Anterior tibial translation during a maximum quadriceps contraction: Is it clinically significant?*

STEPHEN M. HOWELL,† MAJ, USAFR, MC

From the David Grant Medical Center, Travis Air Force Base, California

ABSTRACT

Quadriceps exercises are used sparingly in the early rehabilitation of ACL reconstructions because of concern about prematurely stretching the ACL graft. The aim of this study was to determine if a maximum isometric quadriceps contraction significantly translates the tibia anteriorly at 15°, 30°, 45°, 60°, and 75° of flexion. Secondly, the role of the ACL in knee stability was analyzed by comparing the amount of tibial translation in normal ACL deficient, and reconstructed knees. Thirdly, the location in the motion arc where a quadriceps contraction produces anterior tibial translation was determined. Anterior tibial translation was measured using an arthrometer (KT-1000) during an 89 N and manual maximum translation applied to the knee at rest. The manual maximum translation test determines the magnitude of anterior tibial translation produced by a high anterior force applied directly to the proximal calf. These translations were compared to the tibial translation intrinsically induced by a quadriceps contraction. Testing was performed in normal (N - 22), ACL deficient (N=10), and reconstructed (N = 10) knees.

Anterior tibial translation produced by a maximum quadriceps contraction was measured at 15°, 30°, 45°, 60°, and 7 5° of flexion. The extension exercise resulted in less anterior tibial displacement than an 89 N drawer and half the translation produced by a manual maximum translation (P < 0.001). Instrumented laxity testing produced greater anterior translation of the tibia than a maximum isometric quadriceps contraction. Anterior tibial translation was the same during maximum isometric knee extension in all tested knees. Anterior translation in the isometrically loaded knee occurred during the terminal 60° of knee extension, and was controlled by the compression forces driving the congruent articular surfaces together, and not the ACL.

Instrumented laxity testing is an accepted technique that has been safely used to serially measure knee stability after an ACL reconstruction. Early postoperative knee extension exercises; can be expected to induce less strain in the ACL than instrumented laxity testing. These data raise the question of whether the anterior tibial displacement produced by a maximum quadriceps contraction is detrimental to a recently reconstructed ACL.

One of the concerns that surgeons have had about prescribing quadriceps exercises following ACL reconstructions is the possibility that the ACL graft may stretch. This concern is based on the fact that the quadriceps muscle is known to generate both an extensor torque and an anterior drawer. The possibility that this intrinsically induced anterior shear force may produce plastic deformation of an immature ACL graft has been raised. Many authors have therefore recommended avoidance of extension exercises from 0° to 30°, 70° to 45°, 16° to 60°, 15 or 0° to 70° during the “early” (variable time intervals) rehabilitation period. These restrictions are inconsistent because they are based on studies using different experimental techniques and testing conditions. A question that remains is whether the tension produced in the ACL during active knee extension is clinically significant. There are two techniques for determining ACL tension that could be applied to answer this question. Direct measurement of ligament tension could be used. This technique requires that a measuring device be directly attached to the ligament. In vivo analysis in large numbers of patients can be difficult because of inherent problems in placing electrodes in human subjects, in addition to several other technical limitations. The inser-

†Address correspondence and reprint requests to: Stephen M. Howell, MD, 7601 Timberlake Way Suite 103, Sacramento, CA 95823
tion of buckle transducers affects the resting tension of the ligament. Measurements made with buckle or Hall-effect transducers sample tensile changes in only a small portion of the ligament. Alternatively, a relative, indirect estimate of ACL tension could be made by comparing the measured amount of tibial translation produced under different loading conditions. Qualitatively, an increase in anterior tibial translation would be expected to correlate with increasing ACL tension; however, one must remember that this relationship is not linear. Although this indirect technique does not directly measure ACL tension, it is relatively easy to use in vivo.

