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The optimal orthosis and motion protocol for extensor tendon injury in zones IV–VIII: A systematic review

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Abstract

Study Design—Systematic review

Purpose—To determine the optimal combination of motion protocol and orthotic treatment for the rehabilitation of proximal extensor tendon injuries (zones IV–VIII).

Methods—A systematic review of English-language randomized clinical trials and cohort studies investigating extensor tendon rehabilitation from 1960–2016 was conducted in MEDLINE, Embase, Cochrane, CINAHL, PEDro, and OTseeker. Outcomes of total active motion, grip strength, return to work, patient attrition and patient reported outcomes were compared.

Results—Eleven studies of predominantly average quality (1 low, 8 average, 2 high) were included in the final review. Results were difficult to compare due to differences in reporting. Early total active motion and final grip strength was greater with dynamic extension orthoses (191–214°; 35–38 kg/89% contralateral side) and relative motion orthoses (205–236°; 85–95% contralateral side) compared to static orthoses (79–202°; 23–34 kg/59% contralateral side). Four studies excluded patients who did not follow-up and loss to follow-up was 12–33% in the other studies. Patient reported outcomes were not comparable, as they were only included in three studies, and each used a different assessment tool.

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Level of Evidence: 2a

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Conclusion—Average quality evidence supports the use of EAM as the superior motion protocol but optimal orthosis to deliver EAM could not be determined. Prospective research should focus on patient reported outcomes and the design of orthoses that facilitate use of the EAM.

Keywords

extensor tendon; motion protocol; orthosis; rehabilitation; splint; systematic review

1. Background and purpose

The extensor tendons of the hand are commonly injured, with over 45,000 extensor tendon injuries seen in emergency departments in the United States each year (~14/100,000).^{1,2} Extensor tendon injuries are divided into eight anatomical zones (Fig. 1).³ Each zone has a unique combination of anatomical elements and cross-sectional tendon size which dictates the approach to treatment.⁴ Historically, extensor tendons have been treated with prolonged immobilization (6 weeks) followed by gradual mobilization.⁵ This remains the mainstay of treatment for the most distal injuries (zones I and II), as they are too thin to effectively suture; however, the tendons are larger in more proximal zones and are amenable to strong primary repair.^{4,6}

Post-operative rehabilitation protocols can be divided into immobilization, early passive motion (EPM), and early active motion (EAM).⁷ For injuries involving zones II-VIII, immobilization entails restriction of movement of the interphalangeal (IP) joints, metacarpophalangeal (MCP) joints, and wrist in static orthosis or cast to minimize the tension placed upon the repair (Fig. 2a). The orthosis is kept in place for at least 3 weeks, after which the patient gradually begins mobilizing the previously restricted joints.^{5,8} This method limits the tension on the tendon and therefore poses the least risk for tendon rupture, but may contribute to tendon adhesions at all levels.^{9–12} Early motion following tendon repair has become a tenet of tendon rehabilitation, as it promotes healing and decreases tissue adhesions.^{13–15} EPM, also known as early controlled motion, involves the careful movement of the injured digit the contralateral hand, a therapist, or a specialized dynamic extension orthosis (Fig. 2b). These motion protocols are not entirely passive, as there is still activation of the extensor muscles in the usual dynamic orthosis.¹⁶

The EAM protocol generates greater gliding of the healing tendon and increases tendon strength more rapidly than controlled motion.¹³ Though early motion has been used in various forms since the 1980s,^{17–19} there is not yet a consensus on the optimal balance between protecting the repair from rupture and allowing enough movement to prevent stiffness.^{7,20} Though numerous studies have been conducted to determine the force thresholds for various tendon repairs, many clinicians err towards conservative treatment with immobilization, as early motion protocols are considered primarily only for highly compliant patients.^{20–25} In EAM, instead of moving the hand passively, the patient actively flexes and extends. Controlled tendon excursion for repaired extensor tendons can be effected with a variety of dynamic extension splints and the yoke or relative extension orthosis (RMO) as described by Howell et al.¹⁰ (Fig. 2c).

Though orthoses are often considered as only a tool for administering the rehabilitation program, the type of orthosis can affect outcomes as it has a direct effect on both movement and patient adherence.^{24,26} The objective of this study was to systematically evaluate the types of orthoses and adjuvant motion protocols used for the treatment of proximal extensor tendon repair (zones IV–VIII). This analysis may help determine the optimal motion protocol and what orthotic factors are associated with better hand function outcomes.

2. Methods

2.1. Literature Survey

A systematic review of MEDLINE, Embase, Cochrane, CINAHL, PEDro, and OTseeker databases was performed, searching for English-language randomized control trials, cohort trials and meta-analyses published between 1960–2016 using the terms “extensor tendon,” “rehabilitation,” “finger injuries,” “hand injuries,” “hand,” “splint*,” “orthoses,” “therapy,” and “motion.” A more detailed explanation of the search strategy can be seen in the online supplemental material. This review was registered with the PROSPERO Registry of Systematic Reviews (CRD42015029294).

