THE UNIVERSITY OF MANITOBA

RELIABILITY AND VALIDITY OF THE GENUCOM IN ASSESSMENTS OF ACL-DEFICIENT KNEES

by
Lisa A. Wipperman

submitted to
The Faculty of Graduate Studies
in partial fulfillment of the requirements for the
degree of Master of Science in Physical Education

Faculty of Graduate Studies

ISBN 0-315-76985-8

RELIABILITY AND VALIDITY OF THE GENUCOM IN ASSESSMENTS OF ACL-DEFICIENT KNEES

BY

LISA A. WIPPERMAN

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

MASTER OF SCIENCE

TABLE OF CONTENTS

Abstract

Reliability and Validity of the Genucom in Assessments of ACL-Deficient Knees

University of Manitoba Wipperman, L. A.

The purpose of the study was two-fold: to determine the test-retest reliability of the Genucom Knee Analysis System when testing normal subjects, and to determine the validity of the Genucom when testing ACL-deficient knees, compared to clinical assessments. Twenty subjects with no history of knee pathology participated in the study in order to test the reliability of the Genucom. Fifteen subjects who had been previously diagnosed as ACL-deficient in one knee participated in the study in order to test the validity of the Genucom. The subjects were obtained through physician patient records, made available to the investigator from three orthopaedic surgeons. The Genucom testing protocol consisted of a 90 degree anterior drawer test, 30 degree anterior drawer test, varus/valgus test at 0 degrees, varus/valgus test at 20 degrees, a medial compartment subluxation test, and a lateral compartment subluxation test. The twenty normal subjects were tested twice on the Genucom on different days. The fifteen subjects with ACL-deficient knees were tested once on the Genucom and the results were compared to a clinical assessment carried out by two orthopaedic surgeons. The reliability data was analyzed using Pearson's correlation coefficient and frequency distribution. None of the r values calculated for the reliability data resulted in high correlation and only the varus/valgus tests at 0 and 20 degrees resulted in a high level of agreement between the test and retest laxity scores. Only the varus/valgus test at 0 degrees resulted in significant but moderate correlation when the clinical assessments were compared to the Genucom assessments. The results of the validity study also suggested a testing order effect as the subjects with ACL-deficient left knees had significantly different laxity scores than the subjects with ACL-deficient right knees.

Acknowledgements

The author would like to thank her thesis committee, Dr. M. Alexander, Dr. J. Irving, and Dr. K. Lindner for their assistance and guidance while she was working on this paper. Special thanks to Dr. Alexander, my advisor, for her encouragement and support throughout my Master's program.

Acknowledgement is extended to Dr. V. de Korompay, who along with Dr. Irving contributed his expertise toward the completion of this study. Acknowledgement is also extended to the subjects who participated in the study. Special thanks to Linda, Cathy, Howard, and Rick for their assistance and support throughout the study.

List of Tables

List of Figures

Leaf left blank to correct page numbering

CHAPTER ONE

INTRODUCTION

Injuries to the knee joint, the anterior cruciate ligament in particular, are among the most common injuries experienced by people involved in physical activity (Johnson, 1983). Most knee joint injuries affect the soft tissue structures of the joint, including the ligaments, the menisci, and the joint capsule itself. These soft tissue structures are the main sources of stability for this joint, which is poorly designed to withstand the lateral, anterior/posterior and torsional forces which are produced during rapid athletic movements. When ligaments are partially or completely torn, the bones tend to move out of alignment during knee movement which produces laxity and instability in the joint. Treatment and management of the injured knee can only be undertaken after the diagnosis and mechanisms of the injury have been established. The ability to determine the extent of knee joint laxity or instability in an injured limb, when compared to the uninjured limb, is the key to diagnosis and treatment.

This evaluation of knee joint laxity, or the amount of motion in all three planes between the femur and the tibia (Losee, 1985), has traditionally been determined with the orthopaedic surgeon, physiotherapist or athletic therapist moving the joint by manual

manipulation techniques (Youm, Bass, & Savory, 1987). However, the subjective nature of this type of clinical examination presents a significant problem in diagnosis of anterior cruciate ligament-deficient knees (Oliver & Coughlin, 1987; Frankel, 1971; Marshall, 1976; DeLee, Riley, & Rockwood, 1983; and Youm, Bass, & Savory, 1987). As with any other subjective tests there is little assurance that the results of these tests are accurate, or that there will be any agreement between the findings of two or more different evaluators. Daniel, Stone, Sachs, and Malcom (1985) stated for example that the ability of the clinician to use the Lachman test to detect ACL deficiency is "dependent on the ability of the hands to perceive small movements." It is vital that any examination protocols used be objective methods from which knee joint stability can be studied and recorded (Oliver & Coughlin, 1987).

The Genucom Knee Analysis System (Oliver & Coughlin, 1987), a six-degree-of-freedom computer-based 3-D electrogoniometer is designed specifically to provide objective assessment and recording of knee joint stability. The Genucom has incorporated a six component force dynamometer which records measurement of moments and forces applied to the knee. These two features allow the clinician to perform the tests of knee joint stability while an objective reading of the displacements and applied forces is recorded.

There are several devices available on the market to measure knee joint laxity, including the Genucom, The Medmetric KT-1000, and the Stryker. Most of these devices are based on the techniques of electrogoniometry, in which a goniometer is strapped to the limb and a potentiometer attached to the axis of the device measures the change in angle by the change in electrical potential recorded. Of these devices, the Genucom appears the most versatile as it can simultaneously document anterior-posterior displacement, flexion-extension, varus/valgus displacement and rotation (Anderson & Lipscomb, 1989) while the MEDmetric arthrometer (Daniel, Stone, Sachs, & Malcom, 1985) and the Stryker arthrometer (Steiner, Grana, Chillag, & Schelber-Karnes, 1986) were capable of measuring only anterior displacement. Since these latter two commercially available devices cannot measure rotation or anterior translation of the lateral tibial plateau, which is specifically increased in the absence of the ACL, valid measurements may be difficult to obtain (King & Kumar, 1989).

However, the validity and reliability of the test results from these devices have not yet been examined in enough detail to ensure accurate scores of knee laxity. More study is needed to determine the test-retest reliability of the Genucom, as well as the validity of the scores. If the Genucom scores indicate an anterior-posterior laxity difference of 4mm between the injured and non-injured leg in a subject, would an experienced clinician find a similar result from a

clinical examination? Another associated problem which frequently confuses the clinical examination is the inability of the examiner to precisely reproduce the conditions under which a test is done on the injured and the contralateral leg. For example, during a varus stress test with the knee flexed to approximately 30 degrees, it is extremely difficult to monitor precisely the amount of tibial rotation which occurs in conjunction with this test. Differences of 3 or 4 degrees in the amount of internal tibial rotation, for example, may have significant impact on the interpretation of the varus sign.

There is a need to more closely examine the value of test scores from electromechanical devices such as the Genucom, to determine if these scores can justifiably be used to monitor the severity of a knee injury, or to monitor recovery from injury. If the test results are too variable, then possibly the usefulness of these machines as diagnostic/rehabilitative tools is limited.

Purpose of the Study

The purpose of the study was two-fold: to determine the test-retest reliability of the Genucom Knee Analysis System when testing knees of normal subjects, and to determine the validity of the Genucom when testing ACL-deficient knees, compared to clinical assessments.

Rationale for the Study

The Genucom Knee Analysis System may be important future applications if proven both a reliable and valid tool of assessment of knee joint laxities. It could be used to compare a patient's knee stability pre- and post-surgically, with both the initial injury assessment and the followup documentation stored in the computer for future comparison. It could also become a valuable tool in clinical research, for evaluation of bracing techniques, and for pre- and post-seasonal evaluation and screening for sports teams. Another possible future application would be developing a Genucom system of assessment for defining exact types of instabilities for which direct treatment and rehabilitation could be prescribed.

Limitations and Delimitations

1. All subjects tested for Genucom reliability had no previous history of knee or lower extremity pathology.
2. All previously injured subjects used had a unilateral ACL-deficient knee with no other associated ligament damage. However, subjects with partial meniscus tears were acceptable.
3. All previously injured subjects had arthroscopically confirmed ACL injuries or were candidates for reconstructive surgery.
4. All subjects were tested on the Genucom by the same tester.
5. All clinical assessments were performed by the same two orthopedic surgeons.

Definition of Terms

Laxity - "a quantifiable normal or abnormal displacement of the joint," depending on the degree and variation between the knees (Noyes, Mooar, Matthews, & Butler, 1983).

Instability - displacement of the knee joint that results in unsturdiness and is pathological. It indicates a clinically defined syndrome exists (Noyes, Mooar, Matthews, & Butler, 1983).

ACL-deficient knee - a knee in which damage to the anterior cruciate ligament has caused the knee to become pathologically unstable.

CHAPTER 2

REVIEW OF LITERATURE

Anatomy of the Knee

The knee joint is the largest and most complex joint in the body. To the naked eye it resembles a simple hinge joint, however, the movements of the knee are much more complex than a simple hinge joint. The articular surface on the medial condyle is somewhat longer from front to back and is less curved than the articular surface of the lateral condyle and this causes lateral and medial rotation to occur in the femur and tibia during flexion and extension (Gray, 1985; Spence & Mason, 1983). Incongruence of the articular surfaces make the knee vulnerable to injury, but stability is maintained by the strength and arrangement of the ligaments, tendons and muscles crossing the joint.

Ligaments and tendons, along with the joint capsules, stabilize and connect the joints. The basic structural protein of tendons and ligaments is collagen (Arnoczky, 1983; Carlstedt & Nordin, 1989). The strength and flexibility of tendons and ligaments comes from the mechanical stability of collagen (Carlstedt & Nordin, 1989). Tendons generally have greater collagen content than ligaments (Bessette & Hunter, 1990).

Ligaments, along with the joint capsule, serve to connect bone to bone. According to Carlstedt and Nordin (1989), the role of these

structures is to provide joint stability, guide joint motion and restrict excess motion. Tendons serve to connect muscle to bone and produce joint motion by transmitting tensile loads from the muscles to the bones (Carlstedt & Nordin, 1989).

Articular Surfaces

The knee joint is a compound joint and can be looked at as having three articulations with a common joint cavity (Gray, 1985). There are two condyloid joints, one between each condyle of the femur and the opposing condyles of the tibia, and a third between the femur and the patella.

The tibial condyles are slightly concave cartilage-covered surfaces which are separated by the intercondylar area. The two femoral condyles are cam-shaped and are curved more posteriorly than anteriorly (Dye & Cannon, 1988; Gray, 1985). They are convex both from front to back and from side to side, and are separated by the intercondylar notch. As stated previously, the surface of the medial femoral condyle is longer than the lateral condyle.

Attached to only the outer margins of the tibial condyles are the crescent-shaped fibrocartilages which form the medial and lateral menisci. The menisci are involved in rotation of the femur on the tibia and due to their peripheral attachment can frequently become damaged or torn loose in athletic injuries (Spence & Mason, 1983).

The articular surface of the patella fits rather imperfectly within the concave surface of the femur. The articular surface of the patella is divided into a large lateral and smaller medial portion by a longitudinal ridge (Gray, 1985).

Articular Capsule

The knee joint is completely enclosed by an articular capsule consisting of tendinous expansions between which a few true capsular fibers are found connecting the articulating bones (Gray, 1985). The inner capsular surface is lined by a synovial membrane and the outer fibrous layer is separated from the inner layer by other joint structures such as fat pads and the menisci (Gray, 1985). Anteriorly, the fibrous layer of the capsule is completely lacking above the patella. At the level of the patella and below it, the anteriomedial and anteriolateral aspects of the fibrous capsule blend with tendinous expansions of the vastus medialis and vastus lateralis, as well as with the fascia lata (Gray, 1985). Posteriorly, the capsule consists of vertical fibers which blend posteriorly and above with the tendons of the gastrocnemius (Gray, 1985).

Laterally, the capsule consists of fibers which stretch from the border of the lateral femoral condyle to the lateral aspect of the tibial condyle (Gray, 1985). Medially, the articular capsule stretches from the medial femoral condyle to the medial tibial condyle. The lateral collateral ligament and the cruciate ligaments are distinct from the articular capsule of the knee because of the unique

structure of the capsule which does not form a complete fibrous sac as generally found in other joints (Gray, 1985).

Muscles Acting on the Knee

Muscles are an indispensable factor in maintaining the stability of the knee joint. Normal movement of the knee joint during weight-bearing, extension with lateral tibial rotation and flexion with medial rotation, is under control of the thigh muscles (Helfet, 1974). Only when the thigh muscles are relaxed is it possible to freely rotate the tibia on the femur (Helfet, 1974).

Quadriceps

The vastus medialis of the quadriceps muscle group, the most prominent muscle of the group, passes inward from its origin at the medial lip of the linea aspera of the femur (Spence & Mason, 1983) and is inserted into the tibia through the patella and the patellar ligament with its fibrous expansion stronger on the medial side (Helfet, 1974). The tendon of rectus femoris covers the knee joint anteriorly while the vastus lateralis inserts into the lateral border of the patella and blends with the tendon of the rectus femoris (Gray, 1985). The vastus intermedius also blends with the deep portion of the common tendon which inserts into the tibia.

The quadriceps group act to extend the leg and rotate the tibia outward during knee extension (Helfet, 1974). Fibers, which run from the vastus medialis to the common tendon of the quadriceps and the patella, also help prevent lateral dislocation of the patella.

Medial Hamstrings

The medial hamstrings, semimembranosus and semitendinosus, which originate from the ischial tuberosity, pass downward and inward, inserting into the upper tibia on the anteromedial and posterior surfaces (Spence & Mason, 1983; Helfet, 1974). The main function of the medial hamstrings is to rotate the tibia inward during knee flexion (Helfet, 1974). The semimembranosus also anchors the posterior meniscus due to its insertion into the posteromedial aspect of the knee joint capsule (Helfet, 1974).

Popliteus

The popliteus muscle originates from the proximal posterior tibial surface and winds upward and forward around the knee posterolaterally, inserting into the lateral femoral epicondyle just above the joint line (Helfet, 1974). Due to its unique orientation, the popliteus acts to flex and medially rotate the knee (Spence & Mason, 1983). The popliteus tendon grooves the lateral meniscus and this causes the posterior end of the lateral meniscus to be anchored during flexion of the knee (Helfet, 1974).

The Biceps Femoris and Iliotibial Band

The biceps femoris tendon inserts on the lateral surface of the fibula along with the lateral collateral ligament (Spence & Mason, 1983; Helfet, 1974). The iliotibial band inserts into the tibia via the lateral capsule and into the fibula through the lateral collateral ligament (Helfet, 1974). Both structures aid in stabilization of the

fully extended knee and also play a role in external rotation of the tibia (Helfet, 1974). The biceps femoris is also a knee flexor.

Ligaments

Posterior Ligaments

The capsule is strengthened posteriorly by two ligaments, the oblique popliteal and the arcuate popliteal. The oblique popliteal is a broad flat band that is attached proximally to the posterior surface of the femur just above the articular surface of the lateral condyle and distally to the posterior margin of the medial condyle of the tibia (Gray, 1985; Spence & Mason, 1983). Many of the superficial fibers arise from the tendon of the semimembranosus muscle (Spence & Mason, 1983). The arcuate popliteal passes from the posterior surface of the lateral condyle of the femur to the posterior border of the intercondylar area of the tibia and to the posterior styloid process of the fibula (Gray, 1985).

The oblique popliteal ligament is taut during flexion of the knee (Gray, 1985) and provides secondary stabilization against valgus stress (Marshall & Baugher, 1980). The arcuate popliteal ligament, along with the lateral collateral ligament, stabilizes against varus stress (Marshall & Baugher, 1980; Andrews & Axe, 1985). The arcuate popliteal ligament also provides a check against postero-lateral rotation (Marshall & Baugher, 1980).

Medial/Lateral Ligaments

The knee joint is stabilized medially and laterally by the medial and lateral collateral ligaments. The medial collateral ligament is attached above to the medial femoral epicondyle and below to the medial condyle of the tibia. The anterior margin of the ligament is free while its posterior margin is attached to the medial meniscus (Gray, 1985). The lateral collateral ligament is attached superiorly to the posterior part of the lateral femoral epicondyle and inferiorly to the lateral side of the head of the fibula. The lateral collateral ligament lies outside the joint capsule (Gray, 1985).

The medial collateral ligament is the primary stabilizer against valgus stress in both flexion and extension (Marshall & Baugher, 1980). Conversely, the lateral collateral ligament is a stabilizer against varus stress (Marshall & Baugher, 1980). In extreme flexion of the knee, the collateral ligaments are in a relaxed state while in full extension both ligaments are taut (Gray, 1985). The collateral ligaments also provide a check to medial and lateral rotation (Gray, 1985).

Anterior Ligaments

The anterior knee joint is strengthened by the patellar ligament which extends from the patella to the tibial tuberosity. This ligament is a continuation of the central tendon of the quadriceps muscle group. The posterior surface of the patellar ligament is separated from the synovial membrane of the joint by a large fat pad

and is separated from the tibia by a bursa (Gray, 1985). The patellar ligament is stretched during flexion of the knee and relaxed in full extension. During leg extension, the patellar ligament is tightened by the quadriceps femoris, but in full extension with the heel supported, the patellar ligament is relaxed (Gray, 1985).

Cruciate Ligaments

The joint is also provided with additional stability by the two intra-articular cruciate ligaments (Figure 1). These two ligaments are situated in the center of the joint and are called cruciate ligaments because their paths cross each other. The anterior cruciate ligament (ACL) is attached to the anterior intercondylar area on the tibial plateau surface and blends with the anterior edge of the lateral meniscus (Gray, 1985). The ACL passes upward, backward, and laterally to attach to the posterior aspect of the medial surface of the lateral femoral condyle. Compared to other ligaments of the knee joint, the ACL is the strongest and "least compliant" (Cabaud, 1983). The posterior cruciate ligament (PCL) is attached to the posterior intercondylar area of the tibia and is also attached to the posterior extremity of the lateral meniscus (Gray, 1985). It passes upward, forward, and medially, and attaches to the lateral surface of the condyle of the medial femur.

Because of their unique structural arrangements, the cruciate ligaments perform very specialized functions. When the knee is extended the ACL is taut, thus limiting hyperextension of the knee.

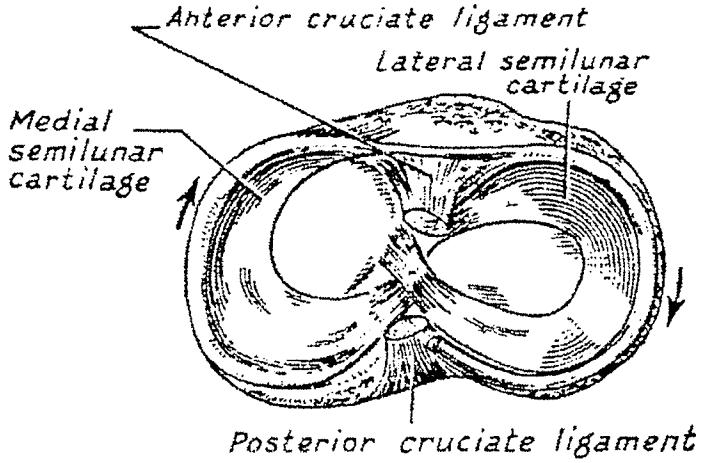

Figure 1 Head of the right tibia from above, showing the menisci and the attachments of the cruciate ligaments onto the tibia. (Adapted from Helfet, 1974)

It also prevents sliding of the femur on the tibial plateau. According to Ellison and Berg (1985), the primary role of the ACL is to resist anterior displacement. Due to the attachment to the lateral condyle, as the ACL extends to its limit during knee extension. The medial condyle continues to move further causing medial femoral rotation until full extension is reached. The collateral ligament and the oblique popliteal ligament then become taut limiting further rotation as the joint locks. This action, to which the ACL is the main contributor, is called the "screw home" mechanism and it allows the knee to attain rigidity (Cabaud, 1983; Ellison & Berg, 1985; Rong & Wang, 1987). The ACL also assists in limiting medial rotation when the foot is solidly on the ground, thus fixing the leg (Ellison & Berg, 1985).

When the knee is flexed, the PCL becomes taut, preventing the tibia from slipping posteriorly. This ligament is especially important when walking down hill or down steps when body weight is transferred to the tibia at the same time as the knee joint flexes (Gray, 1985).

The Menisci

The superior surfaces of the tibial condyles, which are the largest weight-bearing surfaces of the body, are deepened by crescent-shaped cartilages, the medial and lateral menisci (Figure 1). The menisci are only attached at their outer margins and frequently become damaged or torn in athletic injuries (Spence & Mason, 1983; Gray, 1985). The upper surfaces of the menisci are in contact with the femoral condyles and the lower surfaces sit upon the head of the tibia.

The medial meniscus is semicircular in shape and is wider in the back than anteriorly. Its anterior horn is attached to the front of the intercondylar area of the tibia anterior to the ACL. A band of its fibers run behind the tibial attachment and are continuous with the transverse ligament of the knee. The posterior horn is attached to the posterior intercondylar area of the tibia between the attachments of the lateral meniscus and the posterior cruciate ligament (Gray, 1985).

The lateral meniscus forms an incomplete circle. It covers a greater portion of the tibial surface than the medial meniscus but is

less firmly attached (Gray, 1985). The lateral meniscus is separated from the lateral collateral ligament by the tendon of the popliteus muscle. It is attached at its anterior end in front of the intercondylar eminence of the tibia just behind and lateral to the ACL with which it blends (Gray, 1985). The anterior margin is attached to the transverse ligament of the knee. The posterior end is attached behind the intercondylar eminence of the tibia and in front of the posterior end of the medial meniscus (Gray, 1985).

During movement of the knee joint, the role of the menisci is limited to control of rotation (Gray, 1985). The rotation guidance provided by the menisci aids the cruciate ligaments during flexion and extension by keeping the tibia on the helical path related to the screw-home mechanism (Helfet, 1974).

Knee Joint Motion

Motion in the knee joint occurs simultaneously in three planes-sagittal, transverse and frontal (Figure 2) (Nordin & Frankel, 1989). Motion in the sagittal plane is so much greater than in the other two planes that two main movements defined about the knee are flexion and extension (Kapandji, 1987; Nordin & Frankel, 1989; Frankel & Nordin, 1984; Frankel, 1971). Therefore, discussion on knee joint motion will be limited to the sagittal plane except where discussion of the transverse and frontal planes appears relevant to the function of the anterior cruciate ligament.

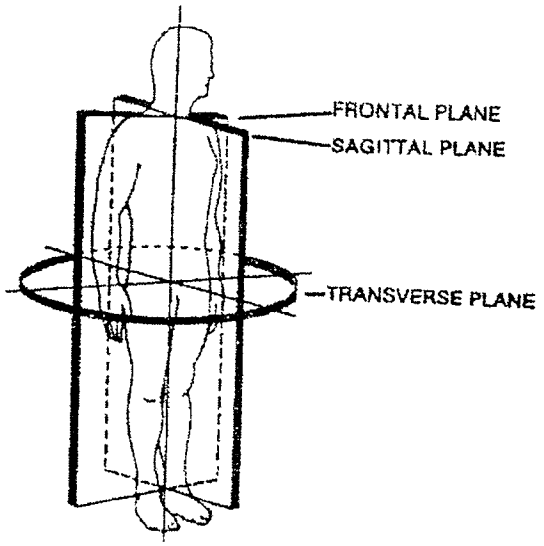

Figure 2 The three planes of motion in the human body. (Taken from Nordin & Frankel, 1989)

Kinematics

In order to study the characteristics of motion in the knee joint an understanding of knee joint kinematics is essential. Kinematic data are used to study the characteristics of motion in a joint without reference to force or mass (Nordin & Frankel, 1989). This branch of mechanics clearly "defines the range of joint motion" in the knee and also describes the surface joint motion along the frontal, sagittal and transverse planes (Nordin & Frankel, 1989).

