SCIENTIFIC ARTICLE

Outcomes of Digital Zone IV and V and Thumb Zone TI to TIV Extensor Tendon Repairs Using a Running Interlocking Horizontal Mattress Technique

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Purpose Biomechanical evidence has demonstrated that the running interlocking horizontal mattress (RIHM) repair for extensor tendon lacerations is significantly stronger, with higher ultimate load to failure and less tendon shortening compared with other techniques. We investigated the efficacy and safety of primary extensor tendon repair using the RIHM repair technique in the fingers followed by the immediate controlled active motion protocol, and in the thumb followed by a dynamic extension protocol.

Methods We conducted a retrospective review of all patients undergoing extensor tendon repair from August 2009 to April 2012 by single surgeon in an academic hand surgery practice. The inclusion criteria were simple extensor tendon lacerations in digital zones IV and V and thumb zones TI to TIV and primary repair performed using the RIHM technique. We included 8 consecutive patients with 9 tendon lacerations (3 in the thumb). One patient underwent a concomitant dorsal hand rotation flap for soft tissue coverage. We used a 3–0 nonabsorbable braided suture to perform a running simple suture in 1 direction to obtain a tension-free tenorrhaphy, followed by an RIHM corset-type suture using the same continuous strand in the opposite direction. Average time to surgery was 10 days (range, 3–33 d). Mean follow-up was 15 weeks (range, 10–26 wk). We applied the immediate controlled active motion protocol to all injuries except those in the thumb, where we used a dynamic extension protocol instead.

Results Using the criteria of Miller, all 9 tendon repairs achieved excellent or good results. There were no tendon ruptures or extensor lags. No patients required secondary surgery for tenolysis or joint release. No wound complications occurred.

Conclusions The RIHM technique for primary extensor tendon repairs in zone IV and V and T1 to TIV is safe, allows for immediate controlled active motion in the fingers and an immediate dynamic extension protocol in the thumb, and achieves good to excellent functional outcomes. These clinical outcomes support prior biomechanical data. *(J Hand Surg 2013;38A:1079–1083. Copyright © 2013 by the American Society for Surgery of the Hand. All rights reserved.)*

Type of study/level of evidence Therapeutic IV.

Key words Extensor tendon laceration, tendon repair, immediate controlled active motion, rehabilitation.

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Received for publication August 29, 2012; accepted in revised form March 18, 2013.

No benefits in any form have been received or will be received related directly or indirectly to the subject of this article.

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0363-5023/13/38A06-0003$36.00/0
http://dx.doi.org/10.1016/j.jhsa.2013.03.031

Many factors influence the outcomes of primary repairs of extensor tendon lacerations. The zone of injury,[1] mechanism of injury, and presence of combined injuries affect functional outcomes.[2] Multiple well-described repair techniques exist with differing biomechanical properties.[3,4] Various rehabilitation protocols after extensor tendon repair represent a spectrum including static immobilization,[5,6] dynamic extension splinting with early motion,[7–10] and immediate controlled active motion (ICAM).[11]

Traditionally, a 4-strand tenorrhaphy has been used for extensor tendon repairs.[3,12–15] A supplemental epitendinous suture has also been advocated.[3,16,17] Recent biomechanical data have demonstrated that a running interlocking horizontal mattress (RIHM) suture configuration takes less time to perform, is biomechanically superior to the augmented Becker and modified Bunnell techniques, and creates less tendon shortening and higher ultimate loads to failure.[4]

Early motion reduces adhesions by creating tendon gliding,[18] allows for activation of the extensor myotendinous junction in some protocols,[19] and has been shown to yield improved functional outcomes compared with static splinting.[20,21] Rehabilitation regimens incorporating early motion with dynamic extension splinting after extensor tendon repairs have yielded satisfactory results.[7–10] Early controlled active motion has benefits and outcomes similar to dynamic splinting and may facilitate improved patient compliance[11,22] but requires a strong repair. Schuind et al[23] measured *in vivo* tension generated on flexor tendons and reported tensions up to almost 9 N with passive digital motion and 34 N with active motion. However, the force required to extend the metacarpophalangeal (MCP) joint to neutral after an extensor tendon repair is up to 15 N,[3] while the maximal force generated by the digital extensors with isometric contraction is up to 59 N.[24] These data suggest that with a load to failure of 51 N,[4] the RIHM technique should support ICAM.

We describe clinical outcomes after the RIHM technique, previously studied biomechanically,[4] and an ICAM protocol for the digits and dynamic extension splinting for thumb extensor tendon lacerations. We hypothesized that the strength of the RIHM repair would support an ICAM protocol and yield satisfactory outcomes.

