Tibial Rotation Affects Anterior Displacement of the Knee

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Abstract:

The purpose of this study was to assess anterior translation of the tibia using the Tibial Fixator Device (a mechanical leg stabilizer that controls tibial alignment) with the leg in three positions: neutral (N), internal rotation of 15° (IR), and external rotation of 15° (ER). Displacement was measured using a modified KT-1000 arthrometer. Eleven subjects with anterior eruciate ligament lesions were examined bilaterally in the three positions at 45, 67, and 89 newtons of anterior force. Three-factor repeated-measures ANOVA revealed a significant position effect regardless of force ($p < .001$). This effect was significant in the injured and noninjured legs. Displaccment was greatest in ER and least in IR. These data indicate that the position of the tibia, maintained with an external leg restraint, has a significant effect on anterior displacement of the knee. Control of tibiofemoral alignment and modifications to the KT-1000 provide new potentials for instrumented arthrometry.

Article:

Instrumented and manual examinations have been developed to identify instability of the knee joint. However, examination protocols and clinical test interpretation have been the source of much debate in the literature. When knee laxity is assessed, manual and instrumented tests are used to determine the severity and clinical implications of knee pathologies.

Several knee motion analysis devices are commercially available. These devices are designed to assess anterior translation of the tibia in the saggital plane. To validate instrumented arthrometry, researchers have described anterior—posterior (5, 13, 15) and rotary (2, 7, 9, 10, 12, 16, 25) instabilities in injured and noninjured populations preoperatively (3, 18, 19), postoperatively (l, 17, 20), and during nonsurgical management of anterior cruciate ligament (ACL) deficient patients (4, 22, 23) to monitor efficacy of treatments and to make serial assessments of knee laxity. Many of these studies have acknowledged that measurements of knee laxity in the injured and noninjured population are complicated by the multiple motions at the knee.

The test—retest reliability of the KT-1000 knee arthrometer (MEDmetric, San Diego, CA) has been reported by many investigators (6, 8, 11, 15, 27) ranging from $r = .79$ (8) to $r = .92$ (15). In addition, the sensitivity of the KT- 1000 in diagnosing lesions of the ACL has been reported (3-5, 18, 21-23).

Daniel et al. (5) and Malcom et al. (13) performed in vitro and in vivo measurements of knee laxity using a mechanical knee arthrometer similar to the KT-1000 knee arthrometer. Both studies suggested that constraint of tibial rotation prior to and during an instrumented examination would affect tibial displacement at the knee. Lack of control of tibiofemoral alignment has been proposed as a limitation of instrumented measures of knee laxity (3, 4, 8, 14, 22, 23, 27). Markolf et al. (14) assessed knee stiffness using the UCLA instrumented knee testing apparatus and noted that anterior displacement was maximal in 15° of external rotation, although the degree of tibial rotation was not an independent variable. Staubli and Jakob (22) controlled tibial rotation by stabilizing the foot prior to displacing the tibiofemoral joint. No studies have described the amount of tibial rotation that takes place during instrumented arthrometry using the KT-1000. Studies using the Genucom knee analysis system (FARO, Montreal, Canada) have quantified rotatory instability but have reported low diagnostic sensitivity (3, 4, 8, 23, 26).

The purpose of this study was to examine the effect of tibial position on anterior displacement at the knee. Several modifications were made to the standard KT-1000 protocol to control displacement force, plane of force application, tibial rotation, and degree of knee flexion.

METHODS AND MATERIALS

Eleven patients (age = 27 years ± 9.8, height = 177 cm ± 9.7, weight = 79 kg ±14.2) with suspected unilateral ACL injury were examined bilaterally at a preoperative appointment. Complete tears of the ACL were confirmed at surgery in all patients. Prior to participation in this study, each subject read and signed a consent form approved by the university institutional review board.

A modified KT-1000 knee arthrometer was used to assess anterior translation of the tibia at the knee. The arthrometer was equipped with a LCCB-50 strain gauge on line with a DP41-V processor (Omega Technologies, Inc., Stamford, CT), which permitted continuous readouts of force from a digital diode (18). Forces were displayed and recorded to 1 x 10-1. A masonry line bubble level (Stanley Works, New Britain, CT) was also attached to the housing of the KT-1000 to ensure that the device was positioned consistently prior to application of the displacement force. During force application, the examiner maintained this level position so that displacement forces were applied in the anatomical saggital (anterior—posterior [A-PJ) plane (Figure 1).

