Pretensioning of Soft Tissue Grafts in Anterior Cruciate Ligament Reconstruction

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To determine which preconditioning and pretensioning techniques should be applied to soft tissue grafts during anterior cruciate ligament (ACL) reconstruction to avoid loss of tension after surgery, fresh semitendinosus and tibialis anterior tendons underwent tensile mechanical testing with 4 pretensioning and/or preconditioning techniques. A mechanical tester was used to collect the data. Group I (n=5) was given only an initial 80 N pull for tensioning, Group II (n=4) was given pretensioning and initial tensioning, Group III (n=5) was given cyclic tensioning and initial tensioning, and Group IV (n=5) was given a combination of the 3 techniques. Group I lost 50% of the initial tension at 30 minutes. The residual tension in Groups II, III, and IV was significantly higher than that in Group I after 1, 10, and 30 minutes (P<.001). Group IV consistently showed significantly higher residual tension than Groups II and III after 10 and 30 minutes (P<.05). All groups experienced elongation during testing: Group I (10.8 mm)<Group IV (14.6 mm)<Group III (15.6 mm)<Group II (16.6 mm), with significant differences observed between groups (P<.05). All experimental groups showed significantly greater stiffness than the control group (Group I) (P<.001). This study confirmed that pretensioning or preconditioning after 30 minutes leaves a graft with higher residual tension. Moreover, pretensioning and preconditioning had an additive effect and resulted in significantly greater retained tension than either method performed individually. A simple pull up to 80 N before fixation does not impart sufficient tension to a graft to prevent it from failing. The authors recommend that clinicians performing ACL reconstructions with soft tissue grafts precondition or pretension the tendons before final tibial fixation to achieve greater retained tension in the graft after placement. [Orthopedics. 2015; 38(7):e582-e587.]
An estimated 200,000 individuals in the United States experience rupture of the anterior cruciate ligament (ACL) annually. Current surgical techniques for ACL reconstruction have failure rates of approximately 10%. Several variables under the control of the surgeon significantly affect the final outcome of ACL surgery. Improper graft material selection, intra-articular tunnel positioning, graft tensioning, choice of fixation in both the femoral and tibial tunnels, and knee flexion angle at the time of fixation can all contribute to a failed ACL reconstruction. Of these variables, graft tensioning has been reported as a critical surgeon-controlled factor that affects outcome. All graft materials used in ACL reconstruction have well-known viscoelastic properties and elongate and lose tension if kept under a constant load. To minimize tension loss, a variety of tensioning protocols for soft tissue grafts have been recommended. These methods include tensioning on the graft preparation board before harvesting, cycling the knee after femoral fixation, and providing maximal pull before final fixation. Some of these methods have been combined, including various numbers of cycles and loads. To describe the issues surrounding tensioning protocols more precisely, Nurmi et al defined 3 specific stages of tensioning. Pretensioning is defined as loading performed on the graft preparation board before the graft is pulled into the bone tunnels. Preconditioning is loading of the graft that is performed after femoral fixation and can be subdivided into cyclic and isometric types. Finally, initial tensioning is the tension applied to the graft before final tibial fixation.

Although many articles on ACL reconstruction have been published, few have focused on tensioning protocols, and none has shown any clear advantage of a single method. Previous studies used arbitrary parameters for pretensioning. In many cases, tendons are not pretensioned at all. Tensioning on the graft preparation board has been reported with values ranging from 44 to 88 N (10 to 20 lb) for 10 to 30 minutes. Not all groups underwent pretensioning, and to reduce the number of variables affecting the results, the current study used the same fixation method throughout the groups. This approach allowed the authors to examine solely tendon behavior.

The goal of this study was to determine which preconditioning technique, if any, should be applied to soft tissue grafts during ACL reconstruction. The authors hypothesized that pretensioning is insufficient to eliminate the viscoelastic creep associated with soft tissue tendon grafts. Regardless of the pretensioning method used, the soft tissue graft should lose a significant amount of tension. Additionally, the authors hypothesized that a single pull before final fixation is equally effective as pretensioning and preconditioning in maintaining adequate tension.

**Materials and Methods**

**Tissue Collection**

Fresh-frozen, nonirradiated cadaveric tissue was obtained from the tissue bank at the University of Texas Health Science Center at San Antonio. A total of 11 semitendinosus tendons and 9 tibialis anterior tendons were collected from 14 cadavers. The average age of the soft tissue grafts was 50.47±16.06 years (range, 20-65 years). The study included 11 male and 3 female specimens. After harvesting, the samples were stored in sealed plastic bags and maintained at -80°C. Nurmi et al showed soft tissue grafts to have similar viscoelastic properties, and studies have shown success with single-loop anterior tibialis allografts when used in ACL reconstruction.

**Tissue Preparation**

Tendons were thawed in 1× phosphate-buffered saline and randomly distributed into 4 groups of 5 tendons each, except for Group II. This group included only 4 specimens because, as a result of human error, a tendon became unusable after being stretched to failure without preconditioning. The tendons were randomized by having an observer (M.P.) who was blind to the origin of the samples select random samples between the 2 types of tendons.