2.2. Inclusion criteria for studies

Subjects—We included studies that investigated patients with acquired, isolated extensor tendon injury of zones IV–VIII. Studies were excluded if they investigated degenerative conditions, traumatic injury involving structures other than the extensor tendons, or post-operative conditions involving structures in addition to the extensor tendons, as those conditions could all independently affect length and quality of recovery.⁴ In addition, studies investigating distal extensor tendon injuries (zones I–III) were excluded since the rehabilitation protocols for those injuries are different from proximal injuries.⁴ Articles examining extensor tendon injuries in the thumb were similarly excluded.⁴

Interventions of interest included type of orthosis (i.e., static, dynamic, hand-based, forearm-based) and motion protocol (static, active, early active). Studies that only evaluated drug therapy were excluded, as were studies failing to specify therapy, motion protocol or primary outcome measures. The primary outcome of included studies was hand function as measured by total active motion (TAM) with the secondary outcomes of grip strength, time to recovery (back to work), patient reported outcome measures (such as the Disabilities of the Arm, Shoulder and Hand, a.k.a. DASH outcome measure), and loss to follow up.

2.3. Study evaluation

Titles and/or abstracts of studies retrieved using the search strategy were screened independently by two review authors (AW and MN) for eligibility. Full text assessment was subsequently conducted by two independent review team members (MW and SG), and any disagreements regarding eligibility were resolved through discussion with reviewer AW.

A form of the relevant inclusion and exclusion criteria; demographics; and outcomes was created and used by all reviewers to extract data from the included studies for assessment of study quality and evidence synthesis. Extracted information included: study setting; study

population, participant demographics and baseline characteristics; details of the intervention and control conditions; study methodology; recruitment and study completion rates; outcomes and times of measurement; indicators of acceptability to users; suggested mechanisms of intervention action; information for assessment of the risk of bias. Two review authors extracted data independently (MW and AW); discrepancies identified were resolved through discussion (with a third reviewer where necessary).

2.4. Quality assessment

Two review authors (MN and AW) independently assessed the risk of bias in included studies by considering randomization, treatment allocation, blinding, completeness of outcome data, and selective outcome reporting. Methodological quality was assessed using the Scottish Intercollegiate Guidelines Network (SIGN) scale.²⁷ Any discrepancies were resolved with discussion and involving a third reviewer.

2.5. Analysis

A qualitative analysis of the included studies was performed, structured around the type of orthosis and motion protocol, target population characteristics (age, etiology of injury), type of outcome and intervention content.

3. Results

3.1. Characteristics of included studies

The initial search resulted in 140 studies. Screening of titles and abstracts identified 27 suitable for review (Fig. 3). After full text screening by two authors each, 11 studies were included in the final review, published between 1989 and 2015 (Table 1). There were 6 randomized control trials, 3 prospective studies, and 2 retrospective studies. Assessment of quality using SIGN showed that all had at least average quality. Ages of patients ranged from 10 to 77 years of age. All of the studies that reported gender (10 of 12) had a majority of male participants. The studies ranged in sample size, from a low of 18 participants to a high of 140 participants. Duration of follow-up varied, with the longest follow-up reaching 9 months. All studies compared an EAM protocol to a control but the orthosis used for delivery of EAM varied. Three studies compared immobilization and EAM protocols using a static orthosis.^{9,21,28} One study using an EAM protocol compared a dynamic orthosis with a static orthosis.²⁹ Four studies investigated EAM with dynamic orthosis compared to immobilization.^{11,30–32} Three studies investigated EAM using RMO compared to static or with no control group.^{10,33,34}

3.2. Results of individual studies

Study designs and outcomes of interest are summarized in Table 2. All of the studies included at least zones V and VI, with many including zones IV and VII and only a few including zone VIII. Reporting of TAM varied across studies with some providing percentages, others a graded rating as per Kleinert and Verdan (Table 3),³⁵ while others classified finger motion as per Miller (Table 4).³⁶ Regardless of the measure, all EAM protocols resulted in better TAM outcomes (higher degrees of motion) compared to static protocols. Early total active motion (4–6 weeks) was greater with dynamic extension

