Effect of Different Preconditioning Protocols on Anterior Knee Laxity After ACL Reconstruction with Four Commonly Used Grafts

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Background: It is currently unknown if preconditioning an anterior cruciate ligament (ACL) graft prior to fixation is helpful in eliminating possible increases in anterior knee laxity. The purpose of this study was to measure cyclic increases in anterior tibial translation of four commonly used graft tissues subjected to four preconditioning protocols.

Methods: A robotic system was used to apply 250 cycles of anteroposterior force (134 N of anterior force followed by 134 N of posterior force) to ten intact knees (ACL controls) and then to a single knee reconstructed, for separate tests, with bone-patellar tendon-bone, bone-Achilles tendon, hamstring tendon, and tibialis tendon grafts following (1) no preconditioning, (2) preconditioning on a tension board (89 N of initial force held for twenty minutes), (3) preconditioning in situ (89 N of force applied to the tibial end of the graft during twenty-five flexion-extension cycles), and (4) a combination of protocols 2 and 3.

Results: Over the 250 cycles, all grafts were associated with a progressive increase in anterior tibial translation that was approximately an order of magnitude greater than that of the ACL, and preconditioning had no significant effect on this increase in translation. There were some significant differences in the progressive anterior tibial translation increase among the graft tissues within a given preconditioning protocol, but these differences were no greater than 1.1 mm. First-cycle and cycle-250 anterior tibial translation varied among the graft tissue types, possibly reflecting an initial "settling in" process. Regardless of the tissue type, ≥75% of the total increase in the anterior tibial translation occurred within the first 125 cycles.

Conclusions: Preconditioning had no significant effect on the progressive increase of anterior tibial translation from the first cycle to cycle 250 for any of the graft tissues tested.

Clinical Relevance: On the basis of these results, current preconditioning methods appear to be ineffective in reducing progressive increases in anterior knee laxity from cyclic loading.

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Patients can experience increased anterior knee laxity after anterior cruciate ligament (ACL) reconstruction[1-4]. Tendinous tissues are known to display viscoelastic creep and stress relaxation under uniaxial tension[5,6]. Cyclic preconditioning of these tissues has been shown to significantly reduce these viscoelastic effects[7]. However, data obtained in the laboratory with uniaxial testing have limited application to the clinical setting, as straight tensile data cannot be directly

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TABLE I Mean Cross-Sectional Area of Each Graft Tissue

	Bone-Patellar Tendon-Bone	Bone-Achilles Tendon	Hamstring Tendon	Tibialis Tendon
Mean cross-sectional area* and stand. dev. *(mm²)*	50.4 ± 8.8[ab]	60.4 ± 8.7[bcd]	43.2 ± 8.1[acd]	49.1 ± 8.3[ab]

*a = significantly different from bone-Achilles tendon graft ($p < 0.01$), b = significantly different from hamstring tendon graft ($p < 0.02$), c = significantly different from bone-patellar tendon-bone graft ($p < 0.02$), and d = significantly different from tibialis tendon graft ($p < 0.02$).

compared with in vivo increases in knee laxity[8]. Knee laxity after ACL reconstruction can be affected by additional factors. The graft must pass around tibial and femoral bone-tunnel edges, subjecting intra-articular graft tissues to contact stresses and local deformations at the tunnel interface. This was demonstrated by Roos et al.[9], who reported increased changes in graft length near the fixation sites compared with those seen at the midsubstance.

It has been suggested that viscoelastic creep or stress relaxation may contribute to decreased graft tension and increased knee laxity over time[10]. Thus, preconditioning prior to fixation has been recommended[5,6,11] and has become routine in clinical practice. However, preconditioning remains controversial as it may not be as beneficial as suggested by in vitro biomechanical studies. Knee laxity depends on the stiffness of both the graft and the fixation[12]. Researchers have observed significant loss of graft tension despite preconditioning[13], and one study showed no advantages in terms of decreased laxity in patients two years following ACL reconstruction done with preconditioned grafts[14].

The objective of the present study was to determine the effect of preconditioning by measuring anterior knee laxity after ACL reconstruction. Anterior knee laxity was defined as the anterior tibial translation recorded during testing. We evaluated four preconditioning protocols on four different types of tissue commonly used for ACL reconstruction by measuring anterior tibial translation during cyclic anteroposterior testing.

