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Case Report

Two case reports—Use of relative motion orthoses to manage extensor tendon zones III and IV and sagittal band injuries in adjacent fingers

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ABSTRACT

Study Design: Case report.
Introduction: Injuries to adjacent fingers with differing extensor tendon (ET) zones and/or sagittal band pose a challenge to therapists as no treatment guidelines exist.
Purpose of the Study: This report highlights how the relative motion flexion/extension (RMF/RME) concepts were combined into one orthosis to manage a zone IV ET repair (RME) and a zone III central slip repair (RMF) in adjacent fingers (Case 1); and how a single RME orthosis was adapted to limit proximal interphalangeal joint motion to manage multi-level ET zone III-IV injuries and a sagittal band repair in adjacent fingers (case 2).
Methods: Adapted relative motion orthoses allowed early active motion and graded exercises based on clinical reasoning and evidence. Outcomes were standard TAM% and Miller's criteria.
Results: 'Excellent' and 'good' outcomes were achieved by twelve weeks post surgery. Both cases returned to unrestricted work at 6 and 7 weeks. Neither reported functional deficits at discharge.
Discussion: Outcomes in 2 cases involving multiple digit injuries exceeded those previously reported for ET zone III-IV repairs.
Conclusions: Relative motion orthoses can be adapted and applied to multi-finger injuries, eliminating the need for multiple, bulky or functionally-limiting orthoses.
Level of Evidence: 4

Introduction

Therapy management of isolated extensor tendon (ET) injuries is largely guided by zone of injury and sagittal band injuries by acuteness of onset and if the structure has been repaired. Zone III and IV ET injuries have been associated with the highest percentage of fair/poor results compared with other zones.[1] These injuries respond well to early controlled active motion programs that create approximately 4 mm of ET excursion.[2] Sagittal band injuries, whether surgically or nonsurgically managed, respond positively to active finger motion provided the metacarpophalangeal joint (MCPJ) is either immobilized in extension or motion is limited so not to sublux the tendon.[3-7]

For complex zones III-IV ET injuries which involve several tendons, bone, joint and even multiple fingers, selection of an appropriate early active motion orthosis program presents a unique challenge. For these cases, the therapist must carefully review the complex ET anatomy (Figs. 1A and 1B) and rehabilitation literature.

Review of key structures

ET zone V and proximal

The sagittal band is a check rein and stabilizer of the long ET tendon at the MCPJ. When the sagittal band is injured, the ET will decentralize and compromise finger extension. With a radial

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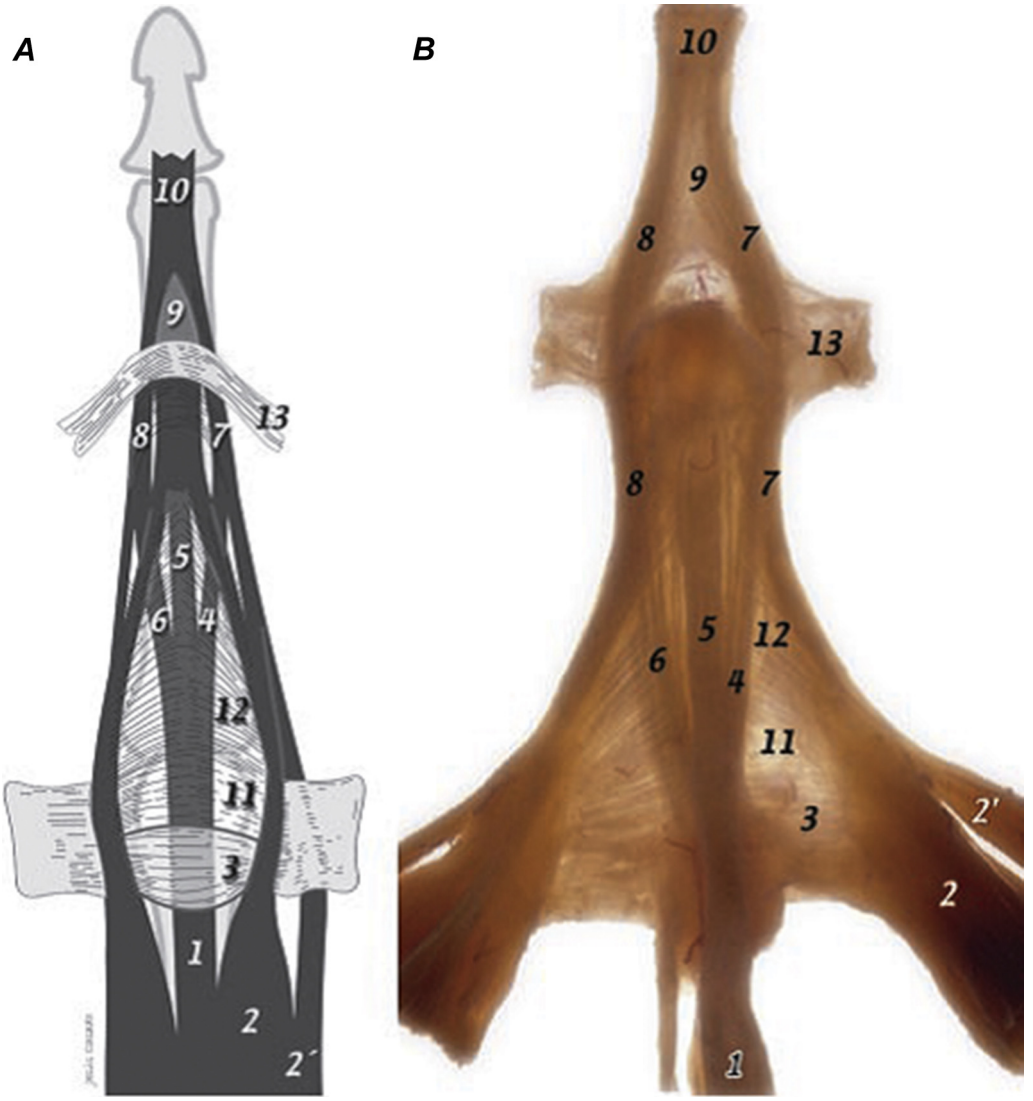

Fig. 1. Drawing (**A**) and transilluminated anatomic specimen (**B**) (dorsal view) show the extensor apparatus of the index finger (removed from its location). 1 = extensor digitorum tendon, 2 = interosseous muscle, 2′ = lumbrical muscle, 3 = sagittal band, 4 = medial slip, 5 = central slip, 6 = lateral slip, 7 = medial conjoined tendon (combined lateral slip and lateral band), 8 = lateral conjoined tendon (combined lateral slip and lateral band), 9 = triangular ligament, 10 = terminal tendon, 11 = transverse fibers (extensor hood/apparatus), 12 = oblique fibers (extensor hood/apparatus), and 13 = retinacular ligament. Reproduced with permission from the Radiological Society of North America. Figures 11A and 11B. Clavero JA, Golanó P, Fariñas O, et al. Extensor mechanism of the fingers: MR imaging—anatomic correlation. *RadioGraphics* 2003;23:593-611.