orthoses (191–214°) and relative motion orthoses (205–236°) compared to static orthoses (79–202°), though three studies found that there was no difference in long-term follow-up.^{9,31,32} Grip strength was not as reliably measured in all studies, but, those that did measure it, found greater improvement in the EAM patients than those treated statically (DEO 35–38 kg/89% contralateral side; RMO 85–95% contralateral side; static 23–34 kg/59% contralateral side).^{9–11,21,30,31,34} The timing of return to work was not reported all studies, but in three studies investigating a specific EAM protocol – the immediate relative motion protocols (IRAM) using the RMO – patients returned to light duties at work around 3 weeks postoperative (3.2–3.9) compared to 9.4 weeks for static orthoses.^{10,33,34} Only one study²⁸ (of 100 subjects) experienced tendon ruptures, with one in the EAM group and 2 in the dynamic extension orthosis group. Patient adherence was not consistently reported, and only three studies measured patient reported outcomes.^{11,21,34} These studies used three different reporting tools, so comparison is not possible. Loss to follow-up ranged from 12–33% in the eight studies that reported attrition. The remaining three studies excluded patients who did not follow-up. No studies reported correlations between rehabilitation protocol (either motion or orthosis) and loss to follow-up.

3.3 Quality of included studies and risk of bias

The overall SIGN study quality rating of the included studies is included in Table 5. Failure to achieve a high score was most often due to lack of randomization and high rate of participant attrition. Most studies did not report enough of their statistical outcomes to calculate effect size of their results.

4. Discussion

The challenge of tendon surgery is the balance between protecting the repair and preventing complications of prolonged immobility.⁷ In the first week after repair the tendon is in the inflammatory stage of healing and it is only the strength of the sutures that prevents rupture.¹³ Historically, this is why many rehabilitation protocols were very conservative with the amount of motion allowed in the first weeks following surgery. However, tendon immobilization and the trauma to the tendon from the initial injury and repair contribute to adhesions, loss of digital flexion and contractures.^{13,29} This has led to the development of different rehabilitation protocols and types of orthoses that aim to allow for earlier safe mobilization to improve outcomes. There have been many studies and reviews that have focused on the rehabilitation protocol as a whole without specific consideration to the role of the orthosis itself. The aim of this review was to more closely examine how orthotic factors affect patient outcomes.^{11,23,30,33,34}

In this review, EAM protocols, regardless of what orthosis was used, were shown to be superior to immobilization in the outcomes of TAM, grip strength, and return to work, without resulting in substantially more complications. There remain barriers to using dynamic protocols and orthoses: 1) The clinical decision of which patients are most suited to EAM vs. immobilization and 2) Problems with orthoses themselves.

Many studies note poor patient adherence to treatment as a barrier to rehabilitation and a reason to choose a particular therapy regimen. Bulstrode et al. (2005) did not measure

adherence, but commented that rehabilitation regimens allowing for more movement, “should not be used for poorly compliant patients,” despite promoting greater TAM.⁹ This is echoed by other authors who have justified static orthoses for poorly adherent patients as a means of self-protection.^{7–9,11} In contrast, Hall et al. (2010) suggested that patients may opt for a dynamic protocol from the beginning, if they were aware of the more complicated and prolonged rehabilitation required after total immobilization.²¹ In addition, in a small retrospective case series, Neuhaus et al. (2012) found that dynamic orthoses with EAM did not result in any tendon ruptures and had excellent outcomes even when adherence was known to be poor.²⁴

The clinical decision to choose a static rehabilitation regimen based on presumed adherence may also reflect a bias relating to young males who sustain the preponderance of extensor tendon injuries (male to female ratio of 8:2; average age of 32–34 years). However, these are working age men and it is usually the dominant hand that is injured (60%) meaning that there should be a strong desire from these patients to regain function.^{2,4} Unfortunately, this is difficult to determine given that very few studies measured patient reported outcomes.

There needs to be a focus on improving patient adherence to orthoses and rehabilitation protocols that are used to administer EAM. Sandford et al. (2008) hypothesized that reasons for orthotic non-adherence may relate to poor cosmesis, discomfort, interference with function, failure to decrease pain, and hygiene. In their study, two thirds of patients reported removing their protective thermoplastic orthosis with the first four weeks postoperatively, despite being told that they were at an increased risk of tendon rupture by doing so.²⁶ They did not examine adherence factors such as knowledge of orthotic benefits or the perceived seriousness of the injury and role of the orthosis. Past research has shown that patients’ retention of medical knowledge is generally poor but that deeper understanding of risks and consequences can significantly improve knowledge retention.³⁷ Future studies should include objective measures of adherence. The BrAIST study of orthoses in scoliosis treatment could serve as a model for such as study design.³⁸

Many of the problems with adherence are due to how the patient is able to cope with his or her activities of daily living (ADLs) while undergoing rehabilitation.³⁹ Many protocols require that ADLs be performed one-handed. There is variation in how well patients are able to do this depending on which hand is affected and their occupation. Orthotic design can further exacerbate this as they can be perceived to be cumbersome, even more so for dynamic orthoses. They also may cause discomfort, are unwieldy, and make daily activities more difficult and time consuming.²⁶ Dynamic orthoses also have moving parts and rubber bands, which may break.^{23,26}

