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Use of a relative motion flexion orthosis for postoperative management of zone I/II flexor digitorum profundus repair: A retrospective consecutive case series

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ABSTRACT

Study Design: A retrospective, single-center, consecutive case series.
Introduction: In concept, a relative motion flexion (RMF) orthosis will induce a "quadriga effect" on a given flexor digitorum profundus (FDP) tendon, limiting its excursion and force of flexion while still permitting a wide range of finger motion. This effect can be exploited in the rehabilitation of zone I and II FDP repairs.
Purpose of the Study: To describe the use of RMF orthoses to manage zone I and II FDP 4-strand repairs.
Methods: Medical record review of 10 consecutive zone I and II FDP tendon repairs managed with RMF orthosis for 8 to 10 weeks in combination with a static dorsal blocking or wrist orthosis for the initial 3 weeks.
Results: Indications included sharp lacerations ($n = 6$), ragged lacerations ($n = 2$), staged flexor tendon reconstruction ($n = 1$), and type IV avulsion ($n = 1$). In 8 of the 10 cases that completed follow-up, the mean arc of proximal interphalangeal/distal interphalangeal active motion were as follows: sharp, 0° to 106°/0° to 75°; ragged, 0° to 90°/0° to 25°; reconstruction, 0° to 90°/10° to 45°; and avulsion, 0° to 95°/0° to 20°. Grip performance available for 6 of 10 cases was 62% to 108% of the dominant hand. There were no tendon ruptures, secondary surgeries, or proximal interphalangeal joint contractures.
Conclusion: Based on this small series, the RMF approach appears to be safe and effective. It can lead to similar mobility and functional recovery as other early active motion protocols, with certain practical advantages and without major complications. Further investigation with larger, multicenter, prospective, longitudinal cohorts and/or randomized clinical trials is necessary.

Introduction

There has been a worldwide shift in the use of relative motion extension (RME) orthosis for the management of zones IV-VII extensor tendon repairs of the fingers.[1,2] This strategy exploits the "quadriga effect" in the extensor digitorum communis (EDC) tendons by positioning the involved digit's metacarpophalangeal (MCP) joint in moderate extension relative to the adjacent MCP joints.[3-6] Similar to the EDC, the flexor digitorum profundus (FDP) muscle has multiple tendons and thus, in concept, is amenable to this strategy.[3,5,6] To impose the "quadriga effect" on the FDP, the involved MCP joint is positioned in moderate flexion relative to the adjacent MCP joints. Because a relative motion flexion (RMF) orthosis is worn full-time, the "quadriga effect" starts as soon as the orthosis is applied, protecting the flexor tendon repair as the fingers actively move through a wide range of motion and functional hand use.[6] Figures 1A and 1B.

Biomechanical studies have offered some "proof of concept" for the "quadriga effect" levied by RMF orthoses.[7,8] In an FDP zone III cadaver study, Chung et al. replicated the RME biomechanical model of Sharma et al to measure tendon elongation in repaired and intact FDP tendons in and out of RMF orthoses.[7,9] The results confirmed that RMF orthoses decreased elongation in both intact and repaired FDP tendons with less than 2-mm elongation compared with repairs without the RMF orthosis that gapped.[7] Another group of investigators designed a "differential splint" that imitates an RMF orthosis to measure flexion forces and tendon excursion in the fingers of healthy subjects. Measurements were taken while the subjects were wearing the differential splint

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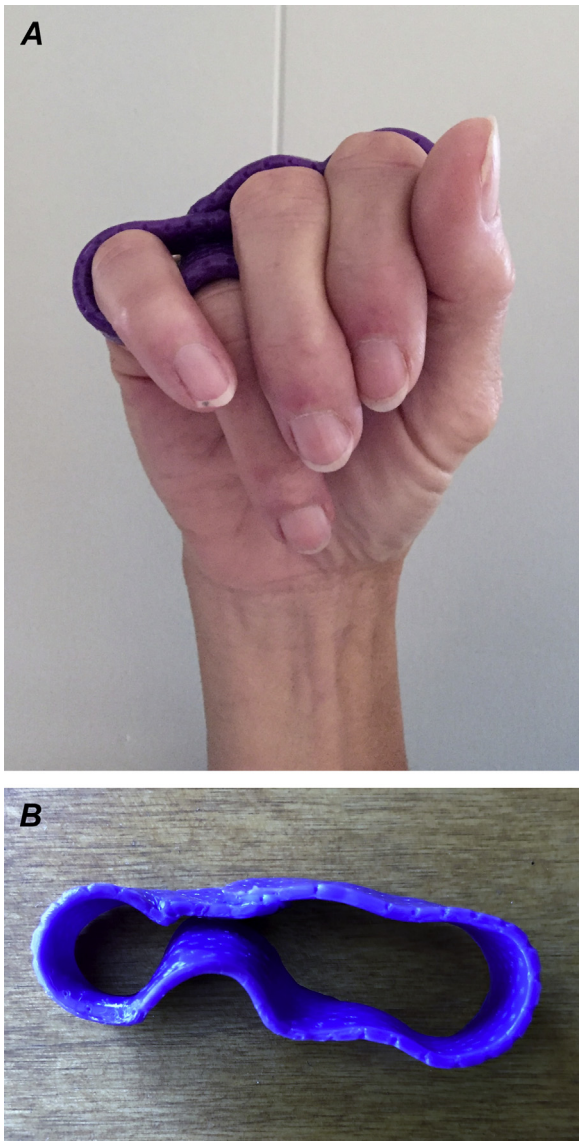

