A Biomechanical Evaluation of Anterior and Posterior Tibialis Tendons as Suitable Single-Loop Anterior Cruciate Ligament Grafts

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Purpose: Because allograft tendons used to replace a torn anterior cruciate ligament are in short supply, it is useful to explore other possible graft sources. The purpose of this study was to determine whether a graft formed from a loop of either an anterior or posterior tibialis tendon has structural, material, and viscoelastic properties similar to those of a double-looped semitendinosus and gracilis (DLSTG) graft. **Type of Study:** Completely randomized design. **Methods:** Four structural and 3 material properties were determined for each type of graft ($n = 10$) by measuring the cross-sectional area, looping the tendon(s) over a post, gripping the free ends of the tendon(s) with a freeze clamp, and pulling the graft to failure by using a materials testing system. Two viscoelastic properties were determined for each type of graft ($n = 10$) by measuring the decrease in load under a constant displacement (i.e., stress relaxation test) and the increase in displacement under a constant load (i.e., creep test). **Results:** For grafts 95 mm in length, the ultimate load and ultimate displacement of a loop of anterior (4,122 N, 12.0 mm) and posterior tibialis (3,594 N, 12.5 mm) tendon were either similar to or significantly greater than those of the DLSTG graft (2,913 N, 8.4 mm) ($P = .204$ for the posterior tibialis ultimate load and $P \leq .007$ for the remaining quantities). The stiffness and cross-sectional area of the anterior (460 N/mm, 48.2 mm^2) and posterior tibialis (379 N/mm, 41.9 mm^2) grafts were similar to those of the DLSTG graft (418 N/mm, 44.4 mm^2) ($P \geq .283$). The tensile modulus, stress at ultimate load, and strain at ultimate load of the anterior tibialis and posterior tibialis grafts were either similar to or significantly greater than those of the DLSTG graft. The decrease in load of the anterior tibialis and posterior tibialis grafts was either greater than or similar to that of the DLSTG graft for the relaxation test ($P \leq .066$). The increase in displacement of the anterior tibialis (0.3 mm) and posterior tibialis (0.4 mm) grafts was minimally but significantly greater than that of the DLSTG graft (0.2 mm) for the creep test ($P \leq .004$). **Conclusions:** The structural, material, and viscoelastic properties of a single loop of anterior tibialis and posterior tibialis tendon are either better than or similar to those of a DLSTG graft. Consequently, single-loop grafts formed from tibialis tendons should function well as a replacement for a torn anterior cruciate ligament. **Key Words:** Anterior cruciate ligament—Tendon graft—Structural properties—Mechanical properties—Viscoelastic.

Allograft tendons can be indispensable in the reconstruction of knees with failed anterior cruciate ligament (ACL) reconstructions and multiple torn ligaments. Also some surgeons prefer to use an allograft instead of autogenous tissue to reconstruct a torn ACL.[1-4] Because of these multiple uses, the demand for allograft tendons exceeds the supply. Consequently, it is useful to explore potential tendons for use as allografts in reconstructing the ACL.

The issues related to either the success or failure of an allograft transplant include immunogenicity, preservation and secondary sterilization, disease transmission, and remodeling and its effect on mechanical properties. Previous clinical studies on the use of allograft tissue to reconstruct the ACL have reported no evidence of rejection when the tissue has been

either freeze dried or frozen.[1-3,5,6] Furthermore, the risk of transmitting diseases, such as human immunodeficiency virus, is minimal with a secondary gamma irradiation[2] and donor screening.[7] Remodeling studies have shown that although ligamentization of allografts takes longer than autografts, the final structures are very similar.[7-9] Although initial cell viability is somewhat lower in allografts, the entire allograft is populated by cells after 9 months with normal orientation of collagen bundles following.[10] At all time points from 3 months to 2 years, autografts and allografts retained the same amount of their original strength, suggesting that there is no difference in the final ultimate strength between allografts and autografts.[7] Therefore, with the current success in immunologic response, preservation, disease transmission, and remodeling, allografts should be able to function as a replacement if their biomechanical properties are similar to commonly used replacements.

