left knee difference of ≥ 3 mm. For the Manual maximal test 30 out of 33 participants fell into this criteria. This led these researchers to conclude that the manual maximal testing technique was superior to the 89N technique and that the aforementioned positive test bench mark of a 3 mm right knee - left knee difference be set. Wroble, Van Ginkel, Grood, Noyes, and Shaffer (1990) supported the bilateral
comparisons, by reporting increased reproducibility in bilateral testing when compared to absolute displacement measures.

Additional research has supported the conclusions of Daniel, Stone, et al. (1985) benchmarks. Rangger et al. (1993) reported that for the normal population 98% produced right / left differences \( \leq 3 \text{ mm} \) for the 89N test and 97% for the manual maximal test. They also reported that in the evaluation of unilateral ACL deficient patients the manual maximal test produced the most favorable results. The KT-1000 has also proven reliable in testing of both acute and chronically injured ACLs. In this same study the manual maximal test of the injured knee compared to normal knee displacement was 3 mm or more in 99% of patients with chronic ACL disruptions and in 95% of patients with acute ACL disruptions.

Other researchers have reported that in comparing injured and uninjured knees that the KT-1000 was not a reliable measuring device. Forster, Warren-Smith, and Tew (1989) reported when testing at 89 N 64% of injured were not distinguishable the from the normal knee when using the KT-1000. Another study (Graham, Johnson, Dent, & Fairclough. 1991), reported that the KT-1000 was correct in detecting an injured knee from a non-injured in 10 out of 21 patients, and found reverse findings in 8 out of 21 patients. This equated to findings that the uninjured knee was the injured knee 38% of the time.

**Inter-tester Reliability**

The KT-1000 reportedly has good inter-tester reliability. (Fiebert. 1994; Highgenboten. 1989; Malcom, 1985). This provides evidence that in a clinical setting
the KT-1000 is relatively consistent when the same clinician renders the test.

Unfortunately, all of the literature does not support inter-tester reliability. The exception to this is Forster et al. (1989) as they reported relatively low levels of inter-tester reliability.

**Intra-tester Reliability**

Investigations of intra-tester reliability have produced discrepancies in the literature with some researchers reporting low levels of reliability ($r=0.64$) (Fiebert et al., 1994) and others reporting relatively high levels of reliability ($r=0.85, r=0.83$) (Hanten & Pace, 1987). The literature is inconsistent when intra-test testing of the same knees on different days. Some researchers have reported the KT-1000 produces significantly contrary results (Forster, 1989; Wroble, 1990). Whereas, other researchers have reported no statistical differences in different day studies (Fukubayashi et al., 1982).

Recent studies (Forster, 1989; Graham, 1991) have provided evidence that the KT-1000 is unreliable and that reproducible results may be unachievable. In 1989, Forster et al. findings led them to question the reliability of the arthrometer because of great variability among all measurements, and that these inconsistencies where produced regardless of tester experience. They reported substantial inter and intra-examiner variation. They made these conclusions after observing the absolute values of single knees and the subsequent differences in displacement between pairs of knees. In 1991 Graham et al. also concluded that the KT-1000 was totally inaccurate, and suggested its preclusion as an objective measure of anterior posterior laxity of the knee.
Reports in the literature as to the reliability and reproducibility of the KT-1000 are not consistent. However, the common thread in most of the literature is that lack of muscle relaxation is a limitation to the reliability and reproducibility of the KT-1000 (Daniel, Malcom et al., 1985; Edixhoven, 1987; Markolf, 1978; Shino, 1987). Therefore, in order to improve the repeatability and reliability it is important to understand the role of muscles in joint stability.

Muscle Guarding Theory

Muscular Role in Joint Stability

There is evidence to support the fact that muscles crossing a joint play a role in stabilization of that joint (Butler, 1980; Magee, 1992). This is true for the knee as it is for all other diarthrotic joints. There is also evidence to support the notion that instrumented displacement measures may be affected by the contraction of these muscles (Markolf, 1981; Shoemaker & Markolf, 1985). However, these muscles should not play a large role as stabilizers when they are relaxed. This is because when a muscle is relaxed it is not taught and it is this taughtness that provides support to the joint.

Numerous muscles surround the knee joint, as is true of most other joints. These muscles, via tendonous attachments are combined with the bony arrangement of the knee making it capable of four movements in two directional planes. These movements are flexion, extension, medial rotation, and lateral rotation.

