Anterolateral rotatory instability of the knee

Cadaver study of extraarticular patellar-tendon transposition

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A cadaver knee-testing system was used to analyze the effect of an extraarticular reconstruction for anterolateral rotatory instability in which the lateral one third of the patellar tendon with a patellar bone block was transposed to the lateral femoral condyle. Ligament and reconstruction tendon forces were measured using buckle transducers, and joint motion was measured using an instrumented spatial linkage as 90 N anteriorly directed tibial loads were applied to seven knee specimens at 0°, 30°, 60°, and 90° of flexion by a pneumatic load apparatus. This was done for each knee with first an intact, then an excised anterior cruciate ligament, and finally the extraarticular reconstruction.

Forces in the transposed graft exhibited an isotonic pattern over the flexion range, unlike the intact anterior cruciate ligament, which was more highly loaded in extension than in flexion. The transposition of the patellar tendon led to external rotation of the tibia in both unloaded and anterior load conditions throughout flexion. Collateral ligament forces increased with anterior cruciate ligament excision, with the force in the medial ligament remaining higher than normal with the reconstruction, while the lateral forces became lower than normal.

Various dynamic (Ellison 1979) and static (Galway et al. 1972, McIntosh and Darby 1976, Losee et al. 1978, Arnold et al. 1979, Hughston 1980, Zarins and Rowe 1980, Benum 1982, James 1983, Andrews et al. 1985) extraarticular procedures have been proposed for the surgical treatment of anterolateral rotatory instability of the knee. However, after an initial period of stability, some of these reconstructions stretch out with the return of anterolateral rotatory instability (Kennedy et al. 1978 and 1979, Odensten et al. 1983, Amirault et al. 1988, Dahlstedt et al. 1988, Trovik et al. 1988). The pendulum has now swung to intraarticular reconstructions in knees with major instabilities using bone-patellar tendon-bone grafts as reported by Clancy et al. (1982) and Noyes et al. (1983). In patients with mild to moderate anterolateral rotatory instability, however, Andrews et al. (1985) have shown good short-term results using an iliotibial-band tenodesis. In 1982, Benum reported a method using transposition of the lateral one third of the patellar tendon with a proximal bone block to the lateral femoral condyle. This graft material was felt to be strong enough to prevent the stretching out experienced with other extraarticular procedures. In a reevaluation of the patients 3 years later, there was no further decrease of the stability compared with 1-year postoperatively (Benum 1986).

We have studied the immediate effect of Benum's extraarticular procedure on the mechanics of the knee.

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Materials and methods

Experimental system

The experimental system used in this study provided for the simultaneous measurement of ligament and graft forces using buckle transducers and three-dimensional joint motion with an instrumented spatial linkage, as external loads were applied to knee specimens by a pneumatic load apparatus with associated load cells. The buckle transducers were of the frame-crossbar type. Frames and crossbars of suitable sizes were chosen to fit a particular tissue in the available space, and to produce an adequate signal to noise ratio without excessive tissue shortening or impingement with surrounding bone. The instrumented spatial linkage was an open-loop kinematic chain with six revolute joints (potentiometers), five intermediate links, and two end links. Physical and electrical parameters describing the linkage were initially measured and then reestimated using a optimization calibration routine. A mechanical pointer was used to locate the linkage relative to the tibia and the femur so that motion parameters would be anatomically meaningful. The load apparatus consisted of a baseplate, a fixed femoral clamp, and a "floating," counterbalanced tibial clamp. Unconstrained loads were pneumatically applied using air cylinders connected to the tibia via cables. A detailed description of the system, as well as an extensive error analysis, has been previously reported by the authors (Lewis et al. 1988).

When a constant load is applied to the anterior cruciate ligament or graft tissue on which a buckle is mounted, the apparent force measured by the buckle decreases due to the creep of the tissue with the buckle (Lewis et al. 1988). The response of buckles on the ligament and patellar tendon grafts were found to have changed 10–50 percent due to a constant load applied over 5 minutes. To account for this creep effect, the ligament force was recorded approximately 5–10 seconds after applying the external joint load, and the load was removed immediately after recording. The authors' data indicate that this should have reduced the creep error to less than 10 percent. Another external load was now applied for several minutes to allow recovery of the tissue. Recovery has been shown to occur because a load repeatedly applied in the time frame described above yielded reproducible anterior-ligament forces to within an average of less than 4 percent.