In addition to the stiffness, ultimate strength, and ultimate displacement, which typically have been used to characterize the biomechanical properties of grafts,[11,12] other biomechanical properties of interest are both relaxation and creep because they are important viscoelastic quantities that affect the function of a graft. Graft initial tension has been shown by several investigators to alter the laxity of joints in cadavers.[13-17] Because tendons are known to be viscoelastic and will show a decrease in load over time if held to a constant displacement, the relaxation response of a graft will alter the graft initial tension and most likely will affect the laxity of the joint. In vivo evidence suggests that ligaments may also function to resist repetitive loading[18] and that grafts will continue to elongate for as long as 3 years after implantation.[2] Therefore, it is important to quantify the creep response of an ACL graft because under-repetitive loading a viscoelastic material will elongate and affect the laxity of the joint.

Four additional tendons that can be harvested from a tissue donor are the anterior and posterior tibialis tendons. Although the anterior and posterior tibialis tendons are stout, to our knowledge their structural, material, and viscoelastic properties have not been measured when looped to form a graft. The purpose of this study was to determine if the structural, material, and viscoelastic properties of a graft formed from a loop of either anterior or posterior tibialis tendons are similar to those of the commonly used double-looped semitendinosus and gracilis (DLSTG) graft.

METHODS

Tissue Procurement and Graft Preparation

The tendons for determining the various properties of interest were obtained from a total of 3 sets of donors. The tendons for determining the structural and material properties were obtained from 2 sets of donors. The anterior tibialis tendon and posterior tibialis tendon were harvested from 10 human donors with an average age of 26 years (range, 20-45 years) and cryopreserved at $-80°C$ (Cryolife, Marietta, GA). The semitendinosus and gracilis tendons were harvested from 10 human donors with an average age of 56 years (range, 46-67 years) and frozen at $-20°C$. The tendons for determining viscoelastic properties were obtained from a third set of 10 donors with an average age of 56 years (range, 22-78 years) and frozen at $-20°C$.

The 4 tendons were prepared by removing the muscle and suturing 4 cm of each end with a #1 suture (Ethibond; Ethicon, Somerville, NJ) using a crisscrossing stitch. The anterior and posterior tibialis tendons were formed into a graft by folding them in half (Fig 1). The semitendinosus and gracilis tendons were
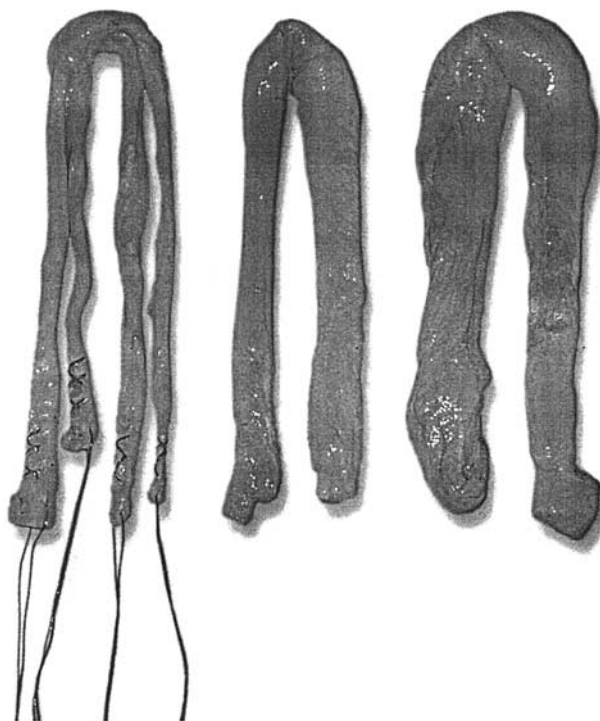

FIGURE 1. The 3 grafts that were tested. DLSTG graft (left), single-loop anterior tibialis tendon graft (middle), and single-loop posterior tibialis tendon graft (right).

formed into a graft by placing them side by side and folding them in half. The cross-sectional area of each graft was calculated by measuring the cross-sectional area at equal increments along the length of the graft by using an area micrometer under a compressive load of 0.12 MPa applied for 2 minutes[2,12] and averaging the results.