Table 1
Operative details

	Case 1: JD		Case 2: HV	
	Right ring finger	Right small finger	Left index finger	Left long finger
Operative findings and surgical intervention	- 50% central slip laceration (zone III); repaired 4.0 nylon. - 5% ulnar digital nerve laceration; repaired 8.0 nylon. - 100% digital artery laceration; repaired 9.0 nylon. - Skin closure 5.0 Vicryl Rapide.	- 80% extensor digitorum communis (EDC) laceration (zone IV); repaired 4.0 nylon - Skin closure 5.0 Vicryl Rapide.	- PIPJ traumatic arthrotomy; irrigated. - >50% EDC laceration (zone IV); repaired 4.0 Tycron - Lacerated ulnar lateral band to central slip (not repaired) - Longitudinal laceration to the central slip (not repaired) - Skin closure 5.0 Nylon.	- MCPJ traumatic arthrotomy; irrigated - Laceration radial sagittal band with EDC instability; repaired 4.0 Tycron. - Drain inserted proximal long finger incision. - Skin closure 5.0 Nylon.
ICD-10 codes	S66.324A	S66.326A	S66.301A	S66.303A

ICD-10 = International Statistical Classification of Diseases and Related Health Problems 10th Revision; MCPJ = metacarpophalangeal joint; PIPJ = proximal interphalangeal joint.

Table 2
Outcome measures

Outcome	ICF name	ICF code	Description of outcome measure
Range of motion	Mobility of joint functions	b710	A 15-cm plastic (MH) and a flat metal (JH) goniometer measured range of motion at each therapy session, according to standardized methodology[17] and recorded to the nearest 5°. Kleinert and Verdan's[18] total active motion (TAM) formula yielded a percentage of recovery/rating compared with the contralateral finger whilst Miller's[19] criteria separates extension from flexion loss. TAM = ([MCP + PIP + DIP flexion] − [MCP + PIP + DIP extension lag]). Calculate percentage of contralateral finger.[18] Ratings: "excellent" equal TAM, "good" TAM >75%, "fair" TAM >50% and "poor" TAM <50%.[18] Miller's active extension lag = (MCP + PIP + DIP extension) − (contralateral finger MCP + PIP + DIP extension) Ratings: "excellent" = no difference, "good" = 5°-10°, "fair" = 11°-45°, poor >45° loss of extension. Miller's terminal flexion loss = (MCP + PIP + DIP flexion contralateral finger) − (MCP + PIP + DIP flexion) Ratings: "excellent" = no difference, "good" ≤20°, "fair: = 21°-45°, "poor" >45° loss of flexion.[19]
Grip strength	Muscle power functions	b730	Grip strength was measured using a Jamar Dynamometer following standardized methodology.[20]
Return to work	Work and employment	d840-d859	Weeks absent from work due to the injury.
Functional hand use	Carrying out daily routine	d230	Patient's self-report.
	Fine hand use	d440	JH used a nonstandardized/nonvalidated set of 7 activities that asked for patient self-report of "how limited are you by your injured hand?" 0% (no limitation) to 100% (can not do at all) with the scale divided into 20 % intervals.
	Hand and arm use	d455	

MCP = metacarpophalangeal; ICF = International Classification of Functioning, Disability and Health; PIP = proximal interphalangeal.

sagittal band injury, ET instability increases with progressive MCPJ flexion from 45° to 90°.[8] Both relative motion extension (RME) orthoses[3,6] and volar hand-based palmar orthoses [3-5,7] that hold the MCPJ in extension and allow proximal interphalangeal joint (PIPJ) motion have been shown to successfully support the healing of sagittal band injuries with/without surgical repair.

ET zone IV

In this zone which comprises the area between the MCPJ and the PIPJ, the long ET transitions into the extensor hood which envelopes two-thirds of the proximal phalangeal surface and is joined by lumbrical and interossei contributions. Progressing distally, these structures give rise to the central slip and lateral bands. Two active motion programs, short arc motion (SAM)[9] and RME (also known as immediate controlled active motion − ICAM)[10,11] report good to excellent outcomes for injuries in this zone.

ET zone III

In this zone, the central slip inserts into the base of the middle phalanx. During finger flexion, unwanted adhesions involving the sagittal band(s) and/or extensor hood and/or lateral band(s) can restrict tendon excursion and increase stress on an injured or repaired central slip. To limit adhesions, the SAM protocol[2] or dynamic extension assist or "Capener" orthoses have been successful.[12-14] Recently, relative motion flexion (RMF) orthoses have been used to manage central slip repairs/injuries.[15,16] In theory, the RMF orthosis limits undesirable adhesions by means of: (1) positioning the injured digit's MCPJ in relatively more flexion for the purpose of restoring passive tension on the sagittal band and extensor hood which then facilitates extensor hood contributions from the intrinsic muscles to actively extend the PIPJ; (2) active MCPJ movement guided by the RMF orthosis combined with PIPJ motion generates zone IV hood excursion; and (3) finally by including active DIPJ flexion exercises with the PIPJ held in extension reduces harmful stress on the central slip and creates distal excursion of the lateral bands and differential gliding at the lateral band/central slip intersect.

Given the preceding anatomy, zone, and active motion program considerations, it is useful to first develop a plan around each injured structure separately and then consider how each plan might impact the other. Once the pros and cons are contemplated, the patient-specific requirements can be integrated to further refine a suitable combination of orthosis and controlled mobilization programs.

