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TRANSLATION OF THE TIBIA DURING ISOMETRIC CONTRACTION OF THE QUADRICEPS

by

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Thesis

submitted in partial fulfillment of the requirements for the degree of Master of Science in the

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ABSTRACT

TRANSLATION OF THE TIBIA DURING ISOMETRIC CONTRACTION OF THE QUADRICEPS

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August 1983

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The purpose of this study was to determine in normal knees, and in knees with anterior cruciate ligament absence, what effect maximal voluntary isometric contraction of the quadriceps has on translation of the tibia on the femur. Ten subjects with bilaterally normal knees, and nine subjects with one normal knee and the contralateral knee having an arthroscopic finding of absent anterior cruciate ligament were tested. Tibial translation was measured with a dial indicator at 15, 45 and 60 degrees of knee flexion. There was a measurable anterior translation of the tibia in all knees. An analysis of variance with post hoc testing of two weighted contrasts showed a significant increase from normal in anterior tibial translation in subjects with absence of the anterior cruciate ligament, $P < 0.05$. In subjects with normal knees, there was no significant difference in tibial translation between subject's right and left knees. Regard-

less of the status of the anterior cruciate ligament, there was no significant difference in translation between maximal voluntary isometric contractions of the quadriceps at 15, 45 or 60 degrees of knee flexion. It was concluded that in subjects with an absent anterior cruciate ligament, voluntary maximal isometric exercises of the quadriceps should be avoided through the range of 60 to 15 degrees of knee flexion. Another conclusion was that a valid comparison of anterior tibial translation during maximal voluntary isometric contraction of the quadriceps may be made between knees within the same subject. A third conclusion was that a difference of greater than 3.1 mm of anterior tibial translation between knees measured during maximal voluntary isometric contraction of the quadriceps may be a sign of anterior cruciate ligament deficiency. Suggestions for further research were proposed.

Chapter 1

INTRODUCTION

Rehabilitation of injuries to the anterior cruciate ligament has received increasing attention in the literature over the past decade (Marshall et al., 1977; Paulos et al., 1982; Giove et al., 1982; Johnson, 1982; Steadman, 1983). Among the primary goals of health practitioners involved in the management of knee rehabilitation following injury to the anterior cruciate ligament are to obtain maximal functional stability of the joint and to minimize potential degenerative processes.

Stability of any joint depends on several factors including joint geometry, joint compressive forces, passive restraints provided by capsule and ligaments, as well as dynamic restraints generated by the muscles acting on the joint (Brantigan and Voshell, 1941; Noyes et al., 1980b). An alteration in any one of these factors will result in change to the other factors and potential joint dysfunction, degeneration, and disability (Kaplan, 1962).

Through Instant Center Analysis it has been shown that anterior translation of the tibia on the femur occurs during normal knee extension (Frankal et al., 1971). Instant Center Analysis is a method of kinematic evaluation of a joint. Although kinematics is a study of relative motion, the

centers of motion are determined while the joint is in a passive state; that is, no significant voluntary muscle contractions are elicited from the subject during the analysis.

Stability of the normal and ligament deficient knee has been studied almost exclusively with externally applied forces. Investigators are in general agreement that the anterior cruciate ligament is a primary restraint to anterior tibial translation on the femur (Brantigan and Voshell, 1941; Kennedy et al., 1974; Girgis et al., 1975; Markolf et al., 1976; Piziali et al., 1980; Fukubayashi et al., 1982). Research has shown that with the absence of the anterior cruciate ligament, there is an increase from normal anterior translation of the tibia on the femur during passive manipulation of the knee joint (Fukubayashi et al., 1982; Hejgaard et al., 1982; Jacobsen, 1977; Markolf et al., 1978; McPhee and Fraser, 1981; Sylvin, 1975; Torzilli et al., 1981). Although this research has been carried out at various degrees of knee flexion, statistical analyses of any differences between angles has not been reported.

Many authors state that active contraction of the quadriceps femoris muscle produces a force causing anterior translation of the tibia on the femur (Johnson, 1982; Markolf et al., 1978; Malone et al., 1980; Johnson and Pope, 1976; Galway and MacIntosh, 1980; Steadman, 1983). With anterior cruciate ligament loss, some authors believe that

excessive tibial translation may occur during active quadriceps contraction (Johnson, 1982; Galway and MacIntosh, 1980; Paulos et al., 1980; Noyes et al., 1980a). Further, Johnson (1982) has advocated the use of a dual pad attachment to existing exercise equipment to help control anterior tibial translation during knee extension exercises. Other authors have suggested that emphasis on strengthening of the hamstring muscles may help decrease anterior tibial translation (Marshall et al., 1977; Fulkerson, 1981; Giove et al., 1983). No experimental evidence of tibial translation during active quadriceps contraction has been published.

There are several authors who argue that injury to the anterior cruciate ligament can cause significant long term knee instability and dysfunction (Fetto and Marshall, 1979; Kennedy et al., 1974; Marshall et al., 1975; Mencio and Bassett, 1982; McLeod and Blackburn, 1980a). Following injury to the anterior cruciate ligament, others have described a progressive process of soft tissue stretching with articular cartilage deterioration and eventual degenerative joint disease (Jacobsen, 1977; Marshall et al., 1975; Noyes et al., 1980a; Tamea and Henning, 1980; Noyes et al., 1983; Galway and MacIntosh, 1980; McDaniel and Dameron, 1980). If contraction of the quadriceps femoris muscle creates an excessive translation of the tibia on the femur in people with anterior cruciate ligament instability, the excessive motion may cause excessive stresses on the remain-

ing restraints to this motion. Thus, precipitate soft tissue stretching, instability, dysfunction and degenerative joint disease.

To provide quality rehabilitation following anterior cruciate ligament injury or surgical repair, it is necessary to know the effect muscle forces acting on the knee have on the movement of bones and potential changes in stress to the remaining restraining elements. The purpose of this investigation was to determine in normal knees, and in knees with an absent anterior cruciate ligament, what effect voluntary maximal isometric contraction of the quadriceps femoris muscle has on sagittal plane translation of the tibia on the femur.

The Definition of Terms

Normal Knee

For the purpose of this study, a normal knee is defined as a knee with no history of disease or trauma requiring medical attention or surgery.

Anterior Cruciate Ligament Absence

For the purpose of this study, anterior cruciate ligament absence is defined as the complete absence of the anterior cruciate ligament, as reported by arthroscopy.

Maximal Voluntary Isometric Contraction of the Quadriceps

For the purpose of this study, maximal voluntary isometric contraction of the quadriceps is defined as the greater of two attempts by the subject to push his knee straight while being restrained at a predetermined joint position. Effort was measured via a cable tensiometer in relative units.

Tibial Translation

For the purpose of this study, tibial translation is defined as a linear displacement of the tibia in the sagittal plane. Displacement was measured relative to the femur from an initial resting position considered to be zero. Measurements were obtained using a dial indicator. The indicator had a plunger that was displaced when movement occurred and the distance displaced was indicated on the dial by a revolving hand. Units of measure were 0.001 inch.

The Statement of the Problem

The First Problem

In subjects with normal knees bilaterally, is there a significant difference in translation of the tibia on the femur between knees in the presence of a maximal voluntary isometric contraction of the quadriceps femoris muscle?

The Second Problem

In the presence of anterior cruciate ligament absence, does a maximal voluntary isometric contraction of the quadriceps femoris muscle create an abnormal translation of the tibia relative to the femur?

Subproblems

The first three subproblems relate to the first problem.

The first subproblem. In the presence of a maximal voluntary isometric contraction of the quadriceps femoris muscle at 15, 45 or 60 degrees of knee flexion, is there a significant difference in translation of the tibia on the femur between bilaterally normal knees?

The second subproblem. In normal knees, is there a significant difference in translation of the tibia on the femur between maximal voluntary isometric contraction of the quadriceps femoris muscle at 15, 45 or 60 degrees of knee flexion?

The third subproblem. With normal knees, in the presence of a maximal voluntary isometric contraction of the quadriceps femoris muscle at 15, 45 or 60 degrees of knee flexion, is there a significant difference in tibial translation on the femur between right and left knees?

Subproblems four and five relate to the second problem.

The fourth subproblem. With anterior cruciate ligament absence of one knee and the contralateral knee normal, in the presence of a maximal voluntary isometric contraction of the quadriceps femoris muscle at 15, 45 or 60 degrees of knee flexion, is there a significant difference in tibial translation between knees?

