Biomechanical Analysis of Partial Flexor Tendon Lacerations in Zone II of Human Cadavers

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Purpose The aims of this study were to examine nonrepaired 90% partial lacerations of human cadaver flexor digitorum profundus (FDP) tendon after simulated active motion, and to assess the residual ultimate tensile strength.

Methods Partial, transverse zone II flexor tendon lacerations were made in the volar 90% of the tendon substance in 10 FDP tendons from 5 fresh-frozen human cadaver hands. The tendons were cycled in the curvilinear fashion described by Greenwald 500 times to a tension 25% greater than the maximum *in vivo* active FDP flexion force measured by Schuind and colleagues. The tendons were then loaded to failure using the same curvilinear model.

Results No tendons ruptured during cycling. Triggering occurred in 3 tendons. All 3 began triggering early in the cycling process, and continued to trigger throughout the remainder of the 500 cycles. The observed triggering mechanics in each case involved the interaction of the proximal face of the lacerated tendon with Camper's chiasm and the pulley edges during extension. The load to failure value of the 90% partially lacerated tendons averaged 141.7 ± 13 N (mean ± standard deviation). Tendon failure occurred by delamination of the intact collagen fibers from the distal, discontinuous 90% of the tendon.

Conclusions Cadaveric transverse zone II partial flexor tendon lacerations have residual tensile strength greater than the force required for protected active mobilization. *(J Hand Surg 2010; 35A:11–18. © 2010 Published by Elsevier Inc. on behalf of the American Society for Surgery of the Hand.)*

Key words Flexor tendon, laceration, zone II, tendon repair, hand.

The treatment of partial flexor digitorum profundus (FDP) tendon lacerations remains controversial. Recommendations range from aggressive, surgical repair of all partial lacerations to nonsurgical options that include early motion protocols.[1–4] A survey of 1000 members of the American Society of Surgery of the Hand documented considerable differences concerning indications for repair, repair methods, and the postoperative management of partial flexor tendon lacerations. However, the tendency among surveyed surgeons was to repair tendon lacerations greater than 50% total cross-sectional area and begin early motion within 48 hours of repair.[5] Clearly, hand surgeons are operating under the hypothesis that partial lacerations greater than 50% total cross-sectional area lack the residual strength necessary to resist rupture during early motion protocols. Surgical manipulation of the flexor system may be associated with adverse effects. Tenorrhaphy has been associated with adhesion formation, decreased excursion, and tendon weakening.[6,7]

Reynolds et al. showed that in chicken FDP tendons, both with and without lacerations, the mean tensile strength of nonsutured tendons was significantly higher than sutured ones.[8] Ollinger et al. also looked at the

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effect of suture on the tensile strength of partially and completely severed tendons to find markedly impaired tendon tensile strength.[9] In both studies, complete tendon rupture was seen only in the sutured tendon groups, which led the authors to believe that suturing interferes with the normal biological process of tendon healing.

Motion and tension, on the other hand, have been shown to decrease adhesion formation, increase excursion, increase the cellular response to healing, and decrease the tendon softening seen during the initial exudative phase of healing.[10–20] As a result, there has been increased interest in the nonsurgical treatment of partial flexor tendon injuries with modalities that include dorsal block splinting and early motion.[21]

Nonsurgical management of partial flexor tendon lacerations must hinge on the knowledge that the residual intact tendon possesses the tensile strength necessary to resist rupture. Those tendons at unacceptably high risk of late failure may be better treated as complete lacerations and surgically repaired. Multiple studies report on the biomechanical properties of human FDP tendons with partial lacerations of less than 75% total cross-sectional area.[1,6,8,9,22–24] Most of these studies reported that suturing and immobilizing partially severed tendons results in inflammation, adhesion formation, and disorganized collagen healing with associated decreased tendon excursion and tensile strength. Early motion, however, improved excursion and orderly collagen formation with improved tensile strength, which suggests that flexor tendon lacerations of up to 75% can withstand *in vivo* force associated with active, unresisted mobilization of the FDP tendon. However, the methodology in those studies did not employ cyclic testing, but rather load to failure testing in a linear *ex vivo* manner.[25] *In vivo*, tendons are not stressed in a simple linear fashion, but with volar compression and dorsal tension owing to the anatomic influences of the pulley system. Similar criticisms apply to the literature's only study investigating the residual tensile strength of lacerations as large as 90% complete.[6] Furthermore, the tendons in that study were canine and the results are not easily translated to the clinical setting.

Two previous clinical studies have assessed the outcomes of partial flexor tendon lacerations of greater than 50% treated without suture repair. Wray et al. in 1977 retrospectively reported their results on the conservative treatment of 20 partial flexor tendon lacerations, and concluded that this approach is suitable for lacerations up to 95% of the tendon substance.[3] Despite these nearly 20-year-old data, in 1995 surgeons who were surveyed preferred to repair lacerations greater than 50% total cross-sectional area.[5] A second clinical study in 2000 by Al-Qattan et al. prospectively treated 11 zone II partial FDP lacerations greater than 50% (average, 72%; range, 55% to 90%) with wound exploration, flexor sheath repair, and skin closure. No late ruptures occurred. The results were considered excellent, with a total active arc of motion averaging 162°.[21] Despite these clinical data, debate as to the indications for repair of partial flexor tendon lacerations persists.

The purposes of this study were to cyclically test nonrepaired 90% partial lacerations of human cadaver FDP tendon after simulated active motion, and to assess tendon excursion during cyclical loading (for triggering, incarceration, and rupture) as well as the residual ultimate tensile strength. The data generated will assist in assessing the risk of rupture during early motion and add to previous authors' clinical findings.

MATERIALS AND METHODS

Hand preparation

Five fresh-frozen human cadaver hands from cadavers of known age and cause of death were individually warmed to 27°C in a circulating water bath for 3 hours. Direct exposure to water was avoided by placing the hands in a polyethylene bag. Once thawed, the hands were sharply divided from the radius and ulna 2 cm proximal to the radiocarpal joint. At the wrist, the individual flexor tendons to the index, long, and ring fingers were isolated and tagged with number 2 Ethibond suture, and all interconnections were sharply divided. The tendons were pulled through a transverse distal palmar crease incision to confirm complete isolation of each tendon. Longitudinal traction of each tendon produced isolated flexion of the appropriate digit. The tendons were returned through the transverse palmar crease incision and through the carpal tunnel. The tendons were kept moist in saline-soaked gauze.

Laceration technique

We surgically exposed long and ring finger FDP tendons in 5 cadaver hands using a Bruner-type incision between the A2 and A4 pulleys. Using a fresh number 15 blade, we longitudinally incised the volar digital sheath between the A2 and A4 pulleys and marked the FDP 2 mm distal to the A2 pulley with an ink marker. The FDP tendon was then delivered through the wound over a flat metal post that would act as a cutting board. The thickness and width of the tendon were recorded 3 times using electronic calipers accurate to 0.01