Fig. 1. (A) Relative motion flexion (RMF) orthosis with the ring finger in relative MCP joint flexion. (B) RMF orthosis closed-loop configuration for the right ring finger.

with the relatively flexed position of the MCP joint changed between the angles of 0°, 15°, 30°, and 45°.[8] These investigators concluded that less flexion force was generated as relative MCP joint flexion increased, particularly at relative MCP joint flexion of 30° and 45°, and tendon excursion decreased as MCP joint flexion increased.[8]

As early active motion (EAM) approaches are being more routinely used in the rehabilitation of multistrand repaired zone I/II FDP tendons, consideration to an RMF orthosis as an EAM approach is within reason, given the results of the "proof-of-concept" biomechanical studies and the safe use of RME orthoses in the management of extensor tendon repairs. If RMF orthoses are added to the toolbox of existing EAM approaches, it would offer an option that is simple and practical and permits active finger motion and functional hand use without having to remove the orthosis—in other words, a "move it and (progressively) use it" EAM approach.

The purpose of this article is to describe what is, to the best of our knowledge, the first clinical use of RMF orthoses in the postoperative management of FDP tenorrhaphies. This report consists of a retrospective consecutive case series of ten zone I or II FDP repairs managed with RMF orthoses as an EAM approach for 8 to 10 weeks in combination with a static dorsal blocking orthosis or wrist orthosis for the initial 3 weeks. In addition, the results from this series are compared with other recently published EAM approaches and orthoses used in the postoperative management of zone I/II FDP injuries.

Methods

This retrospective, single-center, consecutive case series was approved by the Investigational Research Board of Dell Medical School at the University of Texas. The patient records of one hand surgeon (S.L.H.) were searched manually by the primary author to identify all consecutive patients who underwent zone I or II FDP repair followed by rehabilitation with RMF orthoses, excluding those who did not. All patients who qualified signed a standard consent form.

One fellowship-trained hand surgeon with 10 years of practice experience (author S.L.H.) performed all repairs. Primary FDP tenorrhaphies were completed with a 4-strand Kessler-Pennington core suture with 4 to 0 FiberWire (Anthrax, Naples, FL) followed by a running simple epitendinous suture with 6 to 0 Prolene. Cases involving repair of the FDP to the distal phalanx used a 3 to 0 Prolene tie-over button technique. Pulleys were vented as necessary, and concomitant, one-slip flexor digitorum superficialis injuries were not repaired. For immobilization, a forearm-based dorsal blocking plaster splint was applied postoperatively. When possible, the initial hand therapy appointments were scheduled within the first week after surgery. Five certified hand therapists (CHTs) from community-based settings provided the postoperative management. These CHTs made the orthoses for all ten patients, with 8 of 10 managed in hand therapy and 2 of 10 managed by the surgeon because of health insurance coverage issues. The initial 8 of 10 RMF orthoses were fabricated from a low-temperature thermoplastic, and the last 2 of 10 from thermoplastic tape (Orficast; Orfit Industries, Belgium). Each 4-finger designed RMF orthosis positioned the involved digit's MCP joint in 30° to 40° of flexion relative to the adjacent MCP joints. The initial 3 of 10 cases wore a custom static dorsal wrist-hand-finger orthosis (WHFO), with the wrist in 0° to 20° flexion along with the RMF orthosis. Subsequent cases wore a prefabricated static volar wrist-hand orthosis (WHO) with the wrist in 0° to 20° extension along with the RMF orthosis.

For this retrospective study, access to patient therapy records for review was not possible, and there were no written protocols for postoperative management. To compile a summary of the postoperative management, a CHT not involved in the management of the patients in this series (author J.W.H.) led semistructured telephone and email interviews with the hand surgeon and 4 of 5 CHTs, and what follows is a synopsis of the postoperative management information obtained in these interviews (Appendix 1). The hand surgeon saw each patient after the hand therapists issued the orthoses. During the surgeon's appointment, patients were advised to wear both orthoses full-time except for hand hygiene for the initial three weeks postoperatively, to move their fingers actively as allowed by the RMF orthosis, and to avoid strenuous lifting and squeezing with their surgical hand. The hand surgeon also instructed all patients to perform exercises consisting of passive composite interphalangeal (IP) joint flexion, passive IP joint extension to neutral with the MCP joint flexed, and active finger motion in the RMF orthosis. The operated hand was available for light use provided this did not conflict with the advice previously given. At 3 weeks postoperatively, wearing of the RMF orthosis continued full-time with the WHFO or WHO worn only for sleep and "at risk" activities. At this time, safe functional hand use was