Range of Joint Motion

The range of motion in the tibiofemoral joint is greatest in the sagittal plane, where the range from full extension to complete flexion is 0-140 degrees (Nordin & Frankel, 1989). Kapandji (1987) stated, however, if the hip is extended, the range of flexion is reduced to a range of 0-120 degrees due to the fact "the hamstrings lose some of their efficiency with extension of the hip" due to being fully stretched. Muller (1983) described normal sagittal range of motion as including from 5 degrees of hyperextension to 145 degrees of flexion and for this to occur the origins of the cruciate ligaments in the femur must "lie on a line that forms a 40 degree angle with the long axis of the femur" (Figure 3).

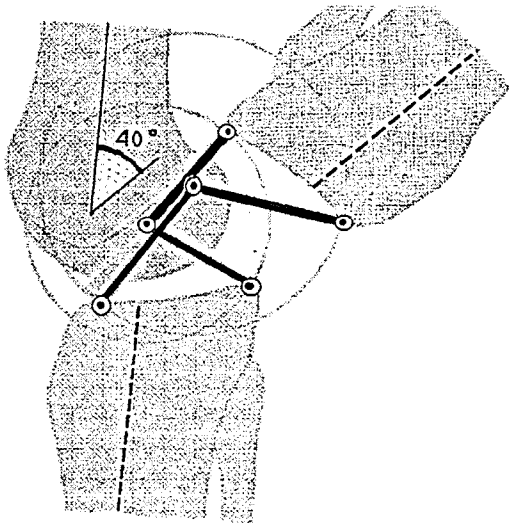

Figure 3 The 40 degree angle of the cruciate attachments to the femur which allows normal knee mobility. If angle is changed, normal range of motion may be disrupted. (Taken from Muller, 1983)

The range of motion of the tibiofemoral joint in the transverse plane increases as the knee articulates from full extension to up to 90 degrees of flexion. These movements include medial and lateral rotation of the tibia on the femur. In full extension there is virtually no motion in the transverse plane due to the interlocking of the femoral and tibial condyles (Nordin & Frankel, 1989; Frankel & Nordin, 1984). At 90 degrees of flexion, external rotation of the knee ranges from approximately 0-45 degrees, while internal rotation ranges from approximately 0-30 degrees (Nordin & Frankel, 1989; Kapandji, 1987).

Movement in the frontal plane includes adduction and abduction of the femur on the tibia. Almost no adduction or abduction is possible when the knee is fully extended. As flexion increases up to 30 degrees, motion in the frontal plane increases. However, maximum adduction/abduction is only a few degrees. Past 30 degrees of knee flexion, motion in the frontal plane decreases due to the restriction of various soft tissue structures (Nordin & Frankel, 1989).

Kinematics of the Rolling-Gliding Principle

In the sagittal plane, the knee moves by a combination of rolling and gliding motions (Figure 4) (Muller, 1983; Ellison & Berg, 1985). These unique dynamics are due to the shape of the femoral condyles, which, in the sagittal plane, are eccentrically curved and the lengths of the circumference of the femoral condyles is twice that

of the tibial condyles (Kapandji, 1987; Ellison & Berg, 1985). Anteriorly, the femoral condyles are flatter and posteriorly they are more curved than the tibial condyles (Muller, 1983). Rolling is predominant in the beginning of flexion, due to the more oval (flatter) shape of the femoral condyles. Gliding comes into play in the latter stages of flexion, at which point the condyles are more curved in shape and offer less surface contact with the tibial surface. Pure rolling for the medial condyle occurs during the first 10-15 degrees of flexion while for the lateral condyle pure rolling continues

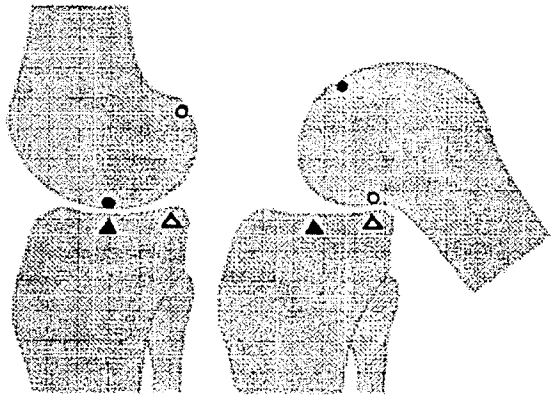

Figure 4 Movement of the femur relative to the tibia during flexion demonstrates contact is a combination of rolling and gliding due to the came-shaped femur. (Taken from Muller, 1983)

until 20 degrees of flexion is reached (Kapandji, 1987). According to Kapandji (1987), the greater range of motion of the lateral condyle than the medial condyle partially explains why the distance covered by the lateral femoral condyle over the opposing tibial condyle is greater than that of the medial femoral condyle.

The changing ratios of rolling to gliding impart a changing axis of rotation in the sagittal plane of the knee during movement through the flexion arc. Muller (1983) has shown this variable axis of rotation biomechanically by using a crossed four-bar linkage system (Figure 5). The crossed bars correspond to the course of the cruciate ligaments. The other two bars of the system are the femur between the origin of the anterior cruciate ligament and the insertion of the posterior cruciate ligament and the tibia between the insertion of the anterior cruciate and the origin of the posterior cruciate (Dye & Cannon, 1988). In Muller's (1983) system the four-bar linkage

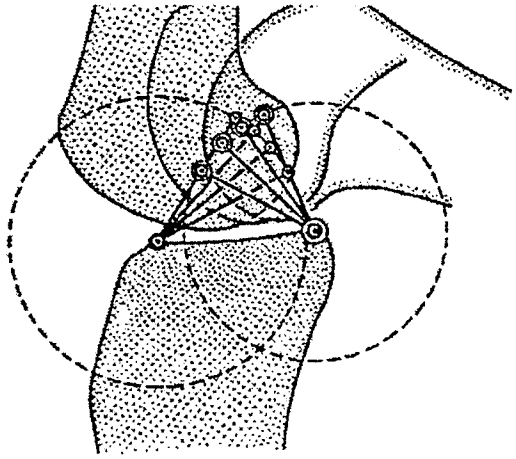

Figure 5 The crossed-bar linkage system demonstrates how the cruciate ligaments move on circular arcs during flexion and extension. (Taken from Muller, 1983)

produces a coupled rolling and gliding motion between the tibia and femur. According to Dye and Cannon (1988), such a four-bar linkage

model can be used to mathematically predict many asymmetries of knee anatomy, as well as kinematics.

Screw-Home Mechanism

Knee joint motion in the transverse plane, when analyzed, reveals a different type of motion. As the knee is extended, the tibial plateau rotates externally and during flexion, it rotates internally (Figure 6) (Ellison & Berg, 1985; Dye & Cannon, 1988; Frankel & Nordin, 1984). This combined action of knee extension and external rotation of the tibial plateau is known as the "screw-home" mechanism and it "affords greater stability to the knee joint in preparation for body weight loading in single-leg stance." (Ellison & Berg, 1985). This mechanism is due to the size difference between

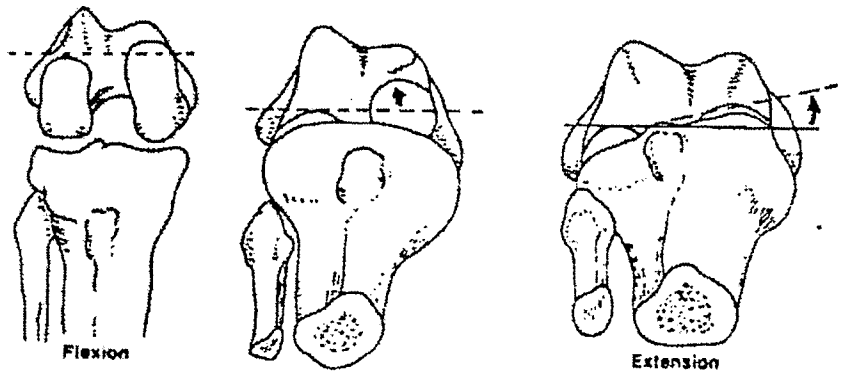

Figure 6 Screw home mechanism. (Adapted from Ellison & Berg, 1985)

the medial and lateral condyles and the shape differences between the medial and lateral tibial plateaus as previously noted.

Ligament Strength

Ligaments are the main stabilizers of the knee joint (Andrish, 1985; Frankel & Nordin, 1984). According to Frankel and Nordin (1984), the strength of a ligament under loading is determined by the speed of loading and the size and shape of the ligament. Carlstedt and Nordin (1989) concluded from their review of literature that as the rate of loading increases, ligaments become more susceptible to injury and the bone becomes less susceptible. For example, at a fast loading rate (0.6 seconds/cycle), which parallels a knee injury mechanism, the ligament fails and at a slow loading rate (60 seconds/cycle), the insertion point of the ligament on the bone produced an avulsion fracture (Noyes,1977).

The strength of the ACL has been explored through loading of cadaver knees (Noyes, Butler, Grood, Zernicke, & Hefzy, 1984; Noyes & Grood, 1976; Kennedy, Hawkins, Willis, & Danylchuck, 1976). It was found that a maximum force to failure of the ACL was approximately 1730 N but it was hypothesized that it is loaded only to approximately 445 N for most normal activities. Noyes (1977) found that the ACL elongated as much as seven millimeters before complete failure. Carlstedt and Nordin (1989) converted the force-elongation curve into a load-displacement curve (Figure 7) and divided it into regions corresponding to the clinical findings: 1) the load applied to the ACL during a anterior drawer stability test; 2) the load on ACL during "physiologic activity"; and 3) the load applied to

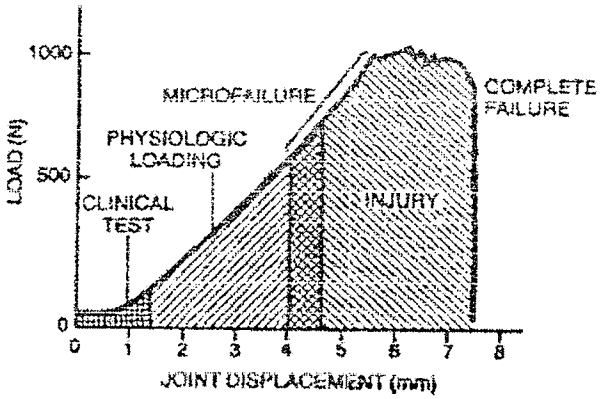

Figure 7 Load-displacement curve for the anterior cruciate ligament. (Adapted from Carlstedt & Nordin, 1989)

the ACL during an injury, from partial tear to complete rupture.

Butler, Noyes, and Grood (1980), in a study using cadaver knees, looked at the average restraining forces at 90 degrees and 30 degrees flexion for five millimeters of anterior/posterior drawer. For the ACL the restraining force was an average of 375 N at 90 degrees and 292 N at 30 degrees of flexion. At 90 degrees, the ACL restraint represented 87% of the total anterior/posterior restraining forces and at 30 degrees, it was approximately 88% of the total restraining force.

Anterior Cruciate Ligament Function

According to Ellison and Berg (1985) biomechanical data has suggested five principal functions of the anterior cruciate ligament: 1) resisting anterior tibial translation on the femur (in flexion); 2) prevention of hyperextension of the knee; 3) restraint to internal

rotation; 4) provides secondary restraint to varus/valgus stress; and 5) stabilizing factor in screw home mechanism as the joint approaches complete extension.

Anterior Tibial Displacement

As the knee moves from full extension into flexion, tension in the ACL varies, reaching its lowest point at approximately 40 degrees of flexion and as flexion increases past 40 degrees tension in the ACL again increases (Ellison, 1980). In a study conducted by Kennedy, Weinberg, and Wilson, (1974) on fresh cadaver knees, it was found that the ACL was taut in full extension to 20 degrees of flexion, most relaxed between 40-50 degrees and taut again from 70-90 degrees. Tension was estimated by visual inspection and palpation of the ACL using a septal elevator and a small curved hook. Butler, Noyes, and Grood (1980), also examined the ACL in cadaver knees and found that the ACL provided 86 percent of the total resisting force to anterior tibial displacement. The anterior drawer forces were applied with the knee in both 90 and 30 degrees of flexion. It is likely, therefore, that the ACL is most susceptible to injury by anterior tibial displacement when it is taut and providing the majority of the resistive force.

Prevention of Hyperextension

During extension and hyperextension from a neutral position, the ACL fibers are stretched (Kapandji, 1987; Muller, 1983). During hyperextension, the floor of the intercondylar fossa hits the ACL and

stretches it further in "the manner of a trestle" (Kapandji, 1987). In normal loading conditions, the ACL prevents hyperextension of the knee (Ellison & Berg, 1985; Mains, Andrews, & Stonecipher, 1977). In a study using cadaver knees (Kennedy, Weinberg, & Wilson, 1974), tears of the ACL were reproducible with complete anterior dislocations of the knee (30 degrees of hyperextension). Mains, Andrews, and Stonecipher (1977), in a study using amputated knees found that the ACL is under tension in hyperextension and could rupture if forced further at that point.

Check to Internal Rotation

It is believed that the ACL acts to check internal rotation of the tibia (Kennedy, Weinberg, & Wilson, 1974; Ellison & Berg,1985; Mains, Andrews, & Stonecipher, 1977). Kennedy, Weinberg, and Wilson (1974), showed, in patients who suffered an isolated ACL injury, that excessive internal rotation appeared to be the mechanism of injury. In trying to reproduce the internal rotation injury mechanism in cadaver knees, Kennedy, Weinberg, and Wilson (1974), found tension increased in the ACL but femur and tibia fractures always occurred at the clamp sites before ACL rupture occurred. Wang and Walker (1974) showed, in a study of cadaver knees, that the ACL provided a secondary restraint to rotatory movement along with the primary restraint of the collateral ligaments.

Varus/Valgus Stress

The anterior cruciate ligament also provides a secondary restraint to excessive varus/valgus stress. The integrity of the ACL is compromised only after collateral ligament failure (Larson, 1980; Kennedy, Weinberg, & Wilson, 1974). With the collateral ligaments disrupted, the ACL is left without any primary restraints to protect it against varus/valgus stress and a secondary lateral laxity develops due to the increased stress load on the ACL (Larson, 1980).

Screw-Home Stabilization

The anterior cruciate ligament adds precision to the screw-home mechanism as the knee nears full extension. It is at this stage that stability is most important, especially in the process of deceleration or sharp changes in direction (Ellison & Berg, 1985). As previously stated, the screw-home mechanism is a product of the knee's bony geometry and tension in the ACL is paramount to the precision of locked full extension. The ACL provides the external rotatory control of the tibia on the femur in terminal extension (Ellision, 1980). As the ACL becomes taut, further rotation is limited and the joint locks into a rigid structure. Interference with the ability to fully extend thus compromises the stability of the knee joint (Welsh, 1980; Ellison, 1980).

Mechanisms of Injury

The diagnosis and severity of an acute knee injury can be aided in great part by understanding the mechanism of injury. According

to Zarins and Nemeth (1985), knowledge of the mechanism of knee injury is usually the single most important piece of information for the physician in arriving at the correct diagnosis.

The mechanism of injury can be defined as a "detailed description of what occurred at the time of injury" (Zarins & Nemeth, 1985). How the knee is injured will vary with the type of activity and the stresses involved, so to identify the mechanisms of injury the following points must be examined: angle of the knee at the time of contact, contact or noncontact injury, and direction of applied force (Baker, 1990; Zarins & Nemeth, 1985).

Contact Injuries

In a contact injury, a force is applied across the knee joint from outside the body (Zarins & Nemeth, 1985; Ellison, 1980). One of the most common contact injuries is the "clipping injury" (Wang, Rubin, & Marshall, 1975; Zarins & Nemeth, 1985). In this injury, the foot is firmly planted on the ground, in slight flexion, while the opposing player hits the leg from the anteriolateral side of the knee (Figure 8). Wang, Rubin, and Marshall (1975), suggested the mechanism of injury is hyperextension with internal rotation and an isolated ACL rupture results. The effect of the opposing player's hit was to drive the knee into hyperextension. It is believed that hyperextension was the movement essential in producing the isolated ACL injury (Wang, Rubin, & Marshall, 1975; Zarins & Nemeth, 1985; Howe & Johnson, 1985; Fetto & Marshall, 1980).

Figure 8 Film sequence showing common mechanism of contact injury where number 72 is blocked from the anterolateral direction as all his weights is coming down on the extended left knee. (Taken from Wang, Rubin, & Marshall, 1975)

If the athlete is hit by the opponent more posteriorly on the lateral side, the medial collateral ligament and medial capsule will be damaged first and only then will damage to the ACL follow (Zarins & Nemeth, 1985). A direct blow to the posterior tibia by the opponent could also cause trauma to the ACL (Baker, 1990).

Noncontact Injuries

Injury to the ACL is the most common severe ligament injury to the knee and typically it does not require contact or external force to occur (Andrish, 1985). Approximately 67 percent of ACL injuries are noncontact injuries (Baker, 1990). A noncontact injury occurs when an indirect force is applied to the knee by a forceful body movement such as in open field running with sudden directional changes (Zarins & Nemeth, 1985; Andrish, 1985).

The most common noncontact injury results from a deceleration mechanism combined with foot fixation, valgus and external rotation (Figure 9) (Fetto & Marshall, 1980; Zarins & Nemeth, 1985; Baker, 1990). The playing surface can significantly contribute to the foot fixation problem. Artificial turf, used in many sports facilities due to its low maintenance and practicality in domed stadiums, can contribute to the foot fixation problem because of the stickiness of the turf shoe/surface interfaces (Baker, 1990). According to Baker (1990), this can "produce torsion with hyperextension or abduction and external rotation stresses on the knee," which may cause trauma to the MCL (medial collateral ligament) and the ACL.

Figure 9 Common mechanism of noncontact injury with the left foot planted externally and body pivoting toward the right. (Taken from Zarins & Nemeth, 1985)

Hyperextension injuries can also result without externally applied forces. A situation, such as landing from a jump on an extended knee may force the knee into further extension resulting in injury to the ACL and associated structures (Zarins & Nemeth, 1985; Baker, 1990). The noncontact hyperextension mechanism usually produces an injury not unlike its contact counterpart, however, the forces are generally lower (Zarins & Nemeth, 1985).

Diagnosis of Injury

Classification of Sprains

Ligament injuries fall into three categories of severity and are called first, second or third degree sprains (Figure 10) (Andrish, 1985). A sprain is defined as "a traumatic joint twist that results in stretching, or tearing stabilizing connective tissues, " in this case, knee ligaments (Klafs & Arnheim, 1981).

A grade I or first degree sprain is a mild injury with the ligament intact and mild pain, swelling, and little or no loss of function (Andrish, 1985; Baugher & White, 1985). According to Andrish (1985), these injuries are usually 5-10 day injuries only and treatment consists of ice application and activity restriction.

A second degree sprain (grade II) is defined as "the partial tearing of a ligament" (Andrish, 1985). This injury is characterized by pain, swelling and some instability (Baugher & White, 1985; Andrish, 1985). According to Andrish (1985) it can be difficult to diagnose this injury clinically since some instability may exist but an

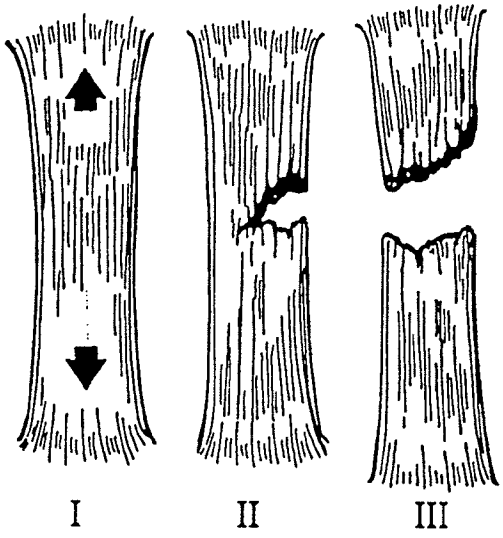

Figure 10 The three degrees of ligament sprains: 1) ligament stretched; 2) partial tear; 3) complete rupture. (Adapted from Andrish, 1985)

"endpoint" may still be present. Treatment of a grade II sprain usually requires 3-6 weeks of recovery time with crutches, brief immobilization, and possibly, a protective brace until full rehabilitation (Andrish, 1985).

A third degree sprain (grade III) is distinguished by its marked instability and a soft or indistinct "endpoint" suggesting a complete tear of the ligament (Andrish, 1985; Baugher & White, 1985). A third degree sprain may require operative repair and, depending on the ligament involved, time for healing can be as little as 4-6 weeks for a capsular tear to as much as one year for an ACL tear (Andrish, 1985). A complete tear of the ACL will produce increased laxity in the knee joint as the main stabilizer is gone.

There will be increased tibial translation on the femur with little or no "endpoint".

Evaluation of Knee Joint Stability

In order to successfully treat injured knee ligaments, and to assess the progress of a knee that has undergone surgical repair or treatment such as strengthening and exercise, a clinical evaluation of joint stability (laxity) is usually undertaken. Positive laxity and instability signs such as the anterior drawer at 90 degrees, the Lachman (30 degree anterior drawer), and the pivot shift test, can provide the clinician with a clearer picture of a "symptomatic anterior cruciate ligament deficient knee" (Noyes, Mooar, Matthews, & Butler, 1983).

According to Losee (1985), it is important to define laxity and instability as separate entities to avoid confusion. Noyes, Mooar, Matthews, and Butler (1983), define laxity as "a quantifiable normal or abnormal displacement of the joint, depending on the type, degree, and variation between the knees." Instability, on the other hand, "implies unsturdiness, is always pathological, and indicates a clinical syndrome" (Noyes, Mooar, Matthews, & Butler, 1983). For example, a positive anterior drawer sign alone may not be of significance to knee function (Losee, 1985).

Instability can be clinically quantified based on the amount of pathologic tibial motion relative to the femur as follows: 1+ (up to 5

mm); 2+ (6-10 mm); 3+ (11-15 mm); and 4+ (greater than 15 mm) (Orthopaedic Knowledge Update, 1984).

When evaluating knee joint, stability should be tested in the medial-lateral, anteroposterior and rotatory directions and the results compared with tests of the uninjured knee. The degree of laxity is not as important as how it differs from the uninvolved (uninjured) knee (Zarins & Nemeth, 1985).

Clinical Tests for Knee Joint Laxity and Instability

Anterior Drawer Sign

The anterior drawer sign with 90 degrees of flexion as described by Losee (1985), is conducted with the patient in a supine position with the hip at 45 degrees of flexion and the foot of the flexed knee braced on the examination table. The clinician's hands are clasped behind the proximal tibia just below the popliteal space. A positive sign is characterized by the tibia sliding under the femoral condyles. The two objectives of the 90 degree anterior drawer sign are to display an increase in anterior tibial translation beneath the femur (indicating laxity of the anterior cruciate ligament) and to show displacement of meniscus (Losee, 1985).

Lachman Test

The Lachman test is an anterior drawer performed in approximately 15-30 degrees of flexion to allow the posterior capsule to relax (Howe & Johnson, 1985; Torg, Conrad, & Kalen,

1976). The femur is stabilized with one hand on the lateral thigh while the other hand applies force to the posterior aspect of the proximal tibia (Figure 11) (Howe & Johnson, 1985). The force is

Figure 11 Clinical Lachman Test

applied in a attempt to evaluate the anterior translation of the tibia in relation to the stabilized femur. If anterior displacement is increased or a "soft endpoint" is present then damage to the ACL has been clinically shown (Howe & Johnson, 1985; Torg, Conrad, & Kalen, 1976).

Valgus Stability Test

Knee in Flexion (20-30 degrees)

To check medial stability of the medial capsular structures and ligaments, a valgus force is applied to the knee with the thigh resting on the examining table and the knee flexed 20-30 degrees and over the side of the table (Fowler, 1980). According to Fowler (1980), the subject is better able to relax in this position. Excessive laxity with this test indicates a injured medial collateral ligament and the mid-third capsular ligament (Zarins & Nemeth, 1985; Fowler, 1980).