Materials and Methods

Ten human cadaveric knees (mean age of donors at the time of death, thirty-four years [range, twenty-one to forty-five years]) were used to collect baseline data for the ACL. Tibiae and femora were potted in cylindrical molds of polymethylmethacrylate (PMMA) for gripping in the test fixtures. To reduce interspecimen variability and obtain direct comparisons, a single knee was selected to test all reconstructions. A board-certified orthopaedic surgeon (F.A.P.) drilled an 11-mm femoral tunnel in the center of the ACL footprint using the anteromedial portal technique[15] and drilled an 11-mm tibial tunnel from the anteromedial aspect of the tibia to the center of the ACL footprint.

Cadaveric tissues for all graft preparations were obtained from thirty-two human donors (mean age at the time of death, forty-three years [range, sixteen to sixty-four years]). Each donor set contained right-left pairs from which bone-patellar tendon-bone, bone-Achilles tendon, semitendinosus and gracilis hamstring tendon, and tibialis tendon grafts were obtained. Because of similar structural and viscoelastic properties of tibialis anterior and posterior tendons[16], the tibialis tendon group consisted of both.

All grafts were trimmed to fit within an 11-mm-diameter sizer. (The thickness was unaltered if the graft was able to pass freely through the sizer.) Bone-patellar tendon-bone preparations were split into two halves down the midline, yielding two identical grafts per tendon. Bone blocks for bone-patellar tendon-bone and bone-Achilles tendon grafts were contoured into 25-mm-long, 10-mm-diameter cylindrical blocks. Tibialis tendon grafts were folded over to produce a two-ply graft (Fig. 1-A). Hamstring tendon allografts, consisting of semitendinosus and gracilis tendons aligned together, were folded to produce a four-ply graft (Fig. 1-B). After preparation, the specimens were stored frozen at –20°C.

A running, locked suture was placed into the free soft-tissue ends of the bone-Achilles tendon, hamstring tendon, and tibialis tendon grafts with use of number-2 braided polyester suture (Ethicon, Somerville, New Jersey) (Figs. 1-A, 1-B, and 1-C). Tibialis tendon and hamstring tendon grafts were looped through a cortical fixation device (EndoButton; Smith & Nephew ACUFEX, Memphis, Tennessee) to produce a double-stranded (tibialis tendon) or

Fig. 1

Preparation of the four graft constructs. **Fig. 1-A** Tibialis tendon graft (TIB). **Fig. 1-B** Hamstring tendon graft (HAM). **Fig. 1-C** Bone-Achilles tendon graft (ACH). **Fig. 1-D** Bone-patellar tendon-bone graft (BTB).

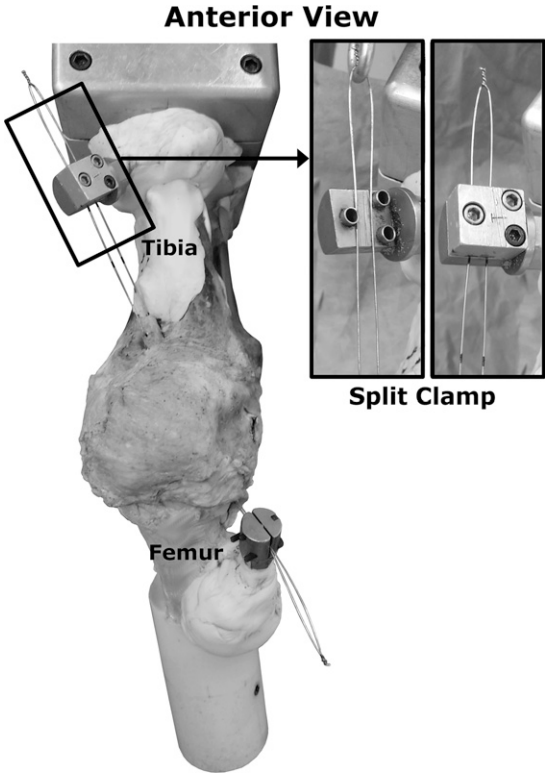

Fig. 2

Anterior view of a knee specimen with a bone-patellar tendon-bone graft secured with split-clamps at the tibial and femoral ends. The inset shows a close-up view of the tibial split-clamp device before and after securing of the wire.

quadruple-stranded (hamstring tendon) construct (Figs. 1-A and 1-B). Cross-sectional areas were measured under 0.12 MPa of compressive pressure after two minutes of compressive-pressure application with use of an established technique[17] (Table I).