Table 1
Patient demographics

Case	Age/gender	Digit/zone	Dominant hand	Mechanism	Injured	Repaired	Days between injury and repair	Days between repair and therapy	Occupation	Insurance
1	18/M	Ring/II	Yes	Knife	FDP RDN	All	3	5	Unemployed	No
2	17/M	Ring/II	Yes	Knife	FDP FDS-R	FDP	9	5	Unemployed	No
3	17/M	Long/I	Yes	Knife	FDP UDN	All	23	6	Unemployed	No
4	40/M	Long/II	Yes	Staged tendon graft	FDP	FDP	217	20	Tool technician	Yes
5	49/M	Long/I	No	Saw	FDP RDN RDA	All	6	5	Backhoe operator	Yes
6	49/M	Long/II	No	Saw	FDP RDN UDN	All	11	13	Machine fabricator	Yes
7	22/F	Ring/I	No	Type IV avulsion	FDP P3	All	10	6	Restaurant manager	Yes
8	19/M	Ring/II	No	Knife	FDP	FDP	0	6	Unemployed	No
9	21/F	Index/II	No	Knife	FDP FDS-R	FDP	0	6	Clerical assistant	Yes
10	12/F	Small/II	Yes	Knife	FDP	FDP	5	18	Student	Yes

FDS = flexor digitorum profundus; RDA = radial digital artery; RDN = radial digital nerve; UDN = ulnar digital nerve; R = radial slip of flexor digitorum superficialis; P3 = fracture of finger distal phalanx.

described as the use of both hands to lift a light bag, and an example of "at risk" activity was described as jogging. At 6 weeks postoperatively, wear of the RMF orthosis continued full-time, the WHFO or WHO was discontinued, and a safe functional use was described as bilateral lift weighing no more than a gallon of water (approximately 8 pounds [3.5 kg]). Throughout the initial six weeks after surgery, patients were advised not to strenuously lift or grip with their postsurgical hand. Wearing the RMF orthosis and all restrictions ended between eight to ten weeks after surgery.

The hand surgeon took the final measurements during each patient's final visit. Measurements included active range of motion of the IP joints, grip performance, and observation of the quality of finger movement. Standardized tools and methods were used to obtain range of motion and grip performance.[10] Evaluation of range of motion applied the original formula described by Strickland and Glogovac to calculate the percentage of total active motion (TAM) and grade.[11] Grip performance was expressed as a percentage of the dominant hand force output. Complications and time to return to work were noted.

Results

Ten patients underwent zone I or II FDP repair and postoperative rehabilitation with RMF orthoses between 2010 and 2018. In this series, there were seven males and three females, mean age 26 years, varying in age from 12 to 49 years with an equal number of dominant and nondominant hand injuries, most often involving the long and ring fingers (Table 1). Injuries in 7 of 10 patients included damage to other structures, some repaired and others not (Table 1). The type and number of injuries were: $n = 6$ sharp, $n = 2$ ragged, $n = 1$ staged flexor reconstruction after removal of silastic rod and placement of a palmaris longus tendon graft, and $n = 1$ type IV FDP avulsion involving the volar base of the distal phalanx with rupture of the FDP insertion from the fracture fragment (Table 1).[12] Time from injury to repair was 11 days or less for 8 out of 10 cases, one at day 23 and the staged tendon reconstruction case at day 217. Orthoses fabrication for 7 of 10 cases occurred on postoperative day five or six, and others on day 13, 18, and 20 (Tables 1 and 2). Two of the knife-injured patients (case 1 and case 8) failed to return after the 3-week postsurgical follow-up, so their outcomes are unknown and are not included in the final analysis. Two patients (case 2 and case 3), who faced health insurance coverage issues, had their orthoses fabricated in hand therapy and had surgeon-guided rehabilitation on a weekly basis for one month and then seen monthly thereafter. All remaining patients were managed on regular basis, at least weekly schedules by hand therapy. Because the patient records for hand therapy were not available for review, details such as the number of visits, specific interventions, and therapy costs cannot be included in this report. Information obtained from the semistructured interviews of 4 out of 5 CHTs established that each patient's hand therapy visits involved modification of the patient's exercises and orthosis contingent based on the therapist's clinical findings for that session. An example of an orthosis modification is shown in Figures 2A-2C which is done to accommodate for excessive edema of the small finger. Weekly therapy sessions were increased in number after the third postoperative week at the therapist's discretion if, for example, the patient's hand was unusually stiff or the patient needed to prepare for return to work. Occasionally modalities such as paraffin or ultrasound were introduced by some therapists to address scar adhesion or resistant finger stiffness.