The knee joint has a multitude of anatomic structures, which are interrelated. The ACL like other structures in the knee does have sensory receptors such as Ruffini and Golgi Mechanoreceptors (Schultz, 1984; Zimney, 1986). Receptors such as these might be expected to proved reflex sensory information regarding ligament loading or
deformation that may request the muscle to assist in maintaining joint stability as conditions arise when the ligaments are overloaded (Solomonow et al., 1987). Mangus, Holcomb, Golestanti, and Tandy (1998) reported similar results when they recorded EMG levels during KT-1000 testing on uninjured knees. As they reported increased EMG levels on normal subjects when tested with the KT-1000. However, it remains unclear if there is a similar reflex that will cause this type of muscle activity when KT-1000 testing knees without ACLs. This change may be expected because as time from injury increases there is a subsequent change in muscle timing and recruitment order in response to an anterior tibial translation when the knee is examined in a weight bearing situation (Wojtys & Huston, 1994). Other researchers Shino, Inoue, Horibe, Nakamura, and Ono (1987) provided clinical evidence opposite to this, that is, when translating the tibia anteriorly on normal participants they recorded reproducible results. This was hypothesized to be due to the participant’s confidence as to the integrity of their joints. However, when participants with ACL-D were tested, reproducibility declined because of a subsequent apprehension. The Solomonow et al. (1987) and Wojtys & Huston (1994) studies show a link between the position of the knee and the subsequent muscle activation. Whereas, the Shino et al. (1987) study suggests that guarding may have a more conscious element to it based on lack of confidence in one’s knee.

Muscle Guarding Evidence

Muscle guarding has been suspected to confound orthopedic evaluation for some time. However, at this time, there is no direct evidence that muscular activity affects arthrometric testing. In a related study, lack of patient relaxation during an anterior
drawer test of the knee resulted in reduction of anterior translation up to 50% (Markolf et al., 1978). Therefore, it is reasonable to conclude that this may be a limiting factor in successfully determining the integrity of the ACL via arthrometric means.

There is indirect evidence to support the fact that muscle guarding maybe taking place during KT-1000 testing. In studies that tested both anesthetized, and conscious ACL deficient subjects. At 89 N accuracy levels increased from 62% to 84% and during maximal manual testing from 92% to 100%. in non-anesthetized and anesthetized subjects (Daniel, Stone et al., 1985). In 1993 Rangger et al. reported that when testing acute cases with the 89N displacement test the side to side differences for participants with a unilateral ACL disruptions was less then 3mm in 66% of conscious patients. However, when the patients were anesthetized 72% of participants produced at least a 3 mm bilateral difference. Whereas, for chronic cases 85% of conscious patients had an injured minus normal displacement of greater then 3 mm. compared to 87% under anesthesia. When using the manual maximal technique Rangger et al. reported that mean side to side differences increased from non-anesthetized to anesthetized from 6.1 mm. to 7.3 mm and 8.6 to 9.4 mm for acute and chronic patients respectively.

Due to the past history of laxity being compromised by either being conscious or the patient being requested to tense the knee musculature most of the research in this area indicates that muscle relaxation is an important factor in obtaining reliable results. However, until now no research has been performed to actually measure how much muscle activity is present during KT-1000 testing on ACL-D subjects.
Summary

From its inception the developers of arthrometers have tried to provide the orthopedic community with relatively harm free, cost effective way to objectively determine the integrity of the ACL. Many researchers report that the KT-1000 has accomplished these goals with acceptable results (Anderson & Lipscomb, 1989; Daniel, Malcom et al., 1985; Daniel, Stone et al., 1985; Daniel & Stone, 1990; Malcom, 1985; Sherman, 1987). Whereas, others have reported results that the KT-1000 is not producing acceptable results (Forster, 1989; Graham, 1991). Some of these problems have been previously addressed, as a majority of the investigators who have studied KT-1000 testing report secondarily that the musculature surrounding the knee may be inadvertently hampering examination of the ACL and providing for less than acceptable results.