Knee in Full Extension

When a valgus force is applied to the knee in full extension and instability is demonstrated, the damage to the knee is more extensive. The injured structures most often include the medial collateral ligament, medial capsular ligament, the posteromedial capsular ligamentous complex and the cruciate ligaments (Fowler, 1980).

Pivot Shift Test

A pivot shift test is characterized by anterior subluxation of the lateral tibial plateau on the femur as the knee is extended (Galway & MacIntosh, 1980). Simultaneously, the lateral knee compartment is impinged (Losee, 1985; Galway & MacIntosh, 1980). The impingement is caused by the lateral compartment of the misfitted joint being compressed during a twist into or out of subluxation (Losee, 1985).

Losee (1985) described a pivot shift test for subluxation. Assuming the right knee is to be tested, the clinician stands on the right side of the table with the patient in a supine position. The clinician picks up the patient's right foot and externally rotates it. The knee is then moved to 45 degrees of flexion and the clinician's left hand is placed against the side of the knee joint. While simultaneously pulling the foot with the right hand, the clinician pushes the knee with the left hand causing a valgus stress on the joint, As the valgus stress in maintained, the knee is extended and the foot is left to rotate internally (Figure 12).

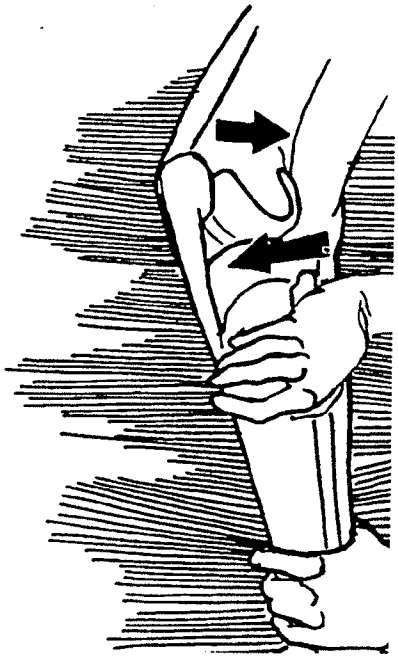

Figure 12 Pivot Shift (Adapted from Galway & MacIntosh, 1980)

A positive test is indicated by knee subluxation between 20 and 10 degrees as full extension nears. A positive pivot shift test nearly always indicates an anterior cruciate ligament insufficiency (Losee, 1985; Galway & MacIntosh, 1980).

Classification of Knee Instabilities

Knee ligament instability can be classified into two major categories based on major anatomical restraints: straight instabilities and rotatory instabilities (Andrews & Axe, 1985; DeHaven, 1978; Fowler, 1980). There can be single or combined forms of each type.

Straight Instabilities

The four main types of straight instabilities - medial, lateral, anterior and posterior - are classified according to the motion of the tibia with regard to the stabilized femur. Straight instabilities exhibit no rotation, only straight translation of the tibia. According to Andrews and Axe (1985), the common factor observed in all straight instabilities is that in hyperextension, the PCL is unable to prevent translation of the tibia and opening of the joint.

Straight Medial Instability

Straight medial instability is characterized by the "widening of the medial joint space with the application of valgus stress" (Figure13) (DeHaven, 1978). Instability is usually indicated when the joint opens more that 5 mm (1+) when a valgus stress is applied in forced hyperextension (Andrews & Axe, 1985).

The medial collateral ligament (MCL) is the primary stabilizer against valgus stress in both flexion and extension. No valgus instability will occur unless the MCL is damaged (Marshall & Baugher, 1980). The secondary stabilizers against valgus stress are the posterior capsule and its ligamentous reinforcements, the ACL and PCL. The posterior capsular structures and the ACL prevent valgus instability as a second line of defence while the deep capsular ligament and the PCL are the last stabilizers to be damaged by valgus stress (in full extension) (Marshall & Baugher, 1980).

If the knee opens in full extension then one can assume that extensive damage has been done to the capsular structures and one or both of the cruciates may be involved (Collins, 1978). If the knee does not open at full extension but opens when the knee is flexed at 20-30 degrees, the medial collateral ligament is the major pathological ligament (Collins, 1978; Andrews & Axe, 1985). There may also be associated ACL damage if the valgus stress causes an opening of greater than 10 mm (Andrews & Axe, 1985).

Straight Lateral Instability

Straight lateral instability is defined as the "widening of the lateral joint space with the application of varus stress" (Figure 14) (DeHaven, 1978). Instability is indicated by a positive adduction stress test in hyperextension and with the knee flexed at 20-30 degrees (Andrews & Axe, 1985).

The lateral ligaments (lateral collateral ligament and the popliteus tendon-arcuate ligament complex with its capsular attachment), the ACL and PCL are the stabilizers to varus stress (Marshall & Baugher, 1980; Andrews & Axe, 1985). If the joint opens in hyperextension, the pathology could include all structures including the last line of defense, the PCL (Andrews & Axe, 1985). If the knee joint opens more than 10 mm in 20-30 degrees of flexion, under varus stress, not only is the lateral collateral ligament

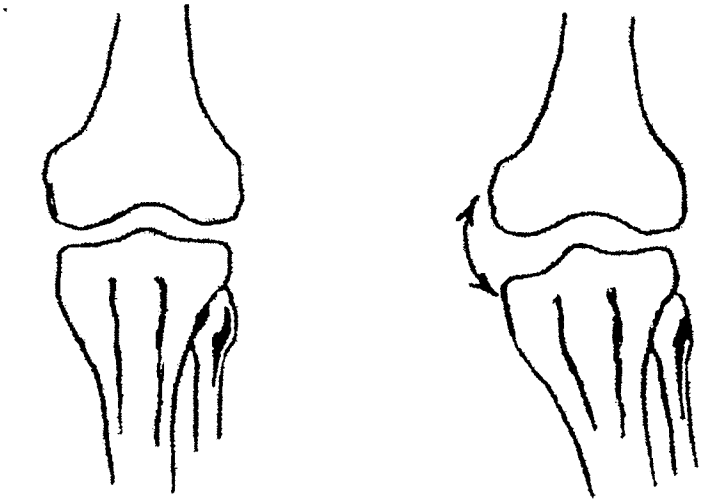

Figure 13 Straight medial instability. (Adapted from DeHaven, 1978)

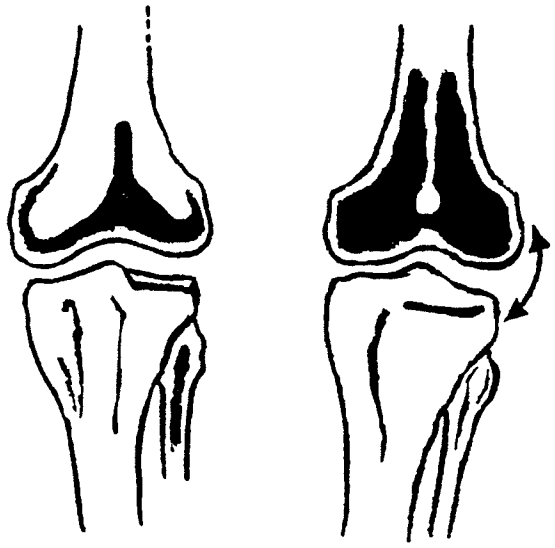

Figure 14 Straight lateral instability. (DeHaven, 1978)

damaged but it is likely the ACL is also damaged (Andrews & Axe, 1985).

Straight Anterior Instability

Straight anterior instability occurs when the "tibia moves anteriorly in relation to the femur with no differential excursion between the medial and lateral tibial condyles" (Figure15) (DeHaven, 1978). The anterior cruciate ligament is the primary stabilizer against anterior tibial displacement with the medial and lateral collateral ligaments and associated structures acting as secondary restraints (Marshall & Baugher, 1980). Therefore, an anterior drawer sign must be positive in internal rotation, neutral position

and external rotation for a straight anterior instability to be diagnosed (Andrews & Axe, 1985).

Straight Posterior Instability

Straight posterior instability is characterized by the "tibia moving posteriorly in relation to the femur with no differential excursion between the medial and lateral tibial condyles" (Figure16) (DeHaven, 1978). The posterior cruciate ligament is the primary stabilizer with the secondary restraint being the posterior capsule (Marshall & Baugher, 1980).

A positive posterior drawer sign in the neutral position demonstrates straight posterior instability (Andrews & Axe, 1985). The knee may also demonstrate laxity to varus/valgus stress in full extension due to associated tears of the medial/lateral ligament

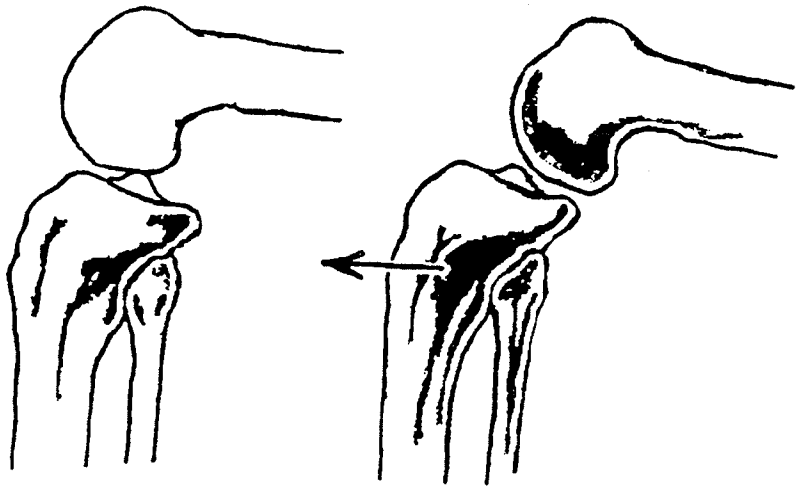

Figure 15 Straight anterior instability. (DeHaven, 1978)

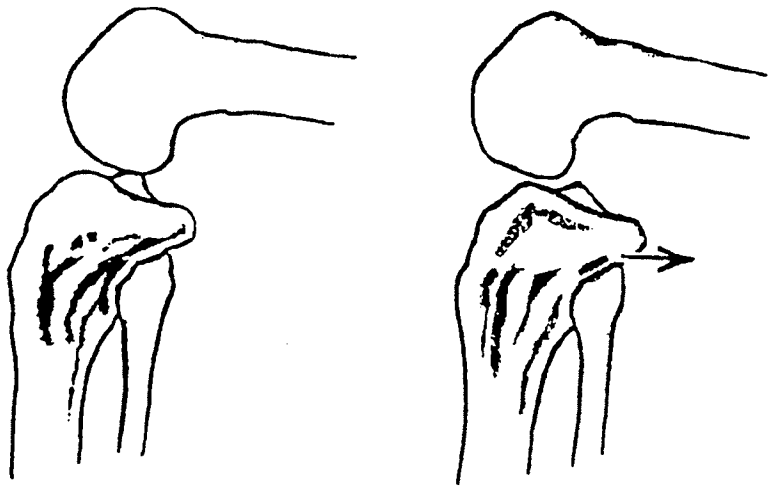

Figure 16 Straight posterior instability. (DeHaven, 1978)

complexes and the "screw-home" mechanism of the PCL that occurs in terminal extension (Cain & Schwab, 1981).

Rotatory Instabilities

Three types of rotatory instability will be addressed: anteriomedial, anteriolateral and posterolateral. A fourth rotatory instability, posteromedial, is uncommon. (DeHaven, 1978) and, according to Andrews and Axe (1985), the lesion cannot be shown by normal clinical laxity tests.

Anteromedial Rotatory Instability

Anteromedial rotatory instability is "abnormal tibial rotation that causes the medial tibial plateau to displace anteriorly in relation

to the femur" and is "associated with a shift of the vertical axis of rotation anteriorly and laterally (Figure 17) (DeHaven, 1978).

The structures damaged are the medial collateral ligament, the posteromedial and posterior capsule, and the ACL (Marshall & Baugher, 1980). Because of the combinations of damaged structures, the tibia is allowed increased excursion anteriorly and external rotation (Marshall & Baugher, 1980).

Anterolateral Rotatory Instability

With anterolateral rotatory instability the lateral tibial plateau moves anteriorly in relation to the femur, with the vertical axis of rotation shifting anteriorly and medially at the same time (DeHaven, 1978; Cabaud & Slocum, 1977). Chronic anterolateral rotatory instability is the most common form of disabling instability in athletes and it is the most frequent cause of ACL deficiency (Ellison, 1980).

A pivot shift sign confirms this instability since as the knee is flexed, anterior subluxation of the lateral tibial plateau occurs with a characteristic "jump" or "thud" (Marshall & Baugher, 1980; DeHaven, 1978; Andrews & Axe, 1985).

Posterolateral Rotatory Instability

Posterolateral rotatory instability is an abnormal tibial rotation that results in posterior tibial subluxation of the lateral tibial plateau and is associated with "a concomitant shift of the vertical axis of rotation medially and posteriorly" (Figure 18) (DeHaven, 1978).

The combination of ligamentous injuries which cause the instability are the lateral collateral ligament, popliteal tendon, arcuate ligament, and the posterior cruciate ligament (Marshall & Baugher, 1980). The mechanism of injury is generally a blow on the medial aspect of the knee, causing a varus deformation of the knee joint along with hyperextension (Andrews & Axe, 1985). It is diagnosed clinically by the posterolateral drawer sign in which the tibia is externally rotated and posterior displacement is increased over the neutral posterior drawer sign (Andrews & Axe, 1985; DeHaven, 1978).

Combined Instabilities

Combinations of these instabilities can also exist. They tend to be chronic instabilities rather than acute (Andrews & Axe, 1985).

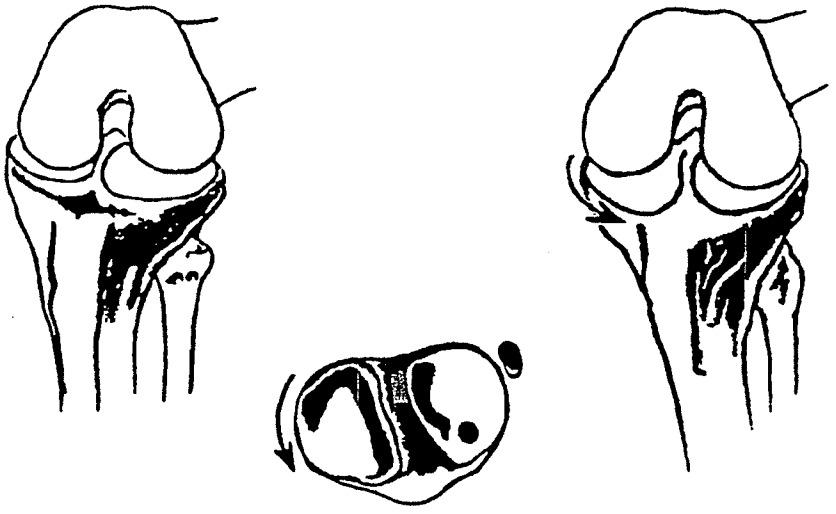

Figure 17 Anteromedial rotatory instability. (DeHaven, 1978)

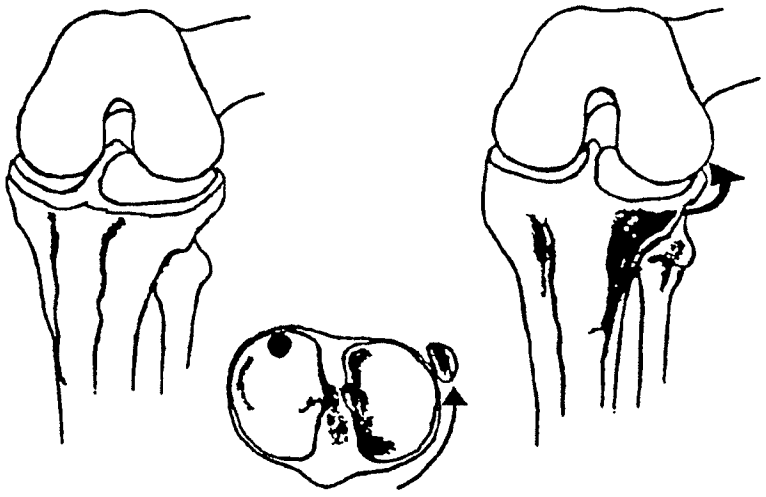

Figure 18 Posterolateral rotatory instability (DeHaven, 1978)

The most common combinations are medial-anteromedial, anterolateral-anteromedial, and anterolateral-posterolateral (Andrews & Axe, 1985; DeHaven, 1978; Larson, 1980).

Clinical Assessment of Knee Laxity

Many clinical methods of examining the athlete's injured knee have been described in past literature (Losee, 1985; Torg, Conrad, & Kalen, 1976; Noyes, Mooar, Matthews, & Butler, 1983; Jonsson, Althoff, Peterson, & Renstron, 1982; and Katz & Fingeroth, 1986). According to Oliver and Coughlin (1987), it is often difficult to use these manual methods in acute situations and it is often difficult to report accurately on knee stability after surgery. Katz and Fingeroth

(1986), for example, found the sensitivity of the anterior drawer sign to be 53.8% for the chronic ACL injuries which dropped to 22.2% in the subjects having acute ACL injuries. They concluded that it is a poor diagnostic indicator in the acute setting. Jonsson, Althoff, Peterson, & Renstrom (1982), in a study of clinical diagnosis of acute knee injuries found that only 33 percent had a positive anterior drawer sign.

Torg, Conrad, and Kalen (1976), concluded from a review of literature that the 90 degree anterior drawer test is not reliable and reveals 3 causes for a "false negative" drawer test in isolated ACL injuries: 1) isolated ACL tears are often accompanied by "tense hemarthrosis and reaction synovitis that preclude flexion of the knee to 90 degrees; 2) hamstring muscle spasm secondary to joint pain can generate great force opposite to anterior tibial translation; and 3) tibial translation may be inhibited by the posterior horn of the medial meniscus "buttressed" against the posteriormost margin of the medial femoral condyle.

A pivot shift test, which almost always indicates ACL-insufficiency, may be difficult to obtain in acute patients due to knee tenderness, hamstring spasm, and guarding (Losee, 1985).

Instrumented Measurement of Knee Laxity

There are several electromechanical devices discussed in the literature which have dealt with the problems of objectivity in stability examination. Kennedy and Fowler (1971) examined knee

laxity with a clinical stress machine. Laxity was quantified by roentgenographic examination of stressed knees using an anterior drawer test with 90 degrees of knee flexion and a valgus stress test both at full extension and 20 degrees of knee flexion.

Markolf, Graff-Radord, and Amstutz (1978), examined knee stability by measuring anterior/posterior laxity, varus/valgus laxity, and internal/external rotation in a flexed position. An instrumented force handle was used to apply forces through the tibia while the subject was positioned in a modified dental chair. The subject was seated erect with the thigh secured in an adjustable tapered metal shell clamped to the seat. An inflatable pad inside the shell helped stabilize the femur. A contoured patellar block locked the femur in place and the ankle was strapped to a footrest to help maintain the desired knee angle. A transducer was used to measure tibial displacements. The instrumented force handle was strapped to the tibia and anterior/posterior forces were recorded on the gauge of the spring-loaded plunger placed on the tibial tubercle.

A relatively complex system was developed by Youm, Bass, and Savory (1987), consisting of load cells and potentiometers attached to the patient's tibia with a goniometer mounted on the frame of the testing unit. The goniometer measured the angular displacement when rotation was applied by a screw in line with the tibia while the load cells measured the forces applied to the leg and displayed the values on a digital light-emitting diode panel. The linear

potentiometer measured displacement as force was applied through a series of cuffs placed around the lower leg.

A five-degree-of-freedom knee testing apparatus was developed by Sullivan, Levy, Sheskier, Torzilli, and Warren (1984), which measured knee joint laxity in both the anterior-posterior and medial-lateral directions. A hydraulic testing machine applied the forces to cadaver knees and the resulting motions of the knee were plotted on the chart-recorder of hydraulic testing machine. Displacement and rotation at 100 newtons force were analyzed using a Talos IY digitizing table interfaced with a Digital RT11 microcomputer. Ten intact knees were tested at zero, 30, 60, and 90 degrees of flexion with the ACL being subsequently cut in five knees. In cadaver knees in which the ACL was cut, anterior tibial displacement increased at all angles of flexion ($p<0.05$) with the greatest increase occurring at 30 degrees of flexion (anterior displacement increased by approximately 13 mm).

The Instrumented Spatial Linkage System electrogoniometer was designed and developed to generate data for 3-dimensional assessment of ACL deficient knees in research (Marans, Jackson, Glossop, & Young, 1989). The system was designed to test the knees of subjects during level walking.

The Stryker Knee Laxity Tester which was studied by Steiner, Grana, Chillag, and Schelberg-Karnes (1986) and later by King and Kumar (1989), determined anterior and posterior displacements by

relative positions of a pad pressed against the patella and a pad on the crest of the tibia during the AP drawer test. The device consists of a bar that is applied to the front of the tibia by elastic straps and pillars that keep it about 4 cm away. A piston at the proximal end, at right angles to the long axis of the leg, contains a plunger which is applied to the patella. It is preloaded so that is always presses against the patella. On the shaft of the device are "stick/slip pointers" which are left at positions of maximum excursion after anterior and posterior displacements from the neutral position. The knee is placed at 30 or 90 degrees of flexion and the tibia is pushed forwards or backwards by the application of a spring loaded gauge, stressed to 10 or 20 lbs. The thigh is held to the seat with velcro straps and the ankle is also held in the same manner at the distal end of the frame.

In the study conducted by King and Kumar (1989), only 40 percent of the clinically proven ACL deficient knees measured an anterior displacement of greater than 2 mm when compared to the normal knee. The sensitivity of the system was therefore tested in the following way. Of 333 readings on the same patient, tested by the same clinician during a 3 week period, only 22.2 percent showed a side to side difference of 2 mm or more. Of 348 tests on the same patient with different testers, only 21.5 percent showed a 2 mm or more side to side difference. The study concluded that Stryker knee

arthrometer may not be adequately sensitive for routine clinical practice, outside of research clinics.

Daniel, Stone, Sachs, and Malcom (1985), reported on the MEDmetric arthrometer KT-1000 which was also designed to measure anterior/posterior force and displacement at various degrees of knee flexion. Subjects were tested in a supine position with the leg held by velcro straps and an adjustable footrest which assured the proper knee flexion angle. Displacement loads were applied through a force sensing handle located 10 cm distal to the joint line. Displacement was quantified through the use of a dial gauge which registered in millimeters. An audiotone signaled when 15 lb (67 N) or 20 lb (89 N) of push or pull force had been applied through the force sensing handle.

Of the 53 subjects who had arthroscopes indicating complete ACL tears, the KT-1000 measurements were suggestive or diagnostic of pathologic anterior laxity in 50 subjects (3 mm or greater difference between two knees) (Daniel, Stone, Sachs, & Malcom, 1985).

Bach, Warren, Flynn, Kroll, and Wickiewiecz (1990) also reported on the KT-1000 and its use in identifying ACL-deficient knees by measuring anterior tibial translation. In testing 153 subjects with chronic ACL-tears and 107 subjects with acute ACL-tears a significant difference (chi square = 79.3) was observed between normal and abnormal knees when using the diagnostic

criteria of a 3 millimeter difference between knees as being indicative of pathology. The authors recommended the use of the KT-1000 in clinical evaluation and followup in assessing ACL-deficient knees. However, the use of the KT-1000 is limited by the ability to only measurement anterior-posterior translation.

In a study conducted by Anderson and Lipscomb (1989) which compared instrumented assessments using MEDmetric KT-1000, Stryker, and the Genucom, the Genucom was found to be the most versatile since the addition of the lateral pivot shift test in its protocol allows it to test for more complex instabilities. However, when compared to the Stryker and KT-1000, the Genucom's diagnostic accuracy in instrumented examination was less than the other two. Both the KT-1000 and the Stryker were diagnostically correct in 75 percent of the subjects tested (n=50; side to side difference of 3 mm or more equaled ACL tear) while the Genucom was correct in 70 percent of the subjects. The clinical examination was diagnostically correct in 95 percent of the cases.