Table 2
Results

Case	Follow-up	PIPJ AROM (degrees)	DIPJ AROM (degrees)	%TAM[a]/grade, Strickland and Glogovac[13]	Grip performance injured/uninjured (% of dominate hand in kilograms)	Return to work (days)
1	3 w	Inadequate follow-up				
2	6 m	0-100	0-60	91/Excellent	40[b]/38 (105%)	Unemployed
3	12 m	0-105	0-80	106/Excellent	30[b]/28 (107%)	Unemployed
4	72 m	0-90	10-45	71/Good	48[b]/77 (63%)	90
5	9 m	0-90	0-30	69/Fair	Not recorded	45
6	12 m	0-90	0-20	63/Fair	27/41 (66%)	112
7	72 m	0-95	0-20	66/Fair	Not recorded	80
8	3 w	Inadequate follow-up				
9	8 m	0-110	0-80	109/Excellent	18/18 (100%)	7
10	5 m	0-110	0-80	109/Excellent	16[b]/16 (100%)	Student

m = months; PIPJ = proximal interphalangeal joint; DIPJ = distal interphalangeal joint; AROM = active range of motion; TAM = total active motion
[a] TAM percentage = (PIP flexion + DIP flexion) - degrees (PIP + DIP extension loss)/175°.
[b] Dominant hand.

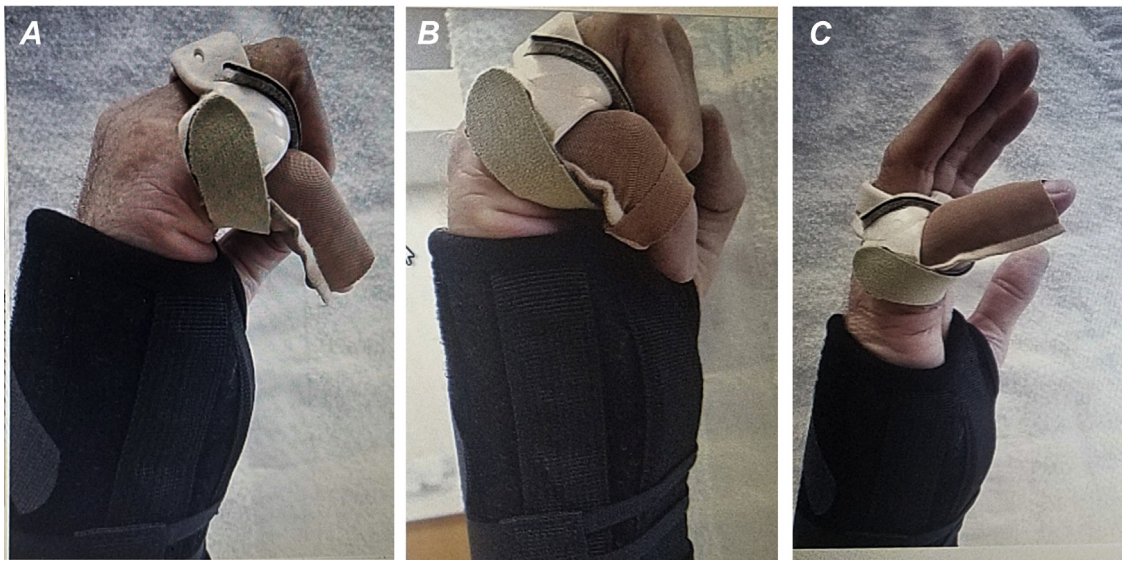

Fig. 2. Modification made to accommodate a postsurgical edematous small finger (A) compression sleeve and soft expandable volar strap. (B) RMF orthotic modification does not interfere with digital flexion. (C) The RMF orthotic modification does not interfere with finger extension. Notice the combination of a prefabricated wrist orthosis with a custom RMF orthosis. RMF = relative motion flexion.

The hand surgeon's final follow-up measurements for the remaining 8 of 10 patients were taken between five and 72 months postoperatively (Table 3). Each patient's range of motion is noted in Table 2. The mean active range of motion for the four sharp injuries at the PIP joint was 0° to 106° (flexion min-max: 100°-110°) and at the DIP joint was 0° to 75° (flexion min-max: 60°-80°) (Figures 3

Table 3
Comparison between eight recent early active motion (EAM) studies, including EAM with relative motion flexion (RMF) orthoses for postoperative management of zone I/II flexor tendon repairs

Author	Suture material peripheral	Flexor zone Simple/ complex	Type of orthosis	Tendon rupture(n) Rupture rate (%)	Tenolysis (n)	Start EAM(days)	EAM approach used notes Exercise "out of orthosis" Yes/No/NA	D/C orthosis (week)
Henry 2019 *P* = 10 *D* = 10	4-Strand FiberWire Yes	I-II S&C	RMF + WHFO RMF + WHO	0 0%	0	5-6	Relative motion NA	8-10
Geisen 2018 *P* = 29 *D* = 27	6-Strand FiberWire No	Ic-II S	WHFO	0 0%	4	ASAP	CAM protocol per Elliot,[14] also modified by Geisen No	No data
Peck 2014 *P* = 28 *D* = 28	4-Strand Unknown Unknown	II S	WHFO	2 7%	No data	4-5	Manchester protocol No	6
Frueh 2014 *P* = ? *D* = 21	4-Strand FiberWire Yes	I-II S	WHFO	1 4% 7%	Yes	3-5	CAM Protocol unknown No	6
Evans 2005 *P* = 41 *D* = 41	2-strand Unknown unknown	I S	WHFO FO	3 7%	No data	3	LEAF Protocol	
Moiemen 2000 *P* = 89 *D* = 93	Core suture + tie over Modified Kirchmayr Kessler Yes	I Bone Tendon S&C	WHFO	4 4%	4	1-3	"Several" CAM/EAM Regimens No	No data
Prowse 2011 *P* = 34 *D* = 39	2-Strand 4-0 Prolene 6-0 Prolene	II S&C	WHFO	4 10%	No data	3- 5	Modified as per study of Small et al[15] No	5
Topa 2011 *P* = 26 *D* = ?	Unknown Unknown Unknown	II No data	WHFO	No data No data	No data	No data	CAM as per the study of Gratton[16] No	No data