Fig. 2. Hand-based resting orthosis (case 1).

Purpose of study

This article highlights 2 unique multidigit finger cases managed via adaptation of the relative motion approach:

Table 3
Orthosis option matrix for case 1

	Ring finger—central slip		
	Short arc motion (SAM)	Dynamic extension assist (DEA)	Relative motion extension (RMF)
Small finger—EDC			
Short arc motion (SAM)	(A) SAM/SAM	(B) DEA/SAM	(C) RMF/SAM
Relative motion extension (RME)	(D) SAM/RME	(E) DEA/RME	(F) RMF/RME

EDC = extensor digitorum communis.

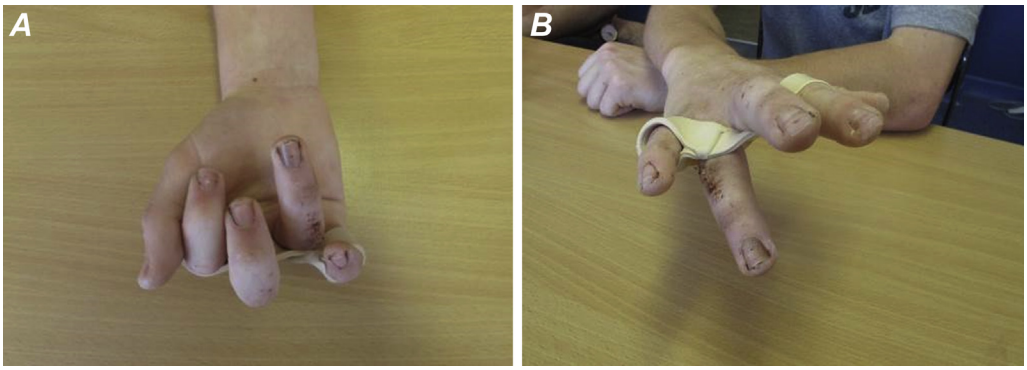

Fig. 3. (**A**) Combined ring finger (RMF) and small finger (RME) orthosis—finger flexion (case 1). (**B**) Combined ring finger (RMF) and small finger (RME) orthosis—finger extension (case 1). RME = relative motion extension; RMF = relative motion flexion.

- Case 1 demonstrates how RME and RMF can be combined into 1 orthosis to manage a zone IV ET (RME) and zone III central slip repair (RMF) in adjacent fingers.
- Case 2 illustrates how the RME orthosis was adapted to limit PIPJ motion to manage multilevel ET zone III-IV injuries and a sagittal band repair in adjacent fingers.

These case reports:

- Discuss the factors that must be considered before significantly modifying usual practice in selection of orthoses;
- Share the rationale for adding exercises to the orthotic programs; and
- Provide intervention timelines and outcome measurements

Methods

Participants

Case 1 (JD), a 17-year-old male fence builder punched a glass window with his right dominant hand lacerating the dorsum of his ring and small fingers. Hand therapy for this case was provided by the author MH. Case 2 (HV) is a 56-year-old female who accidently struck the dorsum of her left nondominant index and long fingers against plate glass at home. Hand therapy was provided by JH.

Informed consent for treatment interventions, photographs, and videos were obtained from the patients and the parent of the underaged patient. International Statistical Classification of Diseases and Related Health Problems 10th Revision codes and details from each patient's operative report are presented in Table 1.

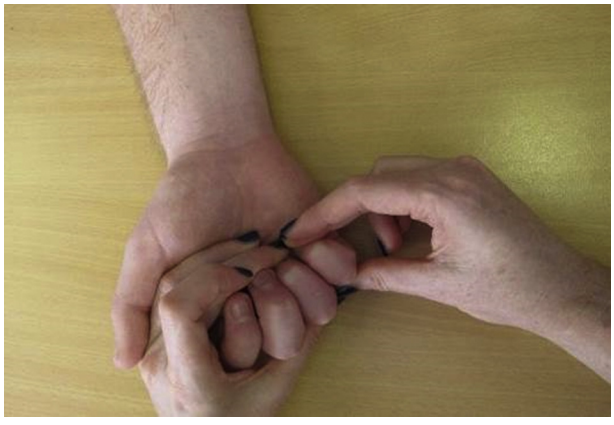

Fig. 4. Passive composite flexion (case 1).

Outcome measures

Measures used to identify body structure and function impairments, activity limitations, and any restrictions (Table 2) with relevant International Classification of Functioning, Disability and Health names and associated codes.

Case 1

Initially, JD was treated by MH's colleague who at 5 days after surgery fabricated a hand-based orthosis with MCPJ flexed at 45° and IPJs 0° (Fig. 2) with the intention of JD returning in 5 days to commence mobilization. With consideration of current practice and the literature, the option to continue immobilization was excluded due to the potential complications of tendon adherence and/or loss of motion. The use of dynamic outrigger orthoses was also excluded as there are less cumbersome options. The orthotic options remaining are outlined in the matrix in Table 3.

Patient factors and therapist preferences were considered in selecting the management program. JD could not assure adherence to a therapy program that included the use of SAM template orthoses that he felt he may misplace. Given his occupation (fence building), functional use of his hand on the job and for daily living tasks was important. Previously, when managing isolated injuries, MH's preference was to implement SAM for the zone III injury and RME for the zone IV injury. Having successfully used RMF for boutonniere deformity, clinical reasoning suggested that this may also be suitable for central slip repairs. Given that JD's partial central slip laceration was repaired, and the lateral bands were intact MH was encouraged to try RMF. Selecting orthosis option F, RMF for the ring finger and RME for the small finger, meant 1 orthosis instead of 2, orthosis removal was not required to perform exercises, and functional activities could commence immediately.

At day 10, the combined orthosis—RMF (ring finger) and RME (small finger)—was fabricated (Figs. 3A and 3B). The RMF/RME orthosis was worn during the day and a hand-based orthosis overnight. JD attended weekly therapy for 6 weeks then every other week until 12 weeks.