Steiner, Brown, Zarins, Brownstein, Koval, and Stone (1990), compared four commercial devices in measurement of anterior-posterior displacement of the knee - the Acufex knee-signature system, the Genucom, the KT-1000, and the Stryker. Anterior and posterior displacement were measured at forces of 20 lb (89 N) and 30 lb (133 N). Both subjects with normal knees (n=13) and subjects with chronic ACL injuries (n=15) were tested. The study found

significant differences in reproducibility of measurements among the devices. The average test variability for anterior displacement measurements was less than 3.2 mm with the KT-1000 and the Stryker, between 3.2 and 5.2 mm with the Acufex, and between 4.6 and 8.3 mm with the Genucom. Test variability in millimeters was greater in the injured knees than in the normal knees. Statistical comparison showed that Acufex, KT-1000, and the Stryker all had more reproducible measurements of anterior displacement than did the Genucom ($p<0.01$). Measurements of anterior displacement of the injured knees were generally smaller with the Genucom than with the other 3 machines. In testing the subjects who had arthroscopically confirmed unilateral isolated ACL-tears, the Acufex was the most diagnostically correct at 90 percent while the Genucom was the diagnostically correct in only 60 percent of the cases.

Neuschwander, Drez, Paine, and Young (1990), compared the anterior laxity measurements in anterior cruciate deficient knees with two instrumented testing devices, the KT-1000 and the KSS (Knee Signature System). Both testing devices used the patella and tibial tubercle as reference points for the calculation of anterior tibial displacement and the testing protocols were essentially the same. The only difference between the two machines is that the KT-1000 applies pressure through the patella thus restricting femur movement anteriorly during anterior tibial displacement and the KSS has no restriction of femoral motion except during a maximal test

when the femur is stabilized by the examiner. The study found that both machines provided comparable objective data in assessing side-to-side differences in pathologic anterior displacement in subjects with an ACL-deficient knee.

Wroble, Noyes, Van Ginkel, and Shaffer (1989), concluded in a test-retest study that the MEDmetric KT-1000's reliability was inadequate despite its popularity. The study was designed to determine the magnitude of installation-to-installation (within-day) and day-to-day (between-day) variability of anterior-posterior translation measurements in normal knees. Installation-to-installation variability was non-significant but day-to-day variability was statistically significant for individual right and left knee displacements at 20 lb (89 N) and 30 lb (133 N). A post hoc test revealed that for all parameters, the first day measurements were significantly less that those on following days, suggesting that the patient and examiner accommodate to the testing procedure.

Highgenboten, Jackson, and Meske (1989), on the other hand, found the reliability of the Genucom for test-retest trials on 50 normal subjects to be acceptable ($r>.80$), indicating the Genucom generates reproducible knee laxity values. No significant differences were found between the trials.

Highgenboten, Jackson, and Meske (1990) in a further study on 20 normal subjects found the reliability of the Genucom for the valgus test at 20 and 0 degrees to have correlation coefficients of

r=.88 and r=.87 respectfully. The values for the 90 degree anterior drawer (r=.91) and the 30 degree anterior drawer (r=.82) also indicated the Genucom reproduces acceptable knee laxity values. However, the scores represented the absolute values of mm of laxity for each knee and not the difference between the knees as would be recorded in a clinical setting.

Soft tissue structures other than the cruciate ligaments may be stressed by the clinical drawer test so it is difficult to precisely diagnose an ACL injury. The Genucom improves the quality of the drawer test by quantifying the amount of force applied to the joint and allowing for soft tissue compensation.

Genucom Knee Analysis System

The present study on knee stability will involve the use of the Genucom Knee Analysis System previously studied by Oliver and Coughlin (1987) and more recently by Peters, Johnson, and Quanbury (1988), Highgenboten, Jackson, and Meske (1990), Wroble, Grood, Noyes, and Schmitt (1990) and Granberry, Noble, and Woods (1990).

The Genucom (Figure 19) is a six degree of freedom computerized electrogoniometer designed specifically to provide objective assessment and recording of knee joint stability. The Genucom has also incorporated a six component force dynamometer which records measurement of forces applied to the knee so the clinician know when the applied forces are outside the prescribed range. These two features allow the clinician to perform the tests

while an objective recording of displacements and applied forces is recorded.

The electrogoniometer, which measures the angles of the knee joint through a computer interface, is attached to the central base of the chair and a free arm is unhooked from the chair for limb attachment. It consists of three bars or "links", 2 long and one short, which are joined together allowing it to extend and collapse as the knee joint angles increase or decrease. The small link, located at the free end of the electrogoniometer, consists of a series of small holes for mounting to to a tibial attachment. The specific hole used for

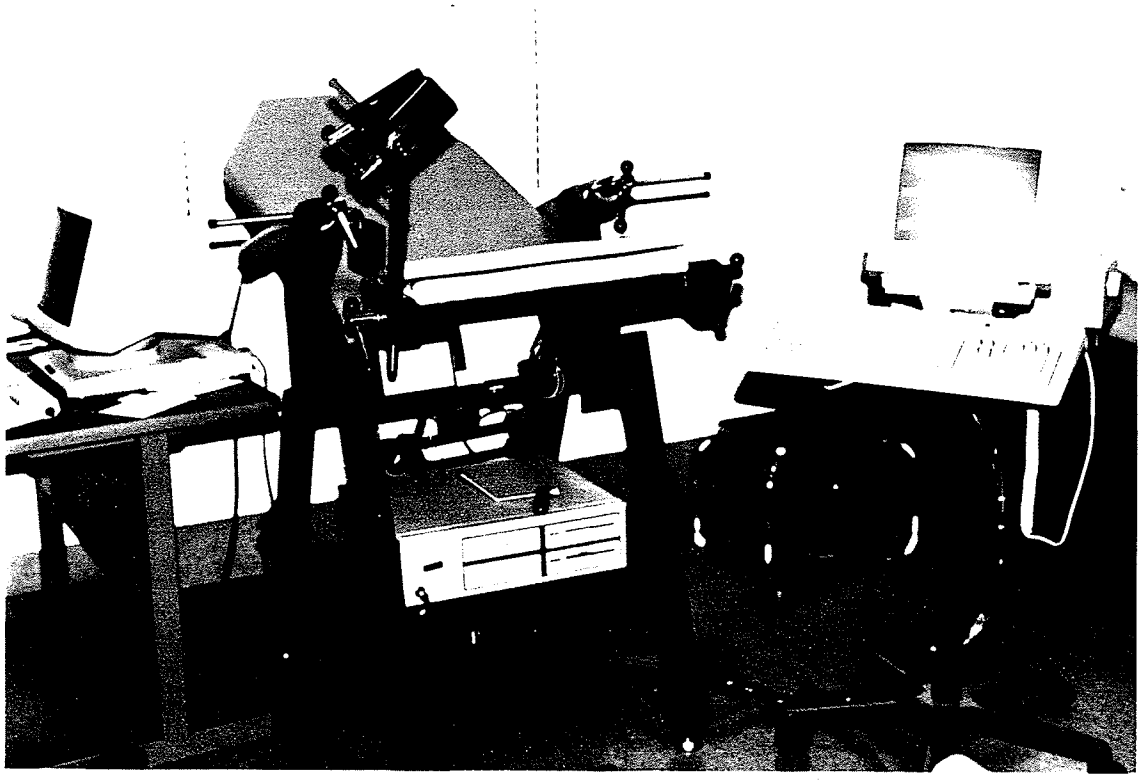

Figure 19 Genucom Knee Analysis System

mounting will vary depending on the length of the subject's leg.

Granberry, Noble, and Woods (1990) determined through a technique of calibration that the accuracy and reliability of the Genucom electrogoniometer was within ± one degree.

The dynamometer, located in the seating system, measures the amount of force, in pounds, applied through the joint and any part of the seating system (i.e. the thigh clamp). The seating system consists of a chair with a reclined back which slides forwards and back to adjust for different body lengths. Attached to the chair are a velcro seatbelt, hip restraint, and thigh restraint. The hip restraint consists of 2 adjustable pads, one for each hip, which, when adjusted to patient width and clamped down, press firmly against the hips. Along with the seatbelt, the hip restraint prevents the subject's body from sliding and hold the body in place.

The thigh restraint (Figure 20), which has a holder on either side of the chair for use on the right or left leg, consists of adjustable medial and lateral restraint pads and a horizontal bar with a rolling pad which rests against the top of the thigh. All the restraint mechanisms are tightened by turning the screw-down knobs attached to each of the three restraints.

The digitizing tip (Figure 21), a metal pointer with a handle, is used in the digitizing process and is attached to the last hole in the last link of the electrogoniometer to use. The digitizing process provides the Genucom computer with the exact location and

geometry of each knee by electronically landmarking 7 points on the lower leg and around the knee. This process allows the electrogoniometer to accurately identify knee joint angles and rotations in all three planes of motion.

Care must be taken in the digitization process as if points are not accurately represented, both the size and frequency of the laxity measurements can be significantly affected (Wroble, Grood, Noyes, & Schmitt, 1990). The range of laxity values due to changes in landmarking has been recorded as great as $\pm$ 6 millimeters (Wroble, Grood, Noyes, & Schmitt, 1990).

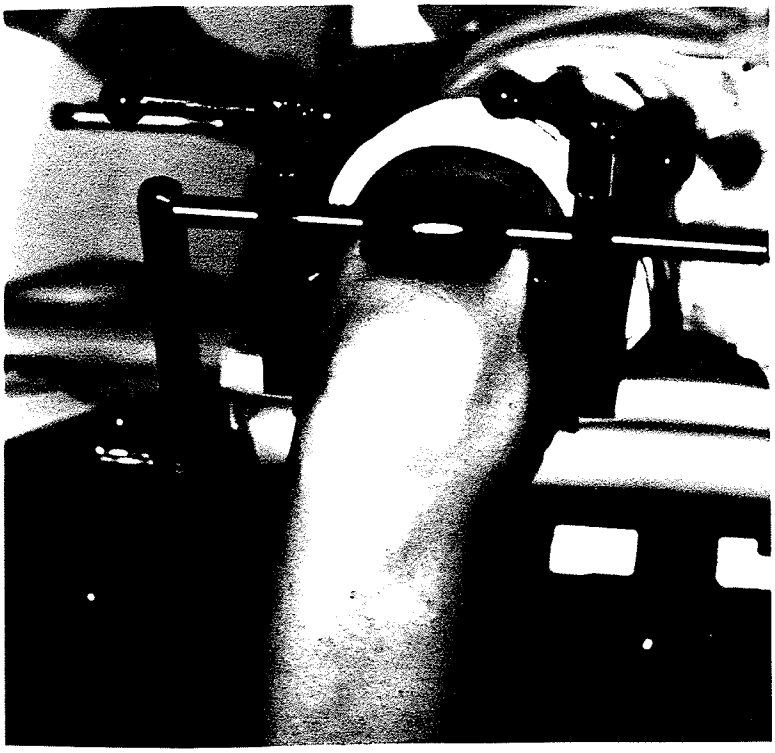

Figure 20 The Genucom Thigh Restraint

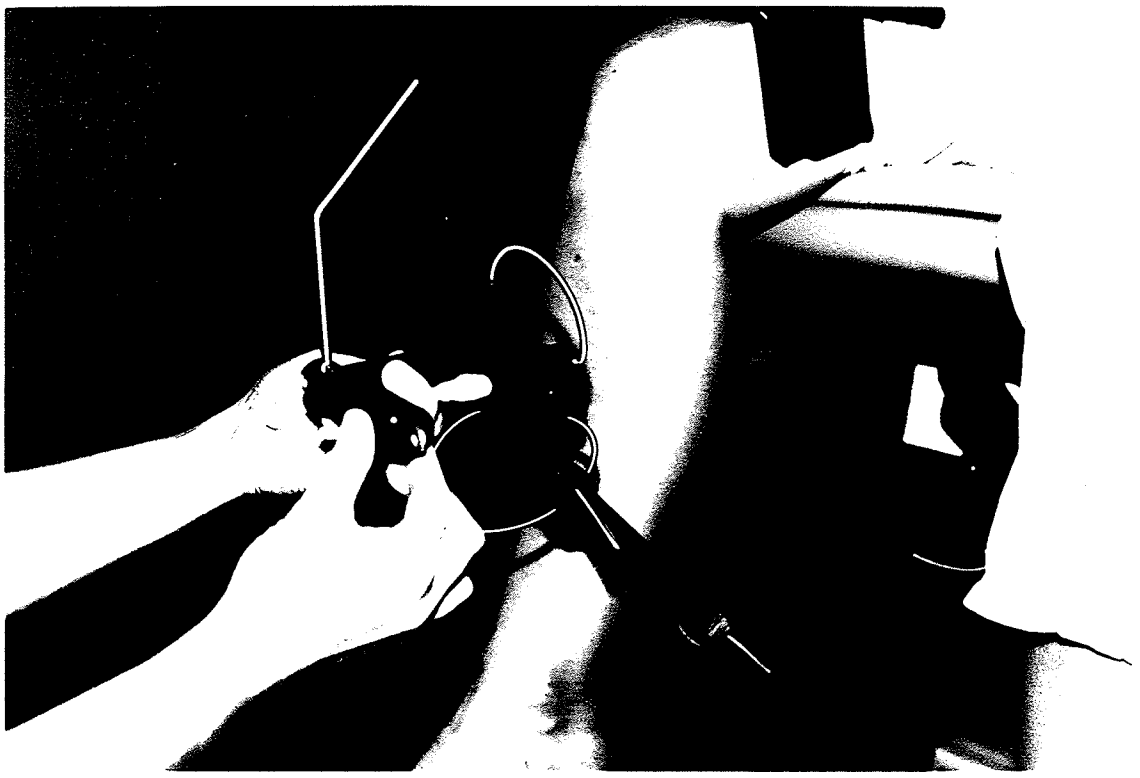

Figure 21 The Genucom Digitizer

The Genucom also has the capacity for soft tissue compensation. Femoral soft tissue is compensated for by teaching the Genucom how much the femur moves as a result of forces applied to it, while the motion module of the tibia is supported by bony prominences, the tibial crest and the malleoli. The compensation process lets the computer know how much the leg moves within the thigh restraint due to soft tissue. The computer identifies how much "play" there is in the leg and subtracts it from the millimeters of actual joint translation.

Granberry, Noble, and Woods (1990) found, however, that the soft tissue compensation did not significantly reduce the variability of the data indicating it did not correct for random error inherent in

the electrogoniometer measurement procedure. So translation of the soft tissue may still mask the true translation of the tibia on the femur. Wroble, Grood, Noyes, and Schmitt (1990) further concluded that the soft tissue compensation process does not account for patient morphology.

An advantage of the Genucom over the Arthrometer reported by Daniel, Stone, Sachs, and Malcom (1985), and the Stryker Knee Laxity Tester reported by Steiner, Grana, Chillag, and Schelberg-Karnes (1986), is that it can test in all three planes of motion (Peters, Johnson, & Quanbury, 1988; Oliver & Coughlin, 1987). In addition to testing anterior/posterior laxity, the Genucom can objectively evaluate a varus/valgus stress test, internal/external rotation stress test, and compartmental subluxation tests.

Another advantage of using the Genucom is the time required for the examination. According to Oliver & Coughlin (1987), a 14 test bilateral knee evaluation required only 25-30 minutes to complete without significant subject discomfort.

Another feature reported by Oliver and Coughlin (1987) that the Genucom provides is the ability to simultaneously compare the results of both the injured and uninjured knees of the subjects. Results can also be stored on computer discs and retests can then be compared with previous results. The results are displayed both graphically and in table form.

The Genucom allows the clinician to palpate, manipulate, and observe the patient through the traditional "hands on" approach, while having critical aspects of the evaluation monitored. The Genucom can improve the quality of the anterior/posterior drawer sign as the clinician is not left to subjectively evaluate either the amount of force applied to the joint or the resulting subluxation. The Genucom also allows the clinician the ability to check unwanted compression forces or tibial rotation which may act as restraints to movement. Peters, Johnson, and Quanbury (1988) noted that the Genucom controls leg rotation which can inhibit clinical evaluation and resistance of the subject can be observed.

The testing protocol of the Genucom largely overshadowed the clinical tests in terms of objectivity. Peters, Johnson, and Quanbury (1988) reported only a moderate correlation between clinical and objective (Genucom) measurement of laxity. A correlation of $r=.44$ ($p<0.05$) was found between the clinical and instrumented drawer sign at 90 degrees and an slightly better correlation of $r=.55$ was found between the clinical Lachman test and the instrumented anterior drawer at 30 degrees.

In comparing the results of the Genucom tests to the clinical findings, Oliver and Coughlin (1987), found that of the 15 subjects who had a clinically positive anterior drawer at 90 degrees (> 5 mm difference between the injured and uninjured legs) 14 also had a positive Genucom anterior drawer at 90 degrees (> 5 mm difference).

Of the 16 subjects who had clinically positive anterior/posterior drawer signs at 30 degrees of flexion all 16 also had a positive instrumented anterior/posterior drawer test at 30 degrees. Oliver and Coughlin (1987) concluded that the Genucom provides a significant contribution to objective measurement of knee joint stability.

CHAPTER 3

METHODS AND PROCEDURES

Subjects

The subjects for the study were 15 patients (including both male and female subjects) who had previously been diagnosed with anterior cruciate ligament (ACL) insufficiency in one knee. In addition, twenty normal subjects with no history of knee pathology were also tested for knee laxity on the Genucom, to determine the reliability of the testing protocols. The fifteen ACL-deficient subjects included those who had either a positive anterior drawer test or Lachman test, and a positive pivot shift test when administered by a skilled clinician. Thirteen of the fifteen subjects had the diagnosis of isolated anterior cruciate insufficiency confirmed arthroscopically, but none of the fifteen subjects had knee surgery. The subjects were obtained through physicians' patient records, made available to the investigator from three orthopaedic surgeons.

The investigator contacted the patients individually, explained the study to them, and asked them if they would agree to participate. The patients selected for participation in the study had only unilateral knee involvement, no other lower extremity joint pathology, and no other ligament pathology in the involved knee. Subjects with associated partial meniscal tears were considered acceptable for the study. It was assumed that the majority of the patients had previously undergone therapy for their injury, and may

have to wear a knee brace for sports. Informed consent was obtained from all subjects prior to the testing procedures.

Test Protocol

The twenty normal subjects who volunteered for the study were tested bilaterally on the Genucom Knee Analysis System during two separate installations on two different days. The fifteen subjects who met the preselected clinical conditions (positive Lachman test or 90 degree anterior drawer test, and positive pivot shift test) were tested bilaterally on the Genucom Knee Analysis System and were tested clinically on the same day. All testing took place at the Winnipeg Health Sciences Centre, Department of Physiotherapy, where the Genucom was located.

Each of the legs of each subject was evaluated on the Genucom for each of the following tests: a) the anterior-posterior drawer sign at 90 degrees and 30 degrees (Lachman Test); 2) varus/valgus was tested with the knee in both 20 degrees of flexion and 0 degrees of flexion; 3) two compartment subluxation tests (pivot shift) were also administered. All knee evaluation tests were administered according to protocols included in the Genucom Users Manual (FARO Medical Technologies Inc., 1984).

Patient Installation

The subjects climbed onto the Genucom with the aid of a footstool. The final testing position of the subject on the machine allowed a 2-3 finger width (approximately 2 inches) between the

front of the Genucom seat and the posterior aspect of the lower leg when the leg was hanging in a relaxed position in the chair with the knee flexed to 90 degrees. The subject was asked to slide forward or back while the tester adjusted the required spacing. The subject remained seated upright during this procedure. Once the required spacing was achieved, the back of the Genucom chair was moved so it touched the back of the patient allowing a comfortable lying position for the subject. From this point onward the subject remained supine (Figure 22).

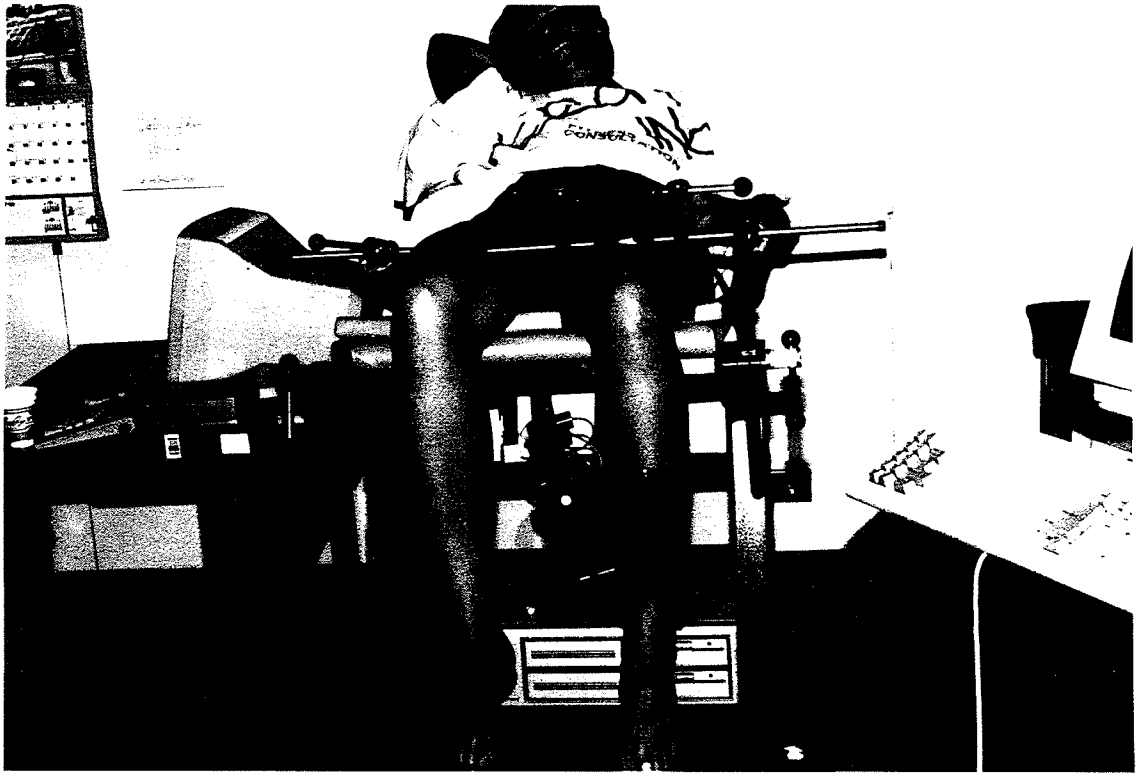

Figure 22 Supine seating position of subject during Genucom assessment.

The thigh restraint, which keeps the thigh in a fixed position during testing, was then positioned and adjusted (Figure 20). As soon as each subject's file was accessed on the computer the "patient installation" prompt appeared on the screen and a live meter of the clamping force of the thigh restraints on the femur was displayed. The live meter gave a continuous readout of the forces the tester applied to the thigh restraint during the restraining process. The meter is a direct readout from the force dynamometer located in the seating system of the Genucom.

The lateral block of the thigh restraint was set just inside the lateral edge of the seat and tightened by turning the knob attachment. Approximately 20 lbs (88 N) was then applied to the medial block before tightening. A downward pressure of 15 lbs (66 N) was then applied to the top of the vertical section of the thigh support bar so the soft tissue was compressed vertically as well as medially and laterally.

The forces applied in this sequence were usually adequate to fix the restraint position, however, with some subjects more force may have been required to fix the limb securely. Care was taken by the tester to ensure that the amount of pressure applied would not lead to a painful response or circulation problems in the subjects, but would just serve to restrain gross motions. Since the examination was a bilateral comparison, this procedure was repeated later for the opposite leg.