The primary purpose of an orthosis after an extensor tendon injury is to protect the surgical repair by minimizing the force transmitted through the repair site. Joint position, external load, and resistance to tendon glide, as determined by friction and adhesions, contribute to the force on the tendon and are therefore all considerations when designing an appropriate orthosis.⁴⁰ Tendon repairs shorten the tendon by up to 6 mm^{40,41} leading to decreased excursion of the repaired tendon relative to the others, and increased force required to flex all fingers.⁴⁰ The active hold of a repaired extensor tendon with the wrist in 20 to 30 degrees

of flexion is about 300 g of internal tension⁴⁰ as the resistance of the antagonistic flexors is negated. This motion is tolerated by even the weakest repairs.^{40,42}

One of the arguments for current techniques and materials of orthoses is that they are considered to be “low-cost”. Reported material costs vary, with some as low as \$15 for a static thermoplastic orthosis with an additional \$45 for the outrigger component²⁹ to as much as \$176 for a static resting orthosis and \$453 for a dynamic orthosis²⁴ but the costs of the clinic appointments must also be considered. In our reviewed studies there was significant variability regarding the number of visits and the total length of rehabilitation, even within the same motion protocol. Dynamic extension orthoses required frequent visits immediately postoperatively (1–3/week). In contrast, static immobilization protocols generally required more visits after orthosis removal, and studies reported discharge as late as 20 weeks after the initial repair.^{10,28} The cost of an orthosis and the subsequent therapy can be a problem for patients as up to 75% of this population only have state assistance, Medicare, Medicaid, or self-pay insurance, and this increased out-of-pocket expense is correlated to poor return for regular follow-up and worse outcomes.⁴³ Thus, when determining the allowable cost of the orthosis, thus a clinician must consider not only the material costs, but also how a particular orthosis affects the rehabilitation protocol, adherence, and the required number of clinic visits necessary.

The RMO is an orthosis that appears to fit the design criteria of low-profile and low material costs. The RMO uses a thin (1 inch) strip of thermoplastic to keep the injured digit in relative extension at the MCP joint, and minimizes the inherent effect of shortening in all extensor tendon repairs.^{40,44,45}

The motion protocols that accompany the RMO are variations of EAM, and include immediate relative active motion (IRAM) and modified IRAM (mIRAM). These protocols encourage immediate active flexion and extension of the MCP and IP joints, and return to light daily activities and work in 3 weeks. As the orthosis itself is low-profile, patients can use it at work or when they are doing heavy duties. There are still only three clinical trials, but the results are promising as they demonstrate excellent TAM, grip strength, and return to work as early as 18 days, without increasing the risk of tendon rupture.^{10,33,34} Patient adherence to the RMO has not yet been formally tested, so future studies need to measure this outcome to ensure if it can be achieved while simultaneously allowing adequate protection and the tendon.^{10,33,34,40}

The limitations of this review are that the included studies are heterogeneous in the orthoses used and the variability the outcome measures. Only two of the studies could be considered high quality,^{11,21} and given the nature of orthoses, blinding was not possible in any of the included studies. While most studies use Kleinert and Verdan’s TAM in some form,³⁵ this was not reported consistently. Some studies employed other measures that have different cutoffs and the majority of studies did not report enough of their statistical outcomes to calculate effect size of their results, making comparisons very difficult. All measures have some amount of inherent measurement error.^{8,34,36} Only three studies measured some form of patient reported outcome, and there was no consistency in the measure used.^{11,21,34} It has previously been suggested that studies examining tendon rehabilitation should follow the

International Classification of Functioning, Disability and Health (ICFDH) to describe functioning, disability and health in a more standardized fashion. Recently, 12 of the 23 ICFDH categories have been validated for use in hand conditions.^{7,46} Extensor tendon injuries are also a very heterogeneous class of injuries often involving significant soft tissue damage that also impairs rehabilitation protocol and healing. Even with simple tendon lacerations, there are many different variables that may affect the final outcome including surgical suture and technique, type of orthosis, initiation of therapy, frequency of therapy visits, initiation of active motion, and the frequency of active motion if the patient is adherent to the orthosis and therapy.^{29,47}

In many of the reviewed studies, a high proportion of patients did not return for follow-up. As previously discussed, it has been hypothesized that poor follow-up is related to the demographics of those who most commonly suffer extensor tendon injuries.²⁸ This raises the possibility that there is a selection bias in that patients who attended their follow-up visits were likely to be more adherent with their rehabilitation in general.^{26,31} Unfortunately, no studies reported a correlation between rehabilitation protocol and completion of all follow-up appointments.