The fifth subproblem. In knees with anterior cruciate ligament absence, is there a significant difference in translation of the tibia on the femur between maximal voluntary isometric contraction of the quadriceps femoris muscle at 15, 45 or 60 degrees of knee flexion?

The Hypotheses

The first four hypotheses are related to the first problem and subproblems one, two and three.

The First Hypothesis

In subjects with bilaterally normal knees, there is no statistically significant difference in translation of the tibia on the femur during maximal voluntary isometric contraction of the quadriceps femoris muscle between knees.

The Second Hypothesis

In normal knees, there is no statistically significant difference in translation of the tibia on the femur during maximal voluntary isometric contraction of the quadriceps femoris muscle at 15, 45 or 60 degrees of knee flexion.

The Third Hypothesis

In normal knees there is no statistically significant difference in tibial translation between a maximal voluntary isometric contraction of the quadriceps femoris muscle at 15, 45 or 60 degrees of knee flexion.

The Fourth Hypothesis

For subjects with normal knees, in the presence of a maximal voluntary isometric contraction of the quadriceps femoris muscle, there is no statistically significant difference in tibial translation between right and left knees.

Hypotheses five, six and seven relate to the second problem and subproblems four and five.

The Fifth Hypothesis

In the presence of a maximal voluntary isometric contraction of the quadriceps femoris muscle, there is no statistically significant difference in the translation of the tibia on the femur between normal knees and knees with anterior cruciate ligament absence.

The Sixth Hypothesis

For subjects with anterior cruciate ligament absence in one knee and their contralateral knee normal, in the presence of a maximal voluntary isometric contraction of the quadri-

ceps femoris muscle at 15, 45 or 60 degrees of knee flexion there is no statistically significant difference in tibial translation between knees.

The Seventh Hypothesis

In the presence of anterior cruciate ligament absence, there is no statistically significant difference in tibial translation between maximal voluntary isometric contraction of the quadriceps femoris at 15, 45 or 60 degrees of knee flexion.

The Assumptions

The assumption was made that the samples were representative of a normal population with no anterior cruciate ligament absence, and a population with one knee having anterior cruciate ligament absence and a contralateral normal knee.

The three angles chosen were assumed to be representative of points within a normal knee range of motion where maximal voluntary isometric contraction of the quadriceps might occur.

Fixation of the femur and the distal tibia was assumed to be adequate to allow motion only at the tibiofemoral joint.

During positioning of the knee, it was assumed that no anterior translation of the tibia on the femur was created.

The Limitations

The tibial translation measurements were limited to three angles of knee flexion: 15, 45 and 60 degrees. Discussion of this investigation is limited to these angles.

Maximal voluntary isometric contraction of the quadriceps femoris muscle was investigated. Caution must be employed when discussion deals with concentric or eccentric muscle contraction, rather than isometric contraction.

The motion measured was in the sagittal plane, and measured as movement of the tibia on the femur. During traditional exercise the tibia moves on the femur. However, during normal daily activities such as gait, the femur moves on a fixed tibia.

Normal subjects for the investigation were volunteers with an age range of 21 to 34 years drawn from a sample of convenience. Study subjects were also from a sample of convenience drawn from a private sports physical therapy practice with an age range of 17 to 39 years. Discussion of the study is limited to these populations.

The Organization of Remaining Chapters

There are four remaining chapters. Chapter 2 is a review of related literature. Chapter 3 contains the test method and test procedure for the investigation. The fourth chapter reports the results, a discussion of the results, conclusions, and recommendations for further research. Chapter 5 is an article in publishable form.

Chapter 2

REVIEW OF RELATED LITERATURE

Chapter two is a review of literature, organized in three sections. The first section is anatomy, including osseous, joint capsule, ligament, menisci and muscle anatomy. The second section is a review of research on the anterior cruciate ligament. The third section is a summary.

Anatomy of the Knee

The osseous components of the knee are the distal femur, proximal tibia, patella and the proximal fibula. The distal femur has a medial and lateral condyle. The shape of these condyles is important to the movement of the tibia on the femur, as well as the stability of the patella. When viewed in a lateral profile these condyles are cam shaped (Welsh, 1980), with the medial condyle's articular surface being longer and more curved than the lateral condyle. Between the condyles is the intercondylar notch. The femoral condyles articulate with the proximal tibia.

The reciprocating tibial surface provides a lateral plateau which is slightly convex and a medial plateau which is slightly biconcave (McLeod *et al.*, 1977). Between the tibial plateaus is an intercondylar eminence. The intercondylar eminence may provide some bony stabilization under

weight bearing conditions as it articulates in the intercondylar notch (McLeod and Hunter, 1980b). The shape of the femorotibial joint provides no strong stability in the anterior-posterior direction, and the femur will slide either anteriorly or posteriorly off the tibia if no other structure is encounted (McLeod and Hunter, 1980b; Brantigan and Voshell, 1941).

The patella articulates with the femur via seven distinct facets, or contact areas. It combines with the dynamic forces of the quadriceps femoris and the static restraining forces of the patella retinaculae to help prevent anterior subluxation of the femur on the tibia (McLeod and Hunter, 1980b).

The integrity of the knee is maintained by a vast capsular envelope reinforced judiciously by a retinaculae, tendons and ligaments (Welsh, 1980). Posteriolateral reinforcement of the knee is provided by the arcuate complex and fibers of the popliteous muscle. Posteriomedial reinforcement is provided by the oblique popliteal ligament and the expansion of the semimembranosus muscle. Medially, the capsule is thickened to form the deep and superficial capsular ligament, or the medial collateral ligament. Further reinforcement of the capsule is provided anteriorly by fibrous expansions from the quadriceps femoris muscle tendon and the fascia forming the patellar retinaculae. Laterally, reinforcement is offered by the iliotibial tract

as it inserts into Gerdy's tubercle of the tibia, and by the fibular collateral ligament (Warwick, 1973; Welsh, 1980).

Located intra-articularly, but extrasynovial, are the two cruciate ligaments, the anterior and posterior. These ligaments are named for their respective attachments to the tibia. The anterior cruciate ligament arises from the tibial plateau, anterior and medial to the tibial spine, or eminence, and extends upward and backwards through the supracondylar notch to an insertion on the posterior aspect of the medial surface of the lateral femoral condyle. The attachment is in the form of a segment of a circle with its anterior side almost straight and the posterior side convex and in an oblique direction from the vertical (Girgis et al., 1975). As the ligament passes backward, it turns on itself and fans out. The form of the anterior cruciate is functionally of great importance, for it means that whatever the position of the knee, portions of the ligament remain functional and under tension (Girgis et al., 1975; Welsh, 1980).

The posterior cruciate ligament originates as a broad flat band from a depression behind the articulating upper surface of the tibia and extending onto the posterior surface of the tibial shaft. It passes almost directly forward and between the femoral condyles medial to the anterior cruciate ligament, converging to attach to the posterior aspect of the lateral surface of the medial

femoral condyle. Its attachment is also in the form of a segment of a circle with a horizontal orientation. As in the anterior cruciate, the fibers of the posterior cruciate ligament twist slightly on themselves allowing tension to remain throughout the range of knee motion (Girgis et al., 1975; Welsh, 1980).

There are two dense fibrocartilagenous semilunar structures, menisci, interposed between the tibia and the femur. These are c-shaped when viewed from above, and triangular in cross section. They are avascular except at their attachments. The medial meniscus is larger and fixed at its anterior and posterior horns by fibrous tissue to the tibia. The medial meniscus also has attachment to the deep medial collateral ligament. The lateral meniscus is likewise attached to the tibia at both its horns, but lacks attachment to the lateral collateral ligament (Welsh, 1980).

McLeod and Hunter (1980) believe that the menisci, through the meniscotibial ligaments, share with the anterior cruciate ligament the role of keeping the femur from sliding posteriorly off the tibia. Levy et al. (1982), on the other hand, state that posterior displacement of the femur on the tibia is not increased with removal of the menisci unless the anterior cruciate ligament is also sectioned which then increases the laxity found with sectioning the anterior cruciate alone.

