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Effect of hyaluronic acid on the excursion resistance of tendon graft: A biomechanical in vitro study in a modified human model

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Abstract

Background. Adhesion between the tendon and tendon sheath after flexor tendon graft inhibits restoration of excursion and strength of the grafted tendons, so post-operative finger function is occasionally unsatisfactory. Early setting rehabilitation is one important factor to prevent the adhesion, and another factor may be a lubricant. We considered the possibility of utilizing hyaluronic acid as a lubricant. The goal of this study is to investigate the in vitro effect of hyaluronic acid on tendon excursion resistance against a digital pulley in a modified human model.

Methods. The excursion resistance between grafted intrasynovial and extrasynovial tendons and A2 pulley were evaluated, and compared before and after soaking in 10 mg/ml hyaluronic acid.

Findings. The resistance increased after extrasynovial tendon graft, and then it decreased after soaking hyaluronic acid solution.

Interpretation. The evidence we collected suggests that some style of administration of the hyaluronic acid might reduce the excursion resistance in the tendon–pulley unit, facilitating post-operative rehabilitation and limiting adhesion, after tendon graft and possibly improve the clinical outcome of flexor tendon graft.

Keywords: Friction; Tendon–pulley unit; Lubricant; Hyaluronic acid

1. Introduction

Tendon graft is occasionally performed to repair serious flexor tendon injuries (Harvey et al., 1983; Strickland, 1987a; Wehbé, 1992; White, 1960). However, post-operative finger function after tendon graft is occasionally unsatisfactory. Adhesions between the tendon and surrounding tissue occur frequently after tendon graft, and furthermore, range of motion of the finger is consequently restricted with joint contracture. Injuries in zone II particularly produce functional loss after surgery. Efforts have been dedicated to improve outcome of the tendon reconstruction by focusing on indications and timing of the procedure, and rehabilitation protocols (Amadio et al., 1988; Bunker et al., 1989; Hunter and Salisbury, 1971; McClinton et al., 1982; Small et al., 1989; Woo et al., 1981). There may be a close relationship between adhesion formation and rehabilitation protocol, as well as donor sources.

Friction between tendon and pulley, which may be influenced by the source of grafted tendon, is another factor that may affect the final surgical outcome. Reduction of the friction may facilitate tendon excursion, and may reduce the risk of adhesion formation and restriction of the range of motion. Potential methods to reduce the friction in the tendon–pulley unit include choice of the tendon

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graft donor source and administration of some kind of lubricant. There have been some reports that the intrasynovial tendons might be better tendon graft donor sources than extrasynovial tendons (Abrahamsson et al., 1994; Ark et al., 1994; Gelberman et al., 1992a,b; Nishida et al., 1998, 1999; Seiler et al., 1993; Uchiyama et al., 1997a,b), and we deliberated upon the possibility of administration of hyaluronic acid (HA) (Nishida et al., 2004). HA, which is a major carbohydrate component of the extracellular matrix naturally produced substance in articular cartilage and synovial fluid, plays an important role to lubricate depending upon its viscoelasticity (Iwata, 1993). In this study, the effect of HA on the excursion resistance between tendons and pulley, simulating a tendon graft in a modified human model in vitro, was evaluated biomechanically.

2. Methods

2.1. Models of tendon graft and administration of HA

Six finger specimens from two human hands (index, middle and ring fingers) were used. The specimens were obtained from one female and one male patient, who underwent amputation for malignant tumors of the upper arm, with ages of 58 and 61 years (average, 60 years). Informed consent was obtained before surgery. All subjects read and signed an institutional review board approved consent form prior to participation. Specimen preparation was identical for each hand. Palmaris longus tendon and extensor digitorum communis tendons were harvested from their insertion to their musculotendinous junction. Each of the palmaris longus tendons was divided into three pieces. Marks were made on the extensor digitorum communis tendon just distal to the distal end of extensor retinaculum in full extension position of the wrist, metacarpophalangeal and proximal interphalangeal joints, and full flexion position of these joints in order to mark the subretinacular area of the extensor digitorum communis tendon. A small transverse incision through the synovial sheath was made just distal to the proximal phalanx annular pulley (A2 pulley) in order to mark the lateral surface of the flexor digitorum profundus tendon with the finger in full extension. The tendon was then pulled proximally until full proximal interphalangeal and distal interphalangeal joint flexion was achieved. In this position, the tendon was again marked through the previous incision. A distance between these two marks represented the physiological excursion range (16–23 mm, 18 mm on average). Then the flexor digitorum superficialis tendons of the finger were harvested from their insertion to the musculotendinous junction. Parietal synovial membrane proximal and distal to the A2 pulley, and all pulleys except A2 were removed. Parietal synovial membrane of A2 pulley, the A2 pulley, and visceral membrane of the flexor digitorum profundus tendon were preserved. The finger was disarticulated at metacarpophalangeal and proximal interphalangeal joints, and proximal phalanx was preserved. These specimens were fresh-frozen after amputation and thawed at room temperature immediately before testing.

The tendons tested were the flexor digitorum superficialis (Group S), the portion of the extensor digitorum communis beneath the extensor retinaculum (Group R), the palmaris longus (Group P) and the extensor digitorum communis distal to the extensor retinaculum (Group E). Groups S and R were considered intrasynovial tendons, while Groups P and E were considered extrasynovial tendons. We chose the flexor digitorum profundus tendon (Group C) to be a control as previous study (Nishida et al., 2004). All specimens were kept moist in a saline bath throughout the testing procedures, and order of testing of graft within each finger was done randomly. After initial testing, each tendon was soaking with HA (Artz®, KAKEN Pharmaceutical Co., Tokyo, Japan, 10 mg/ml, molecular weight 6.0×10^5–1.2×10^6) and the excursion resistances were evaluated again in random sequence, as Groups SH, RH, PH, EH and CH, respectively. All specimens were kept moist in a saline solution bath throughout the testing procedures, and soaked in each concentration of HA for 5 min before testing (Nishida et al., 2004). The temperature of the saline bath is 20 °C.

2.2. Measurement of the interaction between the tendons and pulley

Measurement system comprises one custom-built mechanical actuator with a linear potentiometer and two custom-made tensile load transducers (Fig. 1). Concept of the friction measurement and its application to the tendon–pulley unit has been verified and validated, as reported previously (An et al., 1993; Uchiyama et al., 1995). A tendon sliding through a curved pulley presumes to be a cable wrapped around a fixed mechanical pulley. Load transducers measure the tension in the cable, F1 and F2 at the distal and proximal ends, respectively. When the impending motion of the cable is in the direction from transducer F1 to transducer F2, then the force at F2 is greater than the force at F1 due to the friction f, and

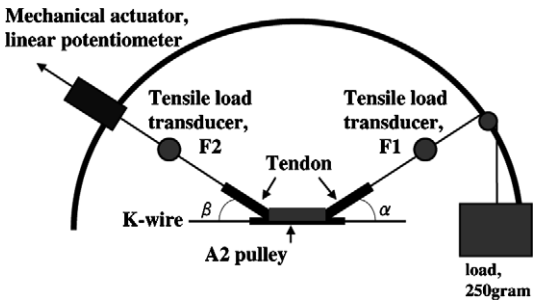

Fig. 1. Experimental setup for the measurement of excursion resistance between the tendon and A2 pulley. Tensions of F1 and F2 were measured by tensile load transducers. Excursion was measured by linear potentiometer. α and β are the angles between the proximal and distal tendon ends, respectively, and the references axis of the proximal phalanx.