While reports of its accuracy in reporting ACL injuries have been subject to some debate, clinicians are still relying on this apparatus for diagnostic purposes. In an attempt to increase the level of reliability, accuracy, and reproducibility of the KT-1000 the manufactures have suggested enhancing the patient’s muscular relaxation by a variety of methods. However, this is difficult because no previous research has been performed to determine if neuromuscular activity actually is affecting the reliability of the KT-1000 on ACL-D patients or some other source of interference. It has also not been determined which muscle(s) are active during the testing. This investigation should help to provide answers to these questions, and in turn help to fill this void in the literature.
CHAPTER 3

METHODOLOGY

This study compared the amount of muscular activity during KT-1000 testing protocols in several muscles. These muscles observed included the Semimembranosus, the Rectus femoris, the Biceps femoris, the lateral head of the Gastrocnemius, and the medial head of the Gastrocnemius. Muscular activity was measured before testing, and during two different KT-1000 testing protocols. All measurements used for studying the hypothesis were taken on participants with knees that were ACL deficient.

Participants

Eight male and two female participants with known ACL deficient pathology aged 20 to 57 (\(\bar{x} = 30.83, SD = 9.97\)), volunteered for this study. The participants ranged in height from 162.6 to 191.77 cm (\(\bar{x} = 179.28, SD = 9.32\)) and in weight from 58.9 to 124.3 kg. (\(\bar{x} = 84.90, SD = 21.15\)). The participants were determined ACL-D by previous physician testing or by arthroscopic exploration. Participants had no prior KT-1000 testing, therefore, for the most part, they were unfamiliar with this apparatus. Other knee pathologies should not have affected the result of this study, with the exception of the presence of hemarthrosis. Any participants that demonstrated significant hemarthrosis, as
assessed by an inability to reach full knee flexion on the injured knee, were eliminated as a participant.

The University’s Institutional Review Board approved the study (Appendix B). An informed consent form (Appendix B) was read and signed by each participant. Further information was then given to and read by the examiner to each participant. (Appendix B) Following reading and acknowledgment of understanding each participant was encouraged to ask questions pertaining to the ensuing test.

**Participant Preparation**

Efficient conduction of electrical impulses from muscle through the skin to EMG electrodes requires the presence of the least amount of resistance between the skin and the electrodes. To ensure this each participant was shaven with electric hair clippers. Following this, the remaining hair was removed with a disposable shaving blade. The area over the muscles being tested was then rubbed clean with a débridment pad. This ensured that any dead skin, which is a poor conductor of electricity was removed. The final stage of cleaning involved using a cotton ball saturated with alcohol. This cotton ball was then rubbed on and around the area being tested. This removed any dirt or other foreign particles from the testing area.

Two electrodes were placed over the motor points of each muscle. The motor points are the position on each muscle that demonstrates the most electrical activity during muscular contraction. These electrodes were placed in an overlapping fashion in order to have very little distance between them, which further reduces resistance. In order to determine correct electrode placement and site preparation, resistance between
the electrodes had to be less than 10,000 ohm as measured by an Ohmmeter. If it was
not, preparation of that particular site was repeated. Site preparation was repeated once
for each of the five muscles being tested. An additional electrode was placed on the head
of the fibula to serve as an electrical ground.

The electrode placement follow the parameters set by Delagi and Perotto (1980)
as shown in table 1.

Table 1

Electrode Placements

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biceps Femoris</td>
<td>On the midpoint of a line between the fibular head and the ischial tuberosity.</td>
</tr>
<tr>
<td>Gastrocnemius: Lateral</td>
<td>One handbreadth below the popliteal crease on the lateral mass of the calf.</td>
</tr>
<tr>
<td>Gastrocnemius: Medial</td>
<td>One handbreadth below the popliteal crease on the medial mass of the calf</td>
</tr>
<tr>
<td>Rectus femoris</td>
<td>On the anterior aspect of the thigh, midway between the superior border of the patella and the anterior superior iliac spine (ASIS)</td>
</tr>
<tr>
<td>Semimembranosus</td>
<td>Lateral to the Semitendinosus tendon in the apex of the “V” between the Semitendinosus tendon and the biceps femoris.</td>
</tr>
</tbody>
</table>

The electrodes were connected via electrical leads to an amplifier. The electrical impulses then traveled along leads to the EMG. From the EMG the signal was transformed from analog to digital and was relayed to a personal computer. Whereby.
with the usage of Myosoft™ software the EMG signal was recorded and analysis was performed.

Testing

The testing was performed at three different KT-1000 loads: 0 N, 89 N, and a manual maximal test (MMT). EMG signals were recorded during each testing phase for approximately 5 seconds, with the first 3 seconds being utilized for analysis and subsequent comparisons.