The muscles crossing the knee provide both motion and

stability to the joint. The quadriceps femoris muscle composed of the rectus femoris, the vastus lateralis, the vastus intermedius, the vastus medialis obliqus, and the vastus medialis longus are the prime extensors of the knee joint (Warwick, 1973). Their insertion into the tibial tuberosity and orientation anterior to the medial-lateral axis of rotation of the distal femur are thought to assist in prevention of posterior subluxation of the tibia on the femur (Johnson and Pope, 1976; McLeod and Hunter, 1980; Andrews et al., 1977).

The semimembranosus muscle has five insertions across the posterior aspect of the knee: the posterior horn of the medial meniscus, the anteriomedial tibia deep to the medial collateral ligament, the posterior tubercle of the tibia into the oblique popliteal ligament, and into the gastrocnemus fascia (Warren and Marshall, 1979; Johnson and Pope, 1976). Its primary purpose is to flex and medially rotate the knee (Warwick, 1973). It may also augment the anterior cruciate ligament in preventing anterior subluxation of the tibia on the femur (Johnson, 1976).

The biceps femoris tendon inserts into the fibula head, proximal tibia, fascia about the leg, posterior capsule of the knee joint, and the lateral collateral ligament. It is a knee flexor and external rotator of the tibia on the femur (Warwick, 1973), and may also augment the anterior cruciate ligament in preventing anterior subluxation of the tibia on

the femur (Johnson, 1976).

The popliteus muscle has origins from the posterior portion of the lateral meniscus and the arcuate complex. It serves to initiate internal rotation of the tibia on the femur and weakly flex the knee (Warwick, 1973). It may work antagonistically to the anterior cruciate ligament by tending to pull the tibia anteriorly beneath the femur (Johnson, 1976).

Anterior Cruciate Ligament Research

Many authors have investigated the anterior cruciate ligament in an attempt to describe its function and relationship to knee stability. Brantigan and Voshell (1941) reviewed work done prior to 1941 on ligament contributions to the human knee, and also presented their own work done on 100 cadaver specimens. When they cut the anterior cruciate ligament and applied an anterior force to the tibia, they found one to two millimeters of forward gliding of the tibia with the knee in extension. In flexion the forward glide was increased about three times, up to 6 mm. They concluded that the anterior cruciate ligament prevents forward gliding of the tibia on the femur.

Several studies have been done since using human cadaver material. Wang and Walker (1973) studied length measurements of the knee ligaments in 12 fresh specimens at 0, 30, 60, 90 and 120 degrees of knee flexion, and with

neutral, internal and external tibial rotation. They reported that with the leg in neutral, the anterior cruciate ligament steadily increased in length by seven percent from 0 to 90 degrees of knee flexion, then remained at the same length beyond 90 degrees of flexion. In internal rotation, it gradually elongated with flexion, reaching a maximum elongation of nine percent at 60 degrees of flexion. The length then decreased slightly. In external rotation, there was little change in length up to 90 degrees of flexion, but from 90 to 120 degrees there was an elongation of 10 percent.

Girgis et al. (1975) did selective cutting, as well as described anatomical and functional details of the cruciate ligaments in 20 embalmed human cadaver knees and 24 fresh specimens. Selective cutting of the anterior cruciate ligament resulted in an increase of anterior translation with the knee flexed and extended. The increase was nearly 250 percent of the intact knee. Girgis did not report at what degree of flexion the translation was measured.

Markolf et al. (1976) quantitatively studied 35 cadaver knees at 0, 20, 45 and 90 degrees of flexion for anterior-posterior displacement with force of up to 100 newtons applied to the tibia. They tested intact knees and knees after sectioning the anterior and posterior cruciate ligaments. Their results showed the greatest increase in anterior displacement with sectioning of the anterior cruciate ligament occurred at 20 degrees of flexion.

Included in their 35 specimens were nine pairs of knees, and they noted some right-left differences for anterior-posterior displacement. They reported values to be within 1.5 mm of each other, 0.3 mm to 3.9 mm.

More recently, Fukubayashi et al. (1982) tested the anterior-posterior tibial motion of nine human cadaver knees in 0, 15, 45, 60, 75 and 90 degrees of knee flexion. They tested with an anterior or posterior force applied to the tibia while allowing tibial rotation, and again while preventing tibial rotation. They tested all nine knees intact, then five knees with the anterior cruciate ligament sectioned. They reported that for intact specimens when the tibia was allowed to rotate freely, tibial translation in both the anterior and the posterior direction increased by an average of 30 percent at all angles, as compared with when the tibia was fixed in the neutral position. For intact knees, maximum anterior translation occurred at 30 degrees of flexion. This averaged 7.0 mm with a 100 newton force anteriorly. Minimum displacement was at full extension. With sectioning of the anterior cruciate ligament, there was a significant increase in anterior translation at all angles tested. Maximum anterior tibial translation occurred between 15 and 45 degrees of flexion. This was 2.5 times the translation noted in the intact knees with a 100 newton force applied in the anterior direction. The maximum difference in translation between the knee with a sectioned

ligament and the intact knee also occurred between 15 and 45 degrees of flexion. These authors noted that tibial rotation did not affect translation with a sectioned cruciate ligament.

Sylvin (1975) studied 50 subjects with normal knees. He measured tibial translation with an externally applied objective measuring device. The force was manually applied in an anterior direction to the proximal tibia and measurements were taken at 90 degrees of knee flexion. The reported mean tibial translation was less than 5 mm, a range of 1 mm to 10 mm. The mean difference between the greater and smaller values for the two knees was about 1 mm. Sylvin concluded that this difference between the two knees is considerably more significant than the value for the individual knee.

Markolf et al. (1978) published a study done on 28 males and 21 females with no history of injury to their knees. They reported anterior-posterior laxity measured with an externally applied testing apparatus during passive manual manipulation of the knee. The knee was positioned in 0, 20 and 90 degrees of flexion. They tested with the muscles relaxed and again with the muscles tensed. They then compared their results to those obtained from 35 fresh cadaver specimens. Their results showed greatest anterior tibial translation at 20 degrees of flexion. Mean displacement for the patients was 2.6 mm, and cadaver displacement

was 3.8 mm. When subjects were requested to tense their knee muscles, these subjects were able to decrease the knee laxity 25 to 50 percent of the normal value. These authors also noted what they felt to be a clinically significant individual right-left difference in laxity of up to 4 mm. There was no tendency for one knee to be more stable than the other.

Several authors have studied tibial translation through the use of stress radiography. Kennedy and Fowler (1971) compared stress results from cadavers, 110 normal knees, and 75 knees with significant injury in the past with recurrent complaints. Lateral radiographs were taken with the knee in 90 degrees of flexion and an anterior stress applied to the tibia. Normal anterior-posterior laxity of up to 5.0 mm was reported. Rotatory instability was suggested in 42 knees out of 75 with the medial tibial condyle displacing 4.4 mm to 11.0 mm, and the lateral tibial condyle displacing less than 5.0 mm.

Jacobsen has published studies in which he used stress radiography to measure passive tibial translation with the knee positioned in 90 degrees of flexion (Jacobsen, 1976; Jacobsen, 1977; Jacobsen, 1978; Jacobsen, 1982). He concluded that comparison with the healthy knee should be used, and that translation of a tibial condyle should exceed 3.0 mm in relation to the healthy knee to be defined as pathological.

Torzilli et al. (1981) reported on a roentgenographic

measurement technique used with a mechanical stress machine on 18 healthy males and 11 healthy females. Measurements were taken with the knee in 90 degrees of flexion and with the thigh and leg constrained, and then unconstrained. Stress was mechanically applied in an anterior direction to the tibia. Anterior laxity measured 2 mm and 3 mm with 50 and 100 newton loads, respectively. They reported no significant difference between right and left sides, male and female subjects, or anterior and posterior directions.

Some authors have used mathematical models when discussing restraint to anterior tibial translation. Smidt (1973) published a biomechanical analysis of knee flexion and extension and calculated shear force at the femoral-tibial joint. At different positions of extension both anterior and posterior shear forces of the tibia on the femur occurred. The maximum anterior shear force was at the 15 degree angle. The shear force would presumably be absorbed by the structures restraining forward displacement of the tibia on the femur.

Johnson and Pope (1976) gave a mathematical estimate of how increased quadriceps force will increase the force necessary to resist anterior translation, or subluxation of the tibia on the femur. They presented a simplified vector analysis to illustrate their point.