Many variables have been shown to affect the amount of anterior tibial translation during active knee extension. Large resistant loads, applied distally on the tibia, increase the anterior translation of the tibia and enlarge the motion arc where this translation occurs. Increasing joint compression decreases anterior tibial translation and the tension in the ACL. Isometric knee extension theoretically increases ACL tension more than isokinetic exercise because it occurs without a hamstring cocontraction.

The integrity of the ACL ligament has been observed to affect the magnitude of anterior tibial translation in vitro. These factors should be accounted for during the formulation of an experimental protocol designed to study anterior tibial translation during active knee extension.

The purpose of this study was three-fold. First, the amount of tibial translation was measured by applying a known anterior drawer (extrinsic drawer), and comparing this translation to the displacement produced by an isometric quadriceps contraction (intrinsic drawer) at 15°, 30°, 45°, 60°, and 75° of flexion. This comparison was made to determine if the quadriceps-induced drawer significantly translates the knee. Second, the role of the ACL in knee stability was analyzed under these same extrinsic and intrinsic loading conditions by comparing the amount of tibial translation in normal, ACL deficient, and reconstructed knees. Finally, the flexion angles were determined where anterior translation of the tibia occurs due to a maximum quadriceps contraction.

**MATERIALS AND METHODS**

The control group consisted of 22 volunteers (20 males, 2 females; average age, 27 years). All had normal knees to clinical testing and no history of significant knee trauma or surgery. Ten patients admitted for elective ACL reconstruction for a chronic anterior knee instability comprised the ACL deficient study group (eight males, two females; average age, 25 years). None had had a previous meniscectomy. Ten patients were studied with stable, reconstructed knees (nine males, one female; average age, 29 years). The inclusion criteria for the reconstructed group was an absent pivot shift, stable Lachman test, and KT-1000 testing measurements of the involved knee at 89 N and manual maximum anterior translation (MMT) within 2 mm of the normal knee: All three groups underwent the same, standardized testing protocol consisting of measuring tibial translation with the knee at rest and during a maximum isometric extension contraction at five different angles of knee flexion.

The subjects were seated in a position giving low back support and secured to the exercise table (Lumex Corp., Ronkonkoma, NY) by two large VELCRO straps (VELCRO USA Inc., Manchester, NH) placed across the chest and waist (Fig. 1). A third strap was applied across the thigh above the knee to be tested. The subjects’ arms were maintained alongside their trunk, and their hands gripped the sides of the table for stability. The rotation axis of the resistance arm (Cybex II Isokinetic Dynamometer, Lumex Corp.) was aligned to the flexion-extension axis of the knee. The distal end of the resistance pad was secured posterior to the tibia 29 cm distal from the joint line. This distal placement of the resistance pad increases the anterior tibial drawer and enlarges the motion arc where this translation occurs. An anterior VELCRO strap secured the distal tibia to the resistance arm. The dynamometer was attached to a dual-channel strip chart recorder that provided a simultaneous display of torque and flexion angle. The angle of knee flexion during testing was controlled at either 15°, 30°, 45°, 60°, or 75° by adjusting the position of the resistance arm. The angle was kept constant by setting the angular velocity of the dynamometer at 0 deg/sec.

A knee arthrometer (KT-1000, MEDmetric Ligament Arthrometer, San Diego, CA) was used to determine the laxity of the knee by measuring the translation of the tibia with a knee arthrometer.
Anterior Tibial Translation

3, 4, 11

within 1 mm. The fourth and final displacement measurement of tibial translation was recorded when the assistant observed that the torque production had peaked and plateaued for 3 seconds on the strip recorder, indicating a sustained, maximum isometric contraction. This testing cycle was repeated until three successive tests indicated the same excursion within 1 mm. The fourth and final displacement measurement consisted of loading the knee extrinsically by applying an MMT test to the isometrically contracted knee. The examiner applied a strong (unmeasured) anterior force directly to the proximal calf during the QAD. The total extrinsic and intrinsic translation produced by the MMT and QAD was recorded after averaging three successive tests that were within 1 mm. The subjects were allowed to rest between each muscle contraction so that the contractions were performed without fatigue. The rotational alignment of the arthrometer case was kept constant at each testing angle to minimize fluctuations in anterior-posterior laxity due to inconsistent alignment of the instrument.