Participant Positioning

The placement of the KT-1000 was in accordance with the manufactures instructions. The participants were placed in a supine position, with their arms at their sides, on an examining table. The participants thighs were then placed on the thigh support platform at a level proximal to the popliteal space. The thigh support platform was then adjusted until a knee flexion angle was reached such that the patella was sitting in the trochlea of the femur. The participants heels were then positioned in the foot support platform. Correct placement of the participant’s heels required the foot platform be under both feet of the participant at a level distal to the lateral malleolus. The participant’s heels were rested comfortably on the foot pad bordering the lateral upright ends. This position insures that the participant’s knees were not in lateral or medial rotation. The angles of the knee were then measured with a goniometer, and adjustments were made to ensure the knee flexion angle was between 20 and 30 degrees. A thigh strap was then placed around both thighs to further limit external rotation of the knee.
Arthrometer Positioning

The arthrometer was placed on the anterior aspect of the participants injured lower leg. The arthrometer was then aligned so that the joint-line arrow was in line with the joint line of the knee. The distal Velcro™ strap was then fastened around the distal aspect of the lower leg. The instrument was then rotated until the pressure of the patella pad stabilized the patella. If the patella remained unstable the thigh support was readjusted to ensure the patella’s correct position in the trochlea. The proximal Velcro strap was then fastened around the proximal lower leg. Once again a confirmation of the alignment of the joint line arrow and the joint line was performed and necessary adjustments were made. Adjustments for patella height were then made. This was accomplished by loosening the patella sensor adjustment knob. Once this knob was loosened and freely movable the tibia and patella rails were aligned parallel with one another. Once this was achieved the patella sensor adjustment knob was completely tightened.

Testing Techniques

The patella and instrument were stabilized prior to testing by positioning one hand on the patella reference pad. A posterior pressure, which was maintained throughout the testing, was then applied to the patella reference pad until there was no further movement on the displacement dial. The force handle, held with the other hand, was then pulled and pushed two to three times, until the displacement dial returned to the same position each time. The dial was then rotated to align the needle with zero. This zeroing gave the tester a testing reference position, whereby, all tests on that patient were measured.
The Zero Newton (Resting Load)

During the 0 N or resting phase the participant had the KT-1000 properly positioned on their injured knee. The EMG recorded the muscular activity while no force was being applied by the KT-1000.

The 89 Newton Test

After the Zero N test was completed and EMG recordings were established the examiner applied 89N of force via the force handle in an anterior direction. As the force was increased audible tones were emitted from the KT-1000 once the third tone was sounded the force was at least 89 N. This force caused the participant’s tibia to be displaced anteriorly from the femur. Once an 89N force was applied another 4 sec. EMG recording was taken. The force was then removed and the participant was instructed to relax.

The Maximal Manual Test

The maximal manual test is set up similar to the 89N test, however the force was applied by positioning the tester’s hand behind the posterior surface of the lower leg. This was followed by pulling the lower leg anteriorly to a manually maximal level. This movement once again provides an anterior displacement of the tibia on the femur. Once the maximal level was reached the a third 3 second EMG recording was taken. The force was then removed and the patient was instructed to relax while the KT-1000 was removed.
Statistical Design

All volunteers were ACL deficient, this made the testing group somewhat homogeneous. Each participant went through the same testing sequence, as this is the sequence suggested by the manufacture. The testing method used during the recording of EMG signals were the three levels of the independent variable. These variables were zero N, 89 N, and Manual Maximal KT-1000 testing. The dependent variable was the amount of electrical activity recorded at each muscle during the various tests. Analysis of the dependent variables for each muscle at each of the testing phases involved four one way repeated measures ANOVA's. This statistical scheme was designed to determine if there was statistically significant difference between the zero N, the 89N and the MMT for each muscle being observed. An alpha level of 0.01 was selected as the level of significance. All statistics were analyzed by the Microsoft ® Excel 5.0 software package on a Power Macintosh ® personal computer.
CHAPTER 4

RESULTS

Muscular activity was analyzed for each of the five muscles being tested via one way repeated measures ANOVAs. Recordings were analyzed to determine if there were differing amounts of muscular activity in any of the three testing times: Rest, 89 Newton testing (89N), and Manual Maximal Testing (MMT). All tests had the same number of trials, and were performed with the same parameters.

Ten participants completed the three testing situations. Two of the participants were bilaterally ACL-D and both of their knees were used as separate trials. Therefore, twelve ACL-D knees were tested.

An alpha level of 0.01 was used in all analyses. The Bonferroni correction was used because as more tests are conducted the chances of making a Type 1 error increase. Therefore, the alpha level must be reduced to reflect those chances.