Digitization

The electrogoniometer was equipped with a "pointer" attachment which, when attached to the electrogoniometer, had the ability to digitize points which can then be located in all three dimensions. The seven points about the knee that were digitized were as follows:

-tibial crest 6-8 inches below the proximal end of the tibia
-tibial crest 2-3 inches below the proximal end of the tibia
-tibial tubercle
-medial joint line
-top of the medial femoral condyle
-top of the lateral femoral condyle
-lateral joint line

A prompt for each of the sites was presented to the tester one at a time on the computer display screen, and since the sites were all identified by significant bony landmarks the repeatability of these measurements is high. A ruler was used to measure the distances during landmarking to increase the accuracy of the first two digitization measurements.

The digitization process was preceded by positioning the double footswitch at a convenient location near the tester's foot. There were two switches on the footswitch, one which was activated when the tester pressed the right side of the switch and the other which was activated when the left side is pressed.

The digitizing process proceeded once the pointer was positioned on the last link of the electrogoniometer and secured to the link by hand tightening the tie-down screw on top of the handle. While holding the pointer in one hand, the tester palpated the site to be digitized with the free hand. Once the point was identified, the tip of the pointer was placed on the site (Figure 23). To digitize the identified sites the right footswitch was pressed. If a mistake was

Figure 23 Genucom digitization of the tibial tubercle

made, for example if the pointer slipped during digitization of a specific point, the measurement was repeated by pressing the right footswitch again. The left footswitch was then pressed, confirming to

the computer that the desired point had been digitized. During the digitization process the leg was in a "resting" position at approximately 90 degrees of flexion.

Soft Tissue Compensation

In addition to digitizing the seven points previously listed, the digitization pointer was used to measure the distal motion of the femur due to applied force, which was the first part of the soft tissue compensation process. The digitizer tip was placed on the patellar surface at the approximate point through which the longitudinal femoral axis passed. The opposing hand was placed behind the tibia to apply at least a 25 lb (110 N) anterior load. During application of the force the ankle was stabilized between the tester's knees or against the tester's chest.

The right footswitch was pressed to start the compensation measurement and pressing the right footswitch a second time ended the procedure and introduced the verification step.

The verification step involved repeating the same compensation force application while the computer checked that a correct compensation curve had been generated. Repetition of the soft tissue compensation procedure should normally result in zeros and ones in the millimeter display, indicating a reliable estimate. Once the verification procedure had been stopped by pressing the right footswitch, a statistical report was produced by the Genucom to indicate how many of the measurements resulted in distal femoral

displacement of less than 2 mm. The tester was then able to repeat compensation or proceed to the next step depending on the verification results. Acceptable compensation was when 85 percent of the measurements were 2 millimeters or less.

Electrogoniometer Attachment

After the digitized distal femur motion compensation had been completed, the tibial supports were attached. The tibial supports provided a place for attachment of the electrogoniometer onto the lower leg. The support was placed just proximal to the tibial malleoli (Figure 24). The anatomical design of the support ensured correct alignment with the tibial crest. Alignment was verified by palpating the tibial crest and verifying that it was within one centimeter of the edge of the proximal end of the tibial support.

The support was secured by an elastic strap with velcro closures. The elastic strap was wrapped around the support by pulling it laterally and posteriorly, it was then closed snugly on the lower tibia.

The electrogoniometer was then attached to the tibial support by pushing the last link on the electrogoniometer into the receptacle on the support and tightening down with the tie-down screw on the receptacle. The last link had a series of holes from which the tester chose the best fit for mounting in the receptacle. The hole chosen allowed the two long arms of the electrogoniometer to be closest

together and almost vertical with the leg in the "relaxed" flexion position.

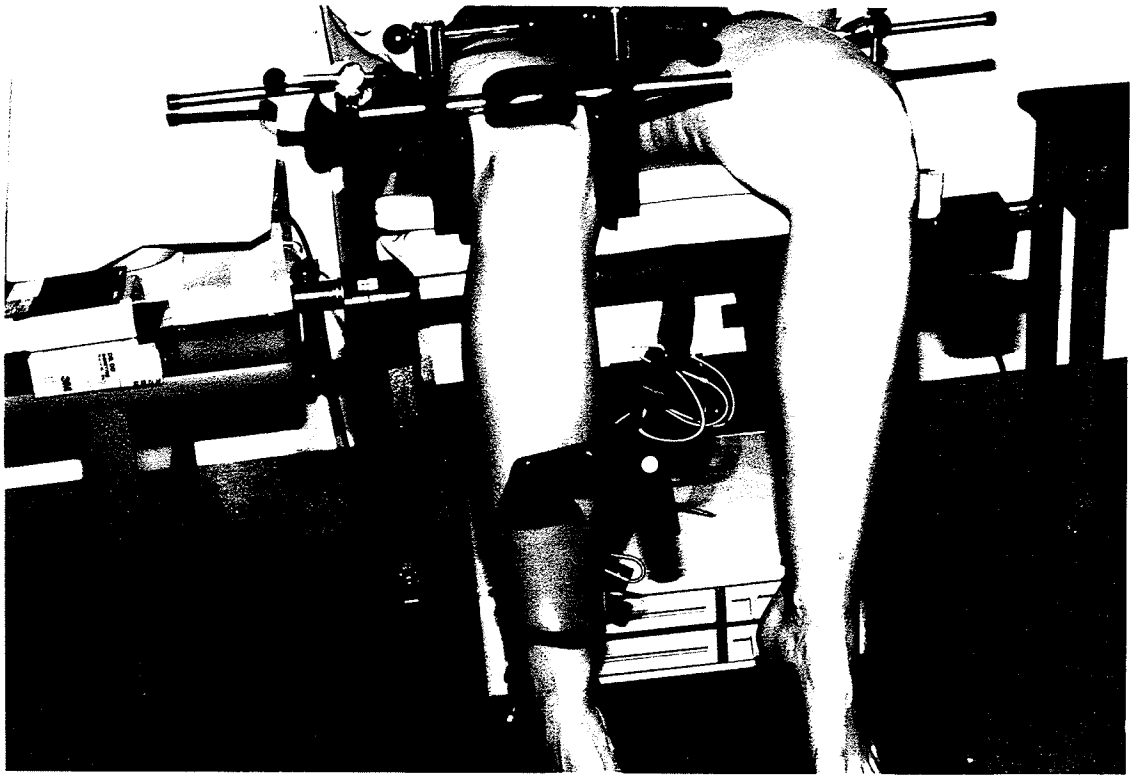

Figure 24 Genucom tibial electrogoniometer holder

In addition to the digitized distal femur compensation, a sequence of hand-applied distal femoral forces was applied before testing proceeded. Femoral soft tissue was compensated for in all three axes by applying forces of 25-35 lbs (110-155 N) to the medial-lateral, anterior-posterior, and proximal-distal axes.

The computer display prompted each of the soft tissue compensations and if inadequate data was obtained, the same

prompt appeared again allowing the tester to repeat the step. Both the footswitch and the verification step were utilized in the same manner as described for digitized distal femoral compensation.

Medial-lateral compensation consisted of a force (25 lbs or 110 N) applied with the palm of the hand to the bony prominence of the femoral condyles at the distal end of the femur, first in the lateral and then in the medial direction (Figure 25). The force application in each direction, for all compensations, took approximately 3 seconds in order to ensure adequate data was collected. The hand load was released after each direction to allow direction of force to "zero out" (i.e.. the plus and minus directions).

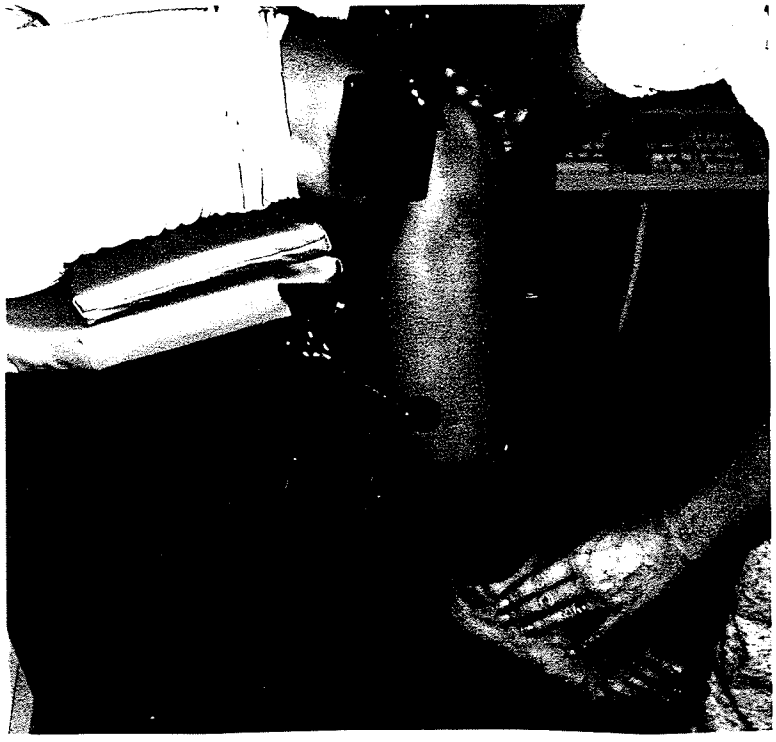

Figure 25 Medial-lateral soft tissue compensation

Anterior-posterior compensation of the femur was measured by applying a 25 lb (110 N) force downward on the femoral condyles, towards the ankle as the leg is hanging at 90 degrees of flexion. The downward force was followed by an upward force of 35 lbs (155 N) which was applied, with the leg flexed to 90 degrees, by firmly grasping the heel of the foot and lifting the leg in an effort to displace anteriorly the proximal end of the femur (Figure 26).

A proximal compensation was identified by applying a proximal force of 25 lbs (110 N) on the patella in the direction of the femoral axis. Since testing is bilateral, the soft tissue compensation process was repeated on the opposite leg after leg change over.

Figure 26 Anterior-posterior femoral soft tissue compensation technique

Genucom Tests

Once all the soft tissue compensation was completed, the joint evaluation tests proceeded. The following order of tests were used for each subject and each leg: anterior/posterior drawer test at 90 degrees, anterior/posterior drawer test at 30 degrees (Lachman), varus/valgus at 0 degrees, varus/valgus at 20 degrees, medial compartment subluxation test, and lateral compartment subluxation test. The right leg was tested first for each subject.

The auto test series program, which allows the tester to proceed through the tests, in the order described, without having to save and return to the menu between each individual test, was used to reduce the subjects' time and discomfort on the Genucom. However, during the auto test series, the individual test results could not be viewed until all the tests were completed unlike the single test function which graphically displays the results after each test.

The computer was instructed to pair the tests for bilateral comparisons of each test, and print the results in both graphic and numerical form following completion of the test series. The computer displayed error messages if test procedures were not carried out appropriately and allowed the tester to repeat tests not done correctly. For example, if the test was not performed smoothly or the flexion angle changed more than 5 degrees, error messages describing these mistakes appeared on the computer screen.

As with the soft tissue compensation, all applied forces were done to a 3-count (3 seconds), release to "zero out", and then switch directions. For all the tests, the right footswitch was depressed to start a test and pressed a second time at test completion.

Anterior/Posterior Drawer (90 and 30 Degrees)

The applied force levels, which the tester applied by hand, was set at 25 lbs in both the anterior and posterior directions for the anterior/posterior drawer tests. The computer checked for excessive rotation. The tester's hand was placed behind the leg near the proximal end and a force was applied in the anterior direction, while the other hand stabilized the ankle and helped maintain the 90 or 30 degree angle (Figure 27). Once the force was released, the hand was placed on the front of the proximal leg and a force in the posterior direction was applied with the opposite hand remaining at the ankle to provide stabilization.

Varus/Valgus Tests

For the varus/valgus test the applied force was 10 lbs in both the medial and lateral directions with no rotation. The leg was flexed to 0 degrees for the first test and 20 degrees for the second test with both hands grasping the ankle. The test was started at neutral position with a varus force applied first, followed by a valgus force and a return to neutral position.

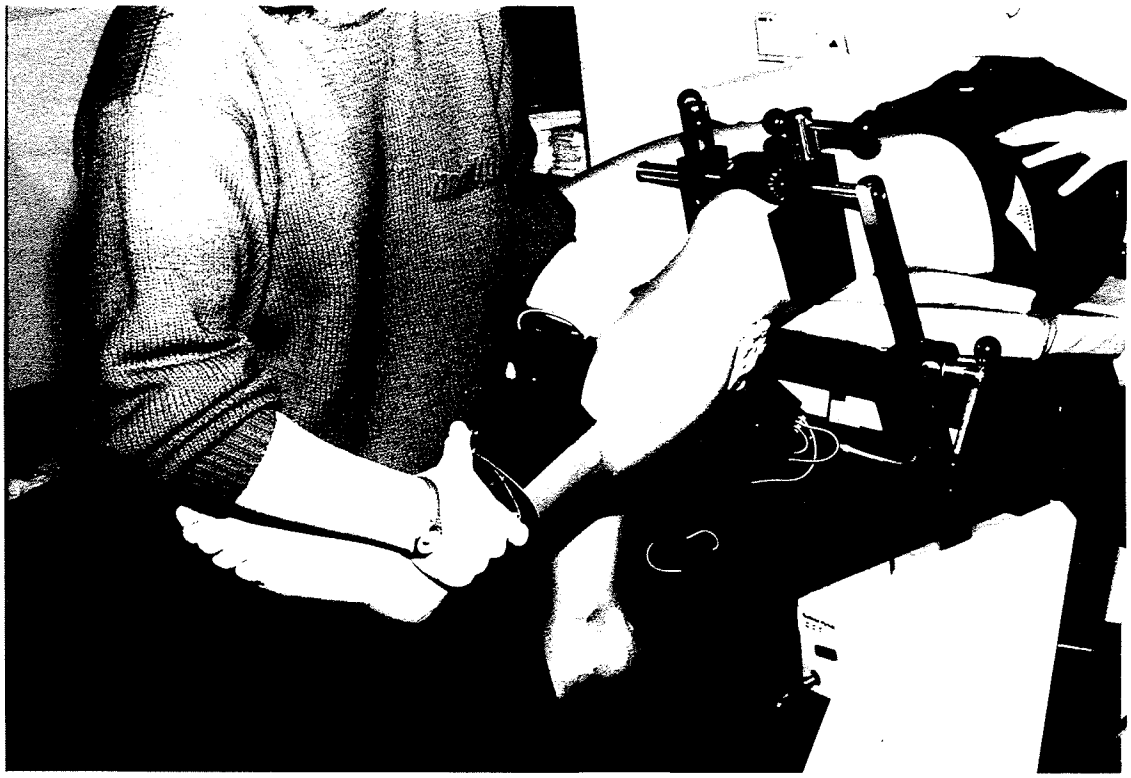

Figure 27 Genucom 30 degree anterior drawer test

Medial Compartment Subluxation Test

The medial compartment subluxation test consisted of an applied force of 25 lbs in the anterior direction along with 15 degrees of external rotation followed by 25 lbs of applied force in the posterior direction and 15 degrees of internal rotation. The tester's hand was positioned behind the proximal leg to apply the anterior force and was moved to the anterior proximal tibia to apply the posterior force. The opposite hand was positioned at the ankle to help maintain the 25 degree angle required for the test and also to apply the internal and external rotations of the leg. If 15 degrees of rotation was not achieved, either internally or externally, the

computer prompt relayed an error message and the test was repeated.

Lateral Compartment Subluxation Test

The applied forces and flexion angle were the same for the lateral compartment subluxation test as for the medial compartment subluxation test. The hand positioning also remained the same. As the anterior force was applied, the leg was internally rotated 15 degrees and as the following posterior force was applied, the leg was externally rotated 15 degrees. The error message check for insufficient rotation also applied to the test.

The tests were analyzed for ACL insufficiency using the normal knee as a control (Peters, Johnson, & Quanbury, 1988; Wroble, Van Ginkel, Grood, Noyes, & Shaffer, 1990). The normal subjects right to left difference in mm laxity was computed for both the test and retest; and also computed for the ACL-deficient subjects and the differences were then compared.

Clinical Assessment Results

Clinical assessment results of laxity were graded on a 1+, 2+, 3+, or 4+ scale (Orthopaedic Knowledge Update, 1984) for each subject by two orthopedic surgeons. The grades of ACL insufficiency, which were recorded for each test on a clinical assessment form, were compiled for comparison with the results of the Genucom assessment.

The following order of tests were used for each subject's clinical evaluation: anterior drawer at 90 degrees, anterior drawer at

30 degrees (Lachman), varus/valgus at 0 degrees, varus/valgus at 20 degrees, and the pivot shift test. The clinical pivot shift was compared to both the Genucom medial and lateral compartment subluxation tests (Peters, Johnson, & Quanbury, 1988).

Data Analysis

The score for each of the six tests of knee laxity from the Genucom consisted of the difference between the laxity of the right and left knees, measured in millimeters of laxity. The laxity scores for each subject, for each of the six tests, for each of the two testing sessions, was entered into a data file using the Statview program on the Macintosh microcomputer. Statistical analyses were conducted using the Statview program.

Reliability of the Genucom Measurements

The reliability of the Genucom measurements was determined by a test-retest method, in which the difference in laxity between the left and right knees from one testing session, was compared to the values obtained several days later in a second testing session. The comparison consisted of calculating a correlation coefficient between the two laxity values, using the Pearson Product moment correlation coefficient. However. due to the small range of values examined in the study, true similarities between the test and retest may not have been detected through correlation. Therefore, a frequency distribution, which has been used in several similar studies of test-retest reliability data, was also used (King & Kumar,

1989; Oliver & Coughlin, 1987; Anderson & Lipscomb, 1989; Stone, Sachs, & Malcom, 1985) to examine the reliability of the measurements.

Perfect agreement of the repeated Genucom measurements referred to cases where the right-left millimeters of laxity of difference for both the test and retest were identical. Slight agreement referred to right-left millimeters of laxity difference between the test and retest were only in disagreement by an acceptable 1-2 millimeters (Wroble, Van Ginkel, Grood, Noyes & Shaffer, 1990; Steiner, Brown, Zarins, Brownstein & Koval, 1990). No agreement accounted for all cases where the test-retest differences were in disagreement by 3 millimeters or more (Peters, Johnson & Quanbury, 1988; Steiner, Brown, Zarins, Brownstein & Koval, 1990).

A sample of test-retest graphics and numeric comparison for anterior displacement are shown in Figures 28 (test graphic and numeric comparison) and 29 (retest graphic and numeric comparison). The right knee to left knee difference for anterior displacement, seen on the left side of the graphs, was three millimeters for the test and two millimeters for the retest. The right side of the graphs represents the amount of internal and external rotation of the knee during the anterior drawer tests.

Validity of the Genucom Measurements

The ability of the Genucom to measure knee laxity accurately was determined by comparing the laxity measurements from the

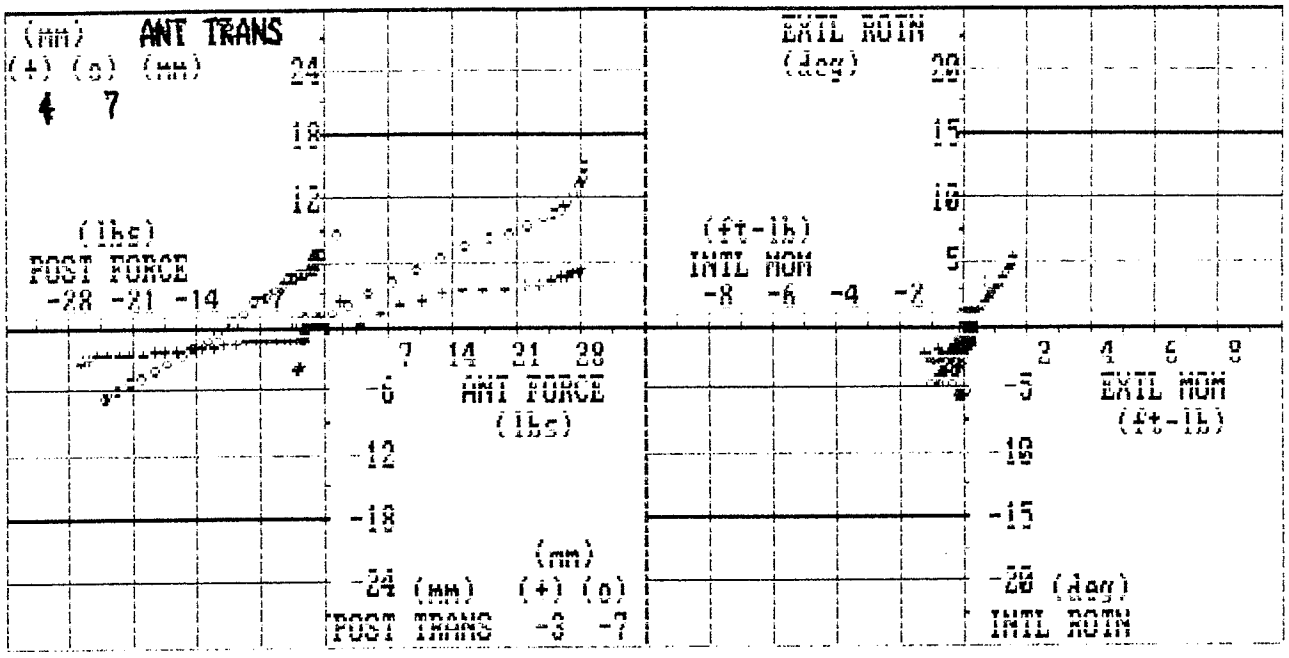

Figure 28 Test graphic and numerical data for Genucom anterior drawer.

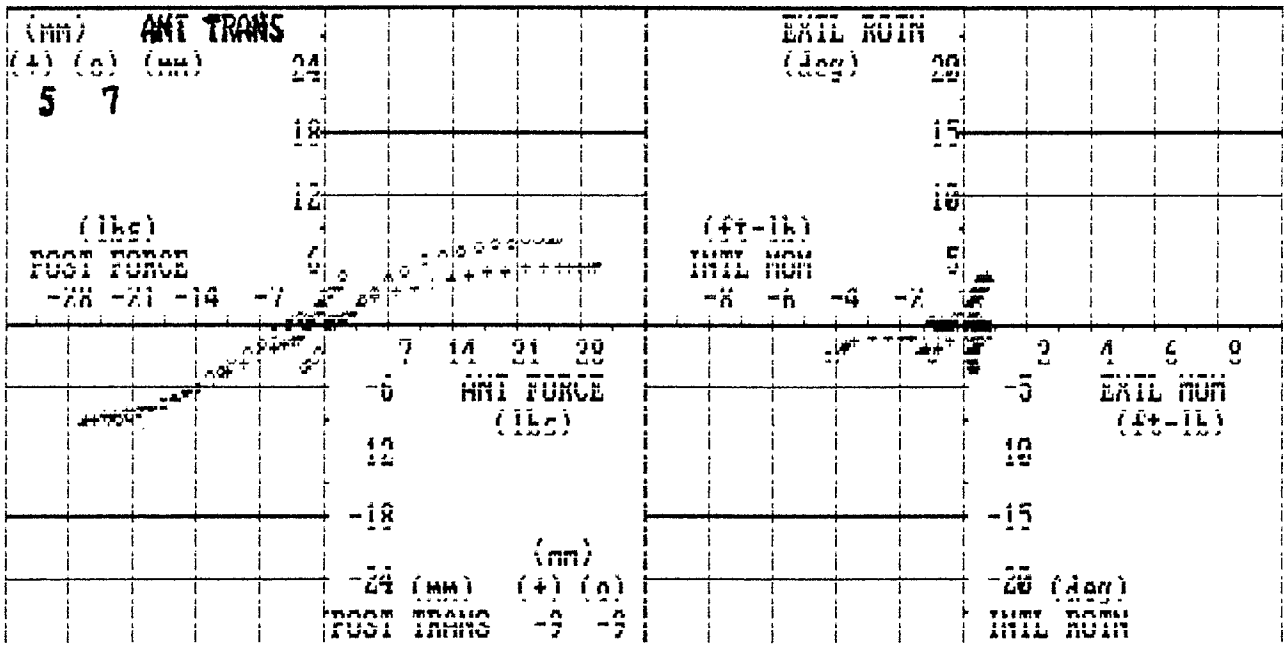

Figure 29 Retest graphic and numerical data for Genucom anterior drawer.

machine to the clinical measurements of laxity. This comparison was conducted using Spearman's Rho correlation coefficient rather than the conventional correlation coefficient, Pearson's product-moment correlation coefficient. The assumption that the measurements involved are on an interval (or ratio) scale and follow a normal distribution, necessary to use Pearson's r, cannot be met because one of the variables (clinical laxity) to be tested is ordinal data (Hassard, 1991). The data was also graphed, with the clinical measurements along one axis, and the Genucom measurements for each of the test along the other axis. The degree of relationship between these measures may be graphically illustrated by this technique.