Structural and Material Test

Structural and material properties of each graft were determined from a load-to-failure test by using a materials testing machine (Model 858; MTS, Minneapolis, MN) with a 13.3 kN load cell. The graft made from either the anterior tibialis tendon or posterior tibialis tendon was tested by looping the midpoint of the tendon over a 6-mm diameter steel bar bolted to the base of the materials testing machine. The 2 free ends were clamped 75 mm from the steel bar with a liquid nitrogen freeze clamp that was bolted to the crosshead of the materials testing machine. The freeze clamp prevented any slipping of the tendons during the experimental tests. The anterior tibialis and posterior tibialis tendons were able to slide over the 6-mm diameter bar, which allowed equilibration of the tension between the 2 strands. The 4 strands of the DLSTG graft were equally tensioned before clamping by tying the suture attached to each strand to a 5-N weight suspended from a pulley attached to a jig (Fig 2). The 4 free ends of the DLSTG graft were clamped 95 mm from the steel bar with the liquid nitrogen freeze clamp. The graft and steel bar were immersed
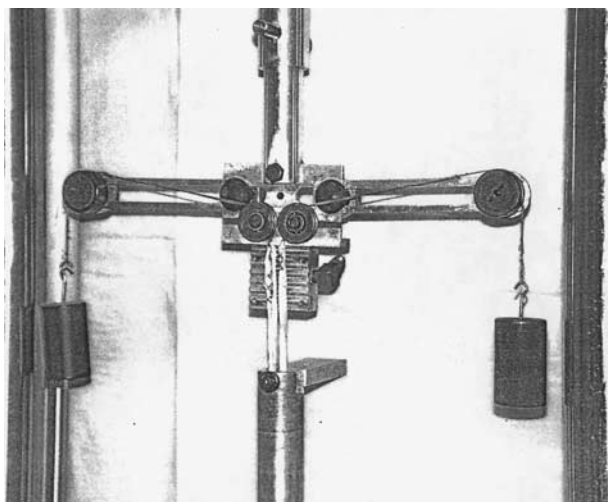

FIGURE 2. The experimental setup showing the method for equally tensioning all limbs of the DLSTG graft. The cap of the freeze clamp and the saline bath have been omitted for clarity.

in a saline bath at room temperature. Each graft was preconditioned between 20 N and 250 N by applying 10 cycles at 0.1 Hz; thereafter, a load of 20 N was maintained to set the initial gauge length until testing. The load-to-failure test was performed 15 minutes after preconditioning by pulling the graft to failure at a strain rate of 2%/s (1.5 mm/s). A computer administered the test and recorded both the load and elongation (Multipurpose Testworks; MTS).

Viscoelastic Tests

Two viscoelastic tests were performed on successive days because a pilot study determined that the grafts recovered their viscoelastic properties after waiting 24 hours.[19] Recovery was determined by the repeatability of the test results from day 1 to day 2 for the pilot study tendons. The free ends of both the single- and double-loop grafts were clamped 75 mm from the steel bar with the liquid nitrogen freeze clamp. Performed 15 minutes after preconditioning, 1 test measured the decrease in load under a constant displacement (i.e., stress relaxation test) and was conducted by elongating the graft to 2.5% strain at a rate of 250 mm/s. The load was recorded at 4 Hz while the displacement was held constant for either 15 minutes or until the load remained unchanged over 1 minute (i.e., less than 0.1% decrease in load). The graft was refrigerated overnight, and 24 hours later it was equilibrated to room temperature and preconditioned. Performed 15 minutes after preconditioning, the second test measured the increase in displacement under a constant load (i.e., creep test) and was conducted by applying a 20 N load and increasing the load to 250 N at a rate of 315 N/s. The displacement was recorded at 1 Hz while the load was held constant at 250 N for either 15 minutes or until the displacement remained unchanged over 1 minute (i.e., less than a 0.1% increase in displacement).