After testing, no significant differences in electrical activity were revealed between the any of the trials in any of the five muscle groups: Rectus femoris ($F_{2,33}=0.1322, p = 0.8766$), Biceps femoris ($F_{2,33}=0.0080, p = 0.9920$), Lateral Gastrocnemius ($F_{2,33}=0.2696, p = 0.7653$), Semimembranosus ($F_{2,33}=0.0403, p = 0.9605$), and Medial Gastrocnemius ($F_{2,33}=0.4038, p = 0.6711$).
The average amount of electrical activity for the various muscles varied from 7.142 uV in the Rectus femoris during rest to 14.458 uV in the Lateral Gastrocnemius during 89 N testing as shown in Table 2.

Table 2

Average muscular electrical activity

<table>
<thead>
<tr>
<th>Test</th>
<th>Rectus Femoris</th>
<th>Biceps Femoris</th>
<th>Lateral Gastrocnemius</th>
<th>Semimembranosus</th>
<th>Medial Gastrocnemius</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rest</td>
<td>7.142</td>
<td>10.808</td>
<td>12.475</td>
<td>9.692</td>
<td>7.883</td>
</tr>
<tr>
<td>89 N</td>
<td>8.025</td>
<td>10.667</td>
<td>14.458</td>
<td>10.433</td>
<td>10.027</td>
</tr>
<tr>
<td>MMT</td>
<td>7.792</td>
<td>11.133</td>
<td>12.667</td>
<td>10.292</td>
<td>8.517</td>
</tr>
</tbody>
</table>

Note. Values in uV

Summary

This study demonstrated that there was no difference in muscular activity between rest and during two KT-1000 testing protocols on ACL-D participants. There was also no statistical difference in muscular contraction levels between the 89N and MMT KT-1000 testing. Therefore, in this study, the results support the hypothesis, that the null hypothesis will not be rejected.
CHAPTER 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

The purpose of this study was to compare the amount of muscular activity in five selected leg muscles before (rest), and during two KT-1000 testing protocols. The protocols tested were the 89 Newton (89N) and the Manual Maximal Test (MMT). Muscular activity was measured via a tethered Noraxon™ electromyographical recorder with surface electrodes.

Ten participants volunteered for this study, which provided twelve ACL-D knees. All participants completed all phases of the study. The participants were tested on all three trials in one session. The protocols consisted of 3 second EMG recordings of each trial. The rest trial consisted of having the KT-1000 on the testing leg as data was collected with no force applied. The 89N trial consisted of the examiner placing 89N of anterior force on the ACL-D knee via the KT-1000. The MMT trial consisted of the examiner manually placing a maximal amount of anterior force on the ACL-D knee via the KT-1000.

The trial variables of Rest, 89N, and MMT were treated statistically by repeated measures ANOVAs. The data collected from the five muscles was analyzed in a
muscle specific manner. Therefore, five separate ANOVAs were performed, one for each muscle.

The results of this study suggest that muscle guarding is not occurring during the two common types of KT-1000 testing in ACL-D knees. These results provided evidence that contradicts the theories of other researchers in this regard. (Daniel, 1988; Edixhoven, 1987; Markolf, 1978; Shino, 1987). Previous research suggests that muscle guarding may be occurring during KT-1000 testing, it is this variable that these researchers have attributed to a number of false negative KT-1000 tests. (Daniel, 1988; Edixhoven, 1987; Markolf, 1978; Shino, 1987). Indirect evidence of muscle guarding provided by conscious vs. unconscious studies is also contradicted. (Daniel, Stone et al., 1985; Rangger, 1993) This is contradicted because the primacy of these studies is that when the patients where anesthetized they would have limited neuromuscular activity, therefore the tests were more reliable. Data from the present study indicates muscle guarding is not occurring during testing of ACL-D participants. If this is true another explanation must be provided to explain why unconscious test results are different from conscious participant testing. Other researchers also reported high degrees of false negative tests with the KT-1000 (Forster, 1989; Graham, 1991). The notion that muscle activity surrounding the knee joint may cause false negative tests has some validity, as Markolf et al. (1978) noted when they had participants tense their musculature during ligamentous testing. However, when they tested people they instructed them to contract the muscles crossing the knee joint, which is the opposite of the KT-1000 testing protocol.
During all trials of this study, there was muscular activity present. However, for any EMG testing there will be a baseline of measurable activity. During this study, efforts were made to reduce the baseline activity as much as possible. To ensure accurate data collection good electrode site preparation, and verbal requests for the participants relax their musculature were completed. Unfortunately, it is unknown if the measured baseline muscular activity might be enough to elicit a false negative test. Therefore, the evidence of this study only provided evidence that there is not a difference in muscular activity during the three test conditions. This assumption is one that is used with some frequency in the EMG testing community.