Correlations were calculated for the knee rating of each physician and the Genucom; and the ratings of physician 1 and physician 2. As with the reliability data, the correlations may not have detected similarity due to the small range of values. Frequency distribution statistics were again employed to test for agreement/disagreement between the Genucom and clinical data.

Perfect agreement between the physicians and the Genucom occurred when the mm of laxity difference of the injured knee minus the noninjured knee is equivalent to the clinical grade (1+, 2+, 3+, 4+) the physicians had assigned to the subject tested. The physicians were in perfect agreement when they each assigned the same clinical grade to a given subject.

Partial agreement between the physicians and the Genucom was designated when it was determined that instability was present but there was no agreement on the grade of the injury. No agreement was assigned when the doctors and the Genucom produced different conclusions regarding whether instability existed or not.

CHAPTER 4
RESULTS AND DISCUSSION

Introduction

The present study was conducted to test the reliability and validity of the Genucom Knee Analysis System. Non-injured subjects were used to test the reliability of the Genucom in a test-retest format using a battery of six bilateral Genucom tests: 90 degree anterior drawer, 30 degree anterior drawer, varus/valgus at 0 and 20 degrees, medial compartment subluxation test and lateral compartment subluxation test. The validity of the Genucom was analyzed by administering the battery of six tests to the previously injured subjects and comparing the results to two separate clinical evaluations also carried out by two orthopedic surgeons on the previously injured subjects. The clinical evaluation consisted of a 90 degree anterior drawer test, Lachman test (30 degree anterior drawer), varus/valgus at 0 and 20 degrees, and a pivot shift test (which was compared to both the medial and lateral compartment subluxation tests).

Results

Subjects

The non-injured group consisted of 20 subjects ranging in age from 21-51 years and consisted of 13 males and 7 females. The mean age was 28 years.

The previously injured group consisted of 16 subjects who had been diagnosed by an orthopedic surgeon with a unilateral anterior cruciate ligament-deficient knee. Thirteen of the sixteen subjects had the injury arthroscopically confirmed prior to the Genucom evaluation. One of the 16 subjects tested, who had not been arthroscopically confirmed, was subsequently excluded from the study after being rediagnosed both clinically and by the Genucom as PCL-deficient. Twelve of the remaining fifteen subjects had suffered their injury within the past 3 years. Table 1 lists the descriptive characteristics of the previously injured group.

The results are reported in two sections. The first section presents the descriptive analysis of the reliability data describing the non-injured subjects. The second section presents the descriptive analysis of the validity data on the previously injured subjects.

Analysis of the Reliability Data

Means and Standard Deviations

The means and standard deviations of the differences in laxity are reported in Table 2 for the test-retest reliability data of the non-injured subjects. The means are expressed as the difference in millimeters of laxity between the right and left knees and were calculated as positive values equal to the absolute value of the difference in laxity (Steiner, Brown, Zarins, Brownstein, Koval & Stone, 1990). The largest difference between test-retest means

Table 1

Descriptive Characteristics of the Previously Injured Group

(n = 15)

Variable	Males	Females	Total Ss
Age (yrs)	26.3	25.4	25.8
ACL-deficient right	4	1	5
ACL-deficient left	3	7	10
Sport Activity Injured In:			
Soccer	2	3	5
Skiing	0	2	2
Basketball	1	1	2
Handball	0	1	1
Squash	1	0	1
Football	1	0	1
Other	2	1	3

occurred in the medial compartment subluxation test which had a difference between the means of 2.65 mm. The lateral compartment subluxation test had the next highest difference between the means at 0.94 mm. The smallest difference between the means was 0.3 mm for the varus/valgus test at 0 degrees. The 30 and 90 degree anterior drawer tests had differences between the means of 0.32 and 0.4 mm respectively.

Correlation Data

The r value for Pearson Product moment correlation coefficient for the test-retest reliability data was calculated using two separate techniques on the Statview program on the Macintosh micro-computer. The r value was first calculated to test for a relationship between the difference in laxity between the right and left knees on one day and the values obtained during the retest several days later. The r value was also calculated to find the relationship between the absolute laxity scores obtained during the test-retest procedure (e. g. right leg laxity value in first testing session versus right leg laxity value in second testing session). Wroble, Van Ginkel, Grood, Noyes, and Shaffer (1990), suggested that paired right-left differences be used for reporting results rather than single knee laxity values as single knee measurements ignore simultaneous changes occurring in both knees that appear due to training, disuse, or rehabilitation. In the present study, however, Pearson's correlation coefficient was

Table 2

Means and Standard Deviations of the Test-Retest Scores for the Six Knee Laxity Tests.

(expressed as difference in mm of laxity between right and left knee)

	TEST	RETEST
	mean±S.D.	mean±S.D.
90 Degree Anterior Drawer	4.5±3.487	4.1±2.024
30 Degree Anterior Drawer	2.58±2.168	3.26±1.695
0 Degrees Varus/Valgus	0.95±0.686	0.65±0.813
20 Degree Varus/Valgus	2.1±1.447	1.75±1.552
Medial Compartment Subluxation	8.45±5.042	5.8±4.008
Lateral Compartment Subluxation	5.18±4.433	4.24±3.052

calculated both ways to reveal any differences between the two methods and any possible error that theoretically is increased by left-right paired differences (Wroble, Van Ginkel, Grood, Noyes, & Shaffer, 1990).

None of the r values calculated showed strong correlation (Tables 3 and 4). When examining the millimeters of difference between the right and left legs, only the varus/valgus at 20 degrees showed significant but moderate correlation with r = .551 (Figure 30). The absolute values (mm of displacement: right vs. right and left vs. left) of the test-retest data showed moderate correlation between the test-retest scores for the 90 degree anterior drawer, 30 degree anterior drawer, and varus/valgus at 0 of the left knee and varus/valgus at 20 degrees of the right knee. Even though these r-values were significant, this still did not represent an important degree of correlation.

Due to the small range of values examined in the study, true similarities between the test and retest may not have been detected through correlation. Frequency distribution, which has been used in several similar studies of the test-retest reliability data, was also used in the analysis of data (King & Kumar, 1989; Daniel, Stone, Sachs, & Malcom, 1985; Anderson & Lipscomb, 1989; Oliver & Coughlin, 1987).

Table 3

Correlation Coefficients for Test-Retest Scores For Knee Laxity on 6 Different Tests

Test	N	R	R-squared
90-anterior drawer	20	.157	.025
30-anterior drawer	19	.032	.001
0-varus/valgus	20	.344	.119
20-varus/valgus	20	.551*	.303
Medial compartment subluxation	20	.156	.024
Lateral compartment subluxation	17	.172	.030

*$p < .05$

Table 4

Correlation Coefficients for Both Left and Right Limbs for the Test-Retest Scores for the Six Tests

(Right knee vs. Right knee/Left knee vs. Left knee)

Test	N	Side	R	R-squared
90-anterior drawer	20	right	.383	.147
90-anterior drawer	20	left	.477*	.227
30-anterior drawer	18	right	.431	.186
30-anterior drawer	18	left	.559*	.312
0-varus/valgus	20	right	.404	.163
0-varus/valgus	20	left	.627*	.394
20-varus/valgus	20	right	.505*	.255
20-varus/valgus	20	left	.345	.119
medial compartment subluxation	20	right	.333	.111
medial compartment subluxation	20	left	.398	.158
lateral compartment subluxation	16	right	.439*	.193
lateral compartment subluxation	16	left	.294	.086

* $p < .05$

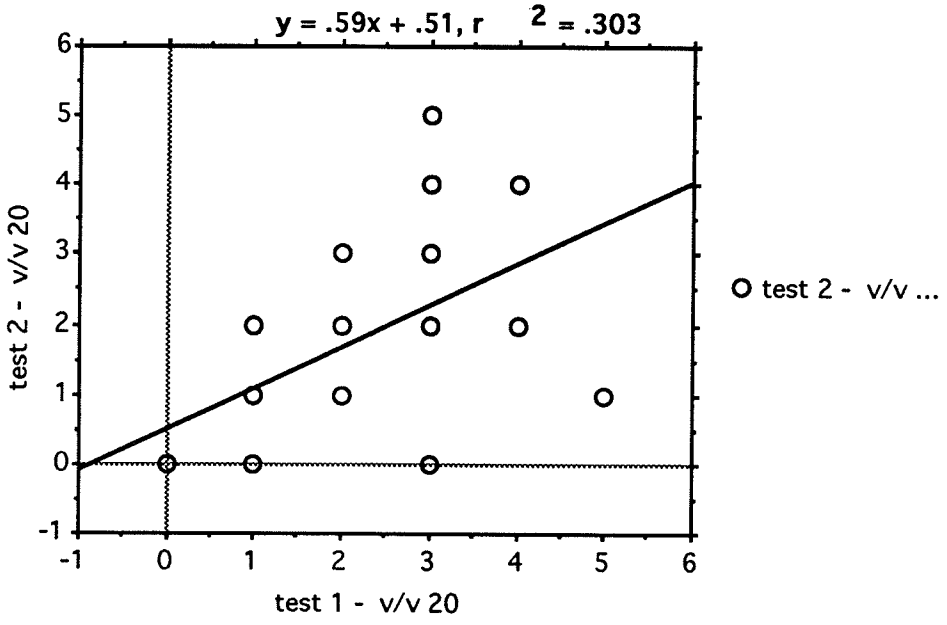

Figure 30 Correlation between test-retest knee laxity scores for varus/valgus at 20 degrees.

Frequency Distribution

The number of subjects and their respective percentage of agreement or disagreement are reported in Table 5.

The 90 degree anterior drawer test had only 5 out of 20 cases of perfect agreement between the test-retest score of laxity difference between knees and only 15.8 % of the knees showed perfect agreement for the 30 degree anterior drawer test. The varus/valgus test at 0 degrees did not have any cases falling into the non-agreement category and along with the varus/valgus test at 20 degrees showed the highest agreement of the all the tests at 100 % complete or partial agreement. The medial compartment subluxation test had 16 out of 20 cases in the non-agreement category and only 1 case (5 %) of perfect agreement. The lateral compartment subluxation test also only had 1 case of perfect agreement and 5 out of 17 cases of slight agreement.

The results of the frequency distribution analysis suggest that the varus/valgus tests are the most reliable while the more complex medial and lateral compartment subluxation tests showed the lowest reliability in a test-retest situation.

Analysis of the Validity Data

Means and Standard Deviations

The means and standard deviations of the Genucom tests on the previously injured subjects are listed in Table 6. In addition to computing the overall mean for each test, the means were also

Table 5

Frequency Distribution of Test-Retest Scores From the Genucom Knee Analysis Tests

(values compared are mm difference in laxity between right and left knees)

	#	%
90 Degree Anterior Drawer (n=20)		
Perfectly Agree	5	25
Slightly Agree	7	35
Do Not Agree	8	40
30 Degree Anterior Drawer (n=19)		
Perfectly Agree	3	15.8
Slightly Agree	10	52.6
Do Not Agree	6	31.6
0 Degree Varus/Valgus (n=20)		
Perfectly Agree	7	35
Slightly Agree	13	65
Do Not Agree	0	0
20 Degree Varus/Valgus (n=20)		
Perfectly Agree	8	40
Slightly Agree	10	50
Do Not Agree	2	10
Medial Compartment Subluxation (n=20)		
Perfectly Agree	1	5
Slightly Agree	3	15
Do Not Agree	16	80
Lateral Compartment Subluxation (n=17)		
Perfectly Agree	1	5.9
Slightly Agree	5	29.4
Do Not Agree	11	64.7

Legend:

perfectly agree - 0 mm difference between test and retest
slightly agree - 1-2 mm difference between test and retest
do not agree - $\geq$ 3 mm difference between test and retest

calculated with regard to injury side (Table 6 and Figures 31, 32, and 33) and a t-test was conducted to determine the significance of the differences between right and left knee injuries. For the previously injured subjects, difference in laxity between the right and left knees was calculated as the laxity of the injured knee minus the laxity of the noninjured knee. If the laxity of the injured knee was less than the laxity of the noninjured knee, the difference was recorded as a negative value (Steiner, Brown, Zarins, Brownstein, Koval & Stone, 1990).

The results of the t-test indicated that the subjects with left knee injuries had significantly different laxity values than the subjects with right knee injuries for all the Genucom tests (Table 6).

The means displayed in Figures 31, 32, and 33 also show a large difference between the subjects with right knee injuries and the subjects with left knee injuries. The differences between the left and right knee injured subjects are so great that the overall means (n=15) rest at close to 0 millimeters of difference between the injured and non-injured knees (Figure 31).

Spearman Correlation Coefficient

Spearman Rho was used to test for significant correlation between the Genucom tests and the clinical tests instead of Pearson's r since the assumption that the measurements involved are on an interval (ratio) scale and follow a normal distribution cannot be met. One of the variables (clinical laxity) to be tested is ordinal

Table 6
MEAN AND S. D. GENUCOM VALUES
OF THE PREVIOUSLY INJURED

Test	All (n=15)	Left (n=10)	Right (n=5)	t-value
90-anterior drawer	-1.6(5.98)	-3.9(5.86)	2.8(3.27)	2.352*
30-anterior drawer	.53(4.28)	-1.5(2.76)	4.6(3.98)	3.499**
0-varus/valgus	.07(1.39)	-0.7(.95)	1.6(.548)	4.965**
20-varus/valgus	-0.6(1.99)	-1.6(1.35)	1.4(1.52)	3.903**
medial compartment subluxation	-0.6(8.18)	-3.8(4.71)	5.8(10.35)	2.521*
lateral compartment subluxation	1.67(9.69)	-3.6(6.52)	12.2(4.97)	4.741**

(Key: MEAN(S. D.))

*significant to p< .05

**significant to p< .005

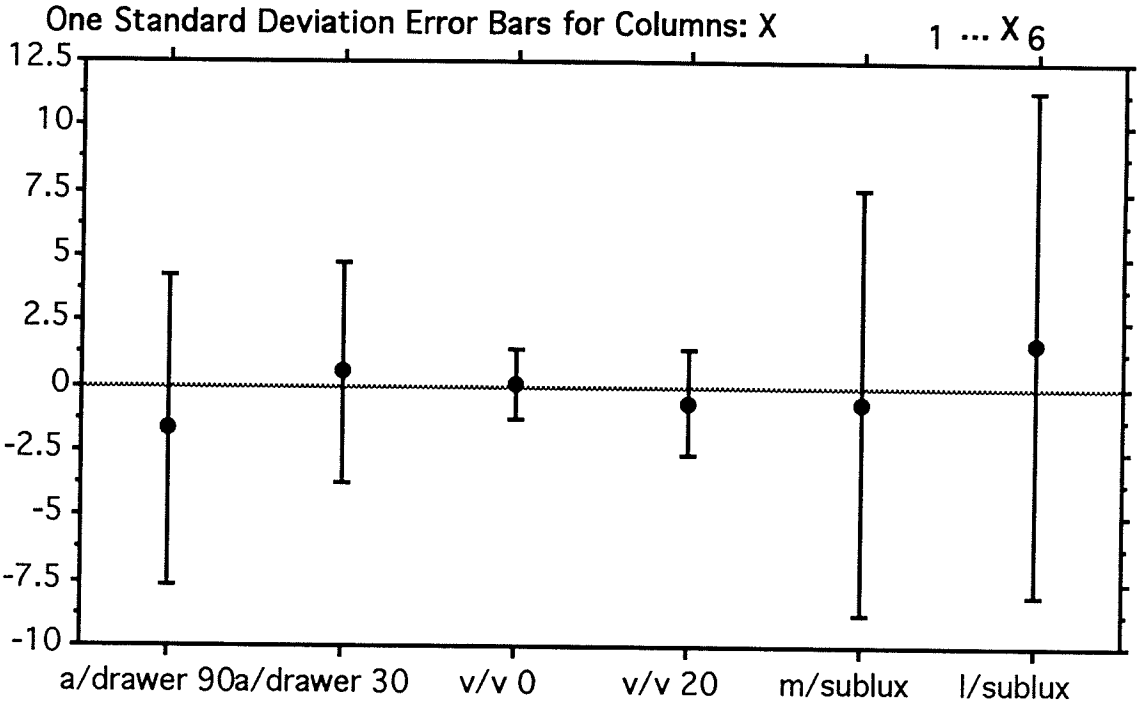

Figure 31 Means and standard deviations of the differences in knee laxity scores for the six Genucom tests for the ACL-deficient subjects.

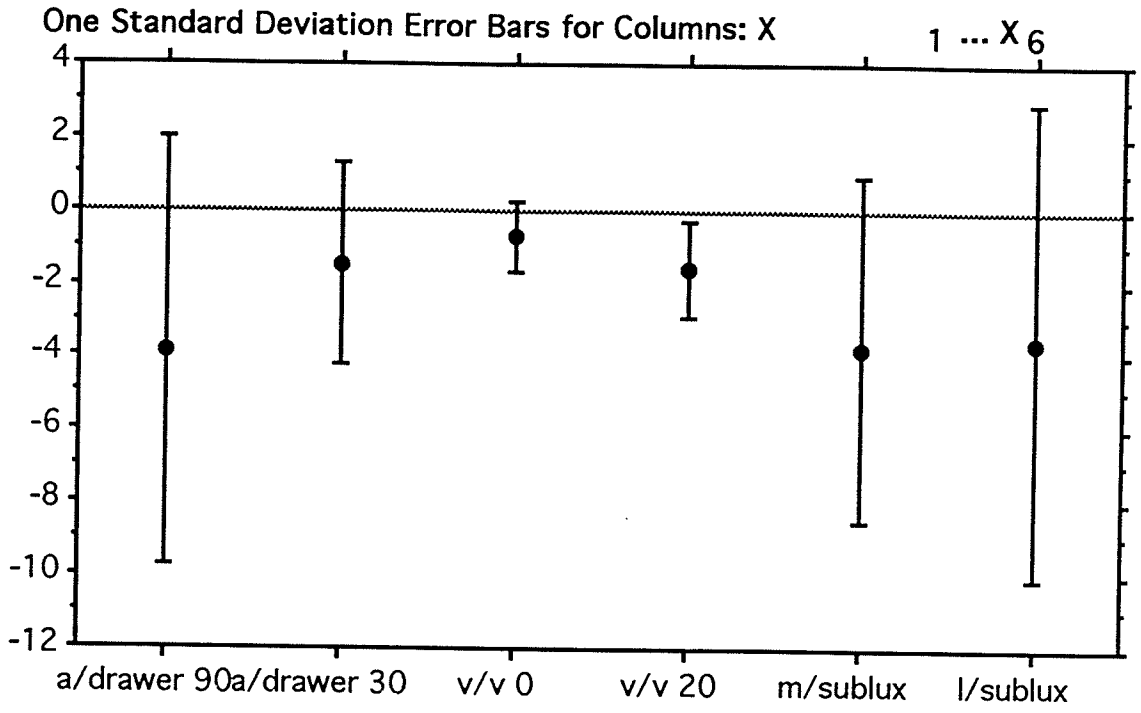

Figure 32 Means and standard deviations of the differences in knee laxity scores for the six Genucom tests for subjects with ACL-deficient left knees.

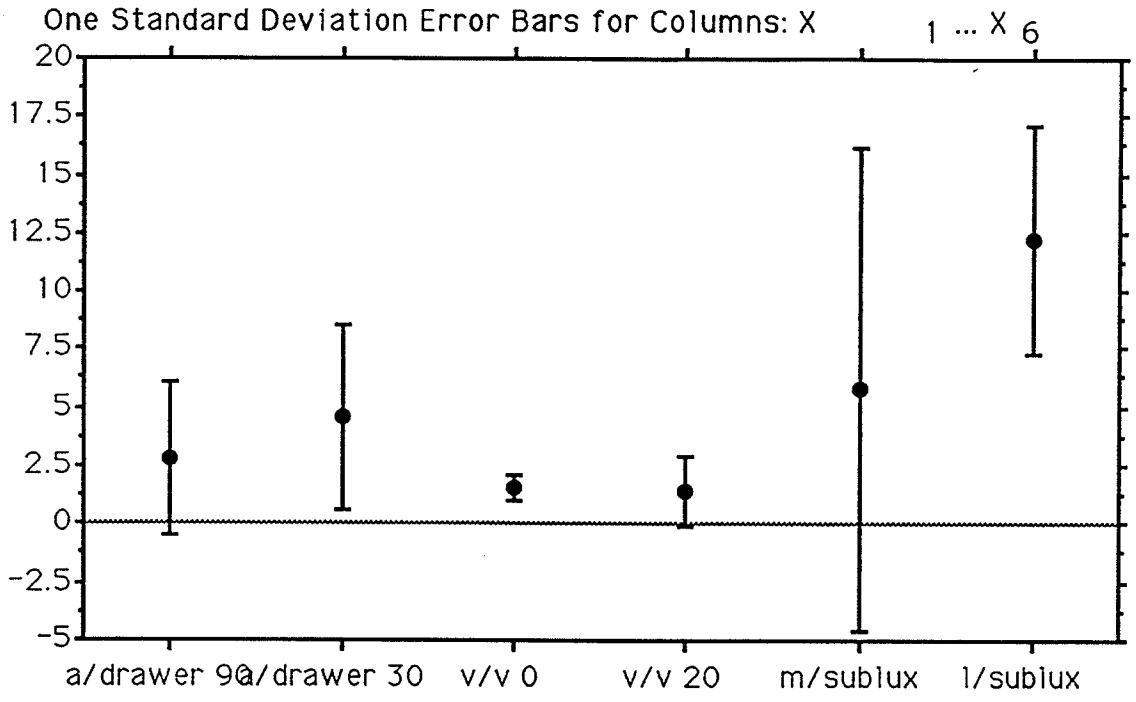

Figure 33 Means and standard deviations of the differences in knee laxity scores for the six Genucom tests for subjects with ACL-deficient right knees.

data (i. e. the scores have values of only 1+, 2+, 3+, or 4+) (Hassard, 1991).

Correlation was calculated for the ratings of each physician and the Genucom and physician 1 versus physician 2 (Table 7). The only highly significant correlation value was between physician 1 and 2 for the varus/valgus test at 0 degrees as there was complete agreement. A moderate correlation between physician 1 and 2 was also apparent for varus/valgus at 20 degrees. The Genucom also had moderate significant correlation with both physician 1 and 2 for the varus/valgus test at 0 degrees. It should be noted that significance is related only to the correlation coefficient's difference from 0 and does not alone indicate strong correlation.

As with the reliability data, the correlations between the clinical evaluations and the Genucom may not have detected any similarity due to the small range of numbers.

Frequency Distribution

The number of subjects tested on the Genucom and compared to the clinical tests conducted by one or both physicians are reported in Table 8. A definite lack of agreement occurred between the physicians' assessments and the Genucom assessment for both the 90 and 30 degree anterior drawer tests. No agreement was reported in approximately 75% of the cases for the 90 degree anterior drawer test and none of the cases had perfect agreement for the 30 degree anterior drawer test.