To avoid tunnel damage from repeated insertion and removal of interference screws for the separate tests of the multiple grafts in the same knee, bone-block fixation was done with split-clamps fixed to the PMMA near the tunnel exits (Fig. 2). A small cannulated screw was inserted into the bone block for passage of stainless-steel wire (0.029 in [0.737 mm] in diameter (Figs. 1-C and 1-D). The wire exited the tunnel and was secured within the split-clamp. Although this method of fixation differs from clinical techniques, it has proven useful for laboratory experimental purposes, including minimizing variability of specimen behavior[18-21]. For femoral-sided soft-tissue fixation of the hamstring tendon and tibialis tendon constructs, the EndoButton was pulled through the tunnel and seated on a washer resting on the lateral femoral cortex. PMMA was added to the lateral femoral cortex to reinforce the cortical bone. Tibial-sided fixation of the bone-Achilles tendon, hamstring tendon, and tibialis tendon grafts was secured with a spiked washer device (Arthrex, Naples, Florida) (Fig. 3). A bicortical screw was inserted through the graft, with an 18-mm-diameter spiked washer on one end and an opposing nut on the opposite end. The graft was positioned to capture the tissue between the peripheral spikes of the washer. Tightening of the opposing nut created a press fit of the tissue between the spiked washer and the cortical bone. PMMA was added to reinforce the cortical bone at the spiked-washer fixation site.

On the day of testing, the allografts were thawed to room temperature while remaining hydrated. Immediately prior to ACL reconstruction, each graft was subjected to one of four preconditioning protocols. The first protocol (control) was no preconditioning prior to fixation. The second protocol was preconditioning on a tension board (Graftmaster II; Smith & Nephew ACUFEX). As is done clinically, the graft was fixed with an initial 89-N tensile force and held in place for twenty minutes. This level of force has been used in previous studies[6,7,22,23]. After preconditioning, the graft was immediately inserted into the knee, and femoral fixation was secured. The third protocol was in situ preconditioning within the knee. This was performed after femoral fixation but prior to tibial fixation. The wire from the tibial-sided bone block (of the bone-patellar tendon-bone grafts) or the sutures from the free ends of the tendinous grafts (bone-Achilles tendon, hamstring tendon, and tibialis tendon grafts) were looped over the hook of a calibrated spring scale so that equal tension was applied to each portion of the construct. The knee was manually cycled twenty-five times between 0° and 90° of flexion (on the basis of the results reported by Kawano et al.[24]) while maintaining a constant 89-N force. This is another common clinical preconditioning method. The fourth protocol combined the second and third protocols (use of a tension board