Another author (Johnson, 1982) has described a dual-pad attachment to use with isokenetic exercise equipment in

order to control anterior tibial translation caused during active quadriceps function. Johnson has shown mathematically that this translation occurs, and that the pad prevents it.

Other authors have suggested that in the face of anterior cruciate laxity, increased strength in the hamstring muscles may provide increased functional stability by decreasing the forward displacing force of the quadriceps (Marshall et al., 1977; Fulkerson, 1981; Giove et al., 1983). No experimental data was found to support this suggestion.

Summary

Summarizing the research reviewed on anterior cruciate ligament research is difficult due to the various designs of study. Authors generally agree that the anterior cruciate ligament is a primary restraint to anterior translation of the tibia on the femur (Brantigan and Voshell, 1941; Girgis et al., 1975; Markolf et al., 1976; Markolf et al., 1978; Fukubayashi et al., 1982). The normal amount of translation varies according to the degree of knee flexion present and the amount of force applied (Brantigan and Voshell, 1941; Girgis et al., 1975; Markolf et al., 1976; Markolf et al., 1978; Fukubayashi et al., 1982). Some authors have suggested that it may be more significant to look at the difference in translation between knees as a meaningful value, however

this too is difficult to compare due to the various experimental designs (Markolf et al., 1976; Markolf et al., 1978; Sylvin, 1975; Jacobsen, 1977).

It is noted that all the research reviewed has been done with external forces applied to the knee. The exception to this was Markolf (1978) who had subjects tense their muscles at the same time an external force was applied, and he noted a decrease in translation during this. Presumably a cocontraction of the muscles about the knee was used, although it is not clearly stated in the report.

There is some mathematical evidence and some weak clinical evidence to indicate that active quadriceps contraction may produce anterior tibial translation on the femur, and that this translation may be increased in the absence of the anterior cruciate ligament (Smidt, 1973; Johnson and Pope, 1976; Johnson, 1982). No experimental data is found to substantiate this claim.

To this investigator's knowledge, there is no data published on anterior tibial translation measured during voluntary active muscle contraction in normal knees, or in knees with torn anterior cruciate ligaments.

Chapter 3

TEST METHOD AND PROCEDURE

Chapter three contains methods and procedures for the study. It is organized into headings of Subjects, Test Instrument, Test Procedure and Method of Data Analysis.

Subjects

Nineteen adults, divided into two groups, were used for this study. The first group, or normal group, was composed of five male and five female volunteers ranging in age from 21 to 34 years, mean of 26.8 years. All subjects denied any history of hip, knee or ankle disease, or trauma for which they had sought medical attention.

The second group, or study group, was made up of eight males and one female with a mean age of 26.4 years, ranging from 17-39 years. All subjects in the study group had undergone arthroscopic examination of one of their knees within four months of their participation in the study, a range of one to four months and a mean of two months. Five subjects had an arthroscopic finding of an absent left anterior cruciate ligament and four subjects had an absent right anterior cruciate ligament. All nine subjects had received a minimum of five physical therapy sessions, and all nine stated they were continuing a home program of

physical therapy. Three of the subjects were still being followed on a once a week basis at the sports physical therapy practice they were drawn from. All nine subjects in the second group wore a Lenox Hill brace[1] for recreational activities, and all nine denied any history of trauma or disease of either hip or ankle and their other knee for which they had sought medical care.

None of the subjects showed any effusion or limitation of motion in either knee, and no subject complained of pain in either knee. All subjects gave no history of either knee being immobilized.

Test Instrument

The dependent variable was translation of the tibia relative to the femur measured in millimeters. The measurement tool was a dial indicator[2] having a sensitivity of 0.001 inch and a range of zero to one inch. The instrument had a plunger which moved in one plane in response to movement. A hand on the face of the dial rotated in response to motion of the plunger; clockwise with forward displacement of the plunger and counterclockwise with backward displacement of the plunger.

The instrument was mounted on a three foot high pedestal.

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[1] Lenox Hill Brace Shop, Inc., 244 East 84th Street, New York, New York 10028.

[2] Yausa, no. 300-005.

Two adjustable six inch extension arms and two adjustable joints allowed movement of the instrument in all planes. The maneuverability of the mounting enabled the plunger to be aligned perpendicular to the tibia during each test for all subjects. The dial measurements were read in inches and converted to metric measure.

Right and left knees for all subjects were tested at 15, 45 and 60 degrees of knee flexion. The angles were tested in random order and the side tested first was determined by random selection. Measurements were obtained during a maximal voluntary isometric contraction of the quadriceps femoris muscle. Two trials at each angle were performed, and the maximal effort was used. Isometric effort was recorded via a cable tensiometer, of the type used in the airline industry[3], and measured in relative units.

Reliability of the measurements was estimated by repeating the procedure at the 45 degree angle for each leg on all subjects. A Pearson Product Correlation Coefficient was computed using the SAS computer package[4]. A summary of initial and repeat measurements is in Table 1. Test-retest reliability for the test instrument was significantly different from 0 at the 0.05 level ($r = 0.95$).

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[3] Pacific Scientific Co., Anahiem, California.

[4] SAS Institute Inc., SAS Circle, Box 8000, Cary, North Carolina 27511-8000.

Table 1

TEST RETEST RELIABILITY FOR THE DIAL INDICATOR AT 45 DEGREES OF KNEE FLEXION

	n	Mean	SD	Range
Test	38	2.61 mm	3.01 mm	0.05 - 13.00 mm
Retest	38	2.71 mm	3.08 mm	0.08 - 13.61 mm

$r = 0.95$: significant at the 0.05 level.

Test Procedure

Each subject was informed of the procedure and the purpose of the investigation, and signed a consent form prior to participation. The subject assumed a reclined position with both legs bent off the end of the table. The leg not being tested was allowed to rest on a stool, such that the hip and knee were comfortably flexed. Three velcro straps were used to firmly fixate the femur; one directly over the anterior superior illiac spines of the pelvis, one approximately midfemur, and one over the distal femur. These straps went around the subject and around the table.

Two three inch wide leather cuffs were attached just superior to the malleoli on the distal leg. The more proximal cuff around the leg was then attached to a rope which threaded through an upright stand. Through use of the rope, the leg was passively moved into the first test position. The knee angle was measured with a goniometer and the rope secured to maintain the position (Figure 1). The distal cuff on the leg was attached to a cable and chain combination, which was secured to the back of the table and used to provide the resistance for the isometric effort. The cable was made as taut as possible, and the angle at which the cable was applied to the tibia was maintained between 60 and 90 degrees throughout the test procedure.

Next, the cable tensiometer was attached to the cable. A reading of two to four units on the tensiometer was

Figure 1. Test Set-up for Measuring Translation of the Tibia on the Femur.

reached through adjustment in the rope holding the knee in position. The position was remeasured with a goniometer, and adjustments made if necessary to insure that the test angle was correct.

The stand with the dial indicator was positioned next. A contured piece of Orthoplast[5] approximately six centimeters by three centimeters was positioned on the tibia just inferior to the attachment of the patella tendon. The dial indicator was then positioned perpendicular to the tibia and allowed to rest in a depression in the Orthoplast. The indicator hand was positioned at approximately midrange allowing a reading of 0.5 inch in either direction. At least two submaximal quadriceps contractions were performed, during which it was confirmed that all the slack was out of the system and no extraneous motion was taking place.

After a two minute rest, the initial readings for the cable tensiometer and the dial indicator were recorded. The subject was then asked to slowly push the knee straight as hard as possible. Verbal encouragement to push hard was continued throughout the contraction. Once the reading on the dial indicator stabilized, the subject was instructed to relax. Peak reading of the tensiometer via a maximum hand was recorded, and peak translation, as read by the investigator, was recorded. The readings were made to the nearest

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[5] Johnson and Johnson Products, Inc., 501 George Street, New Brunswick, New Jersey 08903.

graduated unit; for the dial indicator 0.001 inch and the tensiometer 1.0 unit. At least a one minute rest was given then a second trial was performed. Readings before, and peak readings were again recorded.

The same procedure was followed for each angle with at least a two minute rest given between angles. Once all three angles and the retest angle were tested, the other leg was tested using the same procedure.

Method of Data Analysis

A repeated measures analysis of variance was used for statistical analysis of the investigation. Computations were performed with a computer using the general linear model (GLM) program of the SAS package.

