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Hamstring graft motion in the femoral bone tunnel when using titanium button/ polyester tape fixation

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Abstract The objective of this study was to determine the relative motion of a quadruple hamstring graft within the femoral bone tunnel (graft-tunnel motion) under tensile loading. Six graft constructs were prepared from the semitendinosus and gracilis tendons of human cadavers and were fixed with a titanium button and polyester tape within a bone tunnel in a cadaveric femur. Three different lengths of polyester tape (15, 25, and 35 mm loops) were evaluated. The femur was held stationary and uniaxial tensile loads were applied to the distal end of the graft using a materials testing machine. Each construct was subjected to loading for ten cycles with upper limits of 50 N, 100 N, 200 N and 300 N. Graft-tunnel motion was then determined using the distances between reflective tape markers placed on the hamstring graft and at the entrance to the femoral bone tunnel, which were tracked with a high-resolution video system. Graft-tunnel motion was found to range from 0.7 ± 0.2 mm to 3.3 ± 0.2 mm, and significant increases in graft-tunnel motion were observed with increasing tensile loads ($P < 0.05$). Shorter tape length (15 mm) resulted in significantly less motion when compared to longer tape length (35 mm) ($P < 0.05$). We conclude that graft-tunnel motion is significant and should be considered when using this fixation technique. Early stress on the graft, as seen in postoperative rehabilitation exercises and athletic activities, may cause large graft-tunnel motion before graft incorporation is complete. A shorter distance between the tendon tissue and the titanium button is recommended to minimize the amount of graft-tunnel motion. Alternative fixation materials to polyester tape, or different fixation techniques, need to be developed such that graft-tunnel motion can be reduced. Further studies are needed to evaluate the effect of graft-tunnel motion on graft incorporation in the bone tunnel.

Key words Knee · Anterior cruciate ligament · ACL reconstruction · Hamstring · Graft fixation

Introduction

Autologous hamstring tendons have become a popular replacement graft for anterior cruciate ligament (ACL) reconstruction [8, 11, 13, 15]. Recently, the semitendinosus tendon has been used in combination with the gracilis tendon as four parallel strands to increase the stiffness and strength of the intra-articular portion of the graft construct [1–3, 6, 9, 12, 17].

One of the main challenges introduced when using hamstring grafts is how to achieve good fixation to bone. Many surgical techniques for graft fixation have been introduced; however, tendon-to-bone healing remains a question for debate. Tensile testing in tendon-bone healing models has revealed that the tendon-bone interface re-

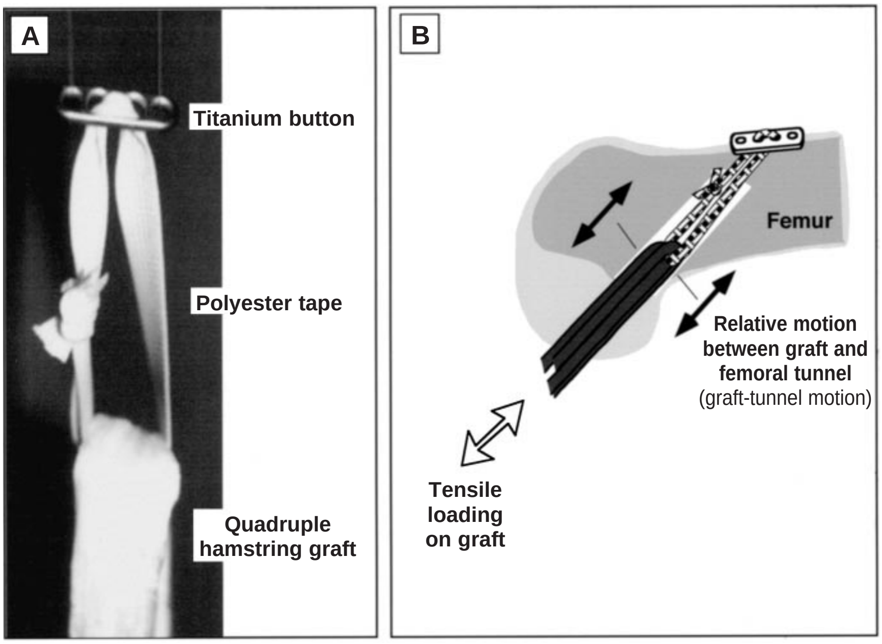

Fig. 1 **A** Femoral fixation construct for a quadruple semitendinosus graft with a polyester tape loop and titanium button. **B** Schematic representation of graft-tunnel motion as it may occur in hamstring grafts with titanium button/tape fixation: cyclic tensile loading of the graft results in motion at the tendon-bone interface within the femoral tunnel

quires 8–12 weeks of healing before sufficient mechanical strength of interface is achieved [5, 16].