This study also provided results that are contrary to those of Mangus et al. (1998). In that study, which was performed with similar parameters, muscle guarding was reported in participants with no ACL damage. The results of the Mangus et al. and the present study provide indirect evidence which support the anatomical findings of Schulz, Miller, Kerr, and Micheli (1984) and Zimney et al. (1986) who reported the presence mechanoreceptors in the undamaged ACL. The results of these two studies (Schulz, 1984; Zimney, 1986), provided indirect evidence that these mechanoreceptors act as protective structures when the ACL is intact. The results of the present study indicate that when the ACL is disrupted the feedback loop of these mechanoreceptors is also disrupted, thus providing for less muscular protection against anterior tibial translation in the KT-1000 testing situation.

If the aforementioned feedback loop is disrupted it might be assumed that other receptors in the knee would cause protective contractions in the surrounding musculature. This study provided evidence to the contrary, because if any other muscular protective
mechanism in the five tested muscles was elicited it would have also been recorded by
the EMG during testing. However, it must be noted that this test was performed in a very
controlled environment, one could assume that several other factors would become
present in a more dynamic setting. Unfortunately in these settings it is very difficult to
isolate and test single groups of mechanoreceptors.

The findings of this research project are extremely relevant to the sports medicine
community. This is due to the information obtained with regard to the receptors in the
ACL. In the past, some patients choose not to replace their ACL due to several factors:
These could have been: fear of surgery, not wanting to do go through a long and painful
rehabilitation, or perhaps they thought they would not need the ligamentous structure to
prevent anterior displacement of the tibia on the femur during their daily activity.
However, the findings of this study may lead ACL-D individuals to have their torn ACL
repaired, because not only is the structure effected, but the protection of the
mechanoreceptor-muscular interaction is also expired. This two-fold effect may provide
an additional incentive to replace the ACL.

**Conclusions**

Within the limitations of this study, the following conclusions can be made.

1. There is no significant difference in muscular activity between rest and KT-
1000 testing at 89N in the ACL-D knee.

2. There is no significant difference in muscular activity between rest and KT-
1000 testing at a manual maximal level in the ACL-D knee.
3. There is no significant difference in muscular activity between KT-1000 testing at 89N and KT-1000 testing a manual maximal level in the ACL-D knee.

Recommendations

Recommendations of an Applied Nature

For all recommendations similar parameters should be used to ensure reliable and comparable results.

1. Since the evidence does not indicate that ACL-D participants muscle guard during application of KT-1000 testing, practitioners that are testing knees to determine the integrity of the ACL should not be concerned with muscular guarding and the false negative tests as a result of that guarding. If the ACL is disrupted muscle activity is minimal and joint laxity measurements should not be confounded by unwanted muscle activity. If the ACL is not disrupted they may have muscle guarding, however, this should be of limited concern because they should have a negative test result in that event.

Recommendations for Future Research

The following are recommendations for future studies:

1. Parameters set up with a more sensitive EMG, perhaps using intramuscular electrodes.

2. Performed on participants that were less than 6 months post injury, even though hemarthrosis might limit the movement of the KT-1000. Electrical patterns in the muscles can still be recorded and may be different prior to 6 months post injury.

3. A double blind study could be performed before participants with injured knees having no information in regards to which structures, if any, are injured. During
those testing times, anxiety might effect muscular activity and apprehension may have a neurological effect on the surrounding musculature. Once the testing was complete the injured participants would have arthroscopic surgery to determine if the ACL was in fact disrupted. If so, the data for those participants could be evaluated by similar measures to the present study.
ANOVA
(Abbbr.) Analysis of variance. A statistical technique for defining and segregating the causes of variability affecting a set of observations. Use of this technique provides a basis for analyzing the effects of various treatments or variables on the subjects or patients being investigated. In an experimental design in which several samples or groups are drawn from the same population, estimates of population variance between samples should differ from each other only by chance. ANOVA provides a method for testing hypothesis that several random and independent samples are from a common normal population (Thomas, 1993).

Acute
Referring to a health effect, brief; not chronic; sometimes loosely used to mean severe. (Dirckx, 1997).