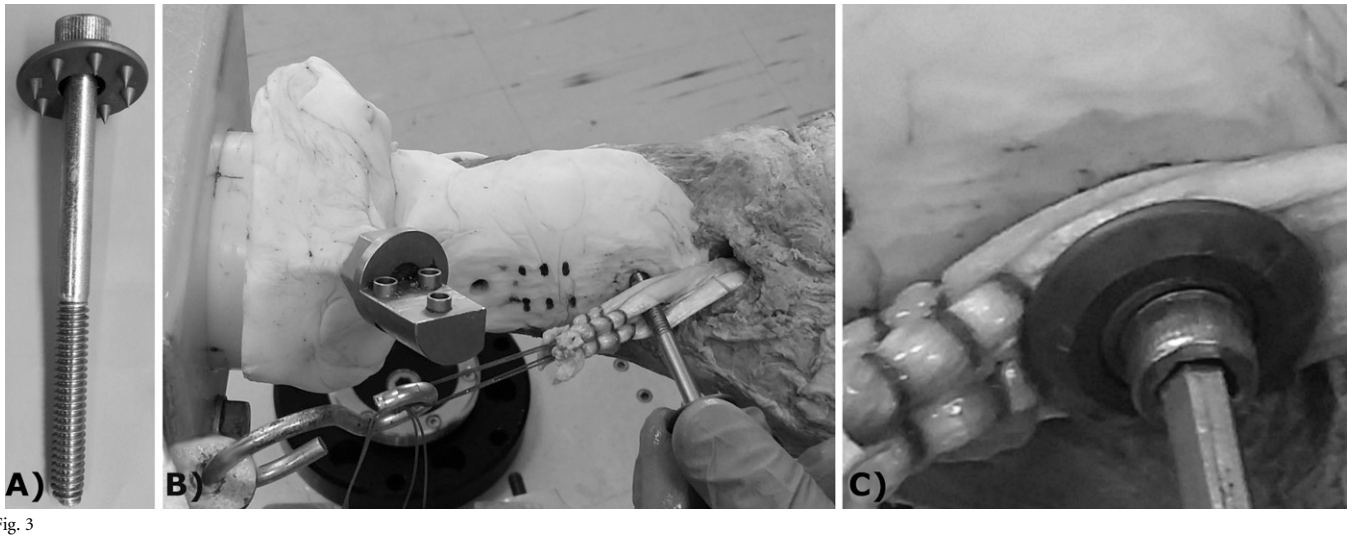

Fig. 3

Soft-tissue graft tibial fixation with use of the spiked washer method. **Fig. 3-A** Spiked washer and bicortical screw. **Fig. 3-B** Insertion of the bicortical screw with maintenance of graft tension. **Fig. 3-C** Close-up view of the graft tissue secured under the spiked washer.

TABLE II First-Cycle Anterior Tibial Translation with 134 N of Applied Anteroposterior Force

	Mean First-Cycle Anterior Tibial Translation* and Stand. Dev. *(mm)*				
Preconditioning	ACL	Bone-Patellar Tendon-Bone	Bone-Achilles Tendon	Hamstring Tendon	Tibialis Tendon
None	4.9 ± 1.8[ab]	6.4 ± 1.0[bcd]	4.6 ± 0.7[abe]	6.0 ± 0.7[bd]	3.1 ± 0.9[acde]
Board	Not applic.	6.1 ± 1.5[bd]	4.0 ± 0.8[ae]	5.9 ± 0.8[bd]	3.0 ± 0.9[ae]
In situ	Not applic.	4.8 ± 1.1[bf]	3.5 ± 0.7[ef]	5.3 ± 1.0[bd]	2.8 ± 1.0[ae]
Combined	Not applic.	4.8 ± 1.1[bf]	3.9 ± 0.9[be]	5.4 ± 0.5[bd]	2.0 ± 1.0[ade]

*a = significantly different from bone-patellar tendon-bone graft (within the given preconditioning protocol; $p < 0.04$), b = significantly different from tibialis tendon graft (within the given preconditioning protocol; $p < 0.05$), c = significantly different from ACL (without preconditioning; $p < 0.04$), d = significantly different from bone-Achilles tendon graft (within the given preconditioning protocol; $p < 0.05$), e = significantly different from hamstring tendon graft (within the given preconditioning protocol; $p < 0.05$), and f = significantly less than the no-preconditioning group (within the given graft tissue type; $p < 0.03$).

followed by in situ preconditioning). This represented the maximum preconditioning effect possible in a clinical setting. After preconditioning, 89 N of graft tension was applied during final tibial fixation at 30° of knee flexion. In total, 160 allograft preparations were tested, ten of each graft tissue type for each preconditioning protocol. The testing order was randomized.

A six degrees-of-freedom robotic manipulator (KR 210; KUKA Robotics, Clinton Township, Michigan) was used to perform all testing. The tibia was clamped in a fixture mounted to a force-moment sensor (Omega Model Industrial Automation Load Cell; ATI Industrial Automation, Apex, North Carolina) at the end of the robot. A three-dimensional digitizer (Faro Gage; FARO Technologies, Lake Mary, Florida) was used to reference a tibial-based x-y-z joint coordinate system. The femur was then clamped to a fixture mounted on a base plate with the knee at 30° of flexion (Fig. 4). The robot permitted only straight anteroposterior movement of the tibia relative to the femur. In the study by Arnold et al.[13], who measured tension in bone-patellar tendon-bone grafts with an arthroscopically implantable force probe during 1500 flexion-extension cycles, 70% of the total loss in graft tension occurred by cycle 100. To account for variation in graft tissue type and study methodology, we applied 250 cycles of anteroposterior tibial force. For each cycle, the robot applied a 134-N posterior tibial force followed by a 134-N anterior tibial force. A target