A popular method for femoral fixation of a quadruple hamstring graft utilizes a titanium button and a polyester tape loop [3, 12, 17] (Fig. 1 A). The polyester tape loop serves to connect the hamstring graft to the titanium button as well as increase the length of the entire graft construct. While the ultimate tensile load of this type of fixation (approximately 400 N) is considered to be sufficient [7], it has recently been suggested that significant motion of the graft tissue may occur during the early phase of rehabilitation [10, 14]. This motion of the hamstring graft within the femoral tunnel (graft-tunnel motion) may impair graft incorporation and lead to potential bone resorption within the tunnel [4, 10] (Fig. 1 B). However, the amount of graft-tunnel motion associated with this type of fixation has yet to be quantified.

For this reason, the objective of our study was to evaluate the amount of graft-tunnel motion that occurs with a quadruple hamstring graft when a titanium button and polyester tape construct is used. We hypothesized that due to the elastic behavior of the polyester tape loop and the relatively large distance between the titanium button and hamstring tendon, there is significant motion of the graft tissue within the femoral bone tunnel under tensile loading. We further hypothesized that this motion is dependent on the length of the tape loop.

Materials and methods

For the graft construct, six human cadaveric semitendinosus and gracilis tendons were harvested (donor age 51–82 years), and double loops of the semitendinosus and the gracilis tendons (ST-G graft) were prepared. A 5-mm-wide, braided polyester tape (Mersilene) was passed through the axilla of the two tendon loops and connected to a titanium button (Endobutton) (Fig. 1 A). The tape was tied with two square knots with a distance of 15, 25, or 35 mm between the tendon and the button to match various clinical situations. For each of the six ST-G grafts used, six tests were performed. Each of the three desired tape loop lengths (15, 25, and 35 mm) were tested twice, with a new tape loop each time. This was done to reduce variation due to different knot tying and variation in actual tape loop length. After a graft and polyester tape loop was prepared, it was held under tension on the preparation board (Acufex graftmaster). Then, three cycles of tension were applied manually to the construct to pretension the graft. The size of the quadruple hamstring graft was determined using sizing tubes in 1 mm steps. The distal ends of the graft were then aligned, placed under manual tension and attached to a custom-made soft tissue sinusoidal clamp.

A single cadaveric femur was cut approximately 20 cm from the joint line, all soft tissue was removed and the femur was potted in polymethylmethacrylate for rigid fixation. An ACL femoral bone tunnel of 9 mm in diameter was created in the cadaveric femur in routine fashion to a length of 45 mm and extended through the lateral cortex with a 4 mm Endobutton drill bit (overall tunnel length: 58 mm). The graft construct was introduced into the bone tunnel and fixed with the titanium button lying flat against the outer surface of the lateral femoral cortex. The femur and the soft tissue clamp holding the distal end of the graft were mounted in a materials testing machine (Instron, Model 4502, Canton, Mass., USA) as shown in Fig. 2. The graft was angled 30° anterior to the longitudinal axis of the femoral bone tunnel to simulate the in vivo orientation corresponding to a knee flexion angle of 30°. This position was chosen because the graft will experience the highest in situ forces at this flexion angle [18]. Retroreflective tape markers were placed on the femur next to the distal edge of the femoral bone tunnel (marker A), on the graft as it exits the bone tunnel (marker B), and on the tendon approximately 2 cm distally (marker C). All data used to determine graft-tunnel motion were obtained by tracking the position of these markers throughout the test by way of a video analysis system (Motion Analysis, Santa Rosa, Calif., USA). Throughout the test sequence, the tendon was kept moist with saline solution.

Once mounted in the materials testing machine, the graft construct was preconditioned for ten cycles through a range that sim-

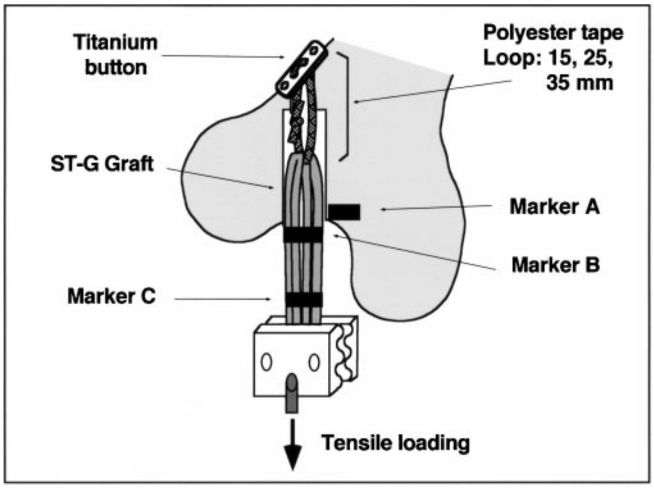

Fig. 2 Schematic drawing of the hamstring graft construct as tested in the materials testing machine. The reflective markers (*A*, *B* and *C*) were used to track the motion of the construct during cyclic loading