Test protocol

Seven fresh lower-limb cadaver specimens were stored at –20 °C, thawed at room temperature, and prepared by removing all the soft tissue except muscle, capsule, and ligaments. Specimens with evidence of severe degenerative changes or ligamentous insufficiency were not included. The fibula was fixed to the tibia with a screw, and each limb was transected approximately 17 cm distal and proximal to the joint. The ends of the tibia, fibula, and femur were potted in cylinders of polymethyl methacrylate. A medial capsulotomy was performed, and buckle transducers were installed on the anterior cruciate and lateral collateral ligaments, and on a 1-cm anterior strip of the superficial medial collateral ligament. Impingement of the buckle transducers with surrounding bone was detected and eliminated. A notchplasty was performed in all knees to avoid impingement in extension. The potted ends of the knee were installed in the load apparatus. The following knee states were tested.

Normal. With application of a 90 N anteriorly directed tibial load, the resulting knee-joint motion and forces in the intact anterior cruciate ligament and collateral ligaments were measured at 0°, 30°, 60°, and 90° of flexion. The force and motion data were also recorded during an unloaded state (absence of pneumatic load) before application of the anterior load at each flexion angle.

Excised anterior ligament. The ligament was excised at its distal insertion site, and the buckle was calibrated at 30° of flexion by directly applying known loads with a spring scale acting through a hemostat and loop of suture. The ligament was then completely excised, and the external load sequence was repeated with resulting ligament force and joint motion data recorded.

Knee with an extraarticular reconstruction. The lateral one third of the patellar tendon was dissected free, was left attached distally, and was detached proximally with a patellar bone block. The iliotibial band was split longitudinally, and the joint was opened through vertical incisions anterior and posterior to the lateral collateral ligament. The popliteal tendon was released from the femoral condyle enabling the preparation of an osseous groove below the origin of the lateral ligament. The groove was directed slightly upwards posteriorly. The dissected portion of the patellar ligament was then pulled through the split in the iliotibial band and passed underneath the lateral ligament. A buckle transducer was installed on the patellar tendon graft tissue. With the knee in 45° of flexion, the graft tissue was pretensioned as tightly as possible by hand, and the

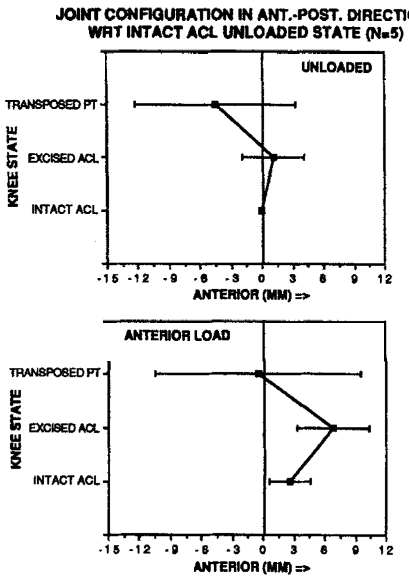

Figure 1. Means and standard deviations of the joint configurations in the anterior-posterior translation direction during the unloaded (top) and anterior tibial load (bottom) conditions, defined relative to the intact anterior cruciate ligament unloaded state, over all four flexion angles in five of the specimens with an intact anterior cruciate ligament, excised anterior cruciate ligament, and reconstruction with the transposed patellar tendon (PT) graft.