? indicates that the data is unknown or not available.
EAM = early active motion; D/C = discontinue; P = patients; D = digits; S = Simple; S&C = simple & complex; CAM = controlled active motion; WHFO = wrist-hand-finger orthosis; WHO = wrist-hand orthosis.

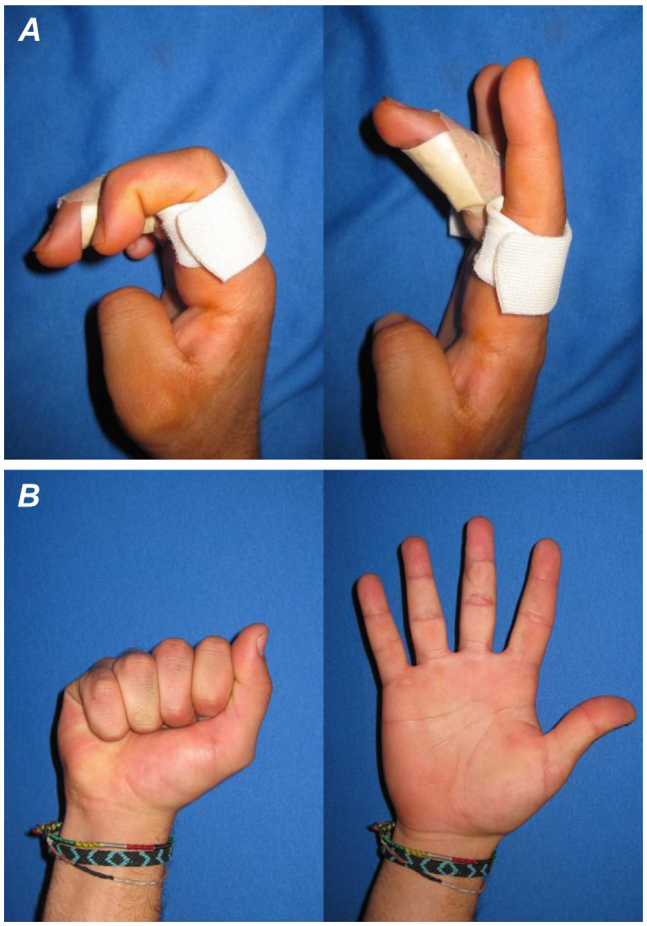

Fig. 3. (A) Case 3, a 17-year-old male who sustained a sharp laceration of the long finger at zone I FDP and a 23-day delay to repair, demonstrates active motion wearing an RMF orthosis fabricated from thermoplastic at less than 2 weeks after surgery. (B) Thirteen weeks after surgery, case 3 demonstrates full active motion. RMF = relative motion flexion; FDP = flexor digitorum profundus.