Data Analysis

The structural and material properties of each graft were determined from a plot of load versus elongation (Fig 3), the calculated cross-sectional area, and the gauge length. As an initial step, the elongation of the 75-mm long anterior tibialis and posterior tibialis single-loop grafts was scaled directly with length to produce an equivalent elongation corresponding to the 95-mm length of the DLSTG grafts.[19] By using the equivalent elongation for both tibialis grafts and the actual elongation for the DLSTG grafts, the stiffness was defined as the slope of the linear region between
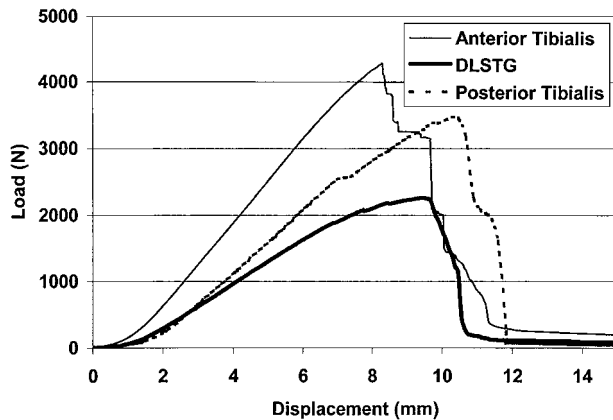
FIGURE 3. Sample load deformation plots for each of the 3 graft types tested to failure. Stiffness and tensile modulus were determined in the linear region from 50% to 75% of the ultimate load. The ultimate load and stiffness of both single-loop tibialis tendon grafts were either similar to or greater than that of the DLSTG graft.

FIGURE 5. Sample creep plot showing the difference in displacement between the initial displacement and the final displacement for each of the 3 graft types tested. Both single-loop tibialis tendon grafts crept more than the DLSTG graft, but the difference is not clinically important.

50% and 75% of the failure load determined by simple regression. The tensile modulus was computed by multiplying the stiffness by the length of the graft and dividing by the cross-sectional area. The ultimate load, stress at ultimate load, displacement at ultimate load, and strain at ultimate load were also determined. The 4 structural and 3 material properties of the anterior tibialis and posterior tibialis grafts were compared with those of the DLSTG graft by using an unpaired t test.

The viscoelastic behavior of each type of graft was determined from the relaxation and creep tests. For the relaxation test (Fig 4), the dependent variable was the difference between the load measured after applying
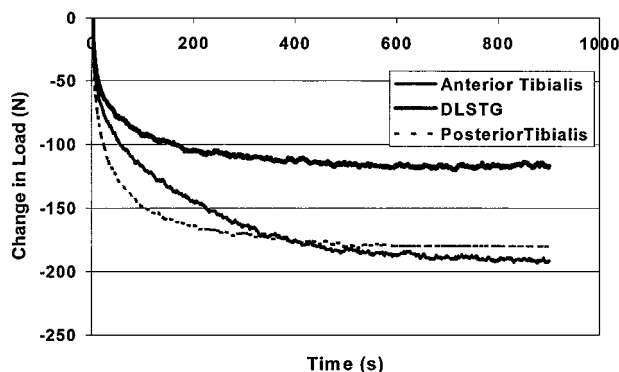