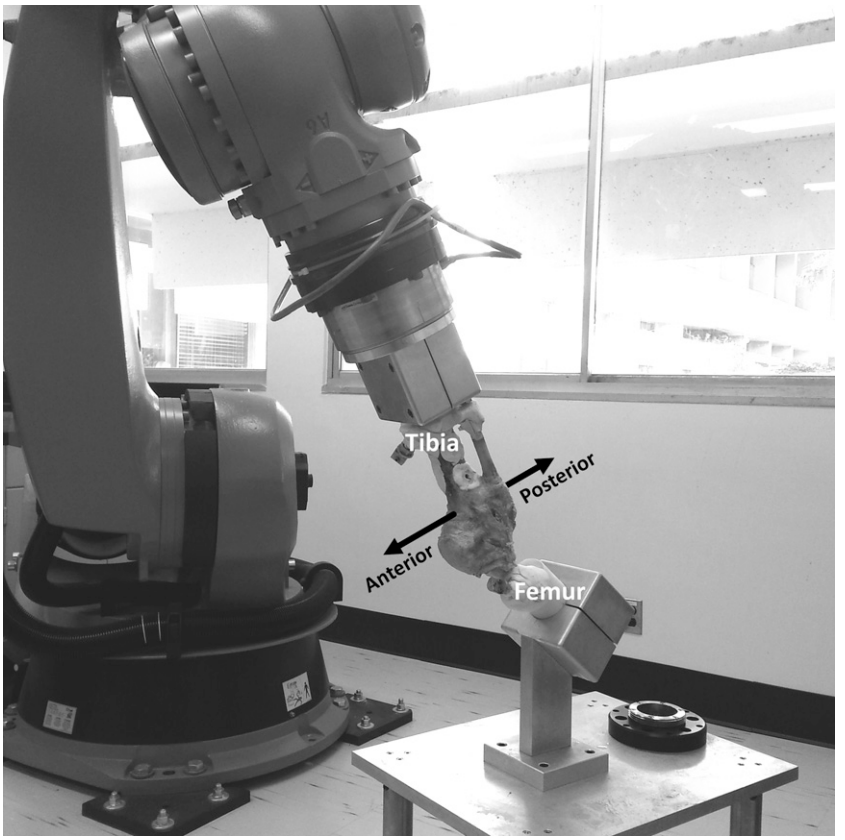

Fig. 4

Robot for mechanical testing of anterior tibial laxity.

TABLE III Cycle-250 Anterior Tibial Translation with 134 N of Applied Anteroposterior Force

	Mean Cycle-250 Anterior Tibial Translation* and Stand. Dev. *(mm)*				
Preconditioning	ACL	Bone-Patellar Tendon-Bone	Bone-Achilles Tendon	Hamstring Tendon	Tibialis Tendon
None	5.1 ± 1.9[abc]	8.7 ± 1.0[de]	7.4 ± 1.0[d]	8.8 ± 0.8[de]	6.0 ± 1.2[ac]
Board	Not applic.	8.1 ± 1.6[e]	6.7 ± 1.0	8.4 ± 0.9[e]	6.2 ± 1.6[ac]
In situ	Not applic.	6.8 ± 1.3[f]	6.0 ± 0.7[cf]	8.1 ± 1.2[be]	5.8 ± 1.6[c]
Combined	Not applic.	6.7 ± 1.3[ef]	6.5 ± 1.2[e]	7.9 ± 0.6[e]	4.3 ± 1.3[abcg]

*a = significantly different from bone-patellar tendon-bone graft (within the given preconditioning protocol; $p < 0.05$), b = significantly different from bone-Achilles tendon graft (within the given preconditioning protocol; $p < 0.05$), c = significantly different from hamstring tendon graft (within the given preconditioning protocol; $p < 0.05$), d = significantly different from ACL (without preconditioning; $p < 0.04$), e = significantly different from tibialis tendon graft (within the given preconditioning protocol; $p < 0.05$), f = significantly less than the no-preconditioning group (within the given graft tissue type; $p < 0.03$), and g = significantly less than the tension-board group (within the given graft tissue type; $p < 0.03$).

force of 134 N has been used previously in robotic studies of ACL reconstruction[25-30]. Both the applied force and the corresponding anteroposterior tibial translations were recorded. Ten intact knees were first tested to document baseline increases in anterior tibial translation in the presence of an intact ACL. Then, one knee was selected for cyclic testing of all graft tissues subjected to each preconditioning protocol.