Although exercises for distal excursion of the lateral bands and DIPJ suppleness via isolated active DIPJ flexion started at day 10 (for the ring finger), DIPJ flexion range of motion (ROM) measurements of both fingers at week 4 did not improve. This lack of response to exercise indicated that isolated DIPJ flexion was not sufficient,

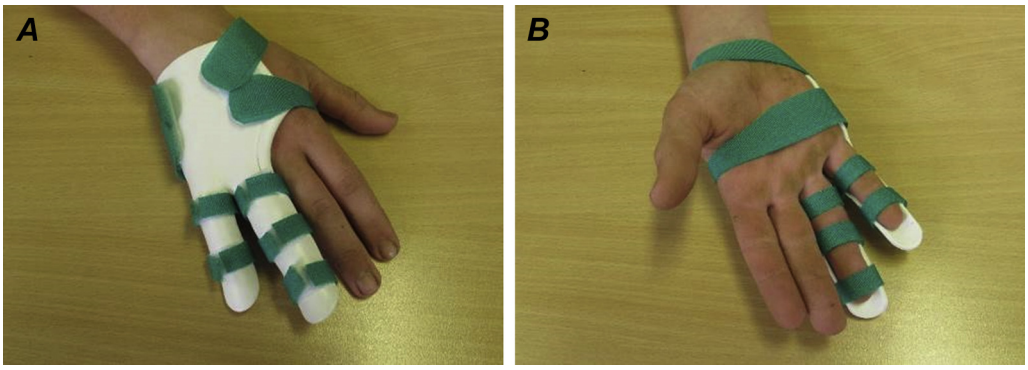

Fig. 5. (**A**) Hand-based PIPJ extension orthosis (dorsal)–(case 1). (**B**) Hand-based PIPJ extension orthosis (volar)–(case 1). PIPJ = proximal interphalangeal joint.

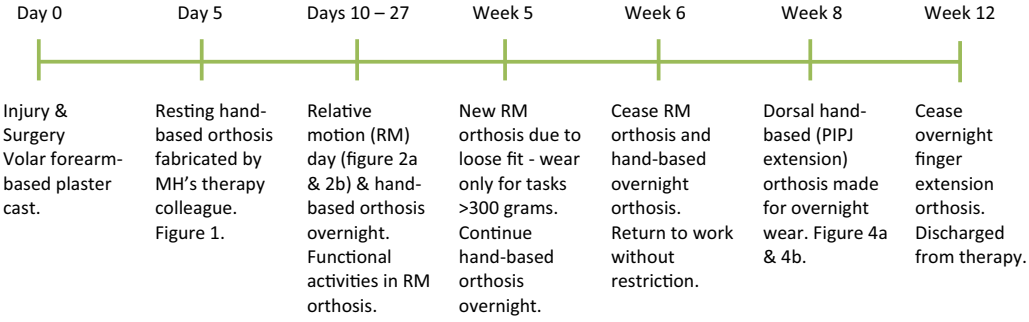

Fig. 6. Orthosis wearing timeframe—case 1.

Fig. 7. (**A**) Dorsal hand laceration (case 2). (**B**) Drain tube in situ after surgery (case 2).

Table 4
Orthosis option matrix for case 2

	Long finger—MCPJ traumatic arthrotomy, sagittal band	
	Palmar orthosis to PIPJ (PO)	Relative motion extension (RME)
Index finger—PIPJ traumatic arthrotomy, EDC zone IV, lateral band, central slip		
Short arc motion (SAM)	(A) PO/SAM	(B) RME/SAM
Relative motion extension (RME)	(C) PO/RME	(D) RME/RME

EDC = extensor digitorum communis; MCPJ = metacarpophalangeal joint; PIPJ = proximal interphalangeal joint.

thereby requiring more distal tendon excursion, which would require combined DIPJ and PIPJ active flexion. In doing this, MH was keenly aware that this could also stress the newly repaired central slip, potentially creating a PIPJ active extension lag. Figure 4 shows that passive composite flexion of ring finger was not limited or adhered; hence, active composite flexion and passive IPJ flexion were commenced out of the orthosis. At week 6, small deficits in active PIPJ extension were noted (20° ring finger and 10° small finger). To recover active PIPJ extension, active PIPJ extension exercises were done in the RMF position and were progressed to less relative MCPJ flexion to entice more proximal excursion of the extensor hood. After 2 weeks of not recording any improvement in active PIPJ extension, MH considered the fact that JD was actively flexing and using his hand throughout the day at work and that a hand-based static night extension orthosis might restore the delicate balance of digital extension (Figs. 5A and 5B). The hand-based design (all joints in 0° extension) blocks MCPJ hyperextension (which negatively impacts PIPJ extension) and enables force applied by the orthosis to be directed to PIPJ extension. The dorsal design was chosen over a volar approach, as this enabled the PIPJs to be individually managed, allowed the PIPJs to move as a hinge into extension avoiding shear force on the fingertip pulps, and avoids DIPJ hyperextension, which is more likely to occur with a volar approach. Subsequently, MCPJ hyperextension decreased in the ring finger and PIPJ extension improved. Further interventions during the course of treatment included education regarding injury and repair, discussion on the do's and don'ts for work and ADLs, warm water baths, scar massage, and use of light compressive dressing. Orthosis implementation timeframes are summarized in Figure 6.

Case 2

Two days after injury (Fig. 7A), wound cultures were taken and structures were repaired by a hand surgeon. (Table 1) Hand therapy was initiated 1 week later, wound cultures were negative, and the surgical drain was removed (Fig. 7B). Postoperative dressings were replaced with compression wraps. Table 4 outlines possible orthosis management options.

From the therapist's (JH) past experience, a RME orthosis would protect the radial sagittal band repair, and permit motion of the open MCPJ and tendon excursion. A palmar orthosis to the PIPJ would do all this except allowing MCPJ motion, so it was rejected. Decision-making about an orthosis for the index finger proved to be more challenging given the multilevel ET injury, zone IV (repaired), ulnar lateral band, and longitudinal laceration zone III central slip (not repaired) and open PIPJ. If this were an isolated ET zone IV repair, the evidence supports the use of a RME orthosis.[10,11] Personal communication with the surgeon revealed that he passively flexed the PIPJ intraoperatively, observed no central slip splitting, and so chose not to repair. Communication of this information supported JH's consideration of either the SAM protocol or RME orthosis. The SAM protocol supported the treatment objectives for the use of controlled motion to discourage PIPJ stiffness and limit adhesions in zones III-IV and at the lateral band/central slip intersect. Pros of the RME orthosis are increased zone V-III ET excursion,

Fig. 8. (**A**) Volar aspect of RME orthosis—wider thermoplastic on volar aspect limits PIPJ motion of the index and long fingers (case 2). (**B**) The orthosis was later reconstructed to allow full PIPJ motion (case 2). PIPJ = proximal interphalangeal joint.