Afferent
Inflowing; conducting toward a center, denoting certain arteries, veins, lymphatics, and nerves. Opposite of efferent (Dirckx, 1997).

Anterior cruciate ligament
the ligament that extends from the anterior intercondylar area of the tibia to the posterior part of the medial surface of the lateral condyle of the femur (Dirckx, 1997).

Anterior Drawer Test
With the knee flexed to a right angle, there is increased anterior glide of the tibia in anterior cruciate ligament rupture (Thomas, 1993).

Arthroscopy
Endoscopic examination of the interior of a joint (Dirckx, 1997).

Chronic
Referring to a health-related state, lasting a long time (Dirckx, 1997).

Contractile
Able to contract or shorten (Dirckx, 1997).

Diarthrosis
An articulation in which opposing bones move freely (Thomas, 1993).

Displacement
Removal from the normal or usual position or place (Thomas, 1993).

Electromyography
The recording of electrical activity generated in muscle for diagnostic purposes: both surface and needle recording electrodes can be used, although characteristically the latter

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is employed, so that the procedure is also called needle electrode examination (Dirckx. 1997).

Goniometer
A calibrated device designed to measure the arc or range of motion of a joint (Dirckx. 1997).

in vivo
In the living body, referring to a process or reaction occurring therein (Dirckx. 1997).

Innervation
The supply of nerve fibers functionally connected with a part (Dirckx. 1997).

Intracapsular
Within a capsule, especially the capsule of a joint (Dirckx. 1997).

Insertion
The attachment of a muscle to the more movable part of the skeleton, as distinguished from origin (Dirckx. 1997).

Joint Capsule
The saclike structure that encloses the ends of bones in a diarthrodial joint. Consists of an outer fibrous layer and an inner synovial layer and contains synovial fluid (Thomas. 1993).

Lachman maneuver
A maneuver to detect deficiency of the anterior cruciate ligament; with the knee flexed 20 to 30 degrees, the tibia is displaced anteriorly relative to the femur; a soft endpoint or greater than 4 millimeters of displacement is positive (abnormal) (Dirckx. 1997).

Long bone
One of the elongated bones of the extremities, consisting of a tubular shaft (diaphysis) and two extremities (epiphyses) usually wider than the shaft; the shaft is composed of compact bone surrounding a central medullary cavity (Dirckx. 1997).

Magnetic Resonance Imaging (MRI)
A diagnostic radiological modality, using nuclear magnetic resonance technology, in which the magnetic nuclei (especially protons) of a patient are aligned in a strong, uniform magnetic field, absorb energy from tuned radiofrequency pulses, and emit radiofrequency signals as their excitation decays. These signals, which vary in intensity according to nuclear abundance and molecular chemical environment, are converted into sets of tomographic images by using field gradients in the magnetic field, which permits 3-dimensional localization of the point sources of the signals (Dirckx. 1997).
Mechanoreceptor
A receptor which responds to mechanical pressure or distortion (Dirckx. 1997).

Meniscus, pl. menisci
A crescent-shaped fibrocartilaginous structure of the knee, the acromio- and sternoclavicular and the temporomandibular joints (Dirckx. 1997).

 Neuromuscular
Referring to the relationship between nerve and muscle, in particular to the motor innervation of skeletal muscles and its pathology (e.g., neuromuscular disorders) (Dirckx. 1997).

Origin
The less movable of the two points of attachment of a muscle. that which is attached to the more fixed part of the skeleton (Dirckx. 1997).

Orthopedics
Branch of medical science that deals with prevention or correction of disorders involving locomotor structures of the body, esp. the skeleton, joints, muscles, fascia, and other supporting structures such as ligaments, and cartilage. (Thomas, 1993).

Pivot Shift Test
A maneuver to detect a deficiency of the anterior cruciate ligament of the knee: when the knee is extended, a sudden subluxation of the lateral tibial condyle upon the distal femur is positive (Dirckx, 1997).

Radiography
Examination of any part of the body for diagnostic purposes by means of x-rays with the record of the findings usually impressed upon a photographic film (Dirckx. 1997).

Sagittal
Resembling an arrow; in the line of an arrow shot from a bow, i.e., in an anteroposterior direction. referring to a sagittal plane or direction (Dirckx. 1997).

Translation
To change to another place or to convert into another form (Thomas. 1993).

Symmetrical
Equality or correspondence in form of parts distributed around a center or an axis, at the extremities or poles, or on the opposite sides of any body (Dirckx. 1997).

