Analysis of Relative Motion Splint in the Treatment of Zone VI Extensor Tendon Injuries

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Purpose: Early protected motion after extensor tendon repair is desirable. The low-profile relative motion splint, described previously by Merritt et al, holds the affected digit in 15° of extension relative to the uninjured digits to allow less-cumbersome early protected motion versus dynamic splinting. Although early clinical results have been favorable, formal biomechanical testing of this approach is lacking. We used an in vitro model to assess the effect of the low-profile relative motion splint on the biomechanics of zone VI extensor tendons by measuring tendon elongation with and without the splint. Tendon elongation also was measured after transection and repair of extensor tendons in zone VI with and without splint protection.

Methods: Ten fresh-frozen cadaveric upper extremities were prepared and mounted on a testing apparatus with the wrist in 25° of extension. Alternating applications of extension and flexion loads to the tendons induced a full range of motion for 25 cycles. Differential variable reluctance transducers were applied to zone VI of the index, middle, and ring extensor tendons. Measurements of intact tendon microelongation (or strain) were obtained with and without the relative motion splint. The middle finger extensor tendon then was transected (in zone VI) and was repaired immediately. Measurements were repeated with and without splint protection. Elongation ratios were calculated and analyzed statistically.

Results: For the intact tendon of the middle finger splinting reduced the elongation by 1% in extension, by 2% in flexion, and by 3% in neutral position. After the transection and repair of this same tendon, the splint reduced the elongation by 5% in extension, by 7% in flexion, and by 6% in neutral position. Cycling without splint protection caused permanent stretching at the repair site. Reapplication of the splint decreased elongation at the repair site by 2% in extension, by 3% in flexion, and by 3% in neutral position.

Conclusions: The relative motion splint reduces the effective strain on intact and repaired zone VI middle finger extensor tendons and supports its clinical use. (J Hand Surg 2006;31A:1118–1122. Copyright © 2006 by the American Society for Surgery of the Hand.)

Key words: Biomechanics, extensor, relative motion splint, tendons.

Controversy exists as to which methods of postoperative management of extensor tendon injuries are most effective. The postoperative management of repaired extensor tendon injuries historically has been static splinting in extension for several weeks followed by gradual mobilization. Although the conventional teaching has been that most extensor tendon injuries do well with this approach, more recent studies have suggested otherwise. The retrospective analysis of Newport et al1 of 101 repaired extensor tendon injuries treated with static splinting identified frequent complications including tendon adhesions, extensor lag, and joint contractures caused by the lack of excursion of the repaired tendons. Alternative approaches to extensor tendon rehabilitation led to the development of dynamic protocols.

Much of the scientific rationale behind a dynamic approach to extensor tendon rehabilitation comes from studies on flexor tendon healing. In one such biochemical study Amiel et al2 used a canine model...
to show improved accumulation of tissue fibronectin associated with early motion. Fibronectin has been shown to stimulate fibroblasts, an important component of tendon healing.\textsuperscript{2,3} Biomechanic studies also have shown an advantage to early mobilization. Feehan and Beauchene\textsuperscript{4} found a greater resistance to rupture in chicken flexor tendons treated with early mobilization versus immobilization.\textsuperscript{4} Gelberman et al\textsuperscript{5–7} have shown that an early passive-motion protocol for repaired canine tendons leads to more rapid recovery of tensile strength, fewer adhesions, and improved excursion. Less repair site gapping or failure was noted when compared with initially immobilized tendons as well.

Although early motion seems to be advantageous concern remains that overly aggressive mobilization can be detrimental, resulting in gapping, stretching, or rupture of the repaired tissue. Khandwala et al\textsuperscript{8} experienced 2 ruptures in their study of 50 patients treated with an active-motion palmar block splint technique for extensor tendon lacerations in zones V and VI. This technique allowed for motion of all 3 joints of the fingers, which were placed in a palmar blocking splint in which the wrist was kept in 30° of extension and the metacarpophalangeal joint in 45° of flexion. The dynamic extension splint (DES), introduced by Evans and Burkhalter,\textsuperscript{9} seems to offer a reasonable compromise and has gained popularity as a useful rehabilitative tool after extensor tendon repairs. This system allows tendon gliding and gentle loading, shielding the repair sites from overload.\textsuperscript{9} Chow et al\textsuperscript{10} showed in a case-control study that 60% of the group treated with static splints suffered a measure of extensor lag or lack of flexion, whereas all patients treated with DESs had no extensor lag or loss of flexion. Other groups\textsuperscript{11–14} have also obtained good results with the DES without clinically significant complications or repair rupture or gapping. The DES has major disadvantages, however; its construction is expensive and time consuming for therapists and patients. Many patients also find the DES cumbersome and functionally inhibiting.

Merritt et al\textsuperscript{15} described a low-profile splint that theoretically allowed early protected motion of zone V and zone VI extensor tendon repairs. The splint consists of 2 components, both of which are custom made from thermoplastic splinting material. One component holds the involved digit in 15° of extension relative to the uninvolved digits. To prevent passive tension at the repair site the wrist is also splinted in 25° of extension. This prevents full wrist flexion at the same time as full finger flexion (Fig. 1) (see Howell et al\textsuperscript{16} for further detail about splint fabrication). Because the 4 extensor digitorum communis tendons share a single muscle belly, holding the involved digit in relative extension should shield the involved tendon regardless of the finger positions. As long as the involved finger is kept in relative extension, active motion of the metacarpophalangeal and interphalangeal joints should be safe. Proposed advantages of this relative motion splint include increased patient convenience and acceptance, decreased time spent with a hand therapist, quicker return to work, and decreased expense. In a clinical study by Merritt et al\textsuperscript{15} of 180 patients using this type of splint, follow-up study at a 10-year interval showed that relative motion splinting permitted 98% recovery of flexion and 96% recovery of total active motion compared with the uninjured side without incidence of rupture.