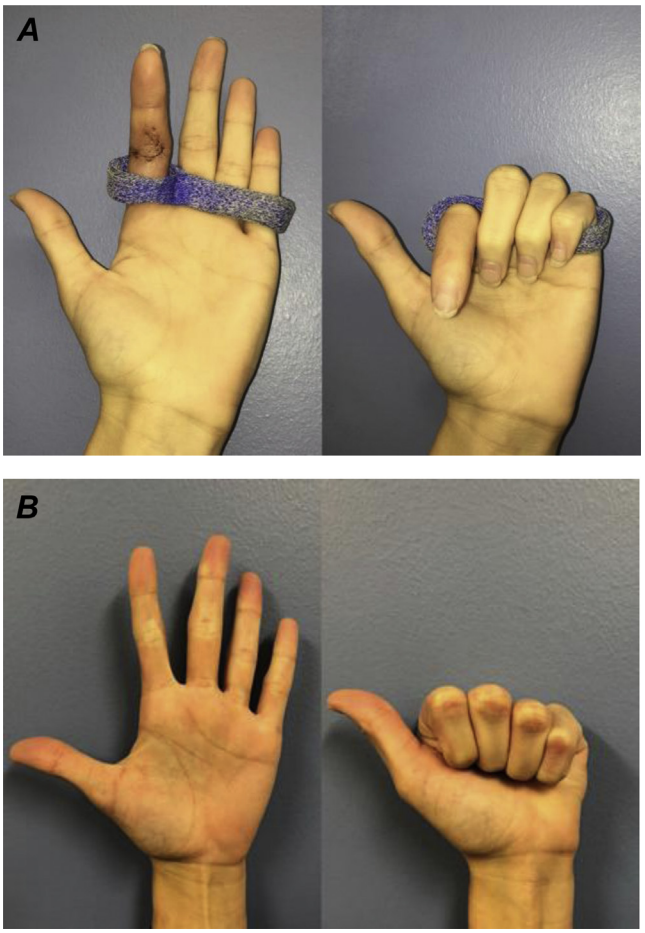

Fig. 4. (A) Case 9, a 21-year-old female who sustained a sharp laceration of the index finger at distal zone II FDP, repaired on the day of injury. Active motion observed at 4 weeks after surgery while wearing an RMF orthosis fabricated with thermoplastic tape. (B) Eight months after operation, case 9 demonstrates full active motion. RMF = relative motion flexion; FDP = flexor digitorum profundus.

and 4). The 2 ragged injuries had PIP joint flexion of 0° to 90° and DIP joint motion of 0° to 25° (flexion min-max: 20°-30°). The patient with the staged flexor reconstructions had a PIP joint motion of 0° to 90° and DIP joint motion of 10° to 45°. The patient with a type IV FDP avulsion had a PIP joint motion 0° to 95° and DIP joint motion of 0° to 20°. The TAM grades as described by Strickland and Glogovac[11] were as follows: 4 excellent, 1 good, and 3 fair (Table 2). A normal quality of motion (Supplemental Videos 1 and 2) was observed in all patients. The mean percentage of the dominant hand's grip performance for 6 of 10 patients was 90% (varying from 63 to 107). Patients who were employed before injury returned to their previous work duties at a mean duration of 9.5 weeks (varying from 7 to 112 days) (Table 2). In the 8 patients who completed postoperative management, there were no tendon ruptures, no secondary procedures, and no PIP joint flexion contractures. Six years after the final follow-up visit, the patient with the type IV FDP avulsion elected to have the DIP joint fused secondary to post-traumatic arthritis pain.

Discussion

To our knowledge, this is the first series to have used RMF orthoses as an EAM approach for postoperative management of zone I-II FDP repairs. EAM in a RMF orthosis was initiated in most patients within the first week after surgery, making a wide range of active finger motion and light functional use of the injured hand available. Postoperative management was completed by 8 out of 10 patients with no tendon ruptures, no secondary surgeries, and no PIP joint flexion contractures. Two out of 10 (20%) patients were lost to follow-up after 3 weeks, with unknown outcomes, although no complications were evident at that time. More total active IP joint flexion was recovered in the sharp injuries and tendon reconstruction cases, 170° (mean PIP flex 98° + DIP flex 72°), than the ragged injuries and type IV FDP avulsion cases, 117° (mean PIP flex 92° + DIP flex 25°). The return-to-work timeframe, not routinely reported by others (Table 2), was a mean of 9.5 weeks for these cases with various occupations.[17]

The EAM studies published since 2011, listed in Table 3, including this series, reflect the surgical trend to use 4- to 6-strand core suture techniques with strong low-glide resistance suture material and vent pulleys and not repair slips of the FDS, followed by postoperative use of EAM. The complexity of the injuries managed with RMF orthoses in this series included single and multiple tendons, with and without digital nerve involvement, staged tendon reconstruction, and type IV FDP avulsion, which is quite different from other EAM reports that include mostly single FDP tendon with/without digital nerve injuries (Table 3).[18-21] Recovery of range of motion in zone II FDP injuries has been directly correlated with the severity of injury,[22] and zone I FDP injuries have been associated with more IP joint contractures, more loss of FDS excursion, and greater dissatisfaction with appearance and

fingertip dexterity than zone II FDP injuries.[23-25] In this series, recovery of range of motion was graded "fair" in 3 out of 10 cases, which included a single ragged zone II injury, and one each ragged and crush-type zone I injury (Tables 1-2). For these patients, the severity of injury appeared to affect TAM more than zone of injury. Regardless of zone, all 3 "fair" cases had substantial loss of active DIP joint motion and incomplete active PIP joint flexion (Tables 1-2). In the type IV FDP avulsion case, the failure to recover DIP joint flexion may be a result of the k-wire placement across the joint for 3 weeks, yet the use of EAM with a RMF orthosis may have prevented stiffness in the adjacent joints and digits. In this series, a sharp mechanism of injury was associated with "good/excellent" TAM more than the zone of injury, although concluding this is difficult given the small numbers in this limited series and the zone distribution was evenly divided (Table 1). "Good/excellent" TAM grades have also been associated in less complex cases by the authors of other EAM approaches (Table 3).[18-21]