Fig. 9. (**A**) "RME pencil trick" MCPJ and PIPJ passive composite extension. (**B**) Pencil maintains RME position during active PIP extension–dermodesis during proximal excursion of EDC. PIPJ extension lag due to scar adherence in zone V. (**C**) To remodel dense scar, repeat (8B) with patient providing push of skin distally simultaneously with active proximal glide of EDC. (**D**) "RMF pencil trick" for active long finger PIPJ extension. No PIPJ extensions lag. (**E**) Composite PIP/DIPJ flexion scratching putty into intrinsic stretch position. EDC = extensor digitorum communis; PIPJ = proximal interphalangeal joint; RME = relative motion extension; RMF = relative motion flexion.

motion of open PIPJ injury to limit stiffness, simplicity of use and fabrication of one orthosis, and therapist preference. Cons include more active PIPJ flexion than desired at week 1 postop, no provision for differential gliding at the lateral band/central slip intersect, and a very active patient. Ultimately, the cons were addressed by fabricating the orthosis (using a wider strip of thermoplastic) to limit the arc of PIPJ flexion, use of a prefabricated wrist orthosis to limit overuse, and DIPJ flexion exercises for lateral band/central slip

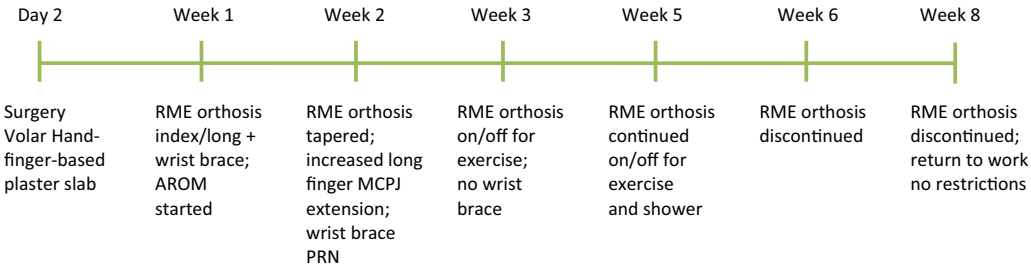

Fig. 10. Orthosis wearing timeframe—case 2. AROM = active range of motion; RME = relative motion extension.

Table 5
Results

Outcome measures	Case 1: JD		Case 2: HV	
	Right ring finger central slip laceration (zone III) 50% ICD-10 code S66.324A	Right small finger right small finger EDC laceration (zone IV) 80% ICD-10 code S66.326A	Left index finger EDC laceration (zones III-IV) ICD-10 code S66.301A	Left long finger sagittal band laceration ICD-10 code S66.303A
TAM %	94%—wk 12	100%—wk 12	96%—wk 11	90%—wk 11
TAM rating	"Good"—wk 12	"Excellent"—wk 12	"Good"—wk 11	"Good"—wk 11
Miller's criteria	Extension loss—wk 12, "Excellent" Flexion loss—wk 12, "Good"	Extension loss—wk 12, "Excellent" Flexion loss—wk 12, "Good"	Extension loss—wk 11, "Good" Flexion loss—wk 12, "Good"	Extension loss—wk 11, "Good" Flexion loss—wk 12, "Good"
Grip strength	12 wk—right: 101 pounds. Left: 99 pounds. Injured right as a percentage of nondominant left = 102%		11 wk—right: 65 pounds. Left: 40 pounds. Injured left as a percentage of dominant right = 62%	
Return to work	JD returned to full duties as a fence builder 6 wk after surgery.		At 7 wk, HV returned to unrestricted work as manager of a garden center.	
Functional hand use	Once in the RM orthosis (10 d), JD reported being able to undertake light functional tasks such as brushing his teeth and buttering his toast. He showered with his orthosis in situ, removing it only to dry his hand. At 12 wk, JD reported no functional impairments.		Initially, HV reported an 80% limitation in safely lifting/carrying, 60% for self-care activities of daily living and 100% returning to work with her left hand, at the wk 11 discharge visit HV voiced no functional limitations.	

EDC = extensor digitorum communis; ICD-10 = International Statistical Classification of Diseases and Related Health Problems, 10th Revision.

Table 6
Goniometric measured degrees of motion—case 1

AROM extension-flexion	Contralateral	Wk 2	Wk 3	Wk 4	Wk 6	Wk 8	Wk 10	Wk 12
Ring MCP	+5-90	0-NA	0-NA	0-105	+25-85	+10-90	+5-90	+10-85
PIP	0-100	5-50	5-45	15-55	20-80	15-90	5-95	0-95
DIP	0-75	0-45	0-25	0-25	0-45	0-55	0-65	0-65
Small MCP	+5-90	+10-NA	+20-NA	+15-90	+20-90	+20-95	+15-90	+20-90
PIP	0-95	10-50	10-45	20-50	10-75	15-90	5-90	5-85
DIP	0-70	5-30	5-40	10-30	0-50	5-60	5-75	5-75

AROM = active ROM; MCP = metacarpophalangeal; NA = not assessed; + = hyperextension; PIP = proximal interphalangeal; ROM = range of motion.

Table 7
Goniometric measured degrees of motion—case 2

(PROM) AROM extension-flexion	Contralateral	Wk 1	Wk 2	Wk 3	Wk 5	Wk 6	Wk 8	Wk 11
Index MCP	0-75	+15-40	0-55	0-60	0-70	0-65	0-75	0-75
PIP	0-105	10-30	(10)10-40	0-65	0-80	0-90	0-90	(0)5-95
DIP	0-55	0-5	0-20	0-40	0-5	0-35	0-45	0-60
Long MCP	0-80	+15-45	+10-65	+10-70	+10-70	0-65	0-75	0-75
PIP	0-110	10-30	(10)20-70	(5)10-70	(0)10-70	(0)10-95	(0)10-95	(0)10-95
DIP	0-60	0-20	0-40	0-40	0-55	0-45	0-65	0-65

AROM = active ROM; MCP = metacarpophalangeal; PIP = proximal interphalangeal; PROM = passive ROM; ROM = range of motion; + = hyperextension.

