Reinforcing The Strength of the Tendon-suture Interface Using 1-ethyl-3-(3-dimethylaminopropyl) Carbodiimide Hydrochloride: A Biomechanical Study And Assessment Of Cell Viability

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Introduction: Postoperative early mobilization is important to improve finger function after tendon injury and repair. Mobilization, on the other hand, can also cause gap formation or even tendon rupture. To eliminate this complication, many tendon repair techniques have been developed to increase repair strength. However, the tendon suture holding strength is difficult to reinforce due to the parallel collagen fiber alignment in tendons, especially when combined with the inevitable postoperative tendon softening in vivo. Many suture loop configurations have been studied to increase the suture/tendon anchoring power, but strangulation of the tendon from locking loops can impair tendon healing. To enhance tendon suture retention, in 2007 Zhao et al presented an “eyelet” concept using a chemical reagent (EDC: 1-ethyl-3-(3-dimethylaminopropyl) carbodiimide hydrochloride) to cross-link collagen around suture materials, thus increasing the tendon holding strength at the tendon/suture interface.1 In that study, the EDC was delivered by injection, which is not clinically applicable. Furthermore, the suture repair strength was tested with a single loop technique, which is also not clinically relevant. Therefore, in this study, we investigated a method that could be clinically applicable using the same concept reported by Zhao et al. We hypothesized that using an EDC soaked suture to repair a flexor tendon could reinforce the repair strength. In addition, the cytotoxicity of EDC was studied in a cell culture model.

Methods: Mechanical Testing: Thirty-six canine flexor digitorum profundus (FDP) tendons obtained from animals used in other IACUC approved studies were used to test EDC reinforcement methods. We studied changes in retention strength resulting from treating sutures with EDC concentrations of 1%, 10% and 50%, with 12 tendons in each group. 4-0 FiberWire suture was soaked in these EDC solutions for 10 minutes. A laceration was created in the center of each tendon creating two parts for testing. One free tendon end was sutured with the experimentally treated material while the other end was sutured with untreated 4-0 Fiberwire to serve as a control, eliminating the effect of nonuniformity in tendon size. In each case a modified Kessler suture technique was used to test the tendon-suture interface. Tensile strength of the repair was evaluated with a servohydraulic test system (858 Mini Bionix II, MTS System, Eden Prairie, MN). Unsutured tendon ends were clamped securely to the machine while sutures on the other end were looped around a rod connected to the actuator which was advanced under displacement control at 20 mm/min until failure. Failure mode and failure strength were noted. Mechanical results were compared between control and EDC treated sutures using a paired t-test, with significance set at P>0.05.

Assessment of cell viability: Two FDP tendons were harvested from the dogs under sterile conditions after euthanasia. Specimens were minced and enzymatically digested at 37°C with 0.1% collagenase (10ml/g tissue) for 24 hours. After digestion, cultured tenocytes were maintained in high-glucose Dulbecco’s Modified Eagle Media, 10% fetal bovine serum and 1% antibiotic (Antibiotic-Antimycotic, Gibco, Grand Island, NY), and incubated at 37°C with 5% CO2 in a 35-mm dish until confluent growth. Sutures treated in EDC solution were placed into a dish of cultured tenocytes to assess EDC cytotoxicity. After incubating the tenocytes for 24 hours with a suture treated in EDC solution, viability was assessed using a LIVE/DEAD cell viability kit (Molecular Probes, Eugene, Oregon). With light microscopy at 100X magnification, we took photographs to create a grid in rows parallel to the suture line, 920 μm in depth. Dead cells were counted in the first five rows, starting at the suture line. Mann-Whitney’s U test was used to analyze the number of dead cells, with significance set at P>0.05.

Results: All specimens failed by the suture cutting through the tendon. In the 1% EDC-reinforced tendon pairs, the mean (range) ultimate strengths of the EDC-reinforced group and the control group were 22 N (15-30 N) and 20 N (14-27 N), respectively; in the 10% EDC-reinforced tendon pairs, 27 N (20-31 N) and 19 N (13-27 N), respectively; and in the 50% EDC-reinforced tendon pairs, 26 N (21-35 N) and 21 N (15-28 N), respectively. In the 10% and 50% EDC-reinforced tendon pairs, the EDC reinforcement was significantly stronger than their respective control group (p < .05) (Figure 1).

Cell viability was assessed for each EDC concentration based on the distance from the suture. The number of dead cells was significantly higher with the 50% EDC solution than with other concentrations (p< .05) (Figure 2).

Discussion: The results suggest that 4-0 Fiberwire suture treated with a 10 minute soak in 10% EDC solution can improve the pull out failure strength of a tendon suture, without any significant cytotoxic effects.

Significance: Flexor tendon repairs are susceptible to failure by suture pull-out. The results of this study demonstrate a simple technique that can be used to significantly improve suture retention strength.
Figure Legends:
Figure 1. Failure strength of EDC reinforced sutures. Treatments with 10% EDC and 50% EDC showed significant improvement over controls.
Figure 2. Assessment of cell viability. The number of dead cells in the 50% EDC solution was significantly higher than in the other concentrations (p< 0.05) except for the 4th row in 1% EDC solution.

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