FIGURE 4. Sample load relaxation plot showing the difference in load between the initial load and the final load for each of the three graft types tested. Only the single-loop anterior tibialis tendon graft relaxed more than the DLSTG graft.
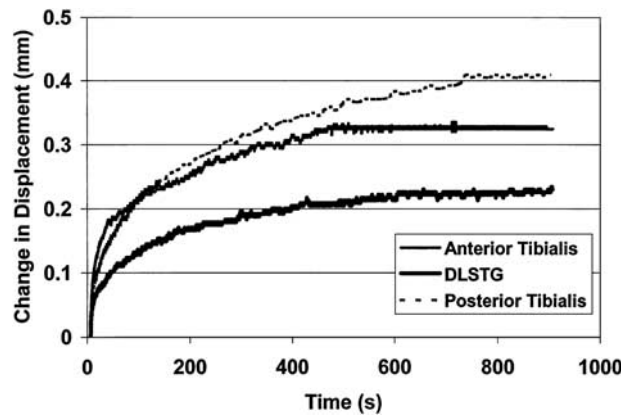
the initial displacement and the load measured at the end of the test. For the creep test (Fig 5), the dependent variable was the difference between the displacement at the end of the test and the displacement after applying the initial load. The decrease in load and increase in displacement of the anterior tibialis and posterior tibialis grafts were compared with those of the DLSTG graft using a paired t test.

RESULTS

Of the 4 structural properties, the average ultimate load, stiffness, displacement at ultimate load, and cross-sectional area of the anterior tibialis and posterior tibialis grafts were either similar to or greater than those of the DLSTG graft (Table 1). The average ultimate load of the anterior tibialis tendon graft (4,122 N) was significantly greater than that of the DLSTG graft (2,913 N) ($P = .005$), whereas the average ultimate load of the posterior tibialis tendon graft (3,594 N) was comparable to that of the DLSTG graft ($P = .204$). The average stiffnesses of the anterior tibialis (460 N/mm) and posterior tibialis (379 N/mm) grafts were similar to that of the DLSTG graft (418 N/mm) ($P \geq .283$). The displacements at ultimate load of the anterior tibialis (12.0 mm) and posterior tibialis (12.5 mm) grafts were both significantly greater than that of the DLSTG graft (8.4 mm) ($P \leq .007$). The average cross-sectional areas of the anterior tibialis (48.2 mm^2) and posterior tibialis (41.9 mm^2) grafts were not significantly different from that of the DLSTG graft (44.4 mm^2) ($P \geq .432$).

TABLE 1. *Comparison of Structural Properties Between the Anterior Tibialis and DLSTG Graft and the Posterior Tibialis and DLSTG Graft for 95-mm Graft Length (mean ± SD)*

Type of Graft	Ultimate Load (N)	Linear Stiffness (N/mm)	Ultimate Displacement (mm)	Area (mm^2)
Anterior Tibialis	4,122 ± 893*	460 ± 101	12.0 ± 3.0*	48.2 ± 11.8
	(*P* = .005)	(NS, *P* = .283)	(*P* = .007)	(NS, *P* = .432)
Posterior Tibialis	3,594 ± 1,330	379 ± 143	12.5 ± 2.3*	41.9 ± 17.3
	(NS, *P* = .204)	(NS, *P* = .467)	(*P* < .001)	(NS, *P* = .695)
DLSTG	2,913 ± 645	418 ± 36	8.4 ± 1.3	44.4 ± 6.7

Abbreviation: NS, not significant.
*Denotes property significantly different from that of DLSTG graft.

Of the 3 material properties, the average tensile modulus, stress at ultimate load, and strain at ultimate load of the anterior tibialis and posterior tibialis grafts were either similar to or greater that those of the DLSTG graft (Table 2). The average tensile moduli of the anterior tibialis (847 MPa) and posterior tibialis (905 MPa) grafts were similar to that of the DLSTG graft (904 MPa) (*P* ≥ .618). The average stresses at ultimate load of the anterior tibialis (89.8 MPa) and posterior tibialis (89.1 MPa) grafts were significantly greater than that of the DLSTG graft (65.6 MPa) (*P* ≤ .007). The average strains at ultimate load of the anterior tibialis (12.7%) and posterior tibialis (13.2%) grafts were significantly greater than that of the DLSTG graft (8.8%) (*P* ≤ .006).