The dependent variable was the tibial translation measurement, in millimeters. There were three independent variables. The first was knee angle, 15, 45 and 60 degrees. The second was group classification of the leg being tested; Group 1 indicated a knee from the study sample with anterior cruciate ligament absence, Group 2 indicated the normal knee from the study sample, and Group 3 indicated a normal knee from the normal sample. The third independent variable was the side tested, right or left.

Chapter 4

THE RESULTS

Chapter four contains the results of the study, a discussion of the study, conclusions and recommendations for further research in this area. Finally, a brief summary of the study is given.

Results

The knees of each subject were classified as to right or left side and group. Group 1 signified the knee was a member of the study sample and was the knee having an absent anterior cruciate ligament. Group 2 signified the knee was a member of the study sample and was the normal knee. Group 3 signified a normal knee from the normal sample. The classifications for all 19 subjects are given in Table 2.

All 19 subjects recorded anterior translation of the tibia relative to the femur during maximal voluntary isometric contraction of the quadriceps femoris muscle at 15, 45 and 60 degrees of knee flexion. The mean anterior translation with the legs grouped by side and group at 15, 45 and 60 degrees of knee flexion is shown in Table 3.

There appears to be a difference in the mean tibial translation between right and left knees in Group 1 and Group 2 at 45 and 60 degrees of flexion. This apparent difference may be explained from the results of one subject

Table 2

CLASSIFICATION OF KNEES FOR THE NORMAL AND STUDY GROUPS

Group	Left Knee	Right Knee
Group 1		
Study sample, absent anterior cruciate ligament	n = 4	n = 5
Group 2		
Study sample, normal knee	n = 5	n = 4
Group 3		
Normal sample, normal knee	n = 10	n = 10

Table 3

MEAN TIBIAL TRANSLATION BY SIDE AND GROUP

	Group	n	Mean	S.D.	Range
15 degrees knee flexion					
Left Knee	1	5	3.35 mm	1.98	1.24 - 6.43
	2	4	1.64 mm	1.30	0.15 - 2.84
	3	10	1.89 mm	1.48	0.30 - 4.42
Right Knee	1	4	3.95 mm	1.81	2.11 - 6.10
	2	5	1.04 mm	0.92	0.20 - 2.59
	3	10	1.77 mm	1.09	0.53 - 4.06
45 degrees knee flexion					
Left Knee	1	5	4.23 mm	3.58	0.89 - 8.64
	2	4	2.07 mm	3.50	0.20 - 7.32
	3	10	2.05 mm	1.47	0.53 - 4.29
Right Knee	1	4	7.28 mm	4.59	1.88 -13.00
	2	5	0.77 mm	1.04	0.05 - 2.51
	3	10	1.63 mm	1.85	0.15 - 5.97
60 degrees knee flexion					
Left Knee	1	5	2.98 mm	2.26	0.71 - 5.59
	2	4	2.79 mm	4.58	0.13 - 9.65
	3	10	2.15 mm	1.32	0.20 - 3.76
Right Knee	1	4	5.63 mm	6.10	1.70 -14.73
	2	5	0.71 mm	0.76	0.08 - 1.70
	3	10	1.90 mm	1.81	0.20 - 5.97

Group 1 = Study sample, absent anterior cruciate ligament
Group 2 = Study sample, normal knee
Group 3 = Normal Sample, normal knee

who generated the high end of the range for tibial translation in both normal and ligament deficient knees.

The data was collapsed by averaging the mean tibial translations across the right and left sides (Table 4). These means show an apparent difference between groups at each of the test angles. Within Group 2 and Group 3, there appears to be small differences in mean translations between angles tested, less than 1 mm. Within Group 1, the differences were larger, but less than a 2 mm difference between angles is noted.

Further collapse of the data was done by averaging the mean tibial translations across the three angles within each group (Table 5). Table 5 shows the mean tibial translation of Group 2, the normal legs of the study sample, to be similar to the mean tibial translation of Group 3, the normal sample. Another apparent finding is the mean tibial translation of the knees with absent anterior cruciate ligaments (Group 1) is greater than the mean tibial translations of either group of normal knees.

A repeated measures analysis of variance was performed in an attempt to answer the six hypotheses proposed during the study. The general linear model procedure from the SAS computer package was used. Values computed are reported in Table 6.

The analysis of variance yielded no statistical significance for any of the interactions tested at the 0.05 level

Table 4

MEAN ANTERIOR TIBIAL TRANSLATION BY ANGLE AND GROUP

	Group	n	Mean	S.D.	Range
15° of knee flexion					
	1	9	3.62 mm	1.81	1.24 - 6.43
	2	9	1.31 mm	1.08	0.15 - 2.84
	3	20	1.83 mm	1.27	0.30 - 4.42
45° of knee flexion					
	1	9	5.59 mm	4.11	0.89 -13.00
	2	9	1.35 mm	2.37	0.05 - 7.32
	3	20	1.84 mm	1.64	0.15 - 5.97
60° of knee flexion					
	1	9	4.16 mm	4.30	0.71 -14.73
	2	9	1.63 mm	3.06	0.08 - 9.65
	3	20	2.03 mm	1.55	0.20 - 5.97

Group 1 = Study sample, knee with absent anterior cruciate ligament
Group 2 = Study sample, normal knee
Group 3 = Normal sample, normal knee

Table 5

MEAN ANTERIOR TIBIAL TRANSLATION BY GROUP

	n	Mean	S.D.	Range
Group 1 Study sample, absent anterior cruciate ligament	27	4.45 mm	3.55	0.71 - 14.73 mm
Group 2 Study sample, normal knee	27	1.43 mm	2.23	0.05 - 9.65 mm
Group 3 Normal sample, normal knee	60	1.90 mm	1.47	0.15 - 5.97 mm

Table 6

ANALYSIS OF VARIANCE OF TRANSLATION OF TIBIA ON FEMUR BY SIDE, GROUP AND ANGLE

Source of Variation	DF	Type IV SS	F Value	PR > F
Group	2	143.42	5.70**	0.01
Error [subj(group)]	23	289.57	-	-
Side	1	.23	0.08	0.78
Angle	2	4.49	0.74	0.48
Side*angle	2	1.91	0.31	0.73
Group*angle	4	12.92	1.06	0.38
Side*group*angle	4	10.08	0.83	0.51
Error [subj(side, group,angle)]	73	222.92	-	-

Group: Group 1: study sample, absent anterior cruciate ligament
Group 2: study sample, normal knee
Group 3: normal sample, normal knee

Side: Left, right knee

Angle: 15, 45, 60 degrees of knee flexion

of significance. Therefore, the hypothesis is accepted that there is no significant difference in tibial translation between bilaterally normal knees during maximal voluntary isometric contraction of the quadriceps. Also accepted are the hypotheses that there are no significant differences in tibial translation between maximal isometric contractions of the quadriceps at 15, 45 and 60 degrees of knee flexion, regardless of the status of the anterior cruciate ligament.

A statistically significant difference in the translation of the tibia on the femur, averaged across sides and angles, was found within groups ($f = 5.70$; $P < 0.01$). Post Hoc testing was done using two weighted contrasts to determine where the differences were. The first comparison between the mean of the normal knees from the study sample and the mean of the normal knees from the normal sample (Table 5) showed no statistically significant difference in mean tibial translation. This was averaged across sides and across angles of 15, 45 and 60 degrees of knee flexion ($f = 0.326$; Table 7).

The second comparison showed a statistically significant difference in mean translation, averaged across sides and across angles, between legs with anterior cruciate ligament absence and normal legs ($f = 11.95$; $P < 0.05$; Table 5, Table 7). The first hypothesis that there is no difference between tibial translation in knees with anterior cruciate ligament loss and normal knees is therefore rejected.

Table 7

POST HOC TEST USING WEIGHTED CONTRASTS

	Group 1	Group 2	Group 3	SS	F Value
Contrast Coefficient 1	0	1	$\frac{-27}{60}$	4.11	0.326
Contrast Coefficient 2	$\frac{-87}{27}$	1	1	150.46	11.95**

** significant at P < .05 level

Comparison 1 = H: Mu 2 = Mu 3

Comparison 2 = H: $\frac{\text{Mu 2 + Mu 3}}{2}$ = Mu 1

Group 1 = Study sample, absent anterior cruciate ligament
Group 2 = Study sample, normal knee
Group 3 = Normal sample, normal knee

Discussion

Lack of published data on tibial translation secondary to active quadriceps contraction makes it difficult to discuss the results of this study. Paulos et al. (1981) reported some conclusions based on unpublished work on measured forces in the anterior cruciate ligament with leg extension exercises. Their conclusion was that the force measured in the anterior cruciate ligament was not significant until approximately 30 degrees of flexion and the force increased up to 0 degrees of flexion.