MATERIALS AND METHODS

We conducted a retrospective review of all patients undergoing extensor tendon repair from August 2009 to April 2012 by a single surgeon in an academic hand surgery practice. The local institutional review board approved the study.

Inclusion criteria were simple extensor tendon repairs in digital zone IV and V and thumb zones TI to TIV and primary repair performed using the RIHM technique. Exclusion criteria were incomplete tendon lacerations, segmental lacerations, crush injuries, burn injuries, and associated fractures (ie, combined injuries). Concomitant joint exposure was not an exclusion criterion.

The senior author (D.E.R.) performed all tendon repairs, using a 3-0 nonabsorbable, braided suture (Ethibond; Ethicon Ltd, Edinburgh, Scotland, UK) placed as a running simple suture in 1 direction to obtain a tension-free tenorrhaphy. Then, using the same continuous strand of suture in the opposing direction, a running interlocking horizontal mattress suture was performed, with the suture needle passing underneath the prior crossing suture, thereby locking each throw (Fig. 1).[4]

A total of 8 consecutive patients with 9 tendon lacerations were included (Table 1). There were 3 thumb tendon lacerations, 1 each in zone T2, T3, and T4. In the other digits, there was 1 zone IV laceration (index finger) and 5 zone V lacerations (1 index, 2 middle, and 2 ring fingers). In 5 digits, we noted a concomitant traumatic arthrotomy, and in 3 patients we observed a stable unicortical metacarpal or proximal phalanx defect that did not require fixation. All lacerations were sharp and without segmental tendon loss. One patient underwent concomitant dorsal hand rotation flap for coverage over the MCP joints. We performed goniometry and recorded it for all joints of the affected digit at all follow-up visits. Outcomes were graded by the criteria of Miller[25]: excellent is 0° extension lag, 0° flexion loss; good is $\leq$ 10° extension lag, $\leq$ 20° flexion loss; fair is 11° to 45° extension lag, 21° to 45° flexion loss; and poor is $>$ 45° extension lag, $>$ 45° flexion loss.

All zone IV and V digital extensor tendon repairs began the ICAM protocol by postoperative day 5.[11] The ICAM protocol consisted of a daytime volar wrist thermoplastic orthosis with the wrist in 20° to 25° extension and a custom-molded finger yoke. The yoke is positioned at the proximal phalanx of all 4 fingers and is designed to position the MCP joint(s) of the involved digit(s) in 15° extension relative to adjacent uninvolved digits. Careful balancing of the yoke preserves the desired relative extension and prevents shifting and unbalanced forces on the tenorrhaphy. A nighttime volar forearm-based extension orthosis with the wrist in neutral and the fingers in full extension at all joints was used for the first 6 weeks. During the first phase (0–3