Of the 2 viscoelastic properties, the average decrease in load and the average increase in displacement of the anterior and posterior tibialis grafts were either similar to or greater than those of the DLSTG graft (Table 3). The average decrease in load of the anterior tibialis (215 N) and posterior tibialis (197 N) grafts was either greater than or similar to that of the DLSTG graft (134 N) at the end of the relaxation test (*P* = .027 and .066, respectively). The average in-

crease in displacement of the anterior tibialis (0.3 mm) and posterior tibialis (0.4 mm) grafts was minimally but significantly greater than that of the DLSTG graft (0.2 mm) for the creep test (*P* = .004 and *P* < .001, respectively).

DISCUSSION

The main finding from our study is that the structural, material, and viscoelastic properties of a graft formed by a single loop of anterior tibialis and posterior tibialis tendon are similar to or greater than those of a DLSTG graft at the time of implantation. Before discussing the results from this study, it is necessary to examine whether several procedural aspects of the study will affect the interpretation of the results.

Methodologic Issues

The testing methodology was chosen to standardize the testing procedures to allow comparisons of biomechanical properties both within the present study and to other studies. To determine the biomechanical

TABLE 2. *Comparison of Material Properties Between the Anterior Tibialis and DLSTG Graft and the Posterior Tibialis and DLSTG Graft (mean ± SD)*

Type of Graft	Modulus (MPa)	Ultimate Stress (MPa)	Ultimate Strain (%)
Anterior Tibialis	847 ± 301	89.8 ± 19.4*	12.7 ± 3.2*
	(NS, *P* = .618)	(*P* = .007)	(*P* = .006)
Posterior Tibialis	905 ± 230	89.1 ± 15.4*	13.2 ± 2.4*
	(NS, *P* = .983)	(*P* = .003)	(*P* < .001)
DLSTG	904 ± 99	65.6 ± 12.0	8.8 ± 1.4

Abbreviation: NS, not significant.
*Denotes property significantly different from that of DLSTG graft.

TABLE 3. *Comparison of Viscoelastic Properties Between the Anterior Tibialis and DLSTG Graft and the Posterior Tibialis and DLSTG Graft for 75 mm Graft Length (mean ± SD)*

Type of Graft	Decrease in Load Under a Constant Displacement (N)	Increase in Displacement Under a Constant Load (mm)
Anterior Tibialis	215 ± 92*	0.3 ± 0.1*
	(*P* = .027)	(*P* = .004)
Posterior Tibialis	197 ± 91	0.4 ± 0.1*
	(NS, *P* = .066)	(*P* < .001)
DLSTG	134 ± 38	0.2 ± 0.0

Abbreviation: NS, not significant.
*Denotes property significantly different from that of DLSTG graft.

properties for comparison purposes, the strands of both the tibialis tendon grafts and the DLSTG graft were equally tensioned before freezing and pulled along the length of the tendon (Fig 2). This was important to the measurement of both stiffness and ultimate load because these measurements may be sensitive to the equality of the initial tension.[11] Moreover, clamping the tendon graft and then pulling the graft along its length was similar to the procedure used in other studies,[11,12,20] thus allowing a comparison of properties between studies.

The methods used to grip the specimens and the use of grip-to-grip distance to determine displacements have been discussed in a previous study,[19] and the details will not be repeated here. The key points were that (1) the gripping methods were essentially rigid compared with the graft so that the grips did not contribute any measurable error to the displacements; (2) the gripping methods did not affect the measurements of the ultimate load and ultimate stress because the grafts always failed in the midsubstance and never at the grips; and (3) the use of grip-to-grip distance to determine displacements was more appropriate than measuring the displacement between 2 lines on the tissue because this provided an average displacement rather than a local displacement, thus allowing a more accurate estimate of the overall stiffness of the graft.