The free ends of each tendon were sutured with No. 5 Ethibond Excel (Ethicon, Somerville, New Jersey) in a Krackow-type whipstitch fashion. The suture was tied to itself to create a closed loop. Each tendon-suture construct measured approximately 200 mm in circumference, creating a 100-mm loop length when implanted. The authors did not test the 2 different materials (tendons and sutures) because sutures have been shown to have much higher stiffness than tendons. Thus, the experimental results were related to the tissue and not the suture.

**Mechanical Testing**

Testing was performed with an Insight 5 mechanical tester (MTS, Eden Prairie, Minnesota) in phosphate-buffered saline solution at 34°C to simulate the knee environment and eliminate stress relaxation associated with temperature change. The proximal tissue end of the loop was placed around the steel bar of the load cell, and the distal suture end was secured to the base. The setup for mechanical testing is shown in **Figure 1**.

Group I served as the control group. In this group, a single initial pull of tensioning was simulated without pretensioning or preconditioning. To maintain clinical relevance, 80 N initial pull force was chosen, as recommended by Yasuda et al and Nurmi et al. This amount of tension also lies within the SD range of the maximum amount that a surgeon can physically pull.

Tension and length measurements were recorded at 1, 10, and 30 minutes. Longer time effects were not sought because of previous studies that showed that tension and strain decrease dramatically within 10 minutes after the application of load. Group II was the pretensioning group. Grafts were tensioned to 88 N (20 lb...
force) and held for 20 minutes to simulate the pretensioning performed on the graft preparation board at 88 N during tunnel preparation. The grafts were unloaded for 5 minutes to simulate transfer from the graft preparation board to the knee, and then a final pull of 80 N was applied to the sutures with a hold at this position. Continuous tension and overall graft loop length were measured at 1, 10, and 30 minutes. Group III was used to measure the effect of cyclic preconditioning without pretensioning on the graft preparation board. Initially, the tendons were pulled cyclically 20 times between 0 and 80 N at 1 mm/s. Successively, a final pull of 80 N was placed on the graft and held. Measurements of tension and length were obtained at the same time points. Group IV was used to measure the additive effect of pretensioning combined with cyclic preconditioning. The grafts first underwent 20 minutes of fixed loading at 88 N and then were unloaded for 5 minutes. The grafts then underwent 20 loading-unloading cycles between 0 and 80 N at a rate of 1 mm/s. Finally, a final pull of 80 N was applied. Tension and elongation measurements were taken at 1, 10, and 30 minutes. Tendon stiffness was measured as the slope of the load-elongation curve. The tensioning protocol for each group is summarized in Table 1.

**Statistical Analysis**

Two-way analysis of variance was performed to analyze differences between the mean values for residual tension in each group after 1, 10, and 30 minutes. Individual group differences were analyzed with Tukey’s multiple comparison tests. One-way analysis of variance was performed to analyze differences between the cumulative elongations after 30 minutes of testing. Tukey’s multiple comparison test was also used to compare individual values. \( P < .05 \) was considered statistically significant.

**RESULTS**

Group I lost 50% of the initial tension at 30 minutes. Residual tension in Groups II, III, and IV was significantly higher than in Group I after 1 minute (\( P < .001 \)), 10 minutes (\( P < .001 \)), and 30 minutes (\( P < .001 \)). When the 3 experimental groups were compared, Group IV consistently showed significantly higher residual tension than Groups II and III after 10 minutes (\( P < .01 \)) and 30 minutes (\( P < .05 \)). Over time, a significant decrease in residual load was seen from 1 to 10 minutes (\( P < .001 \)), and a further decline was seen after 30 minutes (\( P < .05 \)). Mean residual tension for each group is shown in Table 2. All groups showed a linear decrease in tension with time.

During the course of the study, percent load reduction was significantly higher in Group I (\( P < .001 \)) at all time points. Group IV had a significantly lower change in load after 10 minutes (\( P < .01 \)) and 30 minutes (\( P < .05 \)) (Figure 2A). All groups had elongation during testing: Group I (10.8 mm)<Group IV (14.6 mm)<Group III (15.6 mm)<Group II (16.6 mm), with
significant differences observed between groups ($P<.05$) (Figure 2B). Figure 3 shows mean stiffness of the tendons after testing. Groups II, III, and IV had significantly higher stiffness than Group I ($P<.001$).

**Discussion**

As noted earlier, 2 different tendons were used. Although sample homogeneity would have been ideal, given the similar mechanical properties of both grafts and the limited availability of allografts in general, grouping the samples was reasonable and clinically relevant. The viscoelastic properties of the soft tissues used in ACL reconstruction have been well described. The ultimate tensile load across the native ACL is 1730 N, but it is only loaded to 454 N for most activities. Hamner et al showed that quadrupled hamstring tendon grafts can exceed 4500 N in ultimate tensile strength.