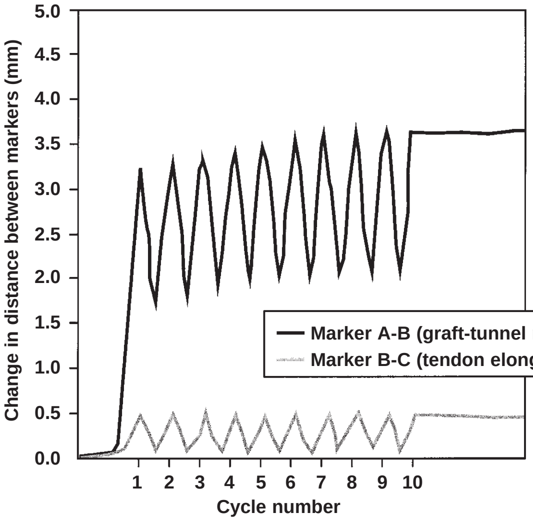

Fig. 3 Representative data obtained for the distance between reflective markers during cyclic tensile loading (loading to 300 N, 10 cycles). The amounts of graft-tunnel motion (marker A–B) and tendon elongation (marker B–C) were calculated as the average from the seventh, eighth and ninth cycles

ulated a surgeon pulling on the graft before fixing the sutures (20–80 N). After this preconditioning, the graft construct was cyclically loaded between 3 N and 50 N at a rate of 100 mm/min for ten cycles. For this and subsequent tests, the first six cycles of each loading condition were used to allow the graft to reach a steady-state condition. A lower limit of 3 N was chosen for experimental considerations to avoid buckling of the graft construct during the loading sequence. The amount of graft-tunnel motion was determined from the change in distance between marker A (bone tunnel marker) and marker B (proximal tendon marker) between the minimum (3 N) and maximum load (50 N), averaged over the seventh, eighth and ninth cycles (Fig. 3). The amount of graft-tunnel motion contributed by the tendon inside the bone tunnel was subsequently estimated from normalized strain measurements (dL/L0) between the two tendon markers (markers B and C). The approximation was performed using the normalized strain of the tendon and the length of tendon material within the 58 mm femoral bone tunnel. In this testing setup, this corresponded to a tendon length of 43, 33 and 23 mm in the femoral bone tunnel for the 15, 25 and 35 mm tape loops, respectively. Three additional cyclic loading tests were performed in the same manner with upper limits of 100 N, 200 N and 300 N. The lower limits were kept constant at 3 N for all tests. Preliminary studies revealed that an upper limit of 400 N would fail the graft construct near the knot in the polyester tape; therefore, these results were not used in this study. The effects of both tensile load and tape length on graft-tunnel motion were analyzed using a repeated measures analysis of variance with multiple contrasts. Significance was set at $P < 0.05$.

Results

The amounts of graft-tunnel motion observed for all cyclic tensile loads and tape lengths are shown in Table 1. Increasing tensile loads produced significantly larger graft-tunnel motion ($P < 0.05$). For example, with a 35-mm tape length, graft-tunnel motion increased from 0.9 ± 0.1 mm (cyclic loading to 50 N) to 3.3 ± 0.2 mm (cyclic loading to 300 N). Doubling the tensile load from 100 N to 200 N resulted in a 56% increase in graft-tunnel motion (Fig. 4).

The length of the polyester tape used in the femoral fixation (15, 25 or 35 mm) also significantly affected the amount of graft-tunnel motion. For each cyclic tensile load tested, the longer tape length resulted in larger graft-tunnel motion ($P < 0.05$; Fig. 4). In response to cyclic loading between 3 and 300 N, graft-tunnel motion varied between 2.5 ± 0.4 for the 15 mm tape length up to 3.3 ± 0.3 mm for the 35 mm tape length – an increase of 33%.

Table 1 Graft-tunnel motion and tendon elongation in relation to tape length and cyclic tensile load range (mean ± SD). Graft-tunnel motion (marker A–B); contribution from tendon tissue

Tape length		Load range			
		3–50 N	3–100 N	3–200 N	3–300 N
15 mm (*n* = 12)	Graft-tunnel motion (mm)	0.7 ± 0.2	1.2 ± 0.3	2.0 ± 0.4	2.5 ± 0.4
	Tendon contribution (mm)	0.4 ± 0.2	0.5 ± 0.2	0.7 ± 0.2	0.8 ± 0.3
25 mm (*n* = 12)	Graft-tunnel motion (mm)	0.9 ± 0.3	1.4 ± 0.3	2.3 ± 0.3	3.0 ± 0.3
	Tendon contribution (mm)	0.2 ± 0.1	0.4 ± 0.1	0.5 ± 0.1	0.6 ± 0.2
35 mm (*n* = 12)	Graft-tunnel motion (mm)	0.9 ± 0.1	1.6 ± 0.2	2.5 ± 0.2	3.3 ± 0.2
	Tendon contribution (mm)	0.2 ± 0.1	0.2 ± 0.1	0.4 ± 0.2	0.4 ± 0.2