Despite most studies noting significant attrition in patient follow-up, and suggesting that this is a surrogate measure of patient adherence, none included in this review formally assessed adherence to the rehabilitation protocol. Sandford et al. (2008) assessed non-adherence in patients with both extensor and flexor tendon injuries, and found that more than 40% of patients removal of their orthoses 2–6 times during the course of immobilization, despite explicit instructions to leave the orthosis in place.²⁶ Unfortunately they did not compare functional outcomes in relation to the frequency of removal.

5. Conclusion

Based on the findings from this systematic review, the authors recommend EAM for simple extensor tendon injuries in the majority of patients. No studies have shown substantial long-term differences in outcomes between immobilization and early mobilization protocols, but all showed an earlier regain of total active motion in patients who were mobilized earlier.^{9–11,21,23,28–31,33,34} Future research should therefore focus on a holistic understanding of the biomechanical and patient-factor design criteria to optimize the ability of patients to perform EAM. Some of these criteria include ease of use, the ability to conduct daily activities, form factor, cost of the splint and financial and time burden of numerous follow-up appointments.²⁶ Though true effect size could not be calculated given the statistical reporting and lack of direct comparisons, the high means scores of early total active motion support the use of the RMO, despite a small number of clinical trials.^{10,26,33,34,40,41}

Given the difficulty in drawing recommendations from the included studies, future clinical trials should more investigate the relationship between orthosis design, adherence to rehabilitation, and patient reported hand function.^{7,24,26,47} For existing and new orthosis designs, the effect on joint position, external load, and resistance to tendon glide should be measured throughout the range of normal hand use. This could be accomplished in healthy

volunteers as the upper limits of force are known.⁴⁰ Careful attention needs to be given to how patients' can achieve their ADLs and how this is effected by orthotic design. Using established measures such as the DASH, QuickDASH or ICFDH categories would increase the comparability of patient outcomes across studies.⁴⁶ In addition, studies should rigorously report patient variables such as hand dominance, zone of injury, surgical intervention, rehabilitation protocol, and the outcome variables of TAM, grip strength, and return to work. Investigating these variables will allow for evidence-based patient-centered treatment of extensor tendon injuries.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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- Many combinations of motion protocols and orthoses exist for the treatment of proximal extensor tendon injuries (zones IV–VIII).
- A systematic review of English-language randomized clinical trials and cohort studies from 1960–2016 was conducted comparing the outcomes of total active motion, grip strength, and return to work.
- From the 11 studies of predominantly average quality (1 low, 8 average, 2 high) included in the final review, early active motion (EAM), regardless of orthosis, was superior to early passive motion or immobilization for all outcomes though 3 studies found that the difference in total active motion disappeared in long-term follow-up. Both dynamic extension and relative motion orthoses had superior outcomes compared to static orthoses but were not compared head-to-head.
- EAM is the superior motion protocol but optimal orthosis to deliver EAM could not be determined due to lack of direct comparisons.
- More research needs to focus on the design of orthoses and patients' abilities to perform ADLs to facilitate use of the EAM.

Figure 1.
The extensor tendon zones of the thumb (T) and fingers, adapted from Kleinert et al. (1981)³

Figure 2. Representative orthoses a) Static orthosis; b) Dynamic extension orthosis; c) Relative motion orthosis on hand and in cross-section, may be used with or without wrist component. For static orthoses, positioning of the metacarpophalangeal (MPC) joints has been described between 0 and 70 degrees.

Figure 3.
Literature search and screening process.

Table 1

Characteristics of included studies

Study	Sample size enrolled (n)	Lost to follow-up (n / %)	Final sample size (n)	Sample characteristics	Number of extensor tendon injuries enrolled	Study design	Assessment timing / Total duration of follow-up
Bulstrode et al. ⁹	42	12 / 29%	30	Mean age: 32 (range: 10–62) yr; male: 95%	46	RCT	4, 6, 8, 12 wk / 12 wk
Chester et al. ²⁹	36	11 / 31%	25	Group A: Median age: 31 (range: 17–63) yr; male: 75%; Group B: Median age: 33 (range: 15–73) yr; male 89%	58	RCT	4, 12 / 3 mo
Chow et al. ³⁰	86	Not specified	86	Age range: 17–62 yr Group A: male: 72% Group B: male: 68.6%	97	PS	6 wk / 1–3 years
Hall et al. ²¹	27	9 / 33%	18	Mean age: 30.4; male: 94.4%	24	RCT	3, 6, 12 wk / 12 wk
Hirth et al. ³³	46	7 / 15%	39	Group 1: mean age: 39.4 (range: 18–69); male: 81.3% Group 2: Mean age: 37.2 (range: 19–72); male: 95.7%	39	RS	6, 12 wk / 12 wk
Howell et al. ¹⁰	192	52 / 27%	140	Mean age: 34 (range: 11–77); male: 87%	140	PS	7 wks
Khandwala et al. ²⁸	Not specified	Excluded those who did not follow-up	100	Group 1: Mean age: 30; male: 96% Group 2: Mean age: 28; male: 98%	162	RCT	4, 8 wk / 16 wk
Kitis et al. ¹¹	52	6 / 12%	46	Age range 21–59; male: 75%	83	RCT	4, 6, 12, 16 wk / 16 wk
Mowlavi et al. ³¹	Not specified	Excluded those who did not follow-up	34	Not specified	34	RCT	4, 6, 8, 12 wk / 6 mo
Russell et al. ³²	84	19 / 23%	65	Not specified	99	RS	4, 6, 10 wk / 10 wk
Svens et al. ³⁴	63	13 / 21%	50	Mean age: 35 yr Group A: male: 89% Group B: male: 77%	67	PS	4, 6, 8 wk / 8 wk