The final outcome after ACL reconstruction depends on many variables, with initial graft tension among the most important factors. Knee laxity is determined by the amount of tension that remains in the graft after reconstruction, and the graft elongation that occurs after fixation is a key factor in mechanical failure. The anterior-to-posterior laxity of the knee decreases with an increase in initial tension of the ACL graft. Inadequate tension with uncorrected laxity can lead to an unstable knee, whereas over-tensioning can lead to pathologic stress on joint cartilage, graft failure, or infrapatellar contracture syndrome. Over-tensioning can also increase postoperative laxity, and this can slow the return of knee motion and normal knee kinematics.

Although it has been shown that the tension across the native ACL is 16 to 87 N, it is unclear what the ideal residual tension should be to restore the normal anterior-to-posterior laxity of the knee and eliminate the deleterious effects of over-tensioning. In a cadaveric study with hamstring tendon grafts, Mae et al showed that an initial tension of 44 N best restored the normal anterior-to-posterior laxity of the knee compared with tension of 22 N and 88 N. Furthermore, it is difficult to quantify the mechanical deformation that actually affects graft tension after reconstruction in vivo. In addition to the inherent viscoelasticity of the graft, graft remodeling, histologic degeneration, and decreased vascularity can contribute to changes in residual graft tension. Extrinsic factors, such as the graft fixation method, tunnel expansion, and knee flexion angle, also must be considered. Thus, attempting to replicate an exact resting tension may be futile and unnecessary.

Countless techniques have been described to replicate and maintain an adequate amount of tension across the graft after reconstruction. Recommend
decrease with an increase in temperature. According to Arnold et al., only 50% of the initial tension applied to a patellar tendon graft remained after 1500 cycles of knee flexion, with the most rapid decrease occurring in the first 100 cycles.

The current study showed that soft tissue grafts can lose up to 50% of the initial tension after 30 minutes, in concordance with previous studies. It is possible to infer that these values would continue to fall with time, based on previous studies. The current data showed that significantly greater tension can be imparted to a graft, however, by pretensioning or cyclic preconditioning. Moreover, combining pretensioning and preconditioning leaves significantly more tension remaining than is provided with either procedure performed alone. According to these results, after 30 minutes, Group I showed the least elongation. When grafts were stretched to 80 N and held for 30 minutes, Group I did not show much deformity but released slack right away (lack of preconditioning). Groups II, III, and IV showed greater elongation because of preconditioning, but maintained the load better (presence of preconditioning). As expected, the investigational tendons that underwent preconditioning resulted in greater stiffness. These findings translated to a much smaller drop in residual tension at fixed elongation and suggested that pretensioning protocols alter the tendons at the level of the underlying fiber structure, thus affecting their load and strain response. This finding indicates that some form of pretensioning or preconditioning is necessary to maintain adequate tension across the graft. A simple pull before fixation, as in Group I, did not retain residual tension comparable to that in pretreated tissue, as originally hypothesized.

Although the study data showed significantly lower residual tension after 30 minutes in soft tissue grafts that were not pretensioned, several prospective clinical studies showed successful outcomes with grafts that were initially tensioned from 20 to 80 N. This finding suggests that as long as the residual graft tension falls within this range and other variables for failure are controlled, an optimal result can be expected. In concordance with Nurmi et al., the authors believe that, regardless of the pretensioning method performed, the soft tissue graft will lose a significant amount of tension. Additionally, the authors hypothesized that a single pull before final fixation is as effective as pretensioning and preconditioning in maintaining adequate tension. In contrast to the study by Nurmi et al., the current study did not use pretensioning in all groups. In addition, the fixation method was eliminated as a variable to allow examination solely of tendon behavior.

Limitations

Although care was taken to perform testing in an environment that closely mimics physiologic conditions, the primary limitation of this study was that it is difficult to predict which method will produce the best clinical outcome based on biomechanical laboratory findings of residual tension in grafts from different tensioning protocols. The benefit and retention of pretensioning and preconditioning techniques should be evaluated in an animal model in situ with functional testing. Additionally, limited parameters of preconditioning were tested, with the primary objective of evaluating whether a combination of pretensioning and preconditioning had an added benefit. Because an effect of such a preconditioning regimen was seen, further optimization could identify the ideal preconditioning regimen for maximal preload retention by testing design variables, such as number of cycles and greater range of loads, for clinical translation.

Conclusion

This study did not actually prove insufficiency of an 80 N pull, but the findings suggested that this approach is less reliable in maintaining tension. Based on the study results, this method is more difficult to use clinically to obtain a desired graft tension and also may increase the risk of losing additional tension. The authors recommend that clinicians who perform ACL reconstructions with allograftic tendons precondition or pretension soft tissue grafts before final tibial fixation. A simple pull up to 80 N before fixation does not provide sufficient tension. The study confirmed the previous finding that pretensioning or preconditioning leaves a graft with higher residual tension after 30 minutes. Moreover, pretensioning and preconditioning had an additive effect and resulted in significantly greater retained tension than either method performed individually.

References

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