EDITOR'S CHOICE

Range of Motion Following Flexor Tendon Repair: Comparing Active Flexion and Extension With Passive Flexion Using Rubber Bands Followed by Active Extension

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Purpose This study aimed to compare the outcome in terms of range of motion between early active flexion and extension (early active motion, [EAM]) and passive flexion using rubber bands followed by active extension (sometimes referred to as a Kleinert regimen) after flexor tendon repair in zones 1 and 2.

Methods Data were collected from the Swedish national health care registry for hand surgery (HAKIR). Rehabilitation regimens were decided by the preference of each caregiver. At 3 months, 828 digits (656 EAM and 172 passive flexion) and at 12 months, 448 digits (373 EAM and 75 passive flexion) were available for analysis. Thumbs were analyzed separately.

Results No notable difference in total active motion was found between the groups at 12 months of follow-up.

Conclusions This large registry study supports the hypothesis that EAM rehabilitation may not lead to better range of motion long-term than passive motion protocols. *(J Hand Surg Am. 2024;■(■):■−■.*

Type of study/level of evidence Therapeutic IV.

Key words Finger, flexor tendon injury, hand, range of motion.

TENDON INJURIES OF THE HAND and wrist are common with an incidence rate of 33.2 per 100,000 person-years.[1] Persons of working age are most often affected, which results in substantial costs both for health care and society.[2] Flexor tendon injuries can permanently impair both hand function and quality of life. The degree to which there is full recovery after the injury is dependent on numerous factors including postoperative rehabilitation.[3] A Cochrane systematic review from 2021 included eight trials comparing different rehabilitation regimens. The authors concluded that the trials were generally at a high risk for bias. Low levels of scientific evidence were reported for all rehabilitation interventions used following flexor tendon repair.[4] Recently, we published a randomized controlled trial where we found that there was no difference between early active motion (EAM) and a regimen with passive flexion using rubber bands followed by active extension, with regards to range of motion (ROM) or Disabilities of the Arm, Shoulder and Hand

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(DASH) questionnaire at 12 months; however, EAM seemed to lead to a quicker recovery in terms of grip strength and DASH score at 3 months.[5] However, the problem with most randomized controlled trials is that patient cohorts are limited and that small differences in results might not be detected. Although registry studies often have problems with loss of follow-up, limited temporal resolution with data registered at specific (but perhaps not optimal) time points, and lack of randomization, they have the benefit of including a larger cohort of patients that may allow detection of those smaller differences. The question remains of whether the differences are clinically relevant. As the minimally clinically important difference for ROM following flexor tendon repair has not been determined, we sought to determine if it was possible to achieve adequate power in a study from a large national registry and see if those results align with previous research findings.

The aim of this study was to examine whether, in a large patient cohort, there was a difference in ROM at 3 or 12 months following flexor tendon repair between patients rehabilitated using an EAM regimen compared with those rehabilitated using passive flexion with rubber bands followed by active extension.

MATERIALS AND METHODS

This study used the Swedish national health care registry for hand surgery (HAKIR). Specialized hand surgery, including flexor tendon repair, in Sweden is mainly performed at one of seven university clinics.[6] The objective is to include all procedures performed at those clinics in the HAKIR registry. The HAKIR registry design has previously been described.[7] In short, surgical codes are registered at the time of surgery. Patients are asked to complete patient-reported outcome measures before surgery and at 3 and 12 months after surgery, when measurements on ROM and grip strength are performed by a therapist. More than 80% of routine hand surgical procedures performed are registered in HAKIR. In this study, outcomes collected after flexor tendon repairs at six hand surgery departments in Sweden were analyzed. Patients with a complete injury to the flexor pollicis longus tendon in zones T1 or T2 (zones 1 and 2 in the thumb), and patients with a complete flexor digitorum profundus tendon injury in zones 1 and 2 registered in HAKIR between October 31, 2010, and December 31, 2019, were included. The registry includes data on the tendon repairs as well as follow-up at 3 and 12 months after surgery. This includes measurements of active ROM and grip strength.[8]

Exclusion criteria in this study were patients with concomitant fractures, extensor tendon injuries, vascular injuries necessitating microvascular repair, reoperation earlier than the appointed follow-up (eg, due to a rerupture), missing data on ROM, if the rehabilitation protocol used was defined as other than EAM or passive flexion using rubber bands followed by the active extension (place and hold, immobilization in the intrinsic plus position in a plaster cast for 3−4 weeks, and other), or if there was missing information on what rehabilitation protocol was used.

At 3 months, data regarding postoperative rehabilitation were collected. Variables for rehabilitation regimens were EAM (defined as starting active flexion and extension movements of the injured digit within the first postoperative week); passive flexion using rubber band flexion on one or several fingers for the first 4 weeks, but allowing active extension (Kleinert regimen); place and hold, immobilization in the intrinsic plus position in a plaster cast for 3−4 