One parameter affecting both the stiffness and displacement at ultimate load was the length of the graft. Ideally, the lengths of both the single-loop and double-loop grafts would have been equal to that of a typical soft-tissue ACL graft. For a graft that loops around the beam of a femoral fixation device inserted 20 mm deep in the femoral tunnel, spans the intra-articular space of 30 mm, traverses through a tibial tunnel 40 mm in length, and fixes to the tibia by a cortical fixation device that is 5 mm from the exit of the tunnel to the fixation, the total effective graft length (i.e., length not including that required by the fixation method) would be 95 mm.[21,22] In our study, the single-loop anterior tibialis and posterior tibialis grafts could not be tested at a length of 95 mm because 40 mm of the graft was inside the freeze clamp, leaving a graft 75 mm in length (i.e., gauge length). Also some of the hamstring tendons used in the viscoelastic tests could not be tested at a length of 95 mm so the lengths of all grafts in that group were set to 75 mm as well.

Although the lengths of the single-loop tendon grafts and the DLSTG graft were not equal in the load-to-failure tests, the stiffness and displacement at ultimate load can still be compared confidently. This is because the displacement is proportional to the length of the graft.[19] Accordingly, the equivalent stiffness and displacement at ultimate load for different length grafts can be determined by scaling these properties inversely and directly with length respectively (Table 1).

When comparing DLSTG grafts from older donors (average age, 56 years) to anterior tibialis and posterior tibialis tendon grafts from younger donors (average age, 27 years), it was assumed that the age of the donors tested did not have an important effect on the structural and material properties of a DLSTG graft. This was a reasonable assumption based on the findings from 2 previous studies that evaluated the effect of age on properties of hamstring tendons. One study did not detect any effect of age on the mechanical properties of hamstring tendons.[11] The other study showed that the tensile moduli of the semitendinosus (903 ± 123 MPa) and gracilis (989 ± 164 MPa) tendons obtained from younger donors (average age, 29 years) were comparable to the modulus of a DLSTG graft (875 ± 122 MPa) obtained from older donors (average age, 56 years).[23] Because the comparison from the latter study showed a trend in the modulus from older donors to be about 8% less than that of younger donors, it is possible that some of the structural and material properties of the DLSTG grafts used in this study were underestimated to some, although minor, degree. However, even if the ultimate load and linear stiffness (Table 1) and tensile modulus and ultimate stress (Table 2) were increased by 8% to correct for any age effect, this would still not change the conclusion of this study that the structural and material properties of single-loop tibialis tendon grafts are either similar to or better than those of the DLSTG graft.

Interpretation of Results

Two clinical studies have shown that either the anterior tibialis or posterior tibialis allograft provides long-term stability without rejection when used as a replacement for a torn ACL.[3,4] The determination of the structural, material, and viscoelastic properties of the anterior tibialis and posterior tibialis grafts allows a comparison between other types of grafts to explain the clinical effectiveness of the tibialis grafts.

Our results indicate that both an anterior tibialis and a posterior tibialis allograft should function as well as a DLSTG allograft. The structural and material properties of the anterior tibialis and posterior tibialis grafts were either similar to or greater than the

DLSTG graft, and the viscoelastic properties were nearly equal when compared for clinical importance. Although both the anterior tibialis and posterior tibialis grafts had a greater decrease in load and greater increase in displacement than the DLSTG graft in the 2 viscoelastic tests, the differences were small and should not cause a clinically detectable difference in stability. The higher stiffness of the tibialis grafts compared with the DLSTG graft should compensate for the small decrease in load (81 N) and the small increase in displacement (0.2 mm) when the grafts are loaded in vivo.