RCT = randomized controlled trial; PS = prospective study; RS = retrospective study

Table 2

Rehabilitation protocol, orthotic design, and means scores $\pm$ standard deviations of outcomes of total active motion (TAM), grip strength (GS) and return to work of included studies

Authors	Group design & motion protocol	Orthosis design	Total time wearing orthosis	Zones of interest	TAM	GS	Return to work	Patient reported outcomes
Bulstrode et al. ⁹	1) EAM , POD 1–5 active MCP flexion/extension 1x/4h in orthosis x4 wk 2) Static no IP , POD 0 active IP flexion/extension 1x/h x4 wk 3) Static x4 wk then progressive mobilization	EAM : IP 0°, MCP 50°F, wrist: 45°F Static no IP : IP free, MCP 0°, wrist 30°F Static : IP 0°, MCP 0°, wrist 30°F	EAM : 4 wk Static no IP : 4 wk Static : 4 wk	V, VI	4 wk : EAM : 160° (95% CI 23°); Static no IP : 165° (95% CI 37°); Static : 79° (95% CI 26°) No difference at 12 wk, values not reported	GS was lower in static group at 12 wk (23 kg; 95% CI 8) compared with uninjured hand (45 kg; 95% CI 8), no difference in EAM and static no IP, values not reported	Did not measure. All groups allowed to return to driving at 8 wk, heavy work at 12 wk	Not measured
Hall et al. ²¹	1) DEO with EPM , POD 1–5 active MCP flexion, passive extension 20x/h x3 wk 2) EAM : POD 1–5 active MCP flexion/extension 10x/h in orthosis x3 wk 3) Static x3 wk then progressive mobilization	DEO : Dynamic: IP 0°, MCP 45°F, wrist 40°F EAM : Static: IP free, MCP 45°F, wrist 30°F Static : IP 0°, MCP 2–20°F, wrist 40°F	DEO : 5 wk EAM : 5 wk Static : 6 wk	V, VI	6 wk : DEO : 197.7 $\pm$ 39.0°; EAM : 248.8 $\pm$ 39.4°; Static : 178.4 $\pm$ 42.3° 12 wk : DEO : 247.8 $\pm$ 22.1°; EAM : 266.2 $\pm$ 19.8°; Static : 239.9 $\pm$ 24.8°	No difference in GS at wk 12 among the three groups 12 wk : DEO : 35.6 $\pm$ 2.98 kg; EAM : 38.9 $\pm$ 2.26 kg; Static : 34.9 $\pm$ 2.91 kg	Not measured	Visual analog scale of ability to perform functional tasks $\pm$ SD at 12 wk DEO : 3.15 $\pm$ 0.61 EAM : 3.45 $\pm$ 0.63 Static : 2.78 $\pm$ 0.56
Chester et al. ²⁹	1) DEO , POD 5–7 active MCP flexion/extension 10x/h in orthosis x4 wk 2) EAM , POD 5–7 active MCP flexion/extension 10x/h out of orthosis x4 wk	DEO : Dynamic: IP 0°, MCP 30°F, wrist 30°F EAM : Static: IP 0°, MCP 30°F, wrist 30°F	DEO & EAM : 6 wk (4 wk full time, 2 wk at night)	IV–VIII	% of Contralateral TAM (range), 4 wk : DEO : 87% (56–102%); EAM : 77% (52–97%) 3 mo : DEO : 98% (78–108%); EAM : 100% (82–109%)	Not measured	Did not measure. Both groups allowed to return to driving at 8 wk, heavy work at 12 wk	Not measured
Khandwala et al. ²⁸	1) DEO , POD 3–4 active MCP flexion/extension 10x/h in orthosis x4 wk 2) EAM , POD 1–2 active MCP flexion/extension 10x/h in orthosis x4 wk	DEO : Dynamic (dorsal); IP free, MCP free, wrist 30°F EAM : Static: IP free, MCP 45°F, wrist 30°F	DEO & EAM : 6 wk (4 wk full time, 2 wk at night)	V–VII	16 wk : DEO : 50% excellent, 48% good; EAM : 49% excellent, 46% good Degree values not reported, no measure of variance	Not measured	Did not measure. Both groups allowed to return to light work at 4 wk, driving at 8 wk, heavy work at 12 wk	Not measured
Chow et al. ³⁰	1) DEO , POD 2 active MCP flexion (wk 1: 30°, wk 2:	DEO : Dynamic (dorsal); IP free,	DEO : 5 wk Static : 3 wk	IV–VII	6 wk : DEO : 100% achieved excellent	2 mo : Mean GS ratio between	DEO returned to work earlier (time not specified)	Not measured