Table 7
Correlation Data for Clinical and Genucom Tests on Previously Injured Subjects

Test	Dr. 1-Genucom (Rho)	Dr. 2-Genucom (Rho)	Dr.1-Dr. 2 (Rho)
90-anterior drawer	-.238	.051	.406
30-anterior drawer	.068	.150	.290
0-varus/valgus	.652**	.654*	1.00***
20-varus/valgus	.088	-.161	.664*
medial compartment subluxation	-.179	-.056	.378#
lateral compartment subluxation	051	-.021	.378#

#the clinical pivot shift test was compared to both the medial and lateral compartment subluxation tests.

* $p < .05$

** $p < .01$

*** $p < .001$

Table 8
Frequency Distribution of Validity Data
(based on clinical grading scale)

Test	Perfectly Agree	Partly Agree	No Agree
DR. 1 - GENUCOM (N=15)			
90-anterior drawer	2 (13.3%)	2 (13.3%)	11(73.4%)
30-anterior drawer	0 (0.0%)	6 (40%)	9 (40%)
0-varus/valgus	10 (66.7%)	5 (33.3%)	0 (0.0%)
20-varus/valgus	7 (46.7%)	2 (13.3%)	6 (40%)
medial compartment subluxation	0 (0.0%)	2 (13.3%)	13 (86.7%)
lateral compartment subluxation	1 (6.7%)	3 (20%)	11 (73%)
DR. 2 - GENUCOM (N=12)			
90-anterior drawer	2 (16.7%)	1 (8.3%)	9 (75%)
30-anterior drawer	0 (0.0%)	5 (41.7%)	7 (58.3%)
0-varus/valgus	8 (66.7%)	4 (33.3%)	0 (0.0%)
20-varus/valgus	4 (33.3%)	1 (8.3%)	7 (58.4%)
medial compartment subluxation	0 (0.0%)	3 (25%)	9 (75%)
lateral compartment subluxation	0 (0.0%)	4 (33.3%)	8 (66.7%)
DR. 1 - DR. 2 (N=12)			
90-anterior drawer	6 (50%)	6 (50%)	0 (0.0%)
30-anterior drawer	4 (33.3%)	8 (66.7%)	0 (0.0%)
0-varus/valgus	12 (100%)	0 (0.0%)	0 (0.0%)
20-varus/valgus	5 (41.7%)	3 (25%)	4 (33.3%)
Pivot Shift	6 (50%)	5 (41.7%)	1 (8.3%)

Both physicians concurred with the Genucom results for the varus/valgus test at 0 degrees, with at least partial agreement in all cases. The results of the varus/valgus test at 20 degrees was less favorable with approximately half of the cases not in agreement. The medial and lateral subluxation tests showed the least agreement between the physicians and the Genucom of all the tests conducted. Physician 1 and physician 2 had the greatest agreement for the varus/valgus test at 0 degrees where there was 100% (12-12) perfect agreement and therefore supporting the Rho value of 1.00 of perfect correlation. Varus/valgus at 20 degrees exhibited the greatest non-agreement between the physicians with 33.3% of the cases having no agreement. The other tests averaged approximately 50% perfect agreement between the physicians.

Discussion

Reliability of the Genucom

There were no highly significant correlations for the reliability data suggesting that the Genucom does not generate reproducible knee laxity values. Only the varus/valgus at 20 degrees, with an r value of .551, displayed moderate correlation for the millimeters laxity in the test-retest data. This does not support the study by Highgenboten, Jackson, and Meske (1989) who found the overall reliability of the Genucom for test-retest trials on 50 normal subjects to be $r>.80$. However, in the Highgenboten, Jackson, and Meske

(1989) study it was not clear how the overall reliability was calculated.

A frequency distribution of the reliability data showed moderate agreement for the 90 and 30 degree anterior drawer tests, high agreement for the 0 and 20 degree varus/valgus tests, and almost no agreement for the medial and lateral compartment subluxation tests.

Steiner, Brown, Zarins, Brownstein, Koval, and Stone (1990) supported the findings of the anterior displacement data as the Genucom showed only moderate reproducibility scores for an anterior drawer at 20 degrees on 13 normal subjects and the difference in displacement between the right and left knees varied as much as 5 millimeters between testing sessions. The three other machines they studied, the Stryker, Acufex, and KT-1000, had more reproducible measurements of anterior displacement at 20 degrees of flexion than did the Genucom.

Worble, Grood, Noyes, and Schmitt (1990), in a test-retest study on 10 subjects with normal knees found that the day-to-day (installation-to-installation) millimeters of laxity difference between the right and left knees was not significantly different. However, the interaction between day and subjects was significant ($p < .003$). The data showed the interaction was a result of significant day-to-day variability in measurements made on individual subjects. Subjects millimeters of laxity difference between the right and left knees

varied randomly from day-to-day. No prediction could be made for individual cases to determine if translation values increased, decreased, or were the same between any 2 test days for anterior drawer tests at 90 and 30 degrees. Since the pattern of variability was different for individual subjects, the average value for all 10 subjects varied little from day to day even though large differences were apparent in individual subjects. This finding concurred with the present study.

Worble, Van Ginkel, Grood, Noyes, and Shaffer (1990), in a study similar to the Worble, Grood, Noyes, and Schmitt (1990) study on the Genucom and the present study, used 6 normal subjects to test the repeatability of the KT-1000. Using an anterior drawer test at 25 degrees, the study also found significant day-to-day (installation-to-installation) differences occurred among individual subjects tested.

The lack of highly reproducible scores may be related to installation to installation differences as the Genucom seating technique is highly subjective, specifically the use of the "2-3 finger" distance measurement system used to mark the distance between the proximal posterior aspect of the lower leg and the edge of the Genucom seat during subject installation. It is not a precise measurement as the tester approximates the distance between the Genucom seat and the back of the subject's lower leg by using the width of 2-3 fingers. Leg mass differences among subjects may

affect this measurement as subjects with larger calves due to muscle or adipose tissue may not be properly seated with the 2-3 finger distance measurement from the proximal posterior aspect of the lower leg to the edge of the seat. The subjectivity of this installation practice can significantly change the position the electrogoniometer perceives as the 90 degree resting angle and displacement measurements taken from these varying flexion angles will result in different laxity scores from test to retest.

To support this point, a test-retest format was adopted during the current study on the same day, during same set-up and same installation period and the absolute scores for 4 tests of a 30 degree anterior drawer were all within ± 1 mm of the original score. Worble, Grood, Noyes, and Schmitt (1990) in a study that looked at within seating test-retest reliability of the Genucom, found for 10 subjects, each tested 3 times during one seating, no significant difference between tests during the same seating session for the 90 degree and 30 degree anterior drawer tests.

The subjectivity of the Genucom installation could be improved by replacing the "2-3 finger" width measurement between the front of the Genucom seat and the posterior aspect of the lower leg with a more precise measurement. This researcher suggests taking a measurement with a ruler from the proximal patella to the midpoint of the thigh restraint. The thigh restraint would be positioned at the intersection point of a line perpendicular to the edge of the seat and

the midline of the anterior femur. The measured distance from the patella to the midpoint of the restraint would then be used for each subsequent installation on the same subject. This would allow the thigh restraint to be placed in an identical position for each subsequent testing session.

The reliability was also affected by subject resistance, due to quadriceps and hamstring muscle contraction against the Genucom tester's applied anterior force. If a subject resisted on the test and was more relaxed at retest the scores did not represent accurate millimeters of laxity. Of the 20 noninjured subjects tested in the reliability study, 17 had conclusive evidence of resistance in the graphic results of either the test, retest or both. Graphically, subject resistance appeared as a baseline measurement or a sudden direction change in an upsloping graph of millimeters of laxity during an applied anterior force (Figure 34). The resistance of the quadriceps and hamstring muscles against the applied anterior force, was not apparent in any of the tests of varus/valgus (medial/lateral plane), which may account for the high level of agreement observed for these 2 tests.

Motion between the tibia and the tibial cuff support may also affect Genucom reliability (Wroble, Grood, Noyes & Schmitt, 1990; Granberry, Noble, & Woods, 1990). Rotation of the tibial cuff support during testing of the knee may be recorded by the Genucom as anterior-posterior translation. According to Granberry, Noble, and

Woods (1990), this is especially true when the joint is loaded in either internal or external rotation. This rotation can affect the apparent measurement of laxity of the knee, so that the reproducibility of the measurement may be further decreased. In the present study, this may have had a large effect during the medial and lateral compartment subluxation tests in which the joint was loaded in 15 degrees of external and internal rotation.

Validity of the Genucom

The significant differences between the means of the subjects with right knee injuries and the subjects with left knee injuries suggests a possible testing effect. Subject muscle resistance and the subsequent baseline mm graphs, which resulted in the negative values for mm of laxity, were much more common on the injured left knees. Since subjects were all tested right knee first, any discomfort suffered on the first leg may have caused anticipatory resistance on the second leg, particularly if it was the injured limb.

Of the 15 previously injured subjects tested, 10 had strong indications of muscle resistance in the second leg tested. In 8 of the 10 cases, with muscle resistance, the second leg tested was the previously injured leg. Subject relaxation was a critical factor for the Genucom testing and must be considered a possible error source (Wroble, Grood, Noyes, & Schmitt, 1990). Markoff, Kochan, and Amstutz (1984), in a study comparing subjects maximally tensed versus maximally relaxed, found that maximum muscle tension

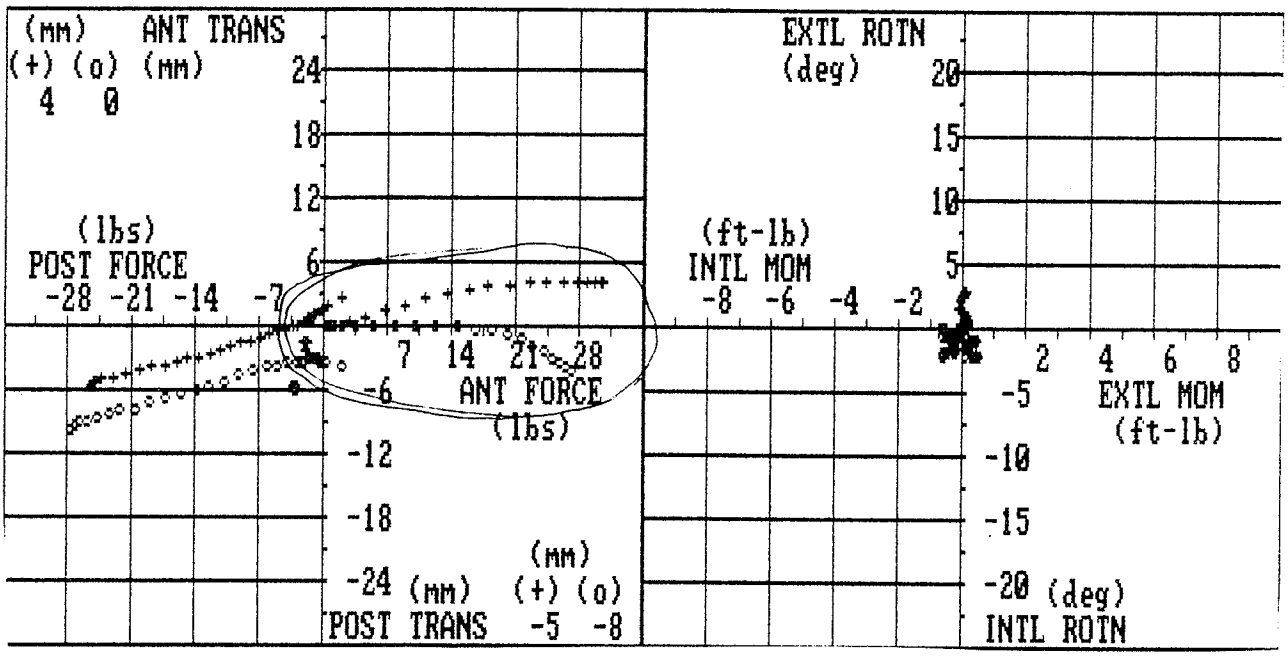

Figure 34 Genucom graphic of muscular resistance of a subject during test

reduced knee laxity by 55% to 76% during an instrumented assessment.

The Genucom Knee Analysis System is equipped with a single test function program for each type of test as well as the auto test series used in the current study. The single test function allows the tester to view the graphic results following each test. With the auto test series, which was used in the present study, the results cannot be viewed until all the tests in the series are completed. By using the single test function, patient muscle resistance could be monitored graphically during each test and multiple measurements of each test could be taken to monitor repeatability of the laxity values. However, with this method a limited number of tests should be used to minimize the amount of patient discomfort since the single test administration time is greater that with the auto test series.

No significant correlations were found for the validity data other than varus/valgus at 0 degrees. Steiner, Brown, Zarins, Brownstein, Koval, and Stone (1990), found, in comparing the clinical Lachman (30 degree anterior drawer) and the pivot shift with instrumented measurements of anterior displacement at 20 degrees of flexion, that the Genucom did not statistically correlate with the Lachman and pivot shift scores, while the other three machines, the Acufex, KT-1000, and the Stryker, all had correlation coefficients that were significant and positive. Although a different flexion angle was used and a somewhat different comparison made, the results of the

Steiner, Brown, Zarins, Brownstein, Koval, and Stone (1990) study support the findings of the present study.

Peters, Johnson, and Quanbury (1988), in a study on 17 subjects with ACL insufficiency, compared the Genucom 90 and 30 degree anterior drawer tests to the clinical 90 degree drawer test and the Lachman (clinical anterior drawer at 30 degrees) and reported only moderate correlation between the Genucom and the clinical measurements of laxity. A correlation of r=.44 was calculated for the anterior drawer at 90 degrees and a slightly better correlation of r=.55 was calculated for the anterior drawer at 30 degrees. These correlation coefficients, although only moderate, are much greater than the -.238 to .150 range of correlation coefficients calculated for the 90 and 30 degree anterior drawer tests of the current study. However, the current study and the study by Peters, Johnson, and Quanbury (1988) used different correlation coefficients. The current study used Spearman's Rho while Peters, Johnson, and Quanbury (1988) used Pearson's r.

The majority of studies similar to the current study (Oliver & Coughlin, 1987; Anderson & Lipscomb, 1989; Daniel, Stone, Sachs & Malcom, 1985; King & Kumar, 1989) used frequency distribution. In the present study, only 26.6% (physician 1) and 25% (physician 2) of the clinically positive ACL-deficient knees measured 90 degree anterior laxity of greater than 2 mm for the 90 degree anterior drawer when compared to the normal knee and at 30 degrees of

flexion only 40% (physician 1) and 41.7% (physician 2) of the clinically positive ACL-deficient knees measured greater than 2 mm of anterior laxity when compared to the uninjured knee.

The study conducted by King and Kumar (1989) supported the present findings as only 40% of the clinically positive ACL-deficient knees measured an anterior displacement of greater than 2 mm when compared to the normal knee. However, King and Kumar (1989) conducted the instrumented 30 degree anterior drawer on the Stryker Knee Arthrometer and not on the more complex Genucom. In a study comparing a Genucom anterior drawer at 20 degrees to the clinical Lachman (30 degree anterior drawer) and pivot shift, Steiner, Brown, Zarins, Brownstein, Koval, and Stone (1990) found the approximate diagnostic correctness of the Genucom to be 60 percent. However, the other three machines they compared to the clinical tests had between 80-90% diagnostic correctness.

Anderson and Lipscomb (1989) found that the Genucom was diagnostically correct in 70% of the 50 subjects who had arthroscopically confirmed knee ligament damage (including subjects with posterior cruciate ligament tears and medial collateral ligament tears). However, thirty of the fifty subjects tested had acute knee injuries (within two weeks) while the present study only tested subjects with chronic (more than three months) isolated ACL-deficient knees.

Oliver and Coughlin (1987) found, in a study testing 38 subjects with a unilateral knee injury, that 77.4% of the clinically positive 90 degree anterior drawer tests were also positive on the Genucom. However, the clinically positive tests were not arthroscopically confirmed as in the present study. The values in the Oliver and Coughlin (1987) study, although among the highest recorded for the Genucom, fall far below those of the KT-1000 which, in a study conducted by Daniel, Stone, Sachs, & Malcom (1985), found that the KT-1000 anterior displacement measurements concurred with the arthroscopically confirmed ACL deficient knees in 94% of the cases (n=53).

The medial compartment subluxation test agreed with physician 1 in only 2 out of 15 cases and for physician 2 agreement occurred in only 3 out of 12 cases. Peters, Johnson, and Quanbury (1988) study supported the current study as they found a positive medial compartment subluxation test in only 5 of the 17 subjects who had a positive clinical pivot shift. The lateral compartment subluxation test, in the present study, agreed with physician 1 in 4 out of 15 cases and agreed with physician 2 in 4 out of 12 cases. Peters, Johnson, and Quanbury (1988) found slightly better results for the lateral compartment subluxation test as 8 out of the 17 subjects, who had a positive clinical pivot shift, also had a positive lateral compartment subluxation test on the Genucom.

With regard to the 90 and 30 degree anterior drawer tests, the physicians agreed there was clinically significant ACL damage in 100% of the cases. Anderson and Lipscomb (1989) study supported this finding as the clinical examinations in their study, which included a 90 degree anterior drawer test and a 30 degree anterior drawer test, were correct in 95% of the cases (n=50).

The only clinical test where the physicians differed to any extent was the varus/valgus test at 20 degrees in which there was no agreement in 33.3% of the cases.

CHAPTER 5
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

The purpose of the study was to test the reliability and validity of the Genucom Knee Analysis System. This was accomplished by conducting a test-retest Genucom assessment on noninjured subjects to test for reliability and to compare Genucom assessments conducted on previously injured subjects to clinical assessments conducted by 2 orthopedic surgeons to test for validity. Comparisons were made involving the test and retest on six separate Genucom tests related to anterior displacement, medial joint opening (varus/valgus tests), and rotatory movements. The testing protocol for the reliability study was conducted on 20 healthy subjects, both male and female, who had no lower limb pathology. The testing protocol for the validity study was conducted on 15 male and female subjects who had a unilateral ACL-deficient knee, which had been arthroscopically confirmed in 13 of the 15 subjects.

The results of the first Genucom test was compared to the results of the Genucom retest in the reliability group portion of the study. Comparisons were conducted involving the 90 degree anterior drawer, 30 degree anterior drawer, varus/valgus at 0 degrees, varus/valgus at 20 degrees, medial compartment subluxation test, and the lateral compartment subluxation test. The results of each

Genucom test in the validity group was compared to equivalent clinical tests conducted by the two orthopedic surgeons. All the tests of the injured subjects were the same as in the reliability study with the exception of the medial and lateral compartment subluxation tests which were compared to the pivot shift test since it is the only clinical test which tests for complex rotatory instabilities similar to the two compartment subluxation tests.

None of the comparisons of the test-retest laxity difference between the subjects' right and left legs showed a high degree of correlation. Only the varus/valgus at 20 degrees showed moderate correlation. The results of the comparisons carried out by frequency distribution for the test-retest data suggest that the varus/valgus tests are the most reliable, the 90 and 30 degree anterior drawer tests are moderately reliable and the medial and lateral compartment subluxation tests are not reliable.

In comparing the means of the right ACL-deficient knees to the left ACL-deficient knees, the results of the t-test showed a significant difference in laxity values between them for all the Genucom tests ($p < .05$). Significant, but moderate correlation was found between the Genucom varus/valgus test at 0 degrees and the clinical varus/valgus test at 0 degrees. The only significant high correlation was found between physicians for the clinical varus/valgus test at 0 degrees.

The result of the frequency distribution calculations showed moderate to strong disagreement between the physicians' clinical assessments and the Genucom assessment for both the 90 and 30 degree anterior drawer tests. Both physicians concurred with the Genucom results, at least partially, for the varus/valgus test at 0 degrees in all cases. The medial and lateral compartment subluxation tests showed the greatest disagreement between the physicians and the Genucom with close to 75% non-agreement in all cases.

Between the doctors, strong agreement, at least partial agreement, was found for all the tests, with the exception of the varus/valgus test at 20 degrees which had 33.3% non-agreement.

Conclusions

The results of the data analysis of this investigation of the reliability and validity of the Genucom Knee Analysis System have led to the following conclusions:

1. The Genucom varus/valgus tests at 0 and 20 degrees were reliable measures of knee joint laxity in the frontal plane, based on the frequency distribution statistics.

2. The Genucom 90 and 30 degree anterior drawer tests were only moderately reliable measures of knee joint laxity in the sagittal plane, based on the frequency distribution statistics.

3. The Genucom medial and lateral compartment subluxation tests were not reliable measures of knee joint laxity in the transverse plane.

4. The Genucom 90 degree anterior drawer test results did not agree with the clinical 90 degree anterior drawer tests in the majority of the cases, based on the frequency distribution statistics.

5. The Genucom 30 degree anterior drawer test results did not agree with the clinical 30 degree anterior drawer test in about half the cases, based on the frequency distribution statistics.

6. The Genucom assessment protocol resulted in a significant testing order effect which affected injured to noninjured measurements of laxity difference between the knees.

7. The Genucom varus/valgus test at 0 degrees was in general agreement with the clinical varus/valgus test at 0 degrees.

8. The Genucom varus/valgus test at 20 degrees agreed with the clinical varus/valgus test at 20 degrees in approximately half the cases.

9. The Genucom medial and lateral compartment subluxation test results did not agree with the clinical pivot shift results in the majority of the cases.

10. The doctors concurred in their clinical assessments for all tests with the exception of the varus/valgus at 20 degrees.

Recommendations

The following recommendations are based on the current study and may be of benefit to other researchers planning to conduct a study of similar design, or to potential Genucom users.

1. A larger sample size is recommended for the test-retest reliability study. A larger sample size may produce more conclusive correlation statistics. A larger sample size of ACL-deficient knees for the validity study may be limited by the availability of subjects who fit the criteria of the study.

2. The tester should randomize the first leg testing order on the Genucom in order to reduce the chance of a testing effect.

3. The tester should use the single test function in the Genucom over the auto test series so patient resistance can be monitored graphically during each test.

4. During installation, replace the "2-3 finger" width seating measurement between the front of the Genucom seat and the posterior aspect of the 90 degree free hanging lower leg with a precise measurement technique.

5. The Genucom should be studied using a blind study in which the Genucom tester and the orthopedic surgeons test both injured and uninjured subjects and do not know in advance which are injured and which are not.

6. A study should be designed using two different Genucom testers for each subject to test for objectivity between testers since in a clinical setting the tester who tests a patient presurgically may not be the same tester who tests a patient postsurgically 9-12 months later.

7. A study should be designed to conduct a test-retest reliability study analyzing both reliability during the same installation session and between installation sessions.

8. Repeated measurements could be used during Genucom tests to assure repeatability of laxity scores.

BIBLIOGRAPHY

American Academy of Orthopaedic Surgeons. (1984). Knee and leg: trauma (soft tissue). (pp. 319-327). Orthopaedic Knowledge Update: Home Study Syllabus. Chicago, Illinois: author.

Anderson, A. F., & Lipscomb, A. B. (1989). Preoperative instrumented testing of anterior and posterior knee laxity. American Journal of Sports Medicine, 17, 387-392.

Andrews, J. R., & Axe, M. J. (1985). Classification of knee ligament instability. Orthopedic Clinics of North America, 16, 69-82.

Andrish, J. (1985). Ligamentous injuries of the knee. Orthopedic Clinics of North America, 16, 273-284.

Arnoczky, S. P. (1983). Anatomy of the anterior cruciate ligament. Clinical Orthopaedics and Related Research, 172, 19-25.

Bach, B. R., Warren, R. F., Flynn, W. M., Kroll, M., & Wickiecz, T. L. (1990). Arthrometric evaluation of knees that have a torn anterior cruciate ligament. Journal of Bone and Joint Surgery, 72-A, 1299-1306.