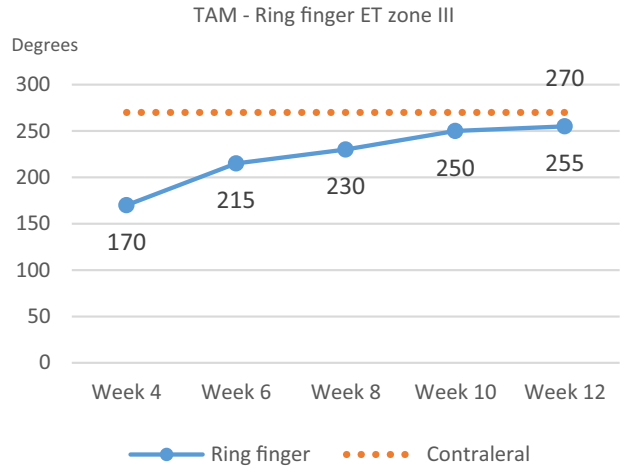

Fig. 11. TAM ring finger (case 1). ET = extensor tendon; TAM = total active motion.

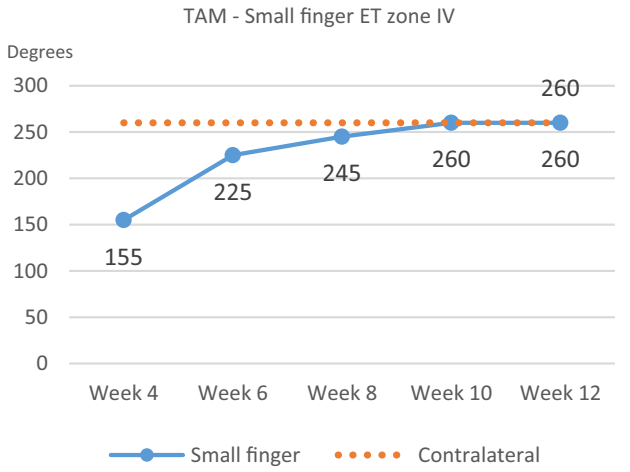

Fig. 12. TAM small finger (case 1). ET = extensor tendon; TAM = total active motion.

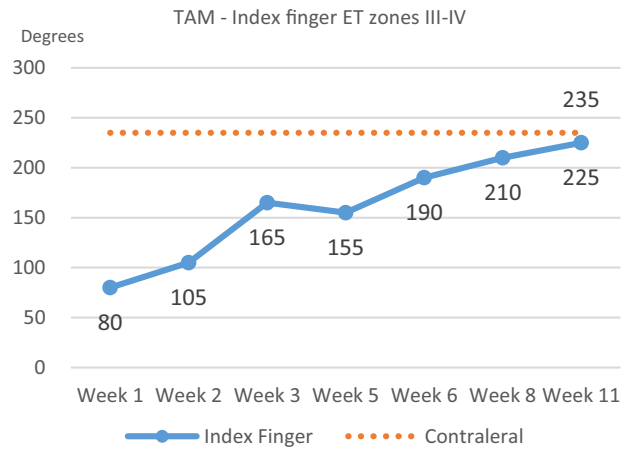

Fig. 13. TAM index finger (case 2). ET = extensor tendon; TAM = total active motion.

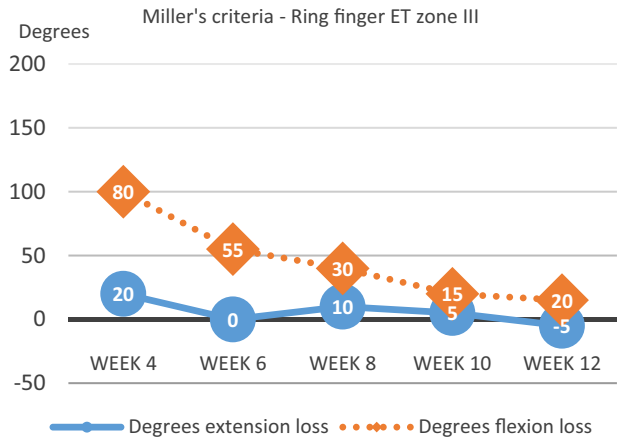

Fig. 15. Miller's criteria ring finger (case 1). ET = extensor tendon.

differential excursion. (Fig. 8A) At week 2, the wrist orthosis was reduced to PRN, the RME orthosis narrowed to permit greater index and long PIPJ flexion (Fig. 8B), and exercises were adjusted to correct the ROM limitations in active index MCPJ flexion and the 10° passive/20° active deficit in PIPJ extension of both fingers. At week 3, the passive/active ROM deficits improved in the long finger and were eliminated in the index finger, which is indicative of better excursion of the extensor hood over the proximal phalanx. Given the improved PIPJ extension and extensor hood excursion, PIP-DIPJ flexion exercises for both fingers were begun out of the orthosis and passive/active long finger PIPJ extension continued (Figs. 9A-9D). At week 5, the long finger extensor digitorum communis (EDC) was centralized and nonpainful, so gentle fisting exercises without the RME orthosis were added. At week 6, the long finger EDC remained asymptomatic, so the RME orthosis was fully discontinued. Given the persistent long finger PIPJ extension lag, HV was cautioned not to exercise to end range in her active or passive composite PIP/DIPJ flexion (hook fist) and full fist as this may worsen the lag. HV continued exercises beyond the final week 11 therapy appointment (Figs. 9A-9E). Figure 10 provides a summary of RME orthosis wearing timetable.

Results

A summary of the results for each case are described in Table 5. Raw ROM scores are detailed in Table 6 (case 1) and Table 7 (case 2).