Authors	Group design & motion protocol	Orthosis design	Total time wearing orthosis	Zones of interest	TAM	GS	Return to work	Patient reported outcomes
	45°, wk 3: 60°, wk 4-5: full), passive extension 10x/h in orthosis x5 wk 2) Static x3 wk then progressive active mobilization	MCP free, wrist 30°E Static: IP 0°, MCP 0-30°E, wrist 30°E			within 6 wk of surgery Static: 40% excellent, 31% good (13 wk for maximum functional recovery) Degree values not reported, no measure of variance	DEO: Static = 5:3		
Kitis et al. ¹¹	1) DEO , POD 1 active MCP flexion to 30°, passive extension 10x/h x4 wk 2) Static no IP : x3 wk, then active MCP flexion/extension 10x/h in orthosis x1 wk	DEO: Dynamic (dorsal); IP free, MCP free, wrist 30°E Static no IP : Static; IP free, MCP 45°E, wrist 30°E	DEO: 5 wk (4 wk full time, 1 wk at night) Static no IP: 4 wk	V-VIII	4 wk: DEO: 191.6±12.3°; Static: 124.5±7.6° 12 wk: DEO: 227±11.7°; Static: 194.8±14.6° 6 mo: DEO: 268.3±10.5°; Static: 210.8±11.6°	12 wk: 95% of DEO vs. 81% of static GS 80% uninjured hand; values not reported 6 months: DEO: 38±2.9 kg; static: 26±3.8 kg	DEO: 7.2 wk Static: 6.3 wk	DASH ± SD at 12 wk DEO: 27.4±3.4 Static: 37.3±3.1
Mowlavi et al. ³¹	1) DEO , POD 1 active MCP flexion to 30° (wk 1: 30°, wk 2: 45°, wk 4-5: full) 10x/h in orthosis 10x/h x4 wk 2) Static x4 wk then progressive mobilization	DEO: Dynamic (dorsal); IP free, MCP free, wrist 30°E Static: IP 0°, MCP 15°E, wrist 30°E	DEO: 6 wk Static: 6 wk (4 wk full time, 2 wk at night)	V, VI	4 wk: DEO: 180.5±45°; Static: 131.3±61° 6 wk: DEO: 239±21.9°; Static: 205.5±53.4° 8 wk: DEO: 247±19.8°; Static: 216.3±36° 6 mo: DEO: 253.1±18.8°; Static: 250.5±32°	GS % of uninjured hand 8 wk: DEO: 81.3±18.0%; Static: 59.2±20.4% 6 mo: DEO: 89.6±5.6%; Static: 82.1±22.0%	Did not measure or comment	Not measured
Russell et al. ³²	1) DEO , POD 7-14 active flexion/extension x4 wk, unspecified frequency 2) Static x4 wk then passive ROM in orthosis x4 wk, unspecified frequency	DEO: orthosis not specified Static: orthosis not specified	DEO: 7 wk (2-3 static, 4 wk dynamic) Static: 8 wk	V-VIII	6 wk: DEO: 214.07±48.99°; Static: 202.21±60.94° 10 wk: DEO: 245.00±34.73°; Static: 258.11±29.20°	Not measured	DEO: 9 wk Static: 9 wk	Not measured
Hirth et al. ³³	1) mRMO POD 2-7 no specific exercise protocol encouraged to do daily activities, resting orthosis at night	mRMO: Static; finger yoke holding injured digit MCP 15-30° relative extension, IP, wrist free Static: IP 0°, MCP 30°E, wrist 30°E	mRMO: 8-10 wk Static: 4 wk	V, VI	% of Contralateral TAM ± SD* 6 wk: mRMO: 80.6±15.3%; Static: 68.7±13.4% 12 wk: mRMO: 97.5±6.9%; Static: 91.2±10.0%	Not measured	Static: 9.4 wk mRMO: 3.3 wk	Not measured