Baker, B. (1990). Prevention of ligament injuries to the knee. Exercise and Sport Sciences Review, 18, 291-305.

Baugher, W. H., & White, G. M. (1985). Primary evaluation and management of knee injuries. Orthopedic Clinics of North America, 16, 315-327.

Bessette, G. C., & Hunter, R. E. (1990). The anterior cruciate ligament. Orthopedics, 13, 551-562.

Butler, D. L., Noyes, F. R., & Grood, E. S. (1980). Ligamentous restraints to anterior-posterior drawer in the human knee. Journal of Bone and Joint Surgery, 62A, 259-269.

Cabaud, H. E. (1983). Biomechanics of the anterior cruciate ligament. Clinical Orthopaedics and Related Research, 172, 26-31.

Cabaud, H. E., & Slocum, D. B. (1977). The diagnosis of chronic anterolateral rotary instability of the knee. American Journal of Sports Medicine, 5, 99-105.

Cain, T. E., & Schwab, G. H. (1981). Performance of an athlete with straight posterior knee instability. American Journal of Sports Medicine, 9, 203-207.

Carlstedt, C. A., & Nordin, M. (1989). Biomechanics of tendons and ligaments. In M. Nordin and V. Frankel (Eds..), Basic Biomechanics of the Musculoskeletal System. (pp. 59-74). Philadelphia: Lea & Febiger.

Collins, H. R. (1978). Medial instability of the knee. In C. McCollister Everts (ed.), Symposium on Reconstructive Surgery of the Knee. (pp. 180-186). St. Louis: C. V. Mosby Co.

Daniel, D. M., Stone, M. L., Sachs, R., & Malcom, L. (1985). Instrumented measurement of anterior knee laxity in patients with acute anterior cruciate ligament disruption. American Journal of Sports Medicine, 13 401-407.

DeHaven, K. E. (1978). Classification and diagnosis of knee instabilities. In C. McCollister Everts (ed.), Symposium on Reconstructive Surgery of the Knee. (pp. 171-179). St. Louis: C. V. Mosby Co.

DeLee, J. C., Riley, M. B., & Rockwood, C. A. (1983). Acute posterolateral rotatory instability of the knee. American Journal of Sports Medicine, 11, 199-207.

Dye, S. & Cannon, W. (1988). Anatomy and biomechanics of the anterior cruciate ligament. Clinics in Sports Medicine, 7, 715-725.

Ellison, A. E. (1980). Pathogenesis and treatment of anterolateral rotatory instability. Clinical Orthopaedics and Related Research, 147, 51-55.

Ellison, A. E., & Berg, E. (1985). Embryology, anatomy, and function of the anterior cruciate ligament. Orthopedic Clinics of North America, 16, 3-14.

Faro Medical Technologies, Inc. (1984). Genucom users manual. Montreal, Canada.

Fetto, J., & Marshall, D. (1980). The natural history and diagnosis of anterior cruciate ligament insufficiency. Clinical Orthopaedics and Related Research, 16, 273-284.

Fowler, P. J. (1980). The classification and early diagnosis of knee joint instability. Clinical Orthopaedics and Related Research, 147, 15-21.

Frankel, V. H. (1971). Biomechanics of the knee. Orthopedic Clinics of North America, 2, 175-190.

Frankel, V., & Nordin, M. (1984). Biomechanics of the knee. In L. Hunter & F. J. Funk (Eds..), Rehabilitation of the Injured Knee. (pp. 25-55). St. Louis: C. V. Mosby Co.

Galway, H. R., & MacIntosh, D. L. (1980). The lateral pivot shift: a symptom and sign of anterior cruciate ligament insufficiency. Clinical Orthopaedics and Related Research, 147, 45-50.

Granberry, W. M., Noble, P. C., & Woods, G. W. (1990). Evaluation of an electrogoniometer instrument for measurement of laxity of the knee. Journal of Bone and Joint Surgery, 72-A, 1316-1322.

Gray, H. (1985). Gray's Anatomy. (C. D. Clemente, Ed.). Philadelphia: Lea & Febiger.

Hassard, T. (1991). Understanding Biostatistics. St. Louis: C. V. Mosby Co.

Helfet, A. J. (1974). Anatomy and mechanics of movement of the knee joint. In A. J. Helfet (Ed.), Disorders of the Knee. (pp. 1-18). Philadelphia: J. B. Lippincott Co.

Highgenboten, C. L., Jackson, A., & Meske, N. B. (1989). Genucom, KT-1000, and Stryker knee laxity measuring device comparisons. American Journal of Sports Medicine, 17 743-746.

Highgenboten, C. L., Jackson, A., & Meske, N. B. (1990). Genucom knee analysis system: reproducibility and data base

development. Medicine and Science in Sport and Exercise, 22, 713-717.

Howe, J., & Johnson, R. (1985). Knee injuries in skiing. Orthopedic Clinics of North America, 16, 303-314.

Hughston, J. C. (1962). Acute knee injuries in athletes. Clinical Orthopaedics, 23, 114-133.

Johnson, R. (1983). The anterior cruciate ligament problem. Clinical Orthopaedics and Related Research, 172, 14-18.

Jonsson, T., Althoff, B., Peterson, L. & Renstrom, P. (1982). Clinical diagnosis of ruptures of the anterior cruciate ligament. American Journal of Sports Medicine, 10, 100-102.

Kapandji, I. A. (1987). The Physiology of the Joints: Volume Two-Lower Limb. Edinburgh: Churchill Livingstone.

Katz, J. W., & Fingeroth, R. J. (1986). The diagnostic accuracy of ruptures of the anterior cruciate ligament comparing the Lachman test, the anterior drawer sign, and the pivot shift test in acute and chronic knee injuries. American Journal of Sports Medicine, 14, 88-91.

Kennedy, J. C., & Fowler, P. J. (1971). Medial and anterior instability of the knee, an anatomical and clinical study using stress machines. Journal of Bone and Joint Surgery, 53A, 1257-1270.

Kennedy, J. C., Hawkins, R., Willis, R., & Danylchuk, K. (1976). Tension studies in human knee ligaments. Journal of Bone and Joint Surgery, 58A, 350-355.

Kennedy, J. C., Weinberg, H., & Wilson, A. (1974). The anatomy and function of the anterior cruciate ligament. Journal of Bone and Joint Surgery, 56A, 223-235.

King, J., & Kumar, S. (1989). The Stryker knee arthrometer in clinical practice. American Journal of Sports Medicine, 17, 649-650.

Klafs, C. E., & Arnheim, D. D. (1981). Modern Principles of Athletic Training. St. Louis: C. V. Mosby Co.

Larson, R. L. (1980). Combined instabilities of the knee. Clinical Orthopaedics and Related Research, 147, 68-75.

Losee, R. E. (1985). Diagnosis of chronic injury to the anterior cruciate ligament. Orthopedic Clinics of North America, 16, 83-97.

Mains, D. B., Andrews, J. G., & Stonecipher, T. (1977). Medial and anterior-posterior ligament stability of the human knee, measured with a stress apparatus. American Journal of Sports Medicine, 5, 144-153.

Marans, H. J., Jackson, R. W., Glossop, N. D., & Young, M. C. (1989). Anterior cruciate ligament insufficiency: a dynamic three-dimensional motion analysis. American Journal of Sports Medicine, 17, 325-332.

Markoff, K. L., Graff-Radord, A., & Amstutz, H. C. (1978). In vivo knee stability, a quantitative assessment using an instrumented clinical testing apparatus. Journal of Bone and Joint Surgery, 60A, 664-674.

Markoff, K. L., Kochan, A., & Amstutz, H. C. (1984). Measurement of knee stiffness and laxity in patients with documented absence of the anterior cruciate ligament. Journal of Bone and Joint Surgery, 66A, 242-253.

Marshall, J. L. (1976). Ligamentous injuries pose major diagnostic problem. Physician and Sportsmedicine, 4, 58-60.

Marshall, J. L., & Baugher, W. H. (1980). Stability examination of the knee: a simple anatomic approach. Clinical Orthopaedics and Related Research, 146, 78-83.

Muller, W. (1983). The Knee: Form, Function and Ligament Reconstruction. New York: Springer-Verleg.

Neuschwander, D. C., Drez, D., Paine, R. M., & Young, J. C. (1990). Comparison of anterior laxity measurements in anterior cruciate deficient knees with two instrumented testing devices. Orthopedics, 13, 299-302.

Nordin, M., & Frankel, V. (1989). Basic Biomechanics of the Musculoskeletal System. Philadelphia: Lea & Febiger.

Noyes, F. R. (1977). Functional properties of knee ligaments and alterations induced by immobilization. Clinical Orthopaedics, 123, 210-218.

Noyes, F. R., & Grood, E. (1976). The strength of the anterior cruciate ligament in humans and rhesus monkeys. Journal of Bone and Joint Surgery, 58A, 1074-1082.

Noyes, F. R., Mooar, P. A., Matthews, D. S., & Butler, D. L. (1983). The symptomatic anterior cruciate-deficient knee. Journal of Bone and Joint Surgery, 65A, 154-162.

Noyes, F. R., Butler, D. L., Grood, E. S., Zernicke, R. F., & Hefzy, M. S. (1984). Biomechanical analysis of human ligament grafts used in knee-ligament repairs and reconstructions. Journal of Bone and Joint Surgery, 66-A, 344-352.

Oliver, J. H., & Coughlin, L. P. (1987). Objective knee evaluation using the Genucom Knee Analysis System. American Journal of Sports Medicine, 15, 571-578.

Peters, J. W., Johnson, G. E., & Quanbury, A. (1988). Objective testing in evaluation of anterior cruciate insufficiency. Unpublished research paper. Department of Orthopaedics, University of Manitoba.

Rong, G., & Wang, Y. (1987). The role of the cruciate ligaments in maintaining joint stability. Clinical Orthopaedics and Related Research, 215, 65-71.

Spence, A. P., & Mason, E. B. (1983). Human Anatomy and Physiology. Menlo Park, California: Benjamin/Cummings Publishing Co.

Steiner, M. E., Brown, C., Zarins, B., Brownstein, B., Koval, P. S., & Stone, P. (1990). Measurement of anterior-posterior displacement of the knee. Journal of Bone and Joint Surgery, 72A, 1307-1315.

Steiner, M. E., Grana, W. A., Chillag, K., & Schelberg-Karnes, E. (1986). The effect of exercise on anterior-posterior knee laxity. American Journal of Sports Medicine, 14, 24-29.

Sullivan, D., Levy, M., Sheskier, S., Torzilli, P., & Warren, R. (1984). Medical restraints to anterior-posterior motion of the knee. Journal of Bone and Joint Surgery, 66A, 930-936.

Torg, J. S., Conrad, W., & Kalen, V. (1976). Clinical diagnosis of anterior cruciate ligament instability in the athlete. American Journal of Sports Medicine, 4, 84-93.

Wang, C., & Walker, P. S. (1974). Rotatory laxity of the human knee joint. Journal of Bone and Joint Surgery, 56A, 161-170.

Wang, J., Rubin, R., & Marshall, J. (1975). A mechanism of isolated anterior cruciate ligament rupture. Journal of Bone and Joint Surgery, 57A, 411-413.

Welsh, R. P. (1980). Knee joint structure and function. Clinical Orthopaedics and Related Research, 147, 7-21.

Worble, R., Noyes, F. R., Van Ginkel, L., & Shaffer, B. (1989). Reliability of the Medmetric KT-1000 arthrometer. Medicine and Science in Sport and Exercise, 21, S81.

Worble, R., Grood, E. S., Noyes, F. R., & Schmitt, D. J. (1990). Reproducibility of Genucom knee analysis system testing. American Journal of Sports Medicine, 18, 387-395.

Youm, Y., Bass, B. G., & Savory, C. G. (1987). Quantification of knee laxity. Soma, 1, 18-23.

Zarins, B., & Nemeth, V. (1985). Acute knee injuries in athletes. Orthopedic Clinics of North America, 16, 285-302.

Appendix A

Informed Consent
and
Clinical Assessment Forms

CONSENT FORM

Instrumented versus clinical assessment of ACL-deficient knees

Description of the study

The proposed study will compare clinical assessments of injuried (ACL-deficient) knees with instrumented, objective assessments of injuried (ACL-deficient) knees using the Genucom Knee Analysis System which quantifies knee laxity into millimeters. An experienced orthopedic surgeon has determined that you meet the qualifications of the study and that the testing procedures will not be detrimental to your injury.

As a participant in the study, you will undergo two separate clinical assessments with two different orthopedic surgeons. An instrumented assessment will also be done on the Genucom Knee Analysis System by an experienced Genucom tester. The results of your Genucom assessment will then be compared to each of the clinical assessments.

The findings of the study will help determine if the Genucom is a reliable and valid tool for assessing knee laxity. If proven both reliable and valid it will be a valuable tool for orthopedic surgeons in assessing pre- and post-surgical knee stability and bracing devices.

Measurements

The following measurements will be conducted by each orthopedic surgeon in the clinical assessments:

-Anterior/Posterior Drawer at 90 and 30 degrees

-Varus/Valgus Test at 20 degrees and full extension

-Lateral Pivot Shift Test

The following tests will be conducted in the instrumented assessment using the Genucom Knee Analysis System:

-Anterior/Posterior Drawer at 90 and 30 degrees

-Varus/Valgus Test at 20 degrees and full extension

-Lateral and Medial Compartment Subluxation Tests

INFORMED CONSENT AND RELEASE

I, THE UNDERSIGNED, AGREE TO PARTICIPATE IN THE KNEE JOINT LAXITY STUDY WHICH WAS EXPLAINED TO ME ON THE PREVIOUS PAGE OF THE CONSENT FORM. I AGREE TO HAVE THE PREVIOUSLY EXPLAINED CLINICAL MEASUREMENTS CONDUCTED BY TWO ORTHOPEDIC SURGEONS AND GENUCOM MEASUREMENTS CONDUCTED ON BOTH KNEES BY AN EXPERIENCED GENUCOM TESTER.

RISKS: I HAVE READ THE ABOVE AND UNDERSTAND THAT I MAY REQUEST THAT THE TESTING BE STOPPED OR DELAYED AT ANY TIME IF I SO DESIRE. THE RISK OF INJURY IS MINIMAL.

WAIVER AND RELEASE:
I UNDERSTAND THAT IN PARTICIPATING IN THIS STUDY, I DO SO AT MY OWN RISK AND I HEREBY RELEASE THE UNIVERSITY OF MANITOBA, ITS AGENTS, OFFICERS, AND EMPLOYEES AGAINST ANY AND ALL LIABILITY THAT MAY ARISE AS A RESULT OF MY PARTICIPATING.

SIGNED_____DATE_____

WITNESS_____DATE_____

INFORMED CONSENT AND RELEASE

I, THE UNDERSIGNED, AGREE TO PARTICIPATE IN THE KNEE JOINT LAXITY STUDY WHICH HAS BEEN PREVIOUSLY EXPLAINED TO ME BY THE RESEARCHER.
I AGREE TO HAVE THE FOLLOWING TESTS CONDUCTED ON BOTH KNEES ON TWO SEPARATE OCCASIONS USING THE GENUCOM KNEE ANALYSIS SYSTEM:

-ANTERIOR/POSTERIOR DRAWER AT 90 DEGREES
-ANTERIOR/POSTERIOR DRAWER AT 30 DEGREES
-ABDUCTION/ADDUCTION TEST AT 20 DEGREES AND EXTENSION
-MEDIAL COMPARTMENT SUBLUXATION TEST
-LATERAL COMPARTMENT SUBLUXATION TEST

RISKS: I HAVE READ THE ABOVE AND UNDERSTAND THAT I MAY REQUEST THAT THE TESTING BE STOPPED OR DELAYED AT ANY TIME IF I SO DESIRE. THE RISK OF INJURY IS MINIMAL.

WAIVER AND RELEASE:
I UNDERSTAND THAT IN PARTICIPATING IN THIS STUDY, I DO SO AT MY OWN RISK AND I HEREBY RELEASE THE UNIVERSITY OF MANITOBA, ITS AGENTS, OFFICERS, AND EMPLOYEES AGAINST ANY AND ALL LIABILITY THAT MAY ARISE AS A RESULT OF MY PARTICIPATING.

SIGNED_____DATE_____

WITNESS_____DATE_____

GENUCOM STUDY

CLINICAL ASSESSMENT FORM

Name_____ **Subject #**_____

TEST	GRADE	COMMENTS
Anterior Drawer - 90 degrees		
Lachman Test - 30 degrees		
Varus/Valgus - 0 degrees		
Varus/Valgus - 20 degrees		
Lateral Pivot Shift		

DATE OF INJURY:

DIAGNOSIS:

ADDITIONAL COMMENTS:

EXAMINED BY: **Dr. James Irving**

Dr. Victor de Krompay

Appendix B

Raw Data

	1 - D/D 0 RT	2 - D/D 0 RT	1 - D/D 0 LFT	2 - D/D 0 LFT	1 - D/D 20 RT	2 - D/D 20 RT
1	2	2	1	2	6	6
2	3	2	2	2	5	4
3	2	1	2	1	3	3
4	3	2	1	1	4	4
5	1	1	1	1	2	3
6	3	3	1	1	3	4
7	3	2	2	2	5	5
8	3	3	4	4	7	5
9	3	2	2	5	7	3
10	4	3	2	2	8	9
11	1	2	2	2	5	8
12	1	2	1	2	3	7
13	2	2	1	2	9	8
14	2	1	1	1	4	5
15	2	3	2	2	7	8
16	1	3	2	3	6	9
17	4	2	2	3	8	4
18	1	1	1	2	4	5
19	2	2	3	3	9	8
20	3	3	2	2	4	6

	1 - 90 RT	2 - 90 RT	1 - 90 LFT	2 - 90 LFT	1 - 30 RT	2 - 30 RT	1 - 30 LFT	2 - 30 LFT
1	7	8	1	6	7	7	8	4
2	7	7	9	13	3	6	5	1
3	4	4	3	2	4	6	4	1
4	2	3	2	0	9	6	7	4
5	4	0	10	8	2	2	2	3
6	1	5	5	1	1	0	2	0
7	3	6	1	4	3	4	1	2
8	5	15	11	10	4	8	12	11
9	0	4	4	0	•	•	•	•
10	7	10	12	6	4	5	7	7
11	6	4	4	10	8	6	5	11
12	6	4	10	3	2	5	6	2
13	4	4	7	7	4	6	9	6
14	8	5	13	8	6	4	6	10
15	9	12	7	8	8	7	4	2
16	9	8	1	4	5	7	0	1
17	22	8	6	4	•	•	•	•
18	1	7	3	0	3	3	0	1
19	1	1	9	9	4	4	1	8
20	4	5	0	7	0	7	0	2

	1 - U/U 20 LFT	2 - U/U 20 LFT	1 - MCS RT	2 - MCS RT	1 - MCS LFT	2 - MCS LFT	1 - LCS RT
1	3	3	33	19	26	23	17
2	4	4	19	24	34	27	15
3	6	6	25	19	26	15	16
4	2	3	17	20	21	31	15
5	2	3	13	14	14	19	10
6	2	2	18	17	15	14	11
7	4	4	12	15	17	21	19
8	12	6	21	29	35	19	•
9	4	5	22	27	35	20	•
10	5	5	34	23	22	18	21
11	5	8	32	20	16	17	•
12	3	7	18	25	28	30	13
13	5	4	22	20	24	21	24
14	3	3	22	15	15	19	20
15	4	3	25	26	10	14	17
16	3	9	23	32	17	16	27
17	4	6	28	27	17	17	16
18	3	5	18	17	31	13	•
19	5	6	18	16	8	12	21
20	5	8	24	23	20	24	19

	2 - LCS RT	1 - LCS LFT	2 - LCS LFT
1	20	17	15
2	12	10	10
3	23	0	28
4	17	21	17
5	13	13	17
6	19	9	14
7	17	9	9
8	•	•	•
9	•	•	•
10	19	21	15
11	•	•	•
12	12	15	20
13	19	15	15
14	17	16	17
15	21	22	12
16	19	17	20
17	18	17	17
18	•	•	•
19	22	18	17
20	19	17	18

	test 1 - 90	test 2 - 90	test 1 - 30	test 2 - 30	test 1 - ν/ν 0
1	6.0	2.0	1.0	3.0	1.0
2	2.0	6.0	2.0	5.0	1.0
3	1.0	2.0	0	5.0	0
4	0	3.0	2.0	2.0	2.0
5	6.0	8.0	0	1.0	0
6	4.0	4.0	0	1.0	2.0
7	2.0	2.0	2.0	2.0	1.0
8	6.0	5.0	8.0	3.0	1.0
9	4.0	4.0	•	•	1.0
10	5.0	4.0	3.0	2.0	2.0
11	2.0	6.0	3.0	5.0	1.0
12	4.0	1.0	4.0	3.0	0
13	3.0	3.0	5.0	0	1.0
14	5.0	3.0	0	4.0	1.0
15	2.0	4.0	4.0	5.0	0
16	8.0	4.0	5.0	6.0	1.0
17	16.0	4.0	4.0	4.0	2.0
18	2.0	7.0	3.0	2.0	0
19	8.0	8.0	3.0	4.0	1.0
20	4.0	2.0	0	5.0	1.0

	test 2 - v/v 0	test 1 - v/v 20	test 2 - v/v 20	test 1 - msublux
1	0	3.0	3.0	7.0
2	0	1.0	0	15.0
3	0	3.0	3.0	1.0
4	1.0	2.0	1.0	4.0
5	0	0	0	1.0
6	2.0	2.0	3.0	3.0
7	0	1.0	1.0	5.0
8	1.0	5.0	1.0	14.0
9	3.0	3.0	2.0	13.0
10	1.0	3.0	4.0	12.0
11	0	0	0	16.0
12	0	0	0	10.0
13	0	4.0	4.0	2.0
14	0	1.0	2.0	7.0
15	1.0	3.0	5.0	15.0
16	0	3.0	0	6.0
17	1.0	4.0	2.0	11.0
18	1.0	1.0	0	13.0
19	1.0	2.0	2.0	10.0
20	1.0	1.0	2.0	4.0

	test 2 - msublux	test 1 - lsublux	test 2 - lsublux
1	4.0	0	5.0
2	3.0	5.0	2.0
3	4.0	16.0	5.0
4	11.0	6.0	0
5	5.0	3.0	5.0
6	3.0	2.0	5.0
7	6.0	10.0	8.0
8	10.0	•	•
9	7.0	•	•
10	5.0	0	4.0
11	3.0	•	•
12	5.0	2.0	8.0
13	1.0	9.0	4.0
14	4.0	4.0	0
15	12.0	5.0	9.0
16	16.0	10.0	1.0
17	10.0	1.0	1.0
18	2.0	10.0	9.0
19	4.0	3.0	5.0
20	1.0	2.0	1.0

	SEX	INJURY SIDE	a/drawer 90	a/drawer 30	v/v 0	v/v 20	m/sublux	l/sublux
1	MALE	RIGHT	8	2	1	1	11	19
2	FEMALE	LEFT	-7	1	-2	0	-1	9
3	FEMALE	LEFT	-10	-4	-1	-3	-9	-11
4	FEMALE	LEFT	5	-3	-1	-2	-10	-4
5	FEMALE	RIGHT	1	6	1	-1	10	6
6	MALE	LEFT	-2	-3	0	0	-4	-10
7	MALE	LEFT	-4	1	-2	-4	-4	-2
8	FEMALE	LEFT	-1	-6	0	-1	-2	-2
9	FEMALE	LEFT	-12	-1	0	-3	-11	-4
10	FEMALE	LEFT	5	0	-1	-1	1	-13
11	MALE	RIGHT	0	2	2	2	-6	15
12	MALE	RIGHT	1	2	2	2	-4	10
13	MALE	LEFT	-9	-3	-1	-1	0	0
14	FEMALE	LEFT	-4	3	1	-1	2	1
15	MALE	RIGHT	4	11	2	3	18	11