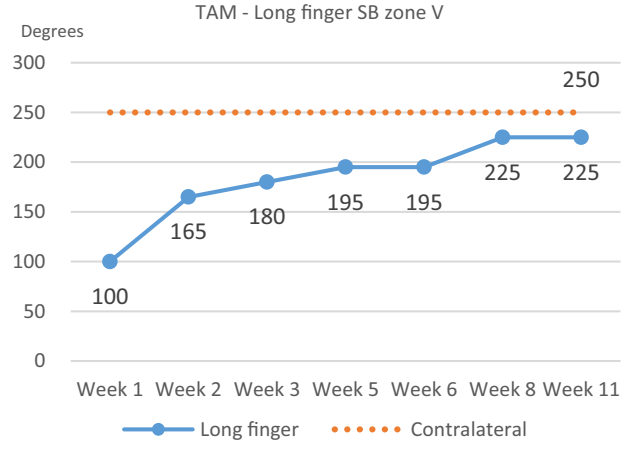

Fig. 14. TAM long finger (case 2). TAM = total active motion.

TAM measures are shown in Figures 11 and 12 (case 1) and in Figures 13 and 14 (case 2). Miller's criteria measures are shown in Figures 15 and 16 (case 1) and in Figures 17 and 18 (case 2). A video showing hand movement is linked here for case 1 (Video 1) and for case 2, patient provided photos at 14 weeks showing continued improvement. (photos linked here) (Video 2).

Discussion

Both JD and HV recorded comparable ROM in similar timeframes for each of their injured fingers to those reported for single finger injuries managed by relative motion,[3,6,10,11] palmar orthosis to the PIPJ,[3,5,7] SAM,[21,22] and dynamic extension assist orthoses.[12-14] Both patients considered their rehabilitation a success, returned to unrestricted work between 6 and 7 weeks after injury and reported no functional limitations at 11-12 weeks after surgery.

We believe that the common complication of tendon adherence over the proximal phalanx was mitigated by the RM orthoses facilitation of early active motion. While alternative early motion programs may have yielded similar outcomes, clear benefits of the RM approach were our ability to manage adjacent finger concomitant injuries with a single low-profile orthosis and immediately perform light functional tasks with the injured hand.

Regular assessment of ROM and examination was essential to guide each therapist's modifications of the exercise and orthosis

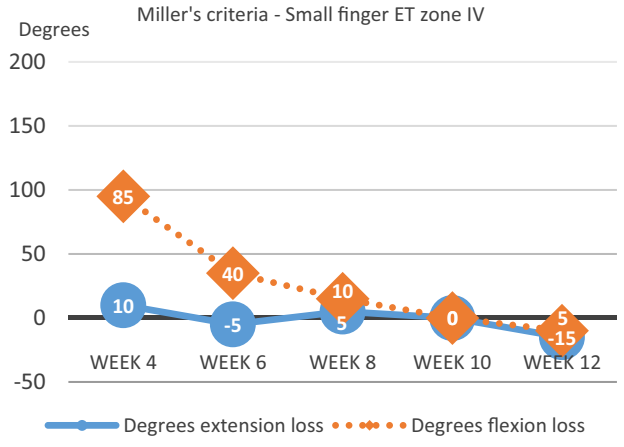

Fig. 16. Miller's criteria small finger (case 1). ET = extensor tendon.

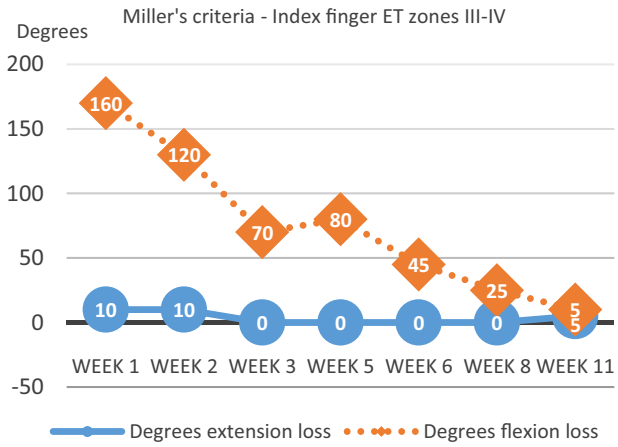

Fig. 17. Miller's criteria index finger (case 2). ET = extensor tendon.

programs. Clinical decisions such as in case 1 to commence passive IPJ flexion exercises at week 4 in the absence of proximal adhesions would not have been implemented had tethering been evident. Similarly, in case 2, had the EDC not been centralized and pain-free at week 5 at the sagittal band repair, composite finger flexion exercises without the orthotic would have been delayed until asymptomatic. We believe that our clinical reasoning which integrated anatomical knowledge, measurement and clinical examination contributed to our "excellent and good" outcomes.

On reflection of case 1, JD could have worn the RM orthosis full-time rather than changing at night to the hand-based orthosis (Fig. 2), although the impact of doing this is unknown. MH was of the opinion that the night orthosis would be more comfortable for JD than full time RM orthosis application and also potentially decrease any ET lag by having both injured fingers IPJs resting in neutral overnight, rather than a flexed position in the RM orthosis. In hindsight, obtaining passive ROM measurements would have clarified if PIP extension loss was due to extensor lag, PIP capsular tightness, or long flexor extrinsic tightness restricting PIP extension. MH believes that the position of JD's index finger in the orthosis was not important, as it could have joined the long finger in relative extension or been excluded altogether for a 3-finger as opposed to 4-finger RM orthosis.