The outcome measures for analysis were first-cycle anterior tibial translation, cycle-250 anterior tibial translation, and the progressive increase in anterior tibial translation from the first cycle to cycle 250. The neutral position of the tibia relative to the femur was determined by finding the midpoint of anteroposterior tibial translation in the intact knee. In the selected specimen, the tibia translated 4.8 mm posteriorly and 4.8 mm anteriorly relative to this neutral position. After ACL reconstruction, all anterior tibial translation measurements were referenced to the anteroposterior neutral position in the intact knee.

A one-way analysis of variance (ANOVA) was used to compare the mean cross-sectional area, first-cycle anterior tibial translation, cycle-250 anterior tibial translation, and progressive increase in anterior tibial translation (from the first cycle to cycle 250) among the four preconditioning protocols (for each graft tissue) and among the four graft tissues (for a given preconditioning protocol). Post hoc comparisons were made with use of the Tukey honest significant difference (HSD) procedure. The Pearson correlation was used to compare the effect of cross-sectional area on anterior tibial translation within a tissue type (target correlation coefficient, $r > 0.80$). Significance was set at $p < 0.05$ for all analyses.

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Results

Without preconditioning, the mean first-cycle anterior tibial translation with the bone-patellar tendon-bone grafts was significantly greater than that with the ACL ($p < 0.04$), whereas the first-cycle anterior tibial translation with the tibialis tendon grafts was significantly less than that with the ACL ($p < 0.01$; Table II). At cycle 250, the mean anterior tibial translations with the bone-patellar tendon-bone, bone-Achilles tendon, and hamstring tendon grafts were all significantly greater than that with the ACL ($p < 0.01$; Table III), whereas the mean anterior tibial translation with the tibialis tendon grafts did not differ significantly from that with the ACL. There were some significant differences in both the first-cycle and cycle-250 anterior tibial translations among the graft tissues tested with the same preconditioning protocol (Tables II and III), but there was no consistent trend in the relative magnitudes.

TABLE IV Increase in Anterior Tibial Translation During 250 Cycles of Applied 134-N Anteroposterior Force

	Mean Increase in Anterior Tibial Translation* and Stand. Dev. *(mm)*				
Preconditioning	ACL	Bone-Patellar Tendon-Bone	Bone-Achilles Tendon	Hamstring Tendon	Tibialis tendon
None	0.2 ± 0.1[a]	2.3 ± 0.5[bcd]	2.8 ± 0.4[e]	2.8 ± 0.3[e]	2.8 ± 0.5[e]
Board	Not applic.	2.0 ± 0.4[d]	2.7 ± 0.3	2.5 ± 0.2	3.1 ± 1.2[e]
In situ	Not applic.	2.0 ± 0.4[cd]	2.5 ± 0.3	2.7 ± 0.3[e]	3.0 ± 1.0[e]
Combined	Not applic.	1.9 ± 0.3[bc]	2.6 ± 0.4[e]	2.5 ± 0.3[e]	2.3 ± 0.5

*a = significantly less than all graft tissues (regardless of preconditioning protocol; $p < 0.01$), b = significantly different from bone-Achilles tendon graft (within the given preconditioning protocol; $p < 0.05$), c = significantly different from hamstring tendon graft (within the given preconditioning protocol; $p < 0.05$). d = significantly different from tibialis tendon graft (within the given preconditioning protocol; $p < 0.05$), and e = significantly different from bone-patellar tendon-bone graft (within the given preconditioning protocol; $p < 0.05$).