The structural properties of the tibialis grafts can also be compared with the ACL and patellar-ligament graft reported in other studies. The anterior tibialis and posterior tibialis grafts have 191% and 166%, respectively, of the strength of the normal ACL[24] (2,160 N) and 138% and 121%, respectively, of the strength of a 10-mm wide patellar-ligament graft[20] (2,977 N). The anterior tibialis (460 N/mm) and posterior tibialis (379 N/mm) grafts at a length of 95 mm have 140% and 124%, respectively, of the stiffness of the normal ACL[25] (305 N/mm), and 103% and 84%, respectively, of the stiffness of a 10-mm wide patellar-ligament graft[20] (455 N/mm). The anterior tibialis and posterior tibialis grafts have 96% and 84%, respectively, of the cross-sectional area of the normal ACL[26] (50 mm^2) and have 151% and 131%, respectively, of the cross-sectional area of a 10-mm wide patellar ligament graft[20] (32 mm^2). Therefore, the strength, stiffness, and cross-sectional area of the anterior tibialis and posterior tibialis graft are similar to or greater than the DLSTG graft, ACL, and patellar-tendon graft. It is not surprising that Shino et al.[3,4] showed that the tibialis tendons can function as a replacement for a torn ACL.

To obtain the structural properties reported herein for a tibialis tendon graft (Table 1), careful consideration should be given to the method used to construct and fix the graft. The graft should be constructed as a single loop to form 2 parallel strands. Looping the tibialis tendon provides a cross-sectional area similar to the ACL, whereas a single-stranded graft has only half the cross-sectional area. Using only a single-stranded graft would severely diminish both the ultimate load and the linear stiffness to only about half of the values reported because the tensile properties are additive with the number of strands.[11] Three or more strands of tibialis tendon should not be used as an ACL graft because the increase in cross-sectional area would exceed the space available in the intercondylar notch.

Also the structural properties of the multistrand tendon graft that we tested may not be the same in vivo unless the method of fixing the graft provides equal tension in each strand. Each strand of a multistrand tendon graft must be equally tensioned for the graft to have optimum biomechanical properties. For example, unequal tension between strands of different tendons in a DLSTG graft must be avoided because it reduces the strength and stiffness of a 4-stranded graft to that of a 2-stranded graft made from a single loop of semitendinosus tendon.[11]

One method for insuring that equal tension is applied to both strands of a single-loop tibialis tendon graft is to use a femoral fixation method that functions like a pulley. In our study, each tendon was looped over a rigid metal post that acted like a pulley, thereby equalizing the tension in each strand. In the operating room, the same effect can be achieved by passing the tendon through the knee around a rigid fixation post in the femoral tunnel because the fixation post functions like a pulley.[27-29] Then, regardless of what fixation method is used to fix the graft to the tibia, the tensions in the 2 strands will be equal.

Equal tensioning of each strand of a 2-strand graft may not be possible with some methods of graft construction and fixation. Constructing the graft by sewing the 2 strands either together or to bone plugs such as has been done for the quadruple hamstring, all-inside technique, and the bone-hamstring-bone construct[30-33] is not likely to produce equal tension between strands. Braiding or weaving of strands is not advisable; braiding decreases the strength and stiffness of a 4-stranded tendon graft by up to 54% and 85%, respectively.[34] Fixation with devices that do not function like a pulley at one of the fixation sites can also lead to unequal tension. For example, the use of interference screws for both tibial and femoral fixations may cause unequal tension because the strands twist during insertion of the screw.[35] Surgeons should understand that the methods chosen to construct and fix a multistrand tendon graft may compromise the strength and stiffness of the graft at implantation.[28,29]

If the tibialis tendon graft is constructed as a single loop and a rigid fixation post is used in the femoral tunnel, then the length of the graft should be sufficient such that it can be fixed on the tibial side with a method that provides superior structural properties. The tibial fixation method must be stiff enough to restore the anterior load-displacement response (i.e., stability), strong enough to avoid failure, and secure enough to resist slippage under cyclic loading during the first 1 to 2 months postoperatively.[36] Inasmuch as cortical fixation methods best satisfy these require-

ments,[36] the length of the graft should be at least 100 mm (total tendon length, 200 mm) to allow the use of these methods.

Although autogenous rather than allograft tissue is still our first choice as a graft,[22,37] some patients have a need for allograft tissue. For a knee with either a failed autogenous graft or multiple ligament injuries, the superior structural properties of an allograft formed from a single loop of either anterior or posterior tibialis tendons justify its use in place of either a DLSTG allograft or a patellar-ligament allograft.

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