Regardless of the changes made to the exercise program for case 2, the long finger PIP extension lag was not corrected. JH's

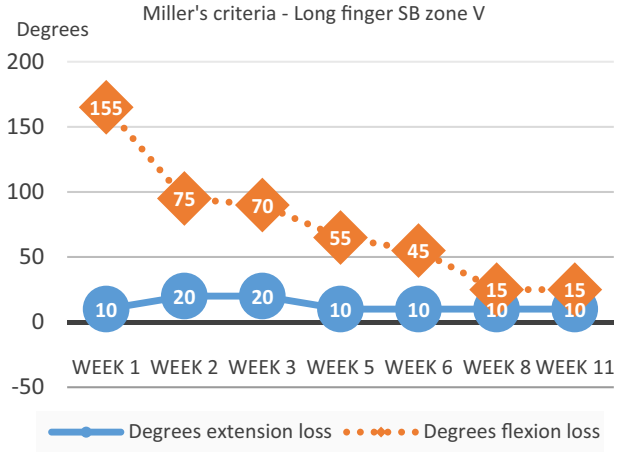

Fig. 18. Miller's criteria long finger (case 2).

theory is that the position of +15°/+10° MCPJ extension in the RM orthosis during weeks 1-2 created ET bunching proximal to the sagittal band, thereby reducing the amount of ET/sagittal band proximal excursion, which in turn may have caused limited excursion by adhesion of the extensor hood over the proximal phalanx which resulted in an active PIPJ extension lag. Figures 6A and 6B clearly illustrates the long finger injury was not merely a radial sagittal band tear, but a large interosseous muscle compartment laceration that required a surgical drain which JH believed set the stage for a strong inflammatory response which included skin, muscle, and tendon. This notion is supported by persistent adherence of the ET zone V (Fig. 8B-8D). Furthermore, involvement of the radial intrinsic muscle was evidenced by HV's inability to abduct her finger when first out of the orthosis. In hindsight, perhaps, these issues may have been addressed by making the RME orthosis with the injured digits in less hyperextension to permit more ET/sagittal band/intrinsic excursion. The radial intrinsic muscle fibrosis and weakness responded positively to exercises directed at long finger radial abduction which were added once out of the RM orthosis.

Limitations were that independent assessment was lacking, although neither therapist had planned to publish at the time of treatment. Outcomes for the 50% (case 1) and longitudinal (case 2) central slip lacerations may have been different had both been complete transverse central slip lacerations. Finally, these are unique case reports, there were no comparison groups; however, we hope our case management gives insight to clinicians should they encounter similar situations.

Future studies might benefit from standardized functional assessments, although self-reported hand use at week 1, orthosis acceptance, and early return to work for JD and HV were positive.

Conclusions

These case reports demonstrate that the RM approach can be adapted to combine RMF/RME to treat 2 injuries on the same hand and that the RME orthosis widened to manage adjacent finger ET/sagittal band injuries. RM eliminated the need for multiple, cumbersome orthoses which cost more and impede usual function. It is imperative that selection and application of RM orthoses be combined with clinical reasoning to optimize outcomes.

Acknowledgments

The authors extended their thanks to our patients for trusting us with our clinical reasoning to apply unique orthoses in the post-operative management of their injuries.

Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jht.2017.04.006

References

1. Newport ML, Blair WF, Steyers Jr CM. Long-term results of extensor tendon repair. *J Hand Surg.* 1990;15(6):961–966.
2. Evans RB. An analysis of factors that support early active short arc motion of the repaired central slip. *J Hand Ther.* 1992;5(4):187–201.
3. Peelman J, Markiewitz A, Kiefhaber T, Stern P. Splintage in the treatment of sagittal band incompetence and extensor tendon subluxation. *J Hand Surg Eur Vol.* 2015;40(3):287–290.
4. Rayan GM, Murray D. Classification and treatment of closed sagittal band injuries. *J Hand Surg.* 1994;19(4):590–594.
5. Inoue G, Tamura Y. Dislocation of the extensor tendons over the metacarpophalangeal joints. *J Hand Surg.* 1996;21(3):464–469.

6. Catalano 3rd LW, Gupta S, Ragland 3rd R, Glickel SZ, Johnson C, Barron OA. Closed treatment of nonrheumatoid extensor tendon dislocations at the metacarpophalangeal joint. *J Hand Surg*. 2006;31(2):242–245.
7. Capo JT, Shamian B, Rossy W, Hashem J. Closed sagittal band injury due to low energy trauma. *Am J Orthop*. 2012;41(8):374–377.
8. Young CM, Rayan GM. The sagittal band: anatomic and biomechanical study. *J Hand Surg*. 2000;25(6):1107–1113.
9. Evans RB. Immediate active short arc motion following extensor tendon repair. *Hand Clin*. 1995;11(3):483–512.
10. Howell JW, Merritt WH, Robinson SJ. Immediate controlled active motion following zone 4-7 extensor tendon repair. *J Hand Ther*. 2005;18(2):182–190.
11. Svens B, Ames E, Burford K, Caplash Y. Relative active motion programs following extensor tendon repair: A pilot study using a prospective cohort and evaluating outcomes following orthotic interventions. *J Hand Ther*. 2015;1(28):11–19.
12. Maddy LS, Meyerdierks EM. Dynamic extension assist splinting of acute central slip lacerations. *J Hand Ther*. 1997;10(3):206–212.
13. O'Dwyer FG, Quinton DN. Early mobilisation of acute middle slip injuries. *J Hand Surg*. 1990;15(4):404–406.
14. Pratt AL, Burr N, Grobbelaar AO. A prospective review of open central slip laceration repair and rehabilitation. *J Hand Surg*. 2002;27(6):530–534.
15. Howell JW, Hirth MJ. *Tips and tricks for using relative motion splinting for extensor tendon injuries. 9th Triennial Congress of the IFSHT*. New Delhi: India; 2013.
16. Lalonde D. *Wide Awake Hand Surgery*. 1st ed. Boca Raton: CRC Press; 2016.
17. Gibson G. Goniometry. In: MacDermid JC, ed. *Clinical Assessment Recommendations*. 3rd ed. USA: American Society of Hand Therapists; 2015:71–80.
18. Kleinert HE, Verdan C. Report of the Committee on Tendon Injuries (International Federation of Societies for Surgery of the Hand). *J Hand Surg*. 1983;8(5 Pt 2):794–798.
19. Miller H. Repair of severed tendons of the hand and wrist; stastical analysis of 300 cases. *Surg Gynecol Obstet*. 1942;75:693–698.
20. Schectman O, Sindu BS. Grip Assessment. In: MacDermid JC, ed. *Clinical Assessment Recommendations*. 3rd ed. USA: American Society of Hand Therapists; 2015:1–8.
21. Evans RB. Early active short arc motion for the repaired central slip. *J Hand Surg*. 1994;19A(6):991–997.
22. McAuliffe JA. Early active short arc motion following central slip repair. *J Hand Surg*. 2011;36A(1):143–146.