IN VIVO EVALUATION OF THE STIFFNESS OF THE HEALING HUMAN PATELLAR TENDON

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INTRODUCTION

Tendon injuries are common among athletes as well as the general population. However, the success of current tendon repair and rehabilitation protocols remains controversial due to the subjective content of clinical assessments of recovery. Tendon mechanical properties have been considered the "gold standard" in evaluating the healing of tendon, but these measures have not been convenient to record *in vivo* due to the invasive nature of conventional mechanical testing. Recently, an *in vivo* ultrasonography technique has been applied in human subjects to detect the change in mechanical properties of healthy tendon with altered loading (Reeves et al., 2003). The objective of this study was to assess the capability of this technique to track the change in stiffness in the healing human patellar tendon.

METHODS AND PROCEDURES

Eight subjects undergoing anterior cruciate ligament reconstruction with a patellar tendon autograft were enrolled in the study as well as 8 healthy matched-control subjects. Surgical subjects had their patellar tendon stiffness evaluated at 2, and 6 months after surgery while control subjects were evaluated at 0 and 4 months after enrollment. Surgical subjects were evaluated for both knees (surgical and contralateral) while the control subjects were evaluated for only the knee that matched to the same side of the matched surgical knee. Each subject performed 6 trials of an isometric maximal contraction of knee extensors at 90° of knee flexion while knee torque was measured on a muscle strength system. During the task, an ultrasonic transducer was alternately used to track the displacement of the inferior border of the patella or distal insertion of the patellar tendon. Hamstrings EMG was monitored during the extension task and was used to account for the counter torque provided by this muscle group. The knee torque, EMG, and ultrasonic video data were initiated and sampled simultaneously. The cross-sectional area and the original length of the patellar tendon were measured from ultrasonic images. The displacements at the tendon insertions were computed using a pattern matching algorithm based on the normalized cross-correlation function and used to estimate the tendon deformation. The deformation at the tibial insertion at the same loading level was adjusted to the deformation at the patellar insertion. Tendon force was computed from the knee torque data and estimates of the patellar tendon moment arm. The force-deformation curve of the tendon was fitted with a nonlinear function and the tangential stiffness was evaluated at an equivalent load across paired subjects and time points. A normalized stiffness was computed as the stiffness multiplied by the ratio of tendon length to area. Subjects filled out a Visual Analog Scale (VAS), Activity Rating Scale (ARS), and International Knee Documentation Subjective Knee Form (IKDC) at each time point. A paired sign-rank test was performed to examine if the outcome measures changed with healing time.

RESULTS

The average time from injury to surgery for the surgical subjects was 49.5 days (range: 20~99). During the second testing session, the tangent stiffness of the surgical tendons relative to the contralateral tendons at the first visit increased from ~63% to ~74%; however, the difference was not significant (P=0.74) (Figure 1). The normalized tendon stiffness of the surgical tendons relative to the contralateral tendons at the first visit increased from ~58% to ~88% (P=0.25) (Table1). For the surgical knee, the max knee torque, IKDC, and ARS scores significantly improved with time and tendon area and VAS decreased with time (Table 1). No difference with time was found in any of outcome measures for the control subjects.

	Surgical		
Parameter	2 month	6 month	Pvalue
Knee torque	547 ± 228	1088 ± 403 *	0.008
Tendon area	119 ± 15	100 ± 26 *	0.039
IKDC	26.7 ± 22.5	47.3 ± 28.4 *	0.008
VAS	3.93 ± 2.40	2.26 ± 1.42 *	0.016
ARS	0.13 ± 0.35	8.38 ± 5.42 *	0.016
Normalized Stiffness	0.57 ± 0.25	0.86 ± 0.68	0.250

Table 1. Outcome measures for surgical knee at the two visits (Mean ± SD)

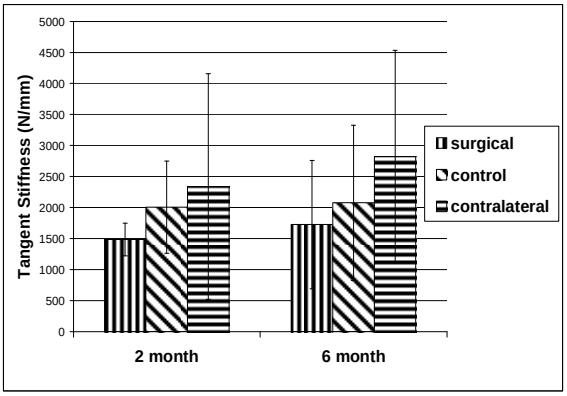

Figure 1. Tangent stiffness of the three groups during the two visits. (Mean ± SD)

DISCUSSION

A priori power analysis was performed to determine the required sample size based on the data of previous animal studies (Ng et al., 1995; Atkinson et al., 1998) and our pilot studies. However, because of the smaller increase and larger variation in stiffness properties of the healing tendons, we were unable to detect a significant change in tendon stiffness during the 4 month time frame. This was despite significant improvements in max knee torque, VAS, ARS, and IKDC scores for the surgical subjects. These contrasting results suggest functional activity level and symptoms should not be used as the only indication for tendon healing as they may allow for the healing tendon to be put at risk of re-injury. Our results suggest a larger time frame or sample size may be needed to observe the healing effects on human tendon stiffness properties. It is possible that subjects who maintained a relative sedentary life style after the surgery may have prevented increases in the tendon stiffness.

Limitations of the study include: 1. The more lateral placement of the US transducer in the surgical knees may increase the probability of misalignment of the ultrasound scan with the line of action of the tendon and thus cause an increase in variation of the data. 2. In order to normalize to the weakest subject and time point, we did not include the data from the higher force region, which may have decreased the chance for us to see a difference in the tangential stiffness across time and between groups. Future studies may have to evaluate stiffness properties using a relative force level approach and use a larger sample size and/or time frame to confirm the healing effects on the stiffness properties of human tendon.

REFERENCES

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