EFFECT OF INCREASED TENDON EXCURSION IN VIVO ON THE BIOMECHANICAL PROPERTIES OF HEALING FLEXOR TENDONS

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Introduction: Rehabilitation protocols that prescribe early passive mobilization following flexor tendon repair improve both digital range of motion and tissue strength compared to immobilization protocols [1-2]. Despite the success of early motion rehabilitation, neither the optimal rehabilitation protocol nor the mechanisms by which functional improvement are achieved have been determined. Digital motion can increase both tendon excursion and force *in vivo*, but it has not been proven that these mechanical factors are important to successful rehabilitation. We investigated the effects of increased *in vivo* tendon excursion on the biomechanical properties of healing flexor tendons in a canine model. We hypothesized that increased excursion would lead to improved digital range of motion and tendon strength.

Methods: Tendon repair surgery was performed on the right forelimb of 33 adult mongrel dogs. The digital sheaths of the second and fifth toes in the region between the annular pulleys proximal and distal to the proximal interphalangeal joints were exposed and the flexor digitorum profundus tendons transversely incised (n=66 tendons). Four-strand repairs were performed using double-stranded 4-0 suture (Supramid, S. Jackson, Inc., Alexandria, VA) supplemented with a 6-0 nylon epitendinous suture [3]. After surgery, the forelimb was cast with the elbow at 90° and the wrist at 45° of flexion. The wrist and digits were immobilized at all times except for 10 minutes of daily controlled passive motion rehabilitation. One group of dogs underwent four digit flexion-extension with the wrist flexed (4F), while the second group underwent the same manipulation with the addition of synergistic wrist extension during digital flexion (SYN) (Fig. 1). The SYN manipulation produces an average tendon excursion that is more than 200% of the excursion produced by the 4F manipulation (3.5 vs. 1.5 mm), with no significant increase in tendon force [4]. Dogs were sacrificed at 10, 21 or 42 days and the 2nd and 5th digits were disarticulated. The range of motion of control (left) and operated (right) digits was assessed using a motion analysis system (PC Reflex, Qualisys, Glastonbury, CT). The change in angle of the distal (DIP) and proximal (PIP) interphalangeal joints and the linear displacement of the flexor tendon was measured as the tendon force was increased from 0.15 to 1.5 N. The ultimate tensile force of the operated tendons were then determined using a materials testing machine (8500R, Instron Corp., Canton, MA). The proximal tendon stump was held in a freeze-clamp and the distal phalanx displaced axially at 0.5 %/sec until failure. Analysis of variance was performed to determine the effect of rehabilitation (4F, SYN) and time (10, 21, 42 days) on range of motion and ultimate force .

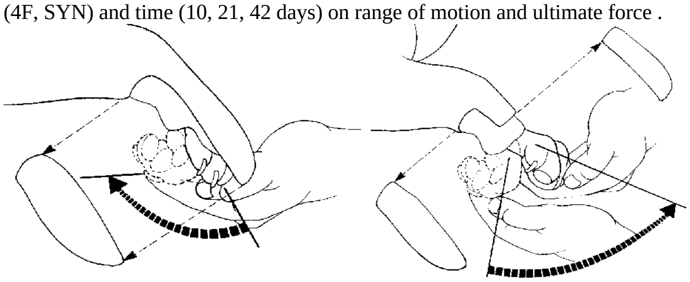

Figure 1. Two rehabilitation methods. (L) Four digit flexion-extension with wrist flexed (4F). (R) Synergistic wrist extension with digits flexed (SYN)

Results: Range of motion parameters and ultimate force were not significantly affected by rehabilitation method ($p > 0.05$). Range of motion parameters were also not significantly affected by time ($p > 0.05$). PIP flexion and tendon displacement for operated tendons were not different from controls ($p > 0.05$), while DIP flexion for operated tendons was only 10% less than controls ($p = 0.01$; Fig. 2). Ultimate force was significantly affected by time ($p < 0.001$). Ultimate force was significantly greater at 42 days than at 10 or 21 days ($p < 0.001$); values at 10 and 21 days were not significantly different ($p = 0.17$; Fig. 3). In all groups, we observed minimal adhesion formation.

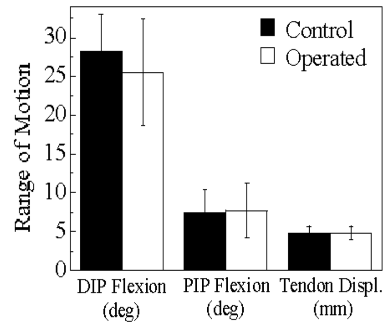

Figure. 2. Digital flexion angles and tendon displacement (rehabilitation and time groups pooled). The only significant difference between control and operated tendons was that DIP flexion was 2.5° less in operated tendons.

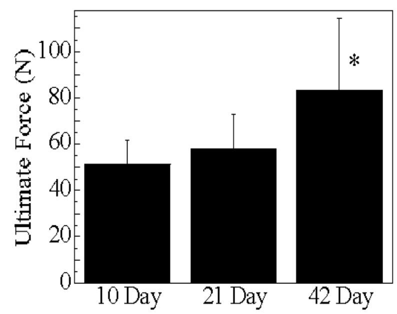

Figure 3. Ultimate force for repaired flexor tendons (4F and SYN specimens pooled). *Significantly different from 10 and 21 days ($p < 0.05$).

Discussion: Immobilization following flexor tendon repair is associated with prolific adhesion formation [5] and leads to a significant reduction in range of motion compared to control [2]. We observed that early motion rehabilitation protocols were successful in preventing adhesion formation and in allowing nearly full recovery of motion, while maintaining high values of tendon ultimate load from 10-42 days. These combined findings indicate that: 1)1.5 mm of tendon excursion exceeds the threshold necessary to prevent adhesions in a sharp tendon transection model in dogs. 2) An increase in excursion of more than two-fold (1.5 to 3.5 mm) does not provide added benefit to either range of motion or ultimate force. 3) For clinical situations that approximate the conditions of our model (a clean laceration), less aggressive early motion rehabilitation may be sufficient to prevent adhesion formation and achieve satisfactory outcomes. 4) The tendon softening behavior reported by others in the early post-operative period [6] may be obviated by early passive motion.

Acknowledgements: N.I.H. AR33097

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