Synovia
A colorless viscid, lubricating fluid of joints, bursae and tendon sheaths secreted within synovial membranes. It contains mucin, albumin, fat, and mineral salts (Thomas, 1993).
APPENDIX B

INSTITUTIONAL REVIEW COMMITTEE APPROVAL

INFORMED CONSENT

ADDITIONAL PARTICIPANT INFORMATION
DATE: March 4, 1997

TO: Tedd Girouard (KIN)
    M/S: 3034

FROM: Dr. Lawrence Golding
    Chairman, Biomedical Committee of the Institutional Review Board

RE: Status of Human Subject Protocol entitled: "Muscle Activity During KT-1000 Testing"

OSP #504s0297-135

This memorandum is official notification that the protocol for the project referenced above has been approved by the Biomedical Committee of the Institutional Review Board. This approval is approved for a period of one year from the date of this notification and work on the project may proceed.

Should the use of human subjects described in this protocol continue beyond a year from the date of this notification, it will be necessary to request an extension.

If you have any questions or require any assistance, please give us a call at 395-1357.

cc: Dr. B. Mangus (KIN-3034)
    OSP File
INFORMED CONSENT

UNLV

SPORTS INJURY RESEARCH CENTER

My name is Tedd Girouard. I am a graduate student at UNLV taking a masters degree in Kinesiology. I am performing this research to fulfill my requirements for a master’s thesis.

As you were diagnosed by your physician as having an anterior cruciate ligament (ACL) deficient knee you are invited to participate in a research study involving the KT-1000 arthrometer. An electromyograph (EMG) will be used to measure muscle activity in your thigh and lower leg during laxity testing with the KT-1000 knee arthrometer. The KT-1000 is a device that is commonly used to measure the degree of laxity in the knee joint, thereby, providing indirect evidence as to the integrity of the cruciate ligaments of the knee. EMG electrodes will be placed on your leg in various positions in order to record muscle activity. You will be asked to attend one session at your convenience. The session will last approximately 30 minutes. During this session, muscle activity in your leg will be measured, while relaxed and during KT-1000 testing.

Any information obtained in connection with this study that can be identified with you will remain confidential.

Your decision whether or not to participate will not prejudice any further relationship with the University of Nevada, Las Vegas. If you have any questions, please call the experimenters, Tedd Girouard at 895-3993, 794-3007, or Dr. Mangus at 895-3158. You may also contact the UNLV Office of Sponsored Programs at 895-1375 for questions concerning the rights of research subjects.

Thank you for participating in this project.

I UNDERSTAND THAT I AM BEING ASKED TO PARTICIPATE IN A RESEARCH PROJECT. I HAVE HAD THE OPPORTUNITY TO ASK QUESTIONS. I UNDERSTAND I AM FREE TO WITHDRAW AT ANY TIME WITHOUT PREJUDICE.

Printed Name ___________________________ Signature ___________________________

Experimenter’s Initials __________________ Date __________________________
Participant Explanation Sheet

You have been asked to participate in this study because you have previously been diagnosed as being Anterior Cruciate Ligament - Deficient. In lay terms this means that due to a past trauma your Anterior Cruciate Ligament or ACL has been completely torn.

During this study you will be tested with a KT-1000 knee arthrometer. An arthrometer is a machine that allows a predetermined amount of force to be put on your lower leg. This force will cause a movement in your knee which the KT-1000 measures. It is this measurement that health care professionals use to determine the integrity of specific knee ligaments.

Secondly, during the KT-1000 testing we will be measuring the amount of muscular activity in 5 muscles surrounding your thigh and lower leg. The muscles will include one on the front of your thigh (The Rectus femoris), two on the back of your thigh (The Biceps femoris, and Semimembranosus), and two on the back of your calf (The medial and lateral Gastrocnemius). In order to measure muscular activity we use a machine called an electromyogram or EMG. Preparation for the EMG includes removing all the hair, dead skin, and other foreign materials from the skin. Two electrodes will be placed on each muscle and the machine will record the electrical activity in the specific muscles.

The testing should take about 20 minutes to complete. If you have any questions please feel free to ask at any time.

I have had these instructions read to me, and have had the chance to read them myself.

Date _______________________

Name _______________________

Signed _________________________  Witness __________________________
REFERENCES


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- Outstanding Student

Thesis Title: Muscle Guarding During KT-1000 Testing as Measured by Electromyography

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