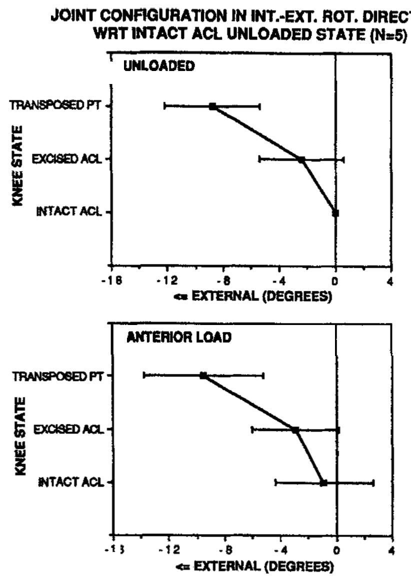

Figure 2. Means and standard deviations of the joint configuration in the internal-external rotation direction during the unloaded (top) and anterior tibial load (bottom) conditions for the three knee states.

tibia was manually held in external rotation. The bone block was then stapled to the groove on the lateral femoral condyle. Before the tendon bone block was completely fixed, the reconstruction was checked to see if it prevented anterolateral subluxation and allowed full range of passive flexion. The poplitial tendon was resutured to its origin, and the posterior incision in the capsule and the proximal portion of the iliotibial band were closed. The external load sequence was repeated for the reconstructed state, with resulting force and motion data recorded.

Analysis of data

Three-dimensional joint motion and forces in the intact anterior ligament, collateral ligaments, and transposed patellar tendon graft were obtained for each specimen during the unloaded and anterior loaded conditions at the four flexion angles for the knee states described above. Motion data are presented as the change in joint configuration in the anterior-posterior translation direction and internal-external rotation direction as monitored by the instrumented spatial linkage, that is, the difference in tibial position at each flexion angle in the above knee states relative to the tibial position at the same flexion angles in the unloaded knee with the intact ligament. Due to technical difficulties with the instrumented spatial linkage, motion data for only five of the specimens are reported. Data generated in the excised ligament and extraarticular reconstruction states were compared with each other or with the intact ligament data within the same knee, that is, each knee served as its own control. Because these data are correlated, the paired Student's *t*-test was used to determine the significance of the differences between the data. Differences were chosen to be significant at the $P \leq 0.05$ level.

Results

The intact anterior cruciate ligament carried higher forces in extension than in flexion (Table 1). By

Table 1. Forces (Newtons) in the intact anterior cruciate ligament and transposed patellar tendon graft during application of the the anterior tibial loads at 0°, 30°, 60°, and 90° of flexion. Mean *SD*, N = 7 specimens

	0°	30°	60°	90°
Intact ligament	121 *54*	60 *40*	41 *23*	41 *21*
Transposed tendon	69 *31*	66 *28*	65 *26*	81 *48*

Table 2. Forces in the intact anterior cruciate ligament and transposed patellar tendon graft during the unloaded states at the four test flexion angles. Mean *SD*, N = 7 specimens

	0°	30°	60°	90°
Intact ligament	22 *23*	1.1 *0.9*	6.5 *5*	7.4 *5.8*
Transposed tendon	25 *15*	11 *6.5*	26 *23*	57 *49*

Table 3. Forces in the medial collateral ligament during the anterior loads at the four flexion angles with an intact anterior cruciate ligament, excised ligament, and reconstruction with the transposed tendon. Mean *SD*, N = 7 specimens

	0°	30°	60°	90°
Intact ligament	25 *17*	33 *25*	44 *30*	37 *33*
Excised ligament	74 *45*	89 *50*	75 *42*	75 *29*
Transposed tendon	74 *44*	75 *57*	82 *55*	106 *56*

Table 4. Forces in the lateral collateral ligament during the anterior loads at the four flexion angles in the three knee states. Mean *SD*, N = 7 specimens

	0°	30°	60°	90°
Intact ant. lig.	20 *24*	17 *23*	13 *13*	13 *19*
Excised ant. lig.	29 *43*	21 *25*	28 *24*	49 *47*
Transposed tendon	25 *13*	2.5 *5.9*	5.8 *7.8*	3.0 *4.3*

contrast, the forces in the transposed patellar tendon graft exhibited an isotonic pattern through the four flexion angles. When averaged over the seven specimens at each flexion angle, the transposed tendon carried one third less force than the intact anterior ligament at extension, but was 49 percent more loaded than the intact ligament from 30 to 90° of flexion. The differences between the forces in the intact ligament and transposed tendon were not significant.

The transposed tendon carried force during the unloaded states, averaging 39 percent of the force in the graft during the anterior load conditions compared with 13 percent for the intact anterior ligament (Tables 1 and 2).