Authors	Group design & motion protocol	Orthosis design	Total time wearing orthosis	Zones of interest	TAM	GS	Return to work	Patient reported outcomes
	2) Static x4 wk then progressive mobilization							
Howell et al. ¹⁰	1) RMO with IRAM POD 0–21 full active flexion/extension in orthosis 1–5x/h POD 22–35 wrist free, daily activities POD 36–49 daily activities with only yoke	RMO : Static; IP free, finger yoke holding injured digit MCP 25–30° relative extension, wrist 30°E	7 wk (3 wk full orthosis, 2 wk yoke + wrist for heavy activities, 2 wk only yoke)	IV–VII	6 wk: 96% TAM of uninjured, standard deviation not reported Degree values not reported, no measure of variance	Mean GS 85% of uninjured hand at the time of discharge, standard deviation not reported	18 d	Not measured
Svens et al. ³⁴	1) RMO with IRAM Same protocol as Howell et al. 2005 ⁹ 2) RMO with mIRAM POD 1 active MCP flexion/extension 1–5x/h x3 wk, then yoke only and light activities x2 wk	RMO : Static; IP free, finger yoke holding injured digit MCP 15–20° relative extension, wrist 20–25°E For mIRAM : RMO with wrist free for IV–V injuries, wrist 20–25°E for IV–VI injuries	IRAM : 7 wk mIRAM : 5 wk	IV–VI	4 wk: IRAM : 205±38°; mIRAM : 211±28° 6 wk: IRAM : 236±38°; mIRAM : 244±23° 8 wk: IRAM : 253±40°; 94% of uninjured hand; mIRAM : 256±22°, 99% of uninjured hand	Mean GS, % of uninjured hand ± SD at 8 wk IRAM : 80±23% mIRAM : 94±10%	IRAM : 3.9±2.4 wk for modified work; 6.7±2.1 wk for full work mIRAM : 3.2±2.3 wk for modified work; 3.7±0.7 wk for full work	Patient evaluation measure ± SD at 12 wk IRAM : 87±13% mIRAM : 93±6%

CI = Confidence interval; DASH = disabilities of arm, shoulder and hand questionnaire; DEO = dynamic extension orthosis; EAM = early active motion; ECM = early controlled motion; EPM = early passive motion; E = extension; F = flexion; GS = grip strength; IP = interphalangeal; IRAM = immediate relative motion; MCP = metacarpophalangeal; mIRAM = modified immediate relative action motion; mo = month; mRMO = modified relative motion orthosis; POD = Postoperative Day; RMO = relative motion orthosis; TAM = total active motion; SD = standard deviation; wk = week

* SD provided by author in personal communication

Table 3

Total active motion (TAM) assessment of extensor tendon repairs³⁵

Excellent	TAM = TAM of contralateral finger
Good	TAM > 75% TAM of contralateral finger
Fair	TAM 50–75% TAM of contralateral finger
Poor	TAM <50% TAM of contralateral finger

$$TAM = [(MP + PIP + DIP \text{ flexion}) - (MP + PIP + DIP \text{ extension lag})]$$

Table 4

Miller's assessment of extensor tendon repairs³⁶

Excellent	Same range of motion as opposite side
Good	Loss of 20° flexion and/or <10° extension lag
Fair	Loss of 45° flexion and/or 45–10° extension lag
Poor	>45° loss of flexion and/or >45° extension lag

Table 5

Risk of bias of included studies

Study	Quality assessment (SIGN)	Random sequence generation	Allocation concealment	Performance bias: blinding of participants and personnel	Blinding of outcome assessment (detection bias; patient-reported outcomes)	Incomplete outcome data (% attrition)	Reporting bias: selective reporting	Statistical analysis: means and variance
Bulstrode et al. ⁹	Average	+	-	-	-	? (29%)	+	+
Chester et al. ²⁹	Average	+	-	-	-	? (31%)	+	?
Chow et al. ³⁰	Low	?	-	-	-	?	?	-
Hall et al. ²¹	High	+	-	-	-	? (33%)	+	+
Hirth et al. ³³	Average	-	-	-	?	+(15%)	+	?
Howell et al. ¹⁰	Average	-	-	-	?	? (27%)	+	-
Khandwala et al. ²⁸	Average	+	-	-	-	-	-	-
Kitis et al. ¹¹	High	+	-	-	-	+(12%)	+	+
Mowlavi et al. ³¹	Average	+	-	-	?	-	-	+
Russell et al. ³²	Average	-	-	-	+	? (23%)	+	+
Svens et al. ³⁴	Average	-	-	-	+	? (21%)	+	+

Note. Categories for risk of bias: + = low risk of bias; ? = unclear risk of bias; - = high risk of bias.