The four measurements of tibial translation (two at rest, and two during maximum isometric extension) were re-peated at 30˚, 45˚, 60˚, and 75˚ of flexion. All measurements of tibial translation were performed by the author.

Statistical analysis of the four measurements derived from each of the normal knees was performed using a two-tailed, paired t-test. Comparisons between the normal and ACL deficient, and normal and reconstructed knees were based on a two-tailed, nonparametric Mann-Whitney test. The “z” statistic was used for comparison with tables of the normal distribution to determine statistical significance.

RESULTS

The measurement of tibial translation in the normal knee revealed that the anterior translation during the QAD never exceeded the translation produced by the 89 N load (Fig. 2). At 15˚ 60˚, and 75˚ of flexion the QAD was significantly less than the translation produced by the extrinsic 89 N load. At 75˚ of flexion the isometric quadriceps contraction produced a posterior drawer. Although intrinsic tibial translation occurred during the maximum isometric contraction, the displacement did not exceed that produced by an extrinsically applied 89 N (20 pounds) anterior drawer.

The anterior translation produced by the MMT applied to the resting knee was significantly greater than the displacement produced by the QAD at all angles tested (P < 0.001; Fig. 3). The MMT was, on average, double the translation measured in the isometrically loaded knee. Instrumented laxity testing displaced the tibia significantly more than a maximum isotonic quadriceps contraction.

The addition of an MMT to a normal knee preload in compression by an isometric contraction (QAD) produced significantly less anterior translation than an MMT of the knee at rest (P < 0.001; Fig. 4). The compression forces generated by the quadriceps muscle increased the stability of the knee to externally applied anterior shear forces.

The comparison of the QAD test between normal and ACL deficient knees, and between normal and reconstructed knees revealed no significant differences in the amount of anterior translation at all angles tested (Fig. 5). At 15˚ and 30˚ of flexion the anterior tibial translation was 1 to 2 mm greater in the ACL deficient knee, but this observation was not statistically different. The integrity of the ACL did not affect the anterior tibial translation measured during a maximum iso-
metric contraction. Anterior tibial translation during a QAD occurred from 15° to 60° of flexion in the ACL deficient and reconstructed knees, identical to the findings in the normal knees. At 75° of flexion the tibia translated posteriorly due to the quadriceps contraction, thereby reducing the tension on the ACL.

A comparison of the difference in tibial translation measured during the MMT and QAD tests between the normal, ACL deficient, and reconstructed knees revealed that the MMT exceeded the QAD by 4 to 13 mm, dependent on the flexion angle of the knee and in the integrity of the ACL Fig. 6. Instrumented laxity testing (MMT) produced more anterior tibial translation than an isometric quadriceps contraction from 15° to 75° of knee flexion.

A comparison of the difference in tibial translation measured during the 89 N and QAD tests was performed in the normal, ACL deficient, and reconstructed knees. At 15°, 45°, 60°, and 75° of knee flexion, the difference was positive, confirming that instrumented laxity testing at 89 N induces more anterior tibial translation than a maximum isometric knee extension contraction (Fig. 7).

Figure 2. Anterior tibial translation during a maximum quadriceps contraction (QAD) was the same or less than the anterior translation produced during an 89 N anterior drawer maneuver in the normal knee.

Figure 3. Anterior tibial translation during an MMT of the normal knee at rest was twice the anterior translation produced during the QAD. Laxity testing resulted in greater anterior tibial translation than a maximum quadriceps contraction.

Figure 4. Superimposing an MMT on a normal knee that had a maximum quadriceps contraction produced less anterior tibial translation than an MMT applied to the knee at rest. The quadriceps-induced compression forces significantly increased knee stability.