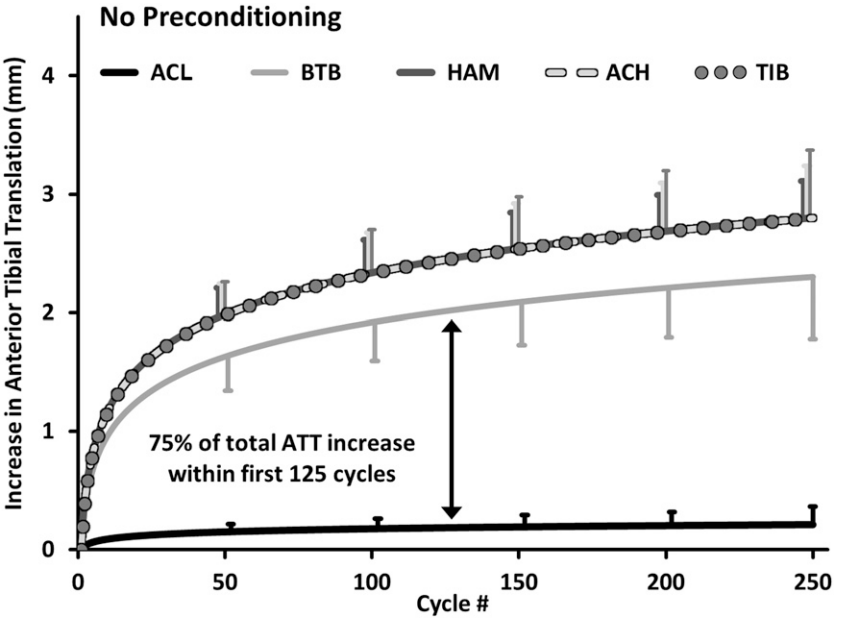

Fig. 5

Increases (mean and standard deviation) in anterior tibial translation (ATT) with the native ACL and each of the grafts without preconditioning. With each graft tissue (regardless of preconditioning), ≥75% of the total increase in anterior tibial translation occurred within the first 125 cycles. BTB = bone-patellar tendon-bone, HAM = hamstring tendon, ACH = bone-Achilles tendon, and TIB = tibialis tendon graft.

Compared with no preconditioning, in situ preconditioning significantly reduced first-cycle and cycle-250 anterior tibial translation with the bone-Achilles tendon and bone-patellar tendon-bone grafts ($p < 0.03$; Tables II and III) and combined preconditioning significantly reduced first-cycle and cycle-250 anterior tibial translation with the bone-patellar tendon-bone grafts ($p < 0.03$). All graft tissues (regardless of the preconditioning protocol) were associated with significantly greater increases in anterior tibial translation over the 250 cycles compared with the translation observed with the native ACL ($p < 0.01$; Table IV). However, within each graft-tissue group there was no significant difference among preconditioning protocols in terms of the progressive increase of anterior tibial translation from the first cycle to cycle 250. Post-hoc power analysis based on the standard deviation indicated that the analysis had an 80% power to detect a difference in means of 0.7 mm. While there were some significant differences in the mean progressive increase of anterior tibial translation from the first cycle to cycle 250 among the graft tissues that had received the same preconditioning protocol, the clinical relevance of those differences is questionable since none of the differences were >1.1 mm.

Analysis of the bone-patellar tendon-bone, bone-Achilles tendon, and tibialis tendon grafts showed no significant correlations between their cross-sectional areas and the first-cycle anterior tibial translation, cycle-250 anterior tibial translation, or cyclically induced increase in anterior tibial translation (correlation coefficient $r < 0.80$ and $p > 0.05$). Analysis of the hamstring tendon grafts also showed no such correlations except between the cross-sectional area of the grafts subjected to in situ preconditioning and first-cycle anterior tibial translation (correlation coefficient $r = 0.87$ and $p < 0.01$).

In the tests of all graft materials, at least 75% of the total measured increase in anterior tibial translation occurred by cycle 125 (Fig. 5). One possible contribution to the cyclically induced progressive increase in anterior tibial translation was tissue deformation due to contact stresses at critical locations of the graft construct. After the grafts were removed at the completion of testing, tissue consolidation was observed at the intra-articular edge of the femoral tunnel (for all graft tissues) and at the contact location with the EndoButton (for the hamstring tendon and tibialis tendon grafts).

Discussion

In this study, we used anterior tibial translation as a measure of anterior knee laxity to determine the effects of different preconditioning protocols on common graft tissues during cyclic testing after reconstruction of the ACL. Typically, after ACL reconstruction, the surgeon performs several Lachman tests to determine knee stability. From that point onward, long-term anterior knee laxity depends on changes in anterior tibial translation over time due to in vivo loading. Clinically, the initial level of anterior tibial translation can be influenced by, among other factors, graft tissue type, fixation method, and tension level during final fixation. In the laboratory setting in which our study was performed, first-cycle anterior tibial translation likely also was influenced by most if not all of those same factors. Total anterior tibial translation is the sum of first-cycle anterior tibial translation plus the progressive increase in anterior tibial translation over time due to cyclic loading. Given the complex interaction of the factors influencing first-cycle anterior tibial translation, the change in anterior tibial translation between the first and the 250th cycle seemingly provides a much less confounded basis for

isolating the effects of preconditioning per se. When we considered just this increase in anterior tibial translation from the first to the 250th cycle, we found that no preconditioning protocol had a significant effect on any of the graft tissues.