Recent commentary did suggest an increased trend for EAM exercises to be performed "out of the orthosis,"[13] although the studies overviewed in Table 1 mostly describe EAM exercises performed while "in the orthosis" for at least the initial 3 weeks postoperatively.[18-21,23,24,26] Whether EAM exercises are performed in or out of the orthosis is where EAM with RMF orthoses vastly differs from other EAM approaches. For as soon as the RMF orthosis is applied, EAM can begin because of the "quadriga effect" levied by the orthosis. The only other EAM approach that we are aware of to advise functional use of the hand is that described by Peck et al. who used the short Manchester splint.[18] These authors permit functional use provided the involved finger is excluded and any resisted flexion avoided.[18] Otherwise, most EAM approaches (Table 3) delayed progressive functional hand use until the orthosis is discontinued between 5 to 7 weeks postoperatively; in this series, the patients were already fully engaged in functional use of their hand when the RMF orthosis was discontinued entirely until between 8 to 10 weeks postoperatively.[19-21,23,24,26]

The rate of tendon rupture is the gold standard against which flexor tendon repair and postoperative approaches have been historically compared. The only studies overviewed in Table 3 without tendon rupture include this series of 8 digits and Geisen et al.'s 27 digits for rupture rates of 0%; Peck et al had two tendon ruptures in 28 digits for a rupture rate of 7%, while Frueh et al. reported one tendon rupture in 21 digits for a rupture rate of 4%.[18-20] Interestingly, the surgeons in these four studies used a 4- to 6-strand core suture technique, and three of four used FiberWire (Arthrex) suture material, including the primary author (S.L.H.).[19,20] A higher rupture rate is reported when EAM is performed following a 2-strand core suture technique than core repairs of 4 to 6 strands (Table 3). The studies of Evans and Moiemen and Elliot were published in the early 2000s when the 2-strand core suture repair was the standard technique; the value in these classic reports is that each provides a foundation from which current FDP zone I EAM approaches can learn and be compared.[23,24] Evan's LEAF approach had 3 tendon ruptures in 41 digits for a rupture rate of 7%, and Moiemen and Elliot had 4 tendons rupture in 93 digits for a rupture rate of 4%.[23,24] A more recent 2011 report made clear that EAM and 2-strand FDP zone II repairs are not compatible, with 4 tendons rupturing in 39 digits for a rupture rate of 10%.[26] Because the need for a secondary tenolysis procedure after zones I-II FDP rehabilitation has been reported to be as high as 5%, some recommend it be reported alongside the percentage of tendon rupture.[23,24,27,28] The suggestion has been made that tenolysis rates might be higher; however, most patients with "fair/poor" TAM may function well enough and therefore do not want a second surgery.[27] Our series of cases had no tenolysis procedures. A comparison of these rates among EAM approaches when documented is provided in Table 3.

Important to realize is that no PIP joint in this series of patients had a flexion contracture as this is often cited as an unwanted outcome.[23-25,29] A possible explanation for this is related to the more relatively flexed position of the involved digit's MCP joint within the RMF orthosis. In concept, the more flexed position of the MCP joint causes relaxation of passive tension in the flexor system so that during active finger extension, the EDC force can be forwarded beyond the MCP joint and added to the extension forces of the intrinsic muscles to encourage full active extension of the PIP joint.[6] Simply by wearing the RMF orthosis, patients in this series engaged this chain of events throughout the day by actively, freely, and safely moving their fingers. Another possibility not used in this series of patients is that the more flexed MCP joint position in the RMF orthosis levies the "quadriga effect," which would allow for "out of wrist orthosis" controlled active wrist flexion. Peck et al also observed fewer PIP joint flexion contractures with the short Manchester orthosis than a longer orthosis, suggesting that by allowing some wrist flexion, passive tension of the long flexors is relaxed.[18]

The most commonly used metrics to report outcomes are the rate of tendon rupture, TAM, and percentage of TAM. In our series, each patient's measurements included range of motion and TAM calculated using the 1980 formula described by Strickland and Glogovac[11] for TAM (Table 4). Regretfully, many flexor tendon reports, including the EAM studies overviewed, use a variety of outcome assessment methods, making comparison difficult (Table 4). Of the studies overviewed for this article, the only comparison of TAM that can be made is between the zone I FDP repairs in our series and the FDP zone I cases of Moiemen and Elliot because the same method for calculating TAM was used and between Geisen et al and Frueh et al because both groups used the American Society for Surgery of the Hand TAM calculations (Table 4).[19,20,24] Flexor tendon repair studies often equate grip performance with function.[30] Grip performance in this series of patients was described as a percentage of the dominant hand. Once again, comparison is difficult since there is no universal standard, with some using a percentage or mean of the contralateral hand or others not reporting it at all.[18-20,23,24,31] The best point in time to take outcome measurements is debatable; however, May and Silfverskiold determined that range of motion in 145 digits after flexor tendon repair improved the most during the first 6 months, concluding at approximately 12 months postoperatively.[32] In our series, these outcome measurements were taken between 5 and 72 months after surgery, and Geisen et al averaged nine months, varying 5 to 14 months.[19] In a comparison study of early passive motion and EAM approaches, Frueh et al determined at 4 weeks that there was a significant difference in range of motion for the EAM group and that there was no difference between approaches at 12 weeks, suggesting that the EPM group caught up with the EAM group by the 12th week.[20] Among the studies overviewed, most measured outcomes at 12 weeks after surgery. Dropout rates are not always reported; in our small series, it was 20%, while another study reported a dropout rate of 30%.[18] Until this rate is well established by additional research, the reason for dropout cannot be linked, in our opinion, with such factors as the EAM approach used patient satisfaction or specific patient demographics.