Despite promising clinical results and appealing theories the effectiveness of the relative motion splint has not been biomechanically evaluated. We hypothesized that the relative motion splint allows active motion while avoiding excessive strain of the repaired zone VI extensor tendon. To test this hypothesis we used strain gauges on a cadaveric model to measure microscopic elongation of re-
paired extensor tendons with and without splint protection.

**Materials and Methods**

Ten fresh-frozen cadaveric upper extremities (age range, 48–76 y) amputated at the distal third of the humerus were used. The extensor digitorum communis, flexor digitorum superficialis, and flexor digitorum profundus tendons were exposed and coupled to 2.3-kg weights. An external fixator (Agee multiplanar WristJack; Hand Biomechanics Lab, Inc., Sacramento, CA) was applied across the wrist by using a standard technique. Two pins were drilled across the base of the index metacarpal and 2 pins were drilled in the distal radius of the specimens to fix the wrist in 25° of extension. The specimens were mounted on a testing apparatus (Fig. 2) with the weights coupled to the flexor and extensor tendons running over a pulley system. Alternating applications of loads, first to the extensor and then to the flexor tendons, induced a full range of motion of the digits for 25 cycles with each cycle lasting 30 seconds, followed by a rest period of 30 minutes. One differential variable reluctance transducer (DVRT) (Microstrain Inc., Williston, VT) per tendon was attached to the index, middle, and ring finger extensor tendons in zone VI by short barbs on the ends of the DVRTs and 5-0 nylon suture. The barbs and suture held the DVRTs secure during testing without interfering with extensor function. The DVRTs measured linear displacement or microelongation between its attachment points on each extensor digitorum communis tendon in zone VI, with data acquisition performed on a personal computer with software (LabView; National Instruments Inc., Austin, TX). During testing specimen hydration was maintained by applying saline solution during the periods between rest periods between cycles.

Measurements of intact tendon length between the DVRT attachment points were obtained with and without the relative motion splint throughout a range of motion for the index, middle, and ring fingers. After this the middle finger extensor tendon was transected in zone VI between the DVRT insertion sites and repaired immediately with 2 simple ties using 3-0 absorbable suture. Measurements of tendon length were repeated with and without the splint for this digit. Ratios of tendon length were calculated with the splint versus without the splint from the last cycle of extension, flexion, and then rest. These ratios were compared statistically with 1 by using a 2-tailed, 1-sample t test. A ratio of greater than 1 indicated greater elongation of the tendon with the splint and a ratio of less than 1 indicated a reduction in elongation with the splint.

**Results**

For the intact tendon of the middle finger the splint reduced the elongation (Fig. 3) by reducing tendon lengths by 1% with the splint in extension (p < .04), by 2% in flexion (p < .04), and by 3% in neutral position (p < .02). After transection and repair of this same tendon the splint reduced the elongation (Fig. 4) by 5% in extension (p < .001), by 7% in flexion (p < .003), and by 6% in neutral position (p < .003).

Cycling through the range of motion without protection caused macroscopic gapping and stretching of the repair site (gapping not measured). When the splint was reapplied it continued to decrease the elongation of the middle finger tendon in the repaired laceration state (Fig. 5) by 2% in extension (p < .02), by 3% in flexion (p < .002), and by 3% in neutral position.
position (p < .002) but to a lesser extent than with immediate application. In no situations were statistical differences in length noted for the tendons of the index and ring fingers by use of the relative motion splint (p value range, >.05 to .76).

**Discussion**

The concept of immediate motion for improving outcomes after tendon repair is supported biochemically, biomechanically, and clinically. The benefits of early motion, however, must be weighed against the risk of gapping or rupture at the repair site. Our data show that the relative motion splint reduces effective strain on both the intact and repaired zone VI middle finger extensor tendon while allowing simulated active motion throughout a full arc of motion. The splint’s effects were most pronounced during flexion, followed by in neutral position and then during extension. Although there was only a 5% to 67% decrease in length after transection and repair of the middle finger extensor tendon, it was enough to prevent gapping and rupture at the repair site when cycling through a range of motion with the relative motion splint. Gapping occurred at the repaired tendon site after cycling through a range of motion without the splint, highlighting the importance of immediate protection after tendon repair.

There was a greater protective effect on the repaired tendons compared with the intact tendons. This probably was attributable to inadvertent shortening of the tendons after the repair was performed. Newport and Williams\(^\text{17}\) observed that repair of extensor tendons results in an average shortening of the tendons of 6 mm. Clinically this undoubtedly subjects the repaired tendon to greater and potentially disruptive strains when they are left unprotected, and use of the relative motion splint in this circumstance is supported by our results.

This study examined only middle finger zone VI extensor tendon repair with the relative motion splint. Repaired index, ring, and small finger extensor tendons were not evaluated. Zone V injuries were not evaluated because of technical difficulties with the DVRT gliding over the metacarpophalangeal joint during a full arc of motion. In addition data recorded from the small finger extensor tendon were not analyzed because in more than half the specimens the extensor digitorum communis consisted of only a slip from the juncturae tendinum from the ring finger. Future studies may look at index, ring, and small finger zone IV through zone VII tendon lacerations because the relative motion splint has been shown to be effective clinically in these zones as well.\(^\text{16}\) In addition the importance of the juncturae tendinum in linking the uninjured to the injured extensor tendons proximal to zone V may be studied with this experimental design. To avoid passive tension at the repair site the wrist was splinted in 25° of extension to prevent wrist flexion at the same time as full finger flexion. Future studies may also evaluate the effect of decreased wrist extension on repair site strain.

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