First-cycle anterior tibial translation deserves further discussion, since its mean values varied by as much as 3.4 mm among the graft tissue types. It seems unlikely that differences in material properties alone could explain the differences in first-cycle anterior tibial translation. Depending on the graft configuration, a "settling-in" process may occur. It has been shown in vivo that, during passive flexion-extension, a four-stranded hamstring tendon graft can have as much as a 37% disparity in load-sharing among its strands[31]. During the first loading cycle, grafts could possibly twist, move, and deform at the tunnel edges as load-sharing is adjusted within the graft tissue and presumably remain there for subsequent loading cycles. Consequently, the initial positioning of the graft may differ from the position that the graft tissue assumes during anterior tibial loading.

Although our methodologies differed, our results best compare with those of Arnold et al.[13], who tested bone-patellar tendon-bone autografts preconditioned on a tension board for twenty minutes. Knees were tested for 1500 flexion-extension cycles with an arthroscopically implantable force probe inserted into the tissue midsubstance. At cycles 0, 500, and 1500, knee laxity was measured under 90 N of anterior tibial force at 20° of flexion. Arnold et al. found that anterior laxity increased 1.3 mm after 500 cycles and 1.6 mm after 1500 cycles, whereas our testing of bone-patellar tendon-bone grafts that had been preconditioned on a tension board showed a 2.0-mm increase in anterior tibial translation after 250 cycles. Arnold et al. also noted that graft tension decreased rapidly within the first 100 cycles (32% reduction) and leveled off after 500 cycles. In our study, 75% of the total increase in anterior tibial translation occurred within the first 125 cycles for all graft tissues. Thus, the early postoperative period prior to graft incorporation may be a critical period of risk for increased anterior knee laxity.

An additional source of laxity could be related to contact stresses at the graft interface with the intra-articular femoral tunnel exit and around the EndoButton during anterior tibial translation, as these locations on the graft showed tissue consolidation. Roos et al.[9] performed cyclic testing of tendon grafts looped over a cross-pin. Using roentgen stereophotogrammetric analysis to measure localized length changes of the graft tissue, they found graft lengthening to be significantly greater in the region of the fixation sites compared with the midsubstance. They noted that increased length in the vicinity of the cross-pin could be related to localized contact stress at the tissue-pin interface.

There were limitations to our study. Degradation of the knee specimen was a concern. As we noted earlier, bone tunnel integrity was preserved by not using interference screws. However, femoral tunnel grooving did occur at the intra-articular exit, where graft tissues repeatedly came into contact with the edge of the tunnel during anterior motion of the tibia. This could have affected anterior tibial translation. However, all testing was randomized, so these effects would have been distributed equally over the entire course of testing and should not have changed the relative differences among graft tissues or among preconditioning protocols. The secondary restraints to tibial translations could also have affected anterior tibial translation. However, it is known that the ACL provides 87% to 90% of the total restraint to anterior tibial translation[32]; thus, any effects would be minimal.

The mechanisms of preconditioning differed between the tension-board and in situ methods. With the tension-board method, an initial force was used to induce viscoelastic stress relaxation of the tissue, whereas, in situ, a constant force was used to induce viscoelastic creep of the tissue. Both preconditioning protocols are commonly employed in the clinical setting, and we adhered to these clinical methodologies in order to examine the efficacy of each.

The strength of our study is that it replicates the clinical situation much more closely than does simple ex situ uniaxial loading. The robotic setup for testing the cadaveric specimens included key anatomic and functional loading factors that a graft would experience in vivo. Anteroposterior loading cycles were performed to emulate graft loading conditions experienced during the early postoperative rehabilitation period before graft incorporation and ligamentization. However, as we already noted, we did not attempt to replicate current clinical fixation techniques, such as aperture fixation, with our graft fixation technique. This distinction is unlikely to have influenced the perceived effects of preconditioning on the progressive increase in anterior tibial translation during cyclic loading; there were no obvious differences in the local loading conditions experienced by the grafts themselves, and the order of testing of both the graft types and the preconditioning regimens was randomized.

In conclusion, preconditioning had no significant effect on the progressive increase of anterior tibial translation during cyclic anteroposterior testing in this study. This was true regardless of the graft tissue type, suggesting that anterior laxity is a product of more than the viscoelastic properties of tendinous graft tissues. As postoperative anterior knee laxity is a clinical concern, there is a need to identify new, more effective methods for preconditioning ACL graft tissues. ■

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