MICROMOTION OF MULTI-STRAND FREE TENDON GRAFTS SECURED WITH INTERFERENCE FIXATION

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INTRODUCTION

Surgical reconstruction of the cruciate ligaments of the knee (ACL and PCL) frequently involves fixing multiple free tendon strands within tunnels drilled at the femoral and tibial insertion sites of the native ligament. One common example of this surgical strategy employs a doubled, or four-strand, semitendinosus and gracilis (hamstring) tendon graft.

Because free tendon grafts do not preserve native insertions to bone, direct fixation of the soft tissue within bone tunnels does not provide initial fixation equal in strength to that achieved for bone-tendon-bone grafts. Free tendon grafts also rely on the integrity of initial fixation for a longer period of time prior to tendon-bone incorporation. Thus, adequate initial fixation of free tendon grafts is critical toward maintaining joint stability post-operatively, particularly since early rehabilitation and loading of the joint is beneficial to clinical outcome.

A primary outcome measure of stability following ACL reconstruction is a side-to-side difference in anterior laxity of less than 3 mm. Knee anatomy dictates that 3 mm anterior displacement of the tibia with respect to the femur is associated with less than 1 mm of lengthening between ACL insertion sites (Hollis et al., 1991). This corresponds to just 0.5 mm of tendon slip within each tunnel, such that cyclic slip on the order of tenths of millimeters (100 µm) should be elucidated at the tendon-tunnel interface when comparing fixation devices.

METHODS

This study compared the cyclic and static strength of three hamstring tendon graft fixation techniques (n = 9/group) commonly used in the United States (Figure 1): a single 35 mm long bioresorbable PLLA delta-shaped interference screw, a single 28 mm long PLLA bioresorbable screw augmented with a peripheral button anchor, and a central expansion sheath/screw device that separates the four individual strands within the tunnel (Mitek Intra-fix™).

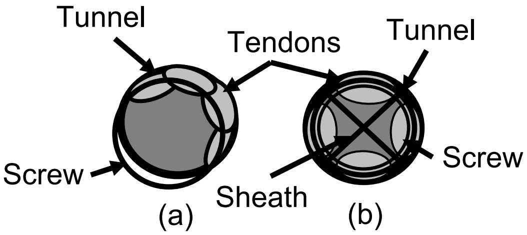

Figure 1: Interference fixation of free tendon strands typically employs (a) screws or (b) sheath and screw devices.

Bovine digital extensor tendons demonstrate static and dynamic mechanical properties similar to human semitendinosus and gracilis tendons (Haut-Donahue et al., 2001), and were configured as doubled four-strand grafts in identical fashion to human hamstring tendon grafts. Bone-analog polyurethane foam (ASTM F1839-97) was used to ensure a uniform testbed for comparing fixation strategies, without the complication of differences in donor bone density and quality. Tibial cancellous bone was modeled at a density of 0.24 g/cm^3 (Last-A-Foam FR-6715).

A custom apparatus was constructed to allow independent control of load applied cyclically to each of four tendon strands, ensuring equal distribution of force at the fixation site. The dynamic compliances of all fixturing, bone, and tendon tissue were measured and subtracted from combined creep-slip data collected for each construct to isolate progressive cyclic slip of fixation.

Tendon grafts were fixed within tunnels drilled in blocks of bone-analog polymer according to clinical guidelines for each technique. Importantly, maximal oversizing of screw versus tunnel diameter was exploited. The four tendon ends were held individually with serpentine clamps connected via ball joints, low-stretch cables, and 250 N load cells to four electromagnetic actuators (EnduraTec 3230).

Each strand was preloaded to 10 N and cycled 2000 times at 1 Hz between 10-50 N (40-200 N entire construct). Peak and valley displacement data were recorded at a resolution of 10 μm. The constructs then were pulled in tension to failure at a rate of 1 mm/sec using a servohydraulic actuator (MTS 858). ANOVA and unpaired t-tests were performed to compare cyclic and static fixation strengths, with statistical significance set at a level of $p = 0.05$.

RESULTS AND DISCUSSION

After subtracting average cyclic elongation associated with fixture compliance and tendon creep after 2000 cycles (0.3 mm and 1.1 mm, respectively), total fixation slip was 0.3 ± 0.4 mm, 0.5 ± 0.3 mm, and 0.3 ± 0.2 mm for the screw, screw + button, and sheath/screw, respectively (Figure 2). These are clinically acceptable magnitudes of slip using the aforementioned strict criteria. No construct failures occurred during cyclic loading tests to 200 N.

Post-cycling static failure loads were 997 ± 230 N, 1020 ± 200 N, and 1223 ± 131 N for the screw, screw + button, and sheath/screw, respectively. Interference screw constructs failed by pulling all four tendon strands past the screw, whereas the sheath/screw constructs failed by pulling the entire device from bone without tendon slip. Given the differences in maintaining tunnel aperture (Figure 1), bone compliance and strength may differentially affect fixation strength afforded by screws versus sheath/screw.

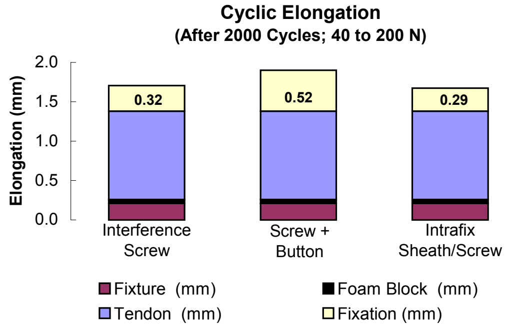

Figure 2: Fixation slip throughout 2000 cycles totaled 300 to 500 micrometers.

SUMMARY

Sub-millimeter slip of four-strand hamstring tendon grafts is clinically relevant and measurable. When maximally (over)sized to bone tunnel diameter, interference fixation can satisfactorily secure free tendons.

REFERENCES

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