With the specimens under anterior load, the tibiae were anteriorly ($P \leq 0.05$) and externally rotated (NS) with anterior ligament excision compared with the intact state (Figures 1 and 2). After reconstruction with the transposed patellar tendon graft, the knees returned to within normal limits in the anterior-posterior direction. However, the tibiae were externally rotated compared with normal in the reconstructed state in both unloaded ($P \leq 0.001$) and anterior load ($P \leq 0.01$) conditions.

Forces in both collateral ligaments were greater than normal after anterior ligament excision, with the increase being significant for the medial ligament (Tables 3 and 4). Forces in the medial ligament remained greater than normal in the reconstructed state, while the forces in the lateral ligament were reduced below normal (NS).

Discussion

The forces in the transposed patellar tendon graft in this study were not greater than in the intact anterior ligament. The rationale for the transposition of the lateral one third of the patellar tendon is to prevent anterolateral rotatory instability using material with sufficient mechanical strength, thereby reducing the risk that the graft will stretch out. Short- and medium-term follow-ups have shown that anterolateral rotatory instability is indeed prevented and does not appear to return with time (Benum 1982 and 1986). The fact that one third of the patellar tendon is known to be stronger than the normal anterior ligament (Noyes et al. 1983) and that the Benum procedure leads to forces close to normal under the same joint load states suggest that the technique may be a good choice if an extraarticular reconstruction is preferred as a sole procedure for the correction of anterolateral rotatory instability. Unlike the intact ligament, however, the forces in the transposed patellar tendon graft in the unloaded flexion conditions were relatively high compared with the graft forces during the anterior loads. That is, an additional nonpneumatic external load was required to flex the joint against the tightened transposed tendon graft. This high force in the extraarticular reconstruction during unloaded flexion may eventually lead to gradual elongation and dysfunction of the transposed tendon, as well as abnormally high joint contact loads with subsequent cartilage degeneration. Perhaps a more suitable fixation site and pretension method could reduce this potential problem. Note that, although we are comparing the forces in the transposed patellar tendon and the anterior cruciate ligament, we do not know the optimal force level that is required for in vivo healing.

Althought the forces in the transposed patellar tendon graft did not exceed those of the ligament under anterior load, the graft force results exhibited large variability, implying less than adequate control over one or more surgical variables, even though the procedure was carefully performed by 1 experienced surgeon. This variability could be due in part to variation in the location of the attachment site of the transposed patellar tendon graft on the lateral femoral condyle among the specimens, although an attempt was made to place the graft at Krackow's F-9 site (Krackow and Brooks 1983). Another source of variability could be differences in pretension applied to the tendon graft at the time of fixation, as well as the manual external rotation of the tibia. We suspect that these factors distorted the relative position of the tibia and femur, which in turn altered the initial maximum unloaded length of the graft and the force that the graft carried with the knee under a load. Another source of variability can be related to the in vitro graft material being stiffer than in vivo tissue, resulting in the bone block in some knees being fixed too far anteriorly. Whether better control and stadardization of the above variables will improve clinical reproducibility remains to be demonstrated.

When the tibia was held in external rotàtion at 45° of flexion during fixation of the transposed patellar tendon graft, a pattern of external tibial rotation with flexion was created that prevented the anterolateral rotatory instability. However, this unnatural motion pattern of the knee will interfere with the normal "screw home" mechanism. Many of the extraarticular reconstruction procedures whose purpose is to eliminate or reduce anterolateral rotatory instability recommend fixing the tibia in an externally rotated position (Losee et al. 1978, Benum 1982, Andrews et al. 1985). This change in normal knee kinematics may subsequently result in the articular surfaces being subjected to higher than normal loads with abnormal contact locations, with the possibility of associated functional abnormalities and predisposition to knee arthrosis.

The authors have previously shown that the medial collateral ligament is highly loaded with external tibial rotation throughout the flexion range (Lewis et al. 1985). The high forces in the medial ligament with the reconstructed knee under anterior load in the present study may be due in part to the externally rotated position of the tibia during fixation of the transposed patellar tendon graft.

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