REDUCING THE GLIDING RESISTANCE BY CROSS-LINKING TISSUES ON THE SURFACE OF EXTRASYNOVIAL TENDON GRAFTS

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INTRODUCTION
Restoration of digital function following flexor tendon injury continues to challenge hand surgeons and therapists. Tendon grafts play an important role, either to replace a damaged tendon or to lengthen a healthy tendon for transfer. Clinically, most tendon grafts are obtained from extrasynovial tendon sources and go into a synovial environment, i.e., a tendon system including a synovially lined sheath. Extrasynovial tendons have a rougher surface and higher friction than intrasynovial tendons [1]. When such tendons are used as grafts, adhesion formation often interferes with tendon gliding, and limits finger motion and function. Animal models have also shown that extrasynovial tendon grafts are associated with more adhesions to the surrounding tissue than intrasynovial tendon grafts[2]. We hypothesize that adhesion formation could be reduced by lowering friction and smoothing the surface of extrasynovial tendon grafts. The present in vitro study explores a method for reducing the gliding resistance of extrasynovial tendons used as tendon grafts by chemically cross-linking to tissues on the extrasynovial tendon surface, as a prelude to in vivo research to test our hypothesis.

EXPERIMENT
Thirty peroneus longus (PL) tendons from thirty canine hind paws were used. The patatenon was carefully removed, so as not to injure the tendon surface. The second digit was dissected from each hind paw. The proximal phalanx and its pulley (analogous to the human A2 pulley) were preserved. The PL tendons were randomly divided into five groups, and immersed for 30 seconds in one of five solutions: a) saline: 0.9% NaCl, 0.1M Mes (Sigma) pH 6.0; b) gelatin: 10% gelatin (Sigma), 0.9% NaCl, 0.1 M Mes pH 6.0; c) cd-gelatin: 10% gelatin, 0.25% EDC, 0.25% NHS, 0.9% NaCl, 0.1 M Mes pH 6.0; d) cd-gelatin-HA: 1% hyaluronic acid (HA) (Acros), 0.25% 1-ethyl-3-(3-dimethylaminopropyl) carbodiimide hydrochloride (EDC) (Sigma), 0.25% N-hydroxysuccinimide (NHS) (Pierce), 0.9% NaCl, 0.1 M Mes pH 6.0; e) cd-gelatin-HA: 1% HA, 10% gelatin, 0.25% EDC, 0.25% NHS, 0.9% NaCl, 0.1 M Mes pH 6.0. Tendons were placed in an incubator at 100% humidity, and a towel was also used to wrap wet towels and kept at 37°C for 1 hour. The gliding resistance test was performed between the PL tendon and the ipsilateral proximal pulley of the 2nd digit, in a saline bath at 37°C as described previously [3]. The tendons were tested for 500 cycles of simulated flexion/extension. Gliding resistance between the tendon and proximal pulley was recorded at selected cycles. Tendon samples, obtained before or after gliding resistance testing, were fixed in Trump's EM fixative and dehydrated. The specimens were mounted on a specimen stub and coated with gold/palladium. The tendon surface was then evaluated with a Hitachi S-4700 Field Emission Scanning Electron Microscope.

RESULTS
Gliding resistance of the treated tendons with saline, gelatin or cd-HA showed similar trends (Fig. 1). Over the first 200 cycles the gliding resistance increased linearly and then reached a plateau. After 500 cycles of simulated flexion/extension, there was no significant difference in gliding resistance between the saline control tendons, tendons treated with gelatin, and tendons treated with cd-HA. For the tendon treated with cd-gelatin and cd-gelatin-HA, the gliding resistance increased at a much more gradual rate over the 500 cycles. Beginning at 100 cycles of simulated flexion/extension, the gliding resistance of tendons treated with cd-gelatin-HA was significantly lower than that of the control tendons. Starting at 200 cycles, the gliding resistance of tendons treated with cd-gelatin was also significantly lower than that of the control, gelatin and cd-HA tendons. Starting at 300 cycles, there was also a significant difference in gliding resistances between tendons treated with cd-gelatin and tendons treated with cd-gelatin-HA (p<0.05), with the latter group having a lower gliding resistance at comparable cycles of simulated flexion/extension.

Collagen fibers on the surface of PL tendon were arrayed randomly, but were distributed uniformly along the tendon (Fig 2T). For tendons treated with saline, gelatin or cd-HA, the tendon surface had a rough appearance after 500 cycles of testing (Fig. 2C, G, HE). The surface after 500 cycles appeared less rough for the tendons treated with cd-gelatin (Fig. 2GE). PL tendons treated with cd-gelatin-HA had the smoothest surface after 500 cycles (Fig. 2GHE).

DISCUSSION
In canine and human studies, extrasynovial tendon has a rougher surface and a higher gliding resistance than intrasynovial tendon, and generates more adhesions to the surrounding tissue than intrasynovial tendon grafts do in vivo. We believe that it is reasonable to assume that a smooth tendon surface could be important in reducing adhesion formation clinically.

In the present study, we found there are irregularly arranged fiber bundles on the PL tendon surface. This surface became much more irregular after multiple cycles of simulated motion. We have developed a method to make the loose surface fibers more resistant to abrasion, by chemically cross-linking fibers to each other and to a potential lubricating agent.

In conclusion, in this study we have shown that it is possible to chemically modify a tendon surface and alter its tribologic properties. The strengths of this study lie in its ability to look at surface modifications both physically and kinematically, in a relevant in vitro animal model. If this approach is supported in vivo, it may provide surgeons with a new and useful method to improve the quality of tendon graft surgery.

REFERENCES:

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Fig. 1. Friction force of PL tendons with the different modification. C: control, G: 10% gelatin alone, HE: 1% HA + 0.25% EDC, GE: 10% gelatin + 0.25% EDC, HGE: 1% HA + 10% gelatin + 0.25% EDC.

Fig. 2. Surface features of PL tendon after 500 cycles of simulated flexion/extension. Untreated, untested PL tendon has a smooth surface (T). Other symbols are same as those in Figure 1.