The Tibial Fixator Device (TFD, developed by D.E.M. and K.M.G., patent pending) was used to control tibial orientation (Figure l). The TFD stabilizes the thigh, maintains knee flexion at approximately 20°, and restrains the foot in an ankle—foot orthosis (AFO). The AFO pivots at the heel and moves in a 30° arc referenced from the distal head of the second metatarsal.

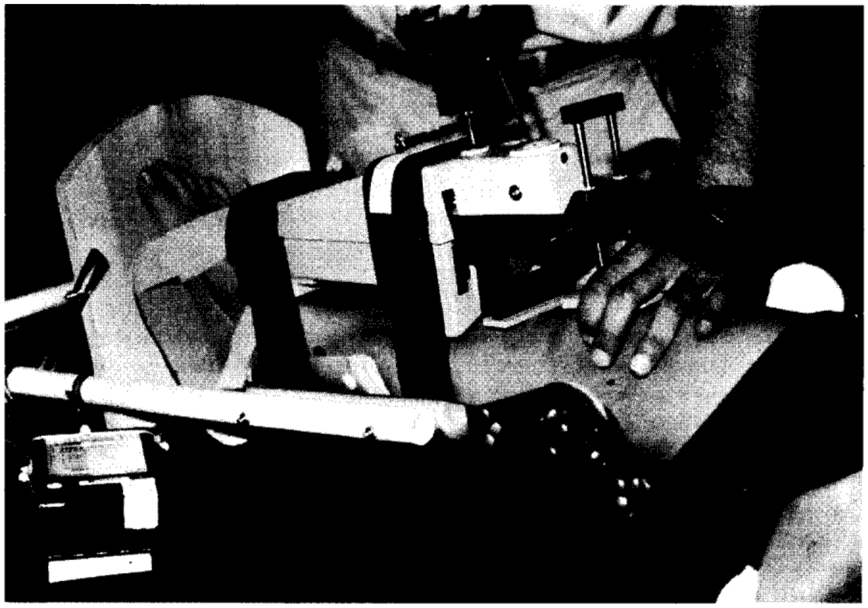

Figure 1— A modified KT-1000 knee arthrometer. The LCCB-50 strain gauge is attached to the displacement handle, forces are displayed digitally, and the bubble level is attached to the upper stabilizing strap of the arthrometer. The Tibial Fixator Device stabilizes the thigh, maintains knee flexion at 20°, and restrains the foot in an ankle–foot orthosis. Variability in leg length is accommodated by repositioning the foot plate.

The leg was examined in neutral (N, straight A-P), internally rotated (IR, 15° rotation), and externally rotated (ER, 15° rotation) positions. The order of testing positions was randomized. Anterior tibial displacement was recorded at 45, 67, and 89 newtons (10, 15, and 20 lb, respectively). All three positions were tested on one knee prior to testing the contralateral knee.

The uninjured leg of 10 subjects was retested at postsurgery appointments (6-8 months) to establish test–retest reliability. Knee laxity assessment was performed in the same three positions of tibial rotation using displacement forces of 67 and 89 newtons.

Statistical analyses were performed using the Statview 512+ (Abacus Concepts, Inc., Calabasas, CA) statistical package. A three-factor repeated-measure analysis of variance was performed to test main effects for position, force, and injured versus uninjured extremities. Scheffe post hoc comparisons were performed to clarify significant main effects. Test–retest reliability was established using the [2,l] intraclass correlation coefficient equation.

RESULTS

Table 1 presents the anterior displacement values for each position at each force. A significant main effect for position was observed regardless of force, $F(2,120) = 103.6$, $p < .01$. Displacement was greatest in ER and least in IR. Post hoc analysis revealed that IR < N < ER ($p < .05$). This relationship was seen on both the injured and noninjured legs, $F(l, 60) = 59.0$, $p < .01$ (Table 2). A significant main effect for force, regardless of position or injury status, was observed, $F(2, 60) = 18.7$, $p < .01$. Displacement was significantly greater ($p < .05$) with each increase in displacement force. Test—retest reliability was $r = .95$ (SEM ± 0.39 mm), $r = .78$ (SEM ± 0.56 mm), and $r = .67$ (SEM ± 0.87 mm) for IR, N, and ER, respectively.