Steadman (1983) citing unpublished works from Daniels and Henning recommends quadriceps exercise in the range of 90 to 45 degrees of flexion to protect an injured anterior cruciate ligament, or the remaining restraints to anterior translation if the anterior cruciate is absent.

The results of this investigation show that with anterior cruciate ligament absence there is a measurable and significant increase from normal in anterior tibial translation at 15, 45 and 60 degrees of knee flexion during maximal voluntary isometric contraction of the quadriceps. This increased translation suggests a potential increase in the stress to the remaining restraints of anterior translation through the range of 60 to 15 degrees of flexion. This finding indicates a need for caution during quadriceps exercises through an even wider range than Steadman and Paulos have suggested when protection of restraints to

anterior tibial translation is desired. It is concluded from the results of this study that maximal isometric quadriceps exercises should be avoided within the range of 60 to 15 degrees of knee flexion in knees with an absent anterior cruciate ligament. There may be a potential decrease in the stresses on the remaining restraints to anterior translation of the tibia on the femur with avoidance of these maximal exercises. With decreased stresses, there may be decreased soft tissue stretching, and potential protection of the knee joint from accelerated degenerative processes caused by exercise.

The results of this study show no difference in mean tibial translation between right and left knees in normals. There was also no difference in mean tibial translation between the normal knees of the study sample and the knees from the normal sample. Based on these results, a valid comparison of anterior tibial translation during maximal voluntary isometric quadriceps contraction may be made between right and left knees within the same subject.

A few authors have expressed the opinion that the difference in translation between knees is the most appropriate value to study (Markolf et al., 1976; Jacobsen, 1978; Markolf et al., 1978; Sylvin, 1975; Ouellet, 1969). Mean differences between knees in the normal sample of this study ranged from 0 to 3.6 mm, a mean of 1.3 mm. Mean differences between knees for subjects in the study group ranged from

0.6 mm to 8.4 mm, a mean of 3.1 mm. The findings for the study group complement those of Jacobsen (1976) and Ouellet (1969), who reported that differences in anterior tibial translation measured with stress radiography of more than 3 mm is likely to be pathological. The normal difference of 1.3 mm found in this study is similar to the slightly greater than 1.0 mm difference Sylvin (1975) reported with passive testing using an objective measurement apparatus. Given that the sample sizes in this study are relatively small, a difference between knees of greater than 3.1 mm of anterior translation of the tibia on the femur measured during maximal voluntary isometric contraction of the quadriceps may be a sign of anterior cruciate ligament deficiency.

Fukubayashi et al. (1982) reported when the anterior cruciate ligament was cut, passive anterior tibial translation was greatest between 15 and 45 degrees of knee flexion, 17.5 mm. They found this to be 2.5 times greater than that found for intact knees, 7 mm. Data from this study showed that at 45 degrees of flexion when the anterior cruciate ligament was absent, mean tibial translation was 5.59 mm, or 3.5 times greater than the normal of 1.59 mm (Table 4). The translations measured during this study in the presence of a maximal isometric quadriceps contraction are more than three times less than those measured passively by Fukubayashi et al. Fukubayashi et al. did no statistical analysis to

compare translations at the various angles tested. In this study, no statistical difference was found between 15, 45 and 60 degrees of flexion.

The decrease in the amount of anterior translation measured in this study compared to the studies done with external forces on cadaver knees is striking. The difference might be explained by the amount, or direction, of the force applied. At least one author (Torzilli, 1981) noted that with increased force, there was increased translation of the tibia. Another possible explanation is that the remaining restraints to anterior translation of the tibia on the femur compensate to some extent for the loss of the anterior cruciate ligament. Not enough data was collected for this study to base any conclusions regarding this difference.

Conclusions

It is concluded that maximal voluntary isometric quadriceps exercises should be avoided within the knee range of motion of 60 to 15 degrees of flexion in subjects with an absent anterior cruciate ligament.

The conclusion is drawn that a valid comparison of anterior translation of the tibia on the femur during maximal voluntary isometric quadriceps contraction may be made between right and left knees within the same subject.

Finally, it is concluded that a greater than 3.1 mm difference in anterior translation of the tibia on the femur

measured during maximal voluntary isometric quadriceps contraction may be a sign of anterior cruciate ligament deficiency.

Recommendations for Further Research

Since no other data has been published on anterior translation of the tibia on the femur during active quadriceps contraction, this study generates several new questions to be investigated. One question is: Is there also a significant increase in translation at other angles of knee flexion, such as 0 and 90 degrees, during maximal voluntary isometric quadriceps contraction?

Another question generated is: What are the effects on anterior translation given a submaximal contraction of the quadriceps? Also, in addition to isometric contractions are the more functional concentric and eccentric muscle contractions; what effects do these contractions have on anterior tibial translation?

Some authors have suggested that the hamstring muscles may provide some dynamic stability to control anterior translation. Others have stated that muscles not already contracting and functioning can not respond quick enough to provide stability during trauma (Johnson and Pope, 1976; Pope et al., 1982). More research needs to be done in these areas to determine any influence the hamstrings may have on preventing anterior tibial translation. Does increased

hamstring strength decrease anterior tibial translation? Does proprioceptive or cocontraction training of the knee musculature decrease anterior tibial translation?

Along with people who have injured the anterior cruciate ligament, those who have had reconstructive surgery for torn anterior cruciate ligaments provide another population on which to study anterior tibial translation during active quadriceps contractions. The question of is there a change over time in anterior tibial translation during quadriceps contraction in people with partial, complete or surgically repaired anterior cruciate ligaments, as well as those with reconstructed or replaced anterior cruciate ligaments can be asked.

Several questions have been stimulated by this study. Answers to these may improve the ability of health practitioners involved in rehabilitation of those with anterior cruciate ligament injuries to achieve the goals of gaining functional stability, decreasing dysfunction, and decreasing degenerative joint disease in the injured knee.

Summary

Data has been carefully collected on the sagittal translation of the tibia on the femur during maximal voluntary isometric contraction of the quadriceps muscle on 19 subjects; ten with two normal knees and nine with one normal knee, and one knee with an absent anterior cruciate ligament.

Measurements were obtained using a dial indicator, and test positions of 15, 45 and 60 degrees of knee flexion were used. The data was analyzed using an analysis of variance, and weighted contrast testing was carried out to analyze any differences. The results indicated that in the absence of the anterior cruciate ligament, with a maximal voluntary isometric contraction of the quadriceps muscle, there was a statistically significant increase in anterior translation of the tibia on the femur compared to normal, $P < 0.01$. For subjects with two normal knees with a maximal voluntary isometric contraction of the quadriceps femoris muscle, there was a measurable translation of the tibia anteriorly. However, no statistically significant difference between normal knees was found. It was also shown that regardless of the status of the anterior cruciate ligament, there was no statistically significant difference in anterior tibial translation between angles of 15, 45 and 60 degrees of knee flexion.

The conclusion was drawn that in subjects with an absent anterior cruciate ligament, maximal voluntary isometric quadriceps exercises should be avoided through the range of 60 to 15 degrees of knee flexion. Another conclusion was that a valid comparison of anterior tibial translation measured during maximal voluntary isometric contractions of the quadriceps may be made between right and left knees within the same subject. A third conclusion from the

results of this study was that a difference of greater than 3.1 mm of anterior translation of the tibia on the femur between knees measured during maximal voluntary isometric contraction of the quadriceps may be a sign of anterior cruciate ligament deficiency.

Several questions were posed to stimulate further research into stability of the knee during dynamic conditions with a goal of improving joint stability following anterior cruciate ligament injury. Thus, decreasing knee joint dysfunction and joint degeneration.

Chapter 5

TRANSLATION OF THE TIBIA DURING ISOMETRIC CONTRACTION OF THE QUADRICEPS

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Dr. Scott is Assistant Professor of Applied Statistics, Department of Mathematical Sciences, Virginia Commonwealth University, Richmond, Virginia.