Figure 5. The anterior tibial translation produced by a maximum quadriceps contraction was the same in the normal, ACL deficient, and reconstructed knees. The ACL did not control anterior translation during a maximum quadriceps contraction.
DISCUSSION

Direct tension in the ACL was not directly measured in this study because of the inherent difficulties of inserting electrodes in human subjects in vivo. Instead, an assumption was made based on the previously described indirect technique that a qualitative, direct relationship exists between tibial displacement and ACL tension. In this study, a known, extrinsic load to the knee was manually applied using the arthrometer. The amount of tibial translation during the 89 N and MMT anterior drawer tests was measured in the knee at rest. The unknown, intrinsic anterior shear force was provided by the maximum isometric quadriceps contraction. The arthrometer was used to measure the tibial translation during a QAD and an MMT superimposed on a QAD. The significance of the differences in tibial translation produced by the extrinsic and intrinsic knee loads was determined.

The anterior tibial translation produced during a maximum isometric knee extension contraction (QAD) was similar in magnitude to the translation produced by an 89 N anterior drawer applied to the knee at rest at 15° to 45° of flexion, and was significantly less at 60° to 75° of flexion. This relationship was consistent in the normal, ACL deficient, and reconstructed knees. The anterior translation produced by the MMT was nearly double the translation produced by the QAD. Therefore, instrumented laxity results in a greater amount of anterior tibial translation than a maximum isometric knee extension contraction from 15° to 75° of flexion. Extension exercises within this motion arc would produce less tension in the ACL than instrumented laxity testing.

The relationship of anterior shear force to tension in the ACL is complex and depends on the magnitude of the compression load across the knee. As compression loads increase (can approach 9 times body weight), the knee gains stability and becomes more resistant to anterior and posterior translation. The increase in knee stability and reduction in ACL tension is produced by driving the congruent articular surfaces of the knee together. The QAD was similar in magnitude between the normal, ACL deficient, and reconstructed knees. Anterior tibial translation was therefore controlled by joint compression and not the integrity of the ACL.

The mechanics of active knee extension also affect the amount of anterior tibial translation. As the tibia moves anterior during a quadriceps contraction, the alignment of the patellar tendon approaches a more normal orientation with respect to the tibial plateau, thereby reducing the shear component (Fig. 8). The anterior translation produced by the quadriceps contraction in this study ranged from 3 to 5 mm in the control and 3 to 7 mm in the ACL deficient knee. This magnitude of anterior motion partially normalized the patellar force vector, reduced the anterior shear component, and limited anterior tibial translation.

In this study tibial translation was specifically measured during a maximal isometric extension contraction to minimize the stabilizing effect of a hamstring cocontraction. The hamstring muscles have been shown to be inactive or minimally active by EMG analysis during active knee extension. Anterior tibial translation was therefore controlled by the mechanics and compressive forces across the joint and not a hamstring cocontraction.

The final purpose of this study was to define the location in the motion arc at which anterior tibial translation occurred during isometric extension of the knee. Anterior tibial translation (loading of the ACL) was observed during the QAD test from 15° to 60° of knee flexion. At 75° of flexion the tibial plateau translated posteriorly, thereby unloading and protecting the ACL. These data confirm and refine observations from theoretical and in vivo studies. There seems to be general agreement that an anterior tibial shearforce is produced by the quadriceps muscle during the terminal 60° of flexion.
active knee extension.

In summary, anterior tibial translation occurred during isometric knee extension from 15° to 60° of flexion. The tension in the ACL during a maximum isometric quadriceps contraction is no greater than the tension produced during instrumented laxity testing. Anterior translation in the pre-loaded knee is controlled by the interactive effects of the compression forces and the congruent articular surfaces, and not the ACL. These data raise the question of whether the anterior tibial displacement produced by a maximum quadriceps contraction is detrimental to a recently reconstructed ACL.

**REFERENCES**


**Figure 8.** The anterior shear (AS) component of the quadriceps contraction is reduced as the tibia translates anteriorly. The angle of the patellar tendon acquires a more perpendicular alignment (25° to 15°) to the tibial joint surface with anterior tibial translation.