Strengths of study

The strength of this series of case reports is that it is the first known account of postoperative management of zones I and II FDP repairs to use an EAM approach with RMF orthoses. Multiple CHTs used this approach successfully without protocols, managing patients with simple and complex injuries without the complications

Table 4
Total active motion (TAM) methods used by early active motion studies, including this series to report range of motion outcomes after zone I/II flexor tendon repairs, which make comparison difficult

Author Formula	Henry Original	Geisen[19] ASSH	Peck[18] Original	Frueh[20] ASSH	Evans[23] Original	Moiemen[24] Original	Prowse[26] ASSH	Topa[21] Original
TAM grade *n* (% of *n*)								
Excellent	4 (50%)	18 (67%)	22%	0%		33 (35%)		
Good	1 (13%)	6 (22%)	27%	65%		22 (24%)		
Fair	3 (38%)	2 (7%)	32%	35%		21 (23%)		
Poor	0 (0%)	1 (4%)	19%	0%		13 (14%)		
Other methods					Mean 142° % TAM Mean (81% or good)		TAM mean 182° varying 56°-254° Mean %TAM Mean (72% or fair) varying 21-81%	TAM Mean (81% or Good)
TAM%	Strickland Original[11]				American Society for Surgery of the Hand[10]			
Excellent	85-100				Normal			
Good	70-84				>75			
Fair	50-69				50-75			
Poor	<50				<50			
Formula	$\frac{(\text{Flexion PIP + DIP}) - (\text{extension deficit PIP + DIP})}{175°} \times 100\%$				TAM = (Flexion MCP + PIP + DIP) − (Extension deficit MCP + PIP + DIP) % = TAM injured digit/TAM contralateral digit			

TAM = total active motion; % TAM = percentage of total active motion; Formula = TAM for flexor tendon repairs; Original = Strickland & Glogovac; ASSH = American Society for Surgery of the Hand; *n* = patients; (% of *n*) = % of patients.

of tendon rupture, PIP joint flexion contractures, or secondary surgical procedures.

Limitations of study

The limitations of this series are that it is retrospective and small in number and that medical records for hand therapy were not available for review. All surgical procedures were performed by one experienced hand surgeon, raising the possibility that similar results may not be generalizable if widely adopted. Outcomes in this study did not appear to be influenced by the use of 2 different forearm-based orthoses with 2 different wrist positions used in combination with the RMF orthosis during the initial 3 weeks postoperatively.

Future research

The outcomes generated by this small series of case reports encourages future investigation to understand the role of RMF orthoses as a postoperative flexor tendon EAM approach through larger, multicenter, prospective longitudinal cohorts and/or randomized clinical trials. Future investigations regarding the use of EAM after flexor tendon repair should endeavor to standardize patient demographics, surgical techniques and materials, and outcome measures and timing of measurement so that comparisons can be easily made among studies.

A possible "side effect" of the beneficial "quadriga effect" levied by the RMF orthosis is less excursion of the FDP tendon. Full-time wear of the RMF orthosis may be why full PIP joint flexion was not recovered or DIP joint flexion was, in some cases, limited. Perhaps future consideration should be given to "out of RMF orthosis" EAM exercises to capture full PIP joint flexion. For the zone I and distal zone II ragged or crush-type injuries in which the recovery of DIP joint flexion is difficult, consideration could be given to wearing an RMF orthosis and Evans' LEAF orthosis and specific zone-dependent EAM exercises to improve PIP and DIP joint flexion results.[18,23]

Conclusions

Based on this small series, the RMF approach is simple and provides some practical advantages, which can lead to similar mobility and functional recovery as other EAM approaches, without secondary complications. Further investigation with larger, multicenter, prospective longitudinal cohorts and/or randomized clinical trials is necessary.

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Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jht.2019.05.002.

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1. The study design is
   a. RCTs
   b. qualitative
   c. a case report
   d. a case series
2. There were_____ reported tendon ruptures
   a. 5
   b. 1
   c. 0
   d. 10
3. The orthosis protects the FDP by
   a. flexing the MP of the involved digit more so than the adjacent digits
   b. eliminating active flexion of the involved digit
   c. coupling IP flexion of the involved digit with the adjacent digits
   d. extending the MP of the involved digit more so than the adjacent digits
4. The early motion protocol is based heavily on the
   a. original work of Sterling Bunnell, MD
   b. quadriga effect
   c. original work of John Mennell, MD
   d. paradoxical extension phenomenon
5. The RMF method appears to be safe and effective
   a. not true
   b. true

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