ABSTRACT

The purpose of this study was to determine in normal knees, and in knees with anterior cruciate ligament absence, what effect maximal voluntary isometric contraction of the quadriceps has on translation of the tibia on the femur. Ten subjects with bilaterally normal knees, and nine subjects with one normal knee and the contralateral knee having an arthroscopic finding of absent anterior cruciate ligament were tested. Tibial translation was measured with a dial indicator at 15, 45 and 60 degrees of knee flexion. There was a measurable anterior translation of the tibia in all knees. An analysis of variance and post hoc testing of two weighted contrasts showed a significant increase from normal in anterior tibial translation in subjects with absence of the anterior cruciate ligament, $P < 0.05$. In subjects with normal knees there was no significant difference in tibial translation between right and left knees. Regardless of the status of the anterior cruciate ligament, there was no significant difference in translation between maximal voluntary isometric contractions of the quadriceps at 15, 45 or 60 degrees of knee flexion. It was concluded that in subjects with an absent anterior cruciate ligament voluntary maximal isometric quadriceps exercises should be avoided through the range of 60 to 15 degrees of knee flexion. Another conclusion was that a valid comparison of anterior translation of the tibia on the femur during maximal volun-

tary isometric contraction of the quadriceps may be made between knees within the same subject. A third conclusion was that a difference of greater than 3.1 mm of anterior tibial translation between knees measured during maximal voluntary isometric contraction of the quadriceps may be a sign of anterior cruciate ligament deficiency.

Rehabilitation of injuries to the anterior cruciate ligament has received increasing attention in the literature over the past decade (8,11,19,28,29). Among the primary goals of health practitioners involved in knee rehabilitation following injury to the anterior cruciate ligament are to obtain maximal functional stability of the joint and to minimize the potential degenerative processes.

Stability of any joint depends on several factors including joint geometry, joint compressive forces, passive restraints provided by capsule and ligaments, as well as dynamic restraints generated by the muscles acting on the joint (1,25). An alteration in any one of these factors will result in change to the other factors and potential joint dysfunction, degeneration and disability (14).

Through Instant Center Analysis, it has been shown that anterior translation of the tibia on the femur occurs during normal knee extension (3). Instant Center Analysis is a method of kinematic evaluation of a joint. Although kinematics is a study of relative motion, the centers of motion are determined while the joint is in a passive state; that is, no significant voluntary muscle contractions are elicited from the subject during the analysis.

Stability of the normal and ligament deficient knee has been studied almost exclusively with externally applied forces. Investigators are in general agreement that the anterior cruciate ligament is a primary restraint to anterior

tibial translation on the femur (1,4,7,13,16). Research has shown that with the absence of the anterior cruciate ligament, there is an increase from normal anterior translation of the tibia on the femur during passive manipulation of the knee joint (4,10,17,22,30,32). Although this research has been carried out at various degrees of knee flexion, statistical analyses of any differences between angles has not been reported.

Many authors state that active contraction of the quadriceps femoris muscle produces a force causing anterior translation of the tibia on the femur (6,11,12,15,17,29). With anterior cruciate ligament loss, some authors believe that excessive tibial translation may occur during active quadriceps contraction (6,11,24,28). Further, Johnson (11) has advocated the use of a dual pad attachment to existing exercise equipment to help control anterior tibial translation during knee extension exercises. Other authors have suggested that emphasis on strengthening of the hamstring muscles may help decrease anterior tibial translation (5,8,19).

There are several authors who argue that injury to the anterior cruciate ligament can cause significant long term knee instability and dysfunction (2,13,18,21,23). Following injury to the anterior cruciate ligament, others have described a progressive process of soft tissue stretching with articular cartilage deterioration and eventual degener-

ative joint disease (6,10,18,20,24,26,31). If contraction of the quadriceps femoris muscle creates an excessive translation of the tibia on the femur in people with anterior cruciate ligament instability, the excessive motion may cause excessive stresses on the remaining restraints to this motion. Thus, precipitate soft tissue stretching and instability, dysfunction, and degenerative joint disease.

To provide quality rehabilitation following anterior cruciate ligament injury or surgical repair, it is necessary to know the effect muscle forces acting on the knee have on the movement of bones and potential changes in stress to the remaining restraining elements. The purpose of this investigation was to determine in normal knees, and in knees with anterior cruciate ligament absence, what effect voluntary maximal isometric contraction of the quadriceps femoris muscle has on sagittal plane translation of the tibia on the femur.

SUBJECTS

Nineteen adults, divided into two groups, were used for this study. The first group, or normal group, was composed of five male and five female volunteers ranging in age from 21 to 34 years, mean of 26.8 years. All subjects denied any history of hip, knee or ankle disease, or trauma for which they had sought medical attention.

The second group, or study group, was made up of eight males and one female with a mean age of 26.4 years, ranging

from 17-39 years. All subjects in the study group had undergone arthroscopic examination of one of their knees within four months of their participation in the study, a range of one to four months and a mean of two months. Five subjects had an arthroscopic finding of absent left anterior cruciate ligament and four subjects had an absent right anterior cruciate ligament. All nine subjects had received a minimum of five physical therapy sessions and all nine stated they were continuing a home program of physical therapy. Three of the subjects were still being followed on a once a week basis at the sports physical therapy practice they were drawn from. All nine subjects in the second group wore a Lenox Hill brace[1] for recreational activities, and all nine denied any history of trauma or disease of either hip or ankle and their other knee for which they had sought medical attention.

None of the subjects showed any effusion or limitation of motion in either knee, and no subject complained of pain in either knee. The subjects gave no history of either knee being immobilized.

METHOD

The dependent variable was translation of the tibia relative to the femur expressed in millimeters. The measure-

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[1] Lenox Hill Brace Shop, Inc., 244 East 84th Street, New York, New York 10028.

ment tool was a dial indicator[2] having a sensitivity of 0.001 inch and a range of 0 to 1 inch. The instrument had a plunger which moved in one plane in response to movement. A hand on the face of the dial rotated in response to motion of the plunger; clockwise with forward displacement of the plunger and counterclockwise with backward displacement of the plunger.

The instrument was mounted on a three foot high pedestal. Two adjustable six inch extension arms and two adjustable joints allowed movement of the instrument in all planes. Maneuverability of the mounting enabled the plunger to be aligned perpendicular to the tibia during each test for all subjects. The dial measurements were read in inches and converted to metric measure.

Right and left knees for each subject were tested at 15, 45 and 60 degrees of knee flexion. The angles were tested in random order and the side tested first was determined by random selection. Measurements of translation of the tibia on the femur were obtained during a maximal voluntary isometric contraction of the quadriceps femoris muscle. Two trials at each angle were performed, and the maximal effort was used. Isometric effort was recorded via a cable tensiometer[3], of the type used in the airline

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[2] Yausa, no. 300-005.

[3] Pacific Scientific Co., Anahiem, California.

industry, and measured in relative units.

Reliability of the measurements was estimated by repeating the procedure at the 45 degree angle for each leg on all subjects. A Pearson Product Correlation Coefficient was computed using the SAS computer package[4]. A summary of initial and repeat measurements is in Table 1. Test-retest reliability for the test instrument was significantly different from 0 at the 0.05 level ($r = 0.95$).

Each subject was informed of the procedure and the purpose of the investigation, and signed a consent form prior to participation. The subject assumed a reclined position with both legs bent off the end of the table. The leg not being tested was allowed to rest on a stool, such that the hip and knee were comfortably flexed. Three velcro straps were used to firmly fixate the femur, one directly over the anterior superior illiac spines of the pelvis, one approximately midfemur, and one over the distal femur. These straps went around the subject and around the table.

Two three-inch wide leather cuffs were attached just superior to the malleoli on the distal leg. The more proximal cuff around the leg was attached to a rope which threaded through an upright stand. Through use of the rope, the leg was passively moved into the first test position. The knee angle was measured with a goniometer and the rope

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[4] SAS Institute Inc., SAS Circle, Box 8000, Cary, North Carolina 27511-8000.

secured to maintain the position (Figure 1). The distal cuff on the leg was attached to a cable and chain combination, which was secured to the back of the table and used to provide the resistance for the isometric effort. The cable was made as taut as possible, and the angle at which the cable was applied to the leg was maintained between 60 and 90 degrees.