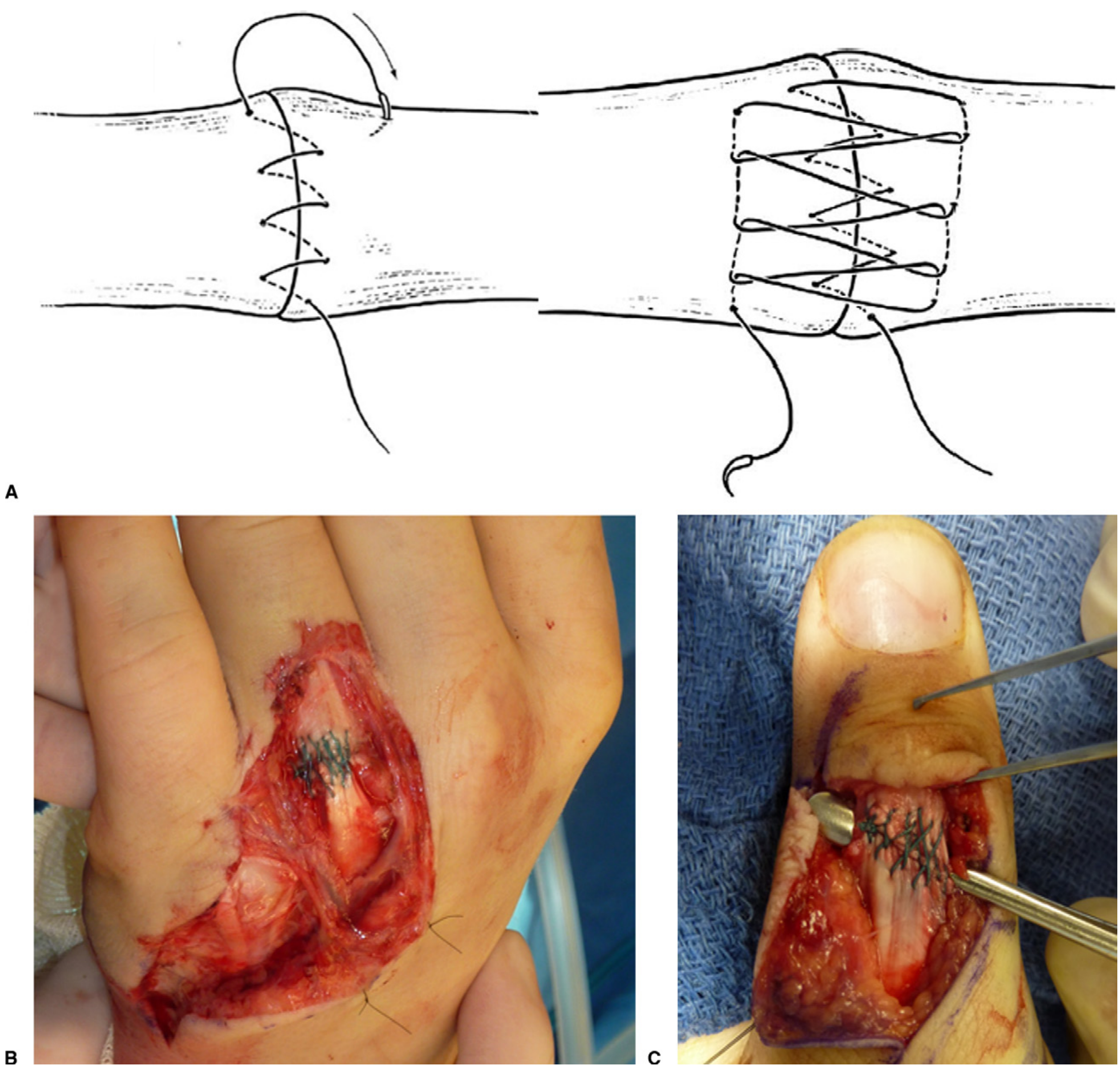

FIGURE 1: **A** Schematic of steps of RIHM repair.[4] **B** Intraoperative photograph of the RIHM technique within zone 5 of the extensor system. **C** Intraoperative photograph of the RIHM technique within zone 1 of the thumb extensor system (T1).

wk), the yoke and wrist orthosis were worn simultaneously at all times, and the patient began active motion. The patient progressed to phase 2 (3–5 wk) when there was no extensor lag. During phase 2, the digital yoke was continued full-time. Isolated active wrist motion, wrist flexion, and extension with the digits in a relaxed position progressed to composite wrist and digital motion, accomplished by performing wrist extension together with digital extension and wrist flexion together with digital flexion. The digital yoke, continued full-time during phase 2, limited the amount of tendon excursion during the exercises. The wrist splint was discontinued once full wrist motion was achieved. During phase 3 (5–7 wk), the digital yoke was worn progressively less, and unprotected active digital motion was increased until full composite wrist and finger motion was achieved. Formal strengthening was initiated at 8 weeks.

We used a dynamic extension protocol for the thumb extensor repairs. A daytime long opponens orthosis with the wrist extended 30° and the MCP joint at 0° extension was worn with the interphalangeal (IP) joint supported by an extension outrigger with an initial 40° IP joint flexion block during the first week. The IP joint flexion block was decreased weekly by 10°, provided no extensor lag developed. The therapist examined the extensor tendon weekly by assessing active extension of the IP joint out of the splint before progression of the

TABLE 1. Patient Demographics, Injury Characteristics, and Outcomes

Age	Sex	Dominant Hand	Mechanism of Injury	Associated Injuries	Affected Digit(s)	Days to Surgery	Follow-Up (wk)	Outcome Using Criteria of Miller
49	M	N	Landscape saw	Dorsal P1 defect	IF	33	26	Good (5° flexion loss)
27	F	Y	Kitchen knife	None	MF	8	13	Good (5° flexion loss)
34	M	N	Kitchen knife	EPB partial laceration, MCP joint arthrotomy, dorsal MC defect	Thumb	6	15	Excellent
46	M	N	Utility knife	Dorsal MC defect	Thumb	3	12	Excellent
25	M	N	Axe	IO myotendinous junction partial laceration	IF	6	10	Excellent
37	M	N	Utility knife	MCP joint arthrotomy	Thumb	6	10	Excellent
26	M	N	Joiner blade	Partial EDQ laceration, MCP joint arthrotomy	RF	3	12	Excellent
19	M	Y	Bamboo	RF MCP joint arthrotomy	MF, RF	13	17	Excellent, excellent

