Proximal Tendon-Prosthesis Junction for Active Tendon Implants of the Hand: A Biomechanical Comparison of Two Techniques

Matthew J. Thompson, MD, John R. Owen, MS, Jennifer S. Wayne, PhD, Charles M. McDowell, MD. Virginia Commonwealth University, Orthopaedic Research Laboratory, Departments of Orthopaedic Surgery and Biomedical Engineering, Richmond, VA, USA.

Disclosures: M.J. Thompson: None. J.R. Owen: None. J.S. Wayne: 5; Medarva Healthcare, Richmond, VA. 6; Wright Medical Technology, Inc, Arlington, TN. C.M. McDowell: 5; Medarva Healthcare, Richmond, VA. 6; Wright Medical Technology, Inc, Arlington, TN.

Introduction: Staged flexor tendon reconstruction utilizing a passive silicone implant is an established method for addressing devastating flexor tendon injuries. [1-3] Active tendon prostheses have also been used to perform staged tendon reconstructions with good clinical results and potential benefits over passive implants - better function between stages, better quality of motion prior to grafting, and avoidance of the complications of disuse of the musculotendinous unit. [4,5] We seek to study the biomechanical characteristics (percent stretch, stiffness, and ultimate load) of two techniques for creating proximal tendon-prosthesis junctions. Our null hypothesis was that no differences between techniques would be observed.

Methods: Flexor digitorum profundus tendons were harvested from frozen cadaveric canine forelimb specimens (n = 16) and cross-sectional dimensions measured with digital calipers. Proximal tendon-prosthesis junctions were created according to published methods [6] for the “tendon loop” and “polyester weave” junction types. Small black glass bead markers were glued onto each specimen to allow digital measurements of stretch. (Figure 1) Utilizing the Instron 1321 biaxial servohydraulic testing machine, specimens were cycled between 2 and 50N at 0.2 Hz for 500 cycles to match the equivalent cyclic frequency of Latendresse [7] but with the peak cyclic load increased to represent maximal reported values of active tendon flexion during rehabilitation plus a safety margin of 10N. Specimens were then loaded to failure at a rate of 20mm/min with mode of failure recorded by gross observation, and later verified by review of the digital recording. Cyclic and load to failure video images were analyzed using NIH Image J Freeware (NIH, Bethesda, MD) to assess bead separation distances. Bead separations were then synchronized with corresponding Instron load data. The “overall” interval was the primary interval for comparison between groups as it represents a composite of the individual intervals and best reflects the clinical characteristics of each style of junction. Overall percent stretch following cyclic loading, overall percent stretch at failure, overall stiffness during load to failure, and ultimate load were then analyzed. Normalizing elongation and stiffness by construct length compensated for a difference in overall length of repairs between specimens. A mixed model analysis of variance followed by Tukey-Kramer post-hoc pairwise comparison was conducted with statistical significance set at p ≤ 0.05 to assess for differences between construct types. Specimens were excluded for inconsistent bead placement or for failures occurring outside of tested segment.

Results: No difference in tendon cross sectional areas between groups was observed (p > 0.22). Overall percent stretch after cyclic loading and at peak load was significantly greater for tendon loop compared
to polyester weave (p < 0.004). (Figure 2) No failures were observed during cyclic testing. Overall stiffness was greater for the polyester weave compared to the tendon loop (n = 16, p < 0.0001). No statistically significant difference was detected in peak load (n = 11, p = 0.20) between the two junction techniques. (Figure 3) Constructs failed catastrophically at peak load. For the polyester weave, the cords remained knotted proximally and shredded through the tendon with failure of sutures at weave sites. For the tendon loop weave, sutures at the weave sites and at the distal tail of the tendon failed in a variable pattern before the distal limb pulled through the proximal limb weave points and through the silicone loop.

Discussion: Flexor tendon constructs able to withstand 15-40N should be able to withstand passive motion and un-resisted active flexion respectively during rehabilitation. [8] As high as 120-200N may be experienced during pinch or power grip.[9] Active tendon implants may not experience the same forces as an anatomic two-tendon, three joint system[10], however they may be able to withstand EAM protocols with active flexion immediately post-op, with a significant safety margin. Proximal tendon-prosthesis junction is at least comparable to tendon-tendon repair constructs currently exposed to EAM in flexor tendon repair.[11]

The observed elongation after cycling is unlikely to have a significant compromising effect on function in the sub-maximal load range. Absolute values for the tested parameters may not be precisely applicable to human tendons however canine models are a prevalent means by which meaningful conclusions have been drawn [12] and biomechanical comparison of two constructs may be less affected by the use of a representative model.

Conclusions regarding rehabilitation protocols may only be applied to the durability of the proximal junction. More may be learned with a more extensive fatigue protocol, however it would be limited ex-vivo due to the absence of biological factors important to biomechanical properties of tendons and tendon healing. Further work investigating the biomechanical characteristics of the distal interface is needed.

Significance: The described proximal junction techniques for active tendon implants are strong enough to resist early active motion in the immediate post-operative period without experiencing significant elongation. The polyester weave construct displayed greater stiffness and ultimate load compared to the tendon loop. Ultimately, development of a durable permanent prosthesis with reliable junctional strength may be realized.
Figure 1: Schematic representation of the Polyester Weave and Tendon Loop junction types.
Figure 2: Overall percent stretch after cycling (at 2N of load) and at peak load during load to failure testing for the Polyester Weave (PW) and Tendon Loop (TL) tendon-prosthesis junction techniques (mean, standard deviation).

Figure 3: Overall stiffness (N/% stretch) and peak load (N) during load to failure testing for the Polyester Weave (PW) and Tendon Loop (TL) tendon-prosthesis junction techniques (mean, standard deviation).