Next, the cable tensiometer was attached to the cable. A reading of two to four units on the tensiometer was reached through adjustment in the rope holding the knee in position. The position was remeasured with a goniometer, and adjustments made if necessary to insure that the test angle was correct.

The stand with the dial indicator was positioned next. A contured piece of Orthoplast[5] approximately six centimeters by three centimeters was positioned on the tibia just inferior to the attachment of the patella tendon. The dial indicator was then positioned perpendicular to the tibia and allowed to rest in a depression in the Orthoplast. The indicator hand was positioned at approximately midrange allowing a reading of 0.5 inch in either direction. At least two submaximal quadriceps contractions were performed, during which it was confirmed that all the slack was out of the system and no extraneous motion was taking place.

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[5] Johnson and Johnson Products, Inc., 501 George Street, New Brunswick, New Jersey 08903.

After a two minute rest, the initial readings for the cable tensiometer and the dial indicator were recorded. The subject was then asked to slowly push the knee straight as hard as possible. Verbal encouragement to push hard was continued throughout the contraction. Once the reading on the dial indicator stabilized, the subject was instructed to relax. Peak reading of the tensiometer via a maximum hand was recorded, and peak translation, as read by the investigator, was recorded. The readings were made to the nearest graduated unit; for the dial indicator 0.001 inch and the tensiometer 1.0 unit. At least a one minute rest was given, then a second trial was performed. Readings before, and peak readings were again recorded.

The same procedure was followed for each angle with at least a two minute rest given between angles. Once all three angles and the retest angle were tested, the other leg was tested using the same procedure.

A repeated measures analysis of variance was used for statistical analysis of the investigation. Computations were performed with a computer using the general linear model (GLM) program of the SAS computer package.

The dependent variable was the tibial translation expressed in millimeters. There were three independent variables. The first was knee angle: 15, 45 or 60 degrees. The second was group classification of the leg being tested; Group 1 indicated a knee from the study sample with anterior

cruciate ligament absence, Group 2 indicated the normal knee from the study sample, and Group 3 indicated a normal knee from the normal sample. The third independent variable was the side tested, right or left. Classifications for the 19 subjects are given in Table 2.

RESULTS

All 19 subjects recorded anterior translation of the tibia relative to the femur during maximal voluntary isometric contraction of the quadriceps femoris muscle at 15, 45 and 60 degrees of knee flexion. The mean anterior translation with the legs grouped by side and group at 15, 45 and 60 degrees of knee flexion is shown in Table 3.

There appears to be a difference in the mean tibial translation between right and left knees in Group 1 and Group 2 at 45 and 60 degrees of flexion. This apparent difference may be explained from the results of one subject who generated the high end of the range for tibial translation in both normal and ligament deficient knees.

The data was collapsed by averaging the mean tibial translations across the right and left sides (Table 4). These means show an apparent difference between groups at each of the test angles. Within Group 2 and Group 3 there appears to be small differences in mean translations between angles tested (less than 1 mm). Within Group 1, the differences were larger, but less than a 2 mm difference between angles is noted.

Further collapse of the data was done by averaging the mean tibial translations across the three angles within each group (Table 5). Table 5 shows the mean tibial translation of Group 2, the normal legs of the study sample to be similar to the mean tibial translation of Group 3, the normal sample. Another apparent finding is the mean tibial translation of the knees with absent anterior cruciate ligaments (Group 1) is greater than the mean tibial translations of either group of normal knees.

A repeated measures analysis of variance yielded no statistical significance for any of the interactions tested. No significant difference in tibial translation between bilaterally normal knees was found. Also, regardless of the status of the anterior cruciate ligament, there was no significant difference in tibial translation between maximal voluntary isometric contractions of the quadriceps at 15, 45 or 60 degrees of knee flexion.

A statistically significant difference in the translation of the tibia on the femur averaged across sides, and angles were found within groups ($f = 5.70$, $P < 0.01$). Post hoc testing was done using two weighted contrasts to determine where the differences were. The first comparison between the mean of the normal knees from the study sample and the mean of the normal knees from the normal sample (Table 5) showed no statistically significant difference in mean translation. This was averaged across sides, and

across angles of 15, 45 and 60 degrees of knee flexion ($f = 0.236$; Table 7).

The second comparison showed a statistically significant difference in mean translation averaged across sides, and across angles between legs with anterior cruciate ligament absence and normal legs ($f = 11.95$; $P < 0.05$; Table 5, Table 7).

DISCUSSION

Lack of published data on tibial translation secondary to active quadriceps contraction makes it difficult to discuss the results of this study. Paulos et al. (26) reported some conclusions based on unpublished work on measured forces in the anterior cruciate ligament with leg extension exercises. Their conclusion was that the force measured in the anterior cruciate ligament was not significant until approximately 30 degrees of flexion and the force increased up to 0 degrees of flexion.

Steadman (27) citing unpublished works from Daniels and Henning recommends quadriceps exercise in the range of 90 to 45 degrees of flexion to protect an injured anterior cruciate ligament, or the remaining restraints to anterior translation if the anterior cruciate is absent.

The results of this investigation show that with anterior cruciate ligament absence there is a measurable and significant increase from normal in anterior tibial translation during maximal voluntary isometric contraction of the

quadriceps at 15, 45 and 60 degrees of knee flexion. This increased translation suggests a potential increase in the stress to the remaining restraints of anterior translation through the range of 60 to 15 degrees of flexion. This finding indicates a need for caution during quadriceps exercises through an even wider range than was previously suggested by Steadman (27) and Paulos (28) when protection of restraints to anterior tibial translation is desired. It is concluded from the results of this study that maximal isometric quadriceps exercises should be avoided within the range of 60 to 15 degrees of knee flexion in knees with absent anterior cruciate ligaments. There may be a potential decrease in the stresses on the remaining restraints to anterior translation of the tibia on the femur with avoidance of these maximal exercises. With decreased stresses, there may be decreased soft tissue stretching, and potential protection of the knee joint from accelerated degenerative processes caused by exercise.

The results of this study show no difference in mean tibial translation between right and left knees in normals. There was also no difference in mean tibial translation between the normal knees of the study sample and the knees from the normal sample. Based on these results, a valid comparison of anterior tibial translation during maximal voluntary isometric quadriceps contraction may be made between right and left knees within the same subject.

A few authors have expressed the opinion that the difference in translation between knees is the most appropriate value to study (9,15,17,27,30). Mean differences between knees in the normal sample of this study ranged from 0 to 3.6 mm, a mean of 1.3 mm. Mean differences between knees for subjects in the study group ranged from 0.6 mm to 8.4 mm, mean of 3.1 mm. The findings for the study group complement those of Jacobsen (9) and Oullet (27), who reported that differences in anterior tibial translation measured with stress radiography of more than 3 mm is likely to be pathological. The normal difference of 1.3 mm found in this study is similar to the slightly greater than 1.0 mm difference Sylvin (30) reported with passive testing using an objective measurement apparatus. Given that the sample sizes used in this study are relatively small, a difference between knees of greater than 3.1 mm of anterior translation of the tibia on the femur measured during maximal voluntary isometric contraction of the quadriceps may be a sign of anterior cruciate ligament deficiency.

Fukubayashi et al. (4) reported when the anterior cruciate was cut passive anterior tibial translation was greatest between 15 and 45 degrees of knee flexion, 17.5 mm. They found this to be 2.5 times greater than that found for intact knees, 7 mm. Data from this study showed when the anterior cruciate ligament was absent, that at 45 degrees of flexion, mean tibial translation was 5.59 mm, or 3.5 times

greater than the normal mean of 1.59 mm. The translations measured in this study in the presence of a maximal isometric quadriceps contraction are more than three times less than those measured passively by Fukubayashi et al. Fukubayashi et al. did no statistical analysis to compare translations at the various angles tested. In this study, no statistical difference was found between 15, 45 and 60 degrees of flexion.

CONCLUSIONS

It is concluded that maximal voluntary isometric quadriceps exercises should be avoided within the knee range of motion of 60 to 15 degrees of flexion in subjects with absent anterior cruciate ligaments.

The conclusion is drawn that a valid comparison of anterior translation of the tibia on the femur during maximal voluntary isometric quadriceps contraction may be made between right and left knees within the same subject.

Finally, it is concluded that a greater than 3.1 mm difference in anterior translation of the tibia on the femur measured during maximal voluntary isometric quadriceps contraction may be a sign of anterior cruciate ligament deficiency.

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