Average age was 31 years; there was an average of 10 days to surgery, and the average weeks to follow-up were 15. Criteria of Miller: excellent = 0° extension lag, 0° flexion loss; good = ≤ 10° extension lag, ≤ 20° flexion loss; fair = 11° to 45° extension lag, 21° to 45° flexion loss; poor = ≥ 45° extension lag, ≥ 45° flexion loss.[25]

IF, index finger; MF, middle finger; RF, ring finger; P1, proximal phalanx; EPB, extensor pollicis brevis; MCP, metacarpophalangeal; MC, metacarpal; IO, intraosseous; EDQ, extensor digiti quinti.

extensor block. A nighttime long opponens orthosis with the wrist in 30° extension and the MCP and IP joints positioned at neutral extension was used for 6 weeks. At 4 weeks, wrist tenodesis and active thumb motion out of the splint were started. Gradual advancement to composite thumb and wrist motion was then allowed. Strengthening began after 8 weeks.

RESULTS

Of 9 tendon repairs, 7 achieved excellent results with full extension and composite flexion (Table 1). Two tendon repairs achieved good results, both with a 5° loss of flexion at the MCP joint of the injured digit. There were no operative complications. There were no tendon repair ruptures. No patients required secondary surgery for extensor tenolysis or joint extension contracture release. No wound complications occurred.

DISCUSSION

A range of treatment strategies exist for extensor tendon lacerations, including different primary repair techniques and rehabilitation protocols. Several centers describe extensor tendon repair results after traditional 4-strand repairs.[3,12–15] Biomechanical data on the RIHM technique[4] have demonstrated that this technique can support immediate controlled active motion in the digits and dynamic extension rehabilitation in the thumb. The good to excellent outcomes reported after the RIHM technique and the ICAM protocol support its use for simple digital extensor tendon lacerations in zones IV and V. Extensor tendon ruptures did not occur despite an early active motion protocol. Our results suggest that the RIHM technique may offer the clinical advantage of tolerating higher forces and allow for early active motion. Furthermore, extensor tenolysis and capsular releases were not required. For simple digital extensor lacerations, the ICAM protocol avoids the use of dynamic outrigger splints, with which patient compliance may be problematic.

Rehabilitation protocols for extensor tendon repairs aim to balance adhesion prevention and risk of tendon rupture.[8,20] Multiple factors may affect this balance, including patient compliance, strength of repair, mechanism and zone of injury, and the presence of other injuries in the same hand. In the noncompliant patient, static immobilization may help protect the repair. Mowlavi et al[20] demonstrated that static and dynamic protocols yielded similar total active motion and grip strength at 6 months after repair. Neuhaus et al[10] reported good to excellent results in 16 patients by 6 weeks with 4-strand core and epitendinous repairs after by a dynamic extension protocol.

The ICAM protocol offers the benefit of relative simplicity and high patient compliance.[11] Compared with static splinting protocols, initial custom splint fabrication and frequent therapy visits are required, but we believe that they are offset by the benefits of early tendon gliding, activation of the myotendinous junction, and the potential of improved functional outcomes.[18–21] Application of the ICAM protocol for lacerations beyond zones IV and V has been reported.[11] Although not observed in this study, risk of tendon rupture with the ICAM protocol exists. When used in conjunction with the biomechanically strong RIHM technique, we believe this risk is minimized. The ICAM protocol cannot be used for thumb extensor tendon repairs because the thumb's position out of plane with the other digits precludes the balanced digital yoke required to effectively limit tendon excursion.

Strengths of this study include consistency of technique performed by a single surgeon and adherence to uniform postoperative protocols. Exclusion criteria were stringent. We do not recommend the RIHM technique for combined injuries with extensor tendon fraying or segmental tendon loss. In addition, this technique is technically difficult to perform within zone VI, given the cross-sectional anatomy of the extensor tendons in this region. Limitations of this study include its retrospective design, limited total number of tendon repairs, inclusion of both fingers and thumbs, and lack of a control group.

Prospective randomized studies evaluating repair techniques and rehabilitation protocols for specific zones and mechanisms of injury are needed to define optimal treatment strategies.

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