DISCUSSION

Tibial orientation during instrumented knee laxity measurement has a significant effect on the magnitude of anterior displacement of the tibia. In injured and noninjured knees, anterior displacement is maximal in ER, less in N, and least in IR ($p < .01$).

The results of this study support the findings of others who have documented that tibial rotation affects displacement (5, 14, 25). Markolf et al. (14) reported that anterior displacement was maximum when the tibia was rotated externally approximately 15°. Our data show that when compared to N, the ER position of the tibia increases anterior displacement measures by 25%, while IR decreases displacement by 22%.

Table 1 Anterior Displacement Values (mm) for All Knees (Injured and Noninjured) at Three Force Levels in Internal Rotation of 15°, Neutral, and External Rotation of 15°

Force (N)	Internal rotation		Neutral		External rotation	
	M	*SD*	*M*	*SD*	*M*	*SD*
45	2.9	1.5	3.7	1.9	4.6	1.7
67	4.0	2.0	5.1	2.5	6.5	2.3
89	5.2	2.5	6.4	2.8	8.0	2.9

Table 2 Anterior Displacement Values (mm) for Injured and Noninjured Knees in Internal Rotation of 15°, Neutral, and External Rotation of 15°

Injury status	Internal rotation		Neutral		External rotation	
	M	*SD*	*M*	*SD*	*M*	*SD*
Injured	5.1	2.3	6.8	2.5	8.0	2.8
Noninjured	3.0	1.5	3.3	1.3	4.9	1.6

Anterior laxity at 67 newtons of force was 6.8 ± 2.l mm in the ACLdeficient knees in the N position. Using a displacement force of 89 newtons, Sherman et al. (21) reported anterior laxity in ACL-deficient knees of 6.8 ± 2.3 mm using the UCLA clinical test apparatus. Similar to the TFD, the UCLA device stabiliZes the leg throughout the examination, thereby limiting tibial rotation. When the leg was not supported in the UCLA apparatus, standard protocol KT-1000 measurements at the same force resulted in 12.l ± 2.6 mm of displacement. The UCLA apparatus clamped the femur into a relatively stable position, and it was suggested that this factor was the primary contributor to the difference between the UCLA apparatus and KT-1000 measurements.

Our study suggests that control of tibial orientation may affect measurement of anterior translation. Using four cadaver knee specimens, McQuade et al. (16) tested tibial rotation and anterior displacement using the Genucom knee analysis device and found that anterior drawer displacement was maximum in the neutral position and less in external and internal rotation. Comparisons to the present study are tenuous, as the methodologies and samples sizes (4 knees in vitro [16] compared to 22 knees in vivo in our study) are not similar.

Several explanations exist for our findings. This is the first study utilizing the TFD with the KT-1000. The TFD controls leg orientation and maintains a fixed orientation throughout the examination. The addition of the strain gauge and digital readout offers advantages to the three-tone system in the standard KT-1000 and may allow the examiner greater precision in the application of displacement force. The vector of force application in the present study was controlled utilizing the bubble level. The reliability of the KT-1000 has been shown to be improved as the direction of force application is controlled in the saggital plane (11). These modifications may enhance the sensitivity of instrumented arthrometry with the KT-1000. However, the individual effects of the TFD, the strain gauge, and the bubble level have not been distinguished, limiting the comparison of our data to existing displacements reported in the literature.

Diagnostic sensitivity (true positives x [true positives + false negatives]-') of the KT-1000 is well documented. Sherman et al. (21) and others (3, 5, 18) have found sensitivity ranging from 80% to 95%, supporting the notion that the KT-1000 has acceptable discriminant diagnostic value (4, 22). The ranges presented in the reliability and sensitivity literature suggest that the KT-1000 may be susceptible to intratester and intertester variability (23). We propose that tibial position may contribute to this variability.

In summary, our findings suggest that tibial rotation has a significant impact on measurements of anterior tibial displacement. As such, control and quantification of tibial rotation seem to be essential for valid instrumented assessment of anterior knee displacement. The clinical validity of making measurements of anterior knee laxity utilizing tibial rotation control deserves further study.

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