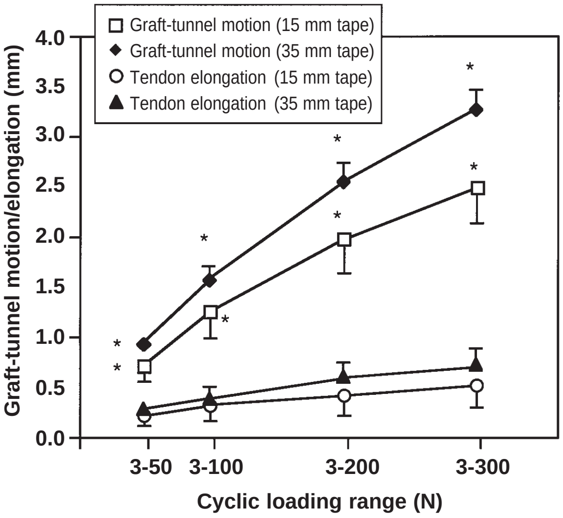

Fig. 4 Graft-tunnel motion and elongation of the tendon tissue as a function of applied cyclic tensile loading (15- and 35-mm tape length, $n = 6$). *Asterisks* denote a significant difference between load ranges and tape length

The amount of tendon elongation in the bone tunnel is also shown in Table 1. Tendon elongation varied between 0.2 ± 0.2 mm and 0.7 ± 0.2 mm and was significantly smaller than graft-tunnel motion for all tape lengths and cyclic tensile loads. The relative amount of elongation as compared to graft-tunnel motion ranged between 14% and 35% in response to a cyclic load up to 300 N. A significant effect of loading on tendon elongation was only demonstrated between 50 N and 300 N.

Discussion

In this study we have quantified the amount of graft-tunnel motion occurring between a quadruple hamstring graft and the femoral bone tunnel when fixation is performed using a titanium button and polyester tape. We confirmed our first hypothesis that with increasing cyclic tensile loads, there are significant increases in the amount of graft-tunnel motion. Graft-tunnel motion ranged from 0.7 to 3.3 mm in response to cyclic tensile loads with upper limits of 50 to 300 N. We also confirmed the hypothesis that a longer tape loop significantly increases the amount of graft-tunnel motion. Specifically, graft-tunnel motion increases 33% between the 15-mm and 35-mm tape lengths in response to a 300 N cyclic tensile load.

Graft-tunnel motion represents the total amount of elongation from the polyester tape, the tendon within the femoral tunnel, the tape-titanium button interface, and the tape-tendon interface. In this study, we have demonstrated that the elongation of the tendon tissue under cyclic loading was small and ranged between 14 to 50% of the graft-tunnel motion (for the 50 N cyclic tensile load), depending on the ratio between tendon and tape length. This percentage is even less for the higher cyclic tensile loads (14%–35% under 300 N). Our data thus suggest that the graft tissue itself contributes only a small amount to the overall graft-tunnel motion. In contrast, the polyester tape material, the tape-titanium button and the tape-tendon interfaces must therefore account for the majority of the observed motion. Doubling the tape length, however, produced only a 10%–33% increase in graft-tunnel motion. This indicates that the tape-titanium button and the tape-tendon interfaces may contribute significantly to the total amount of graft-tunnel motion.

Since our results were obtained from a cadaveric model, they only reflect the time-zero condition. However, it is important to keep in mind that the mechanical strength of the tendon-bone interface remains low until several weeks postoperatively [5, 16]. Therefore, as early postoperative rehabilitation exercises and early return to high-demand activities may lead to graft forces similar to those seen in our study, these activities may produce substantial motion between the hamstring graft and bone tunnel. This graft-tunnel motion may have a detrimental effect on the healing of this interface and could also be a cause of bone tunnel enlargement – which has been clinically observed in a number of patients with this fixation technique [10, 14].

From our study, we can conclude that graft-tunnel motion should be considered when using this fixation method for a hamstring graft. In order to reduce the amount of motion, a shorter tape length is recommended, and high tensile loads on the graft should be avoided prior to graft incorporation. However, further studies are needed to evaluate the effect of graft-tunnel motion on graft incorporation in the bone tunnel. Specifically, it should be determined if aggressive rehabilitation protocols will impair healing when using titanium button and polyester tape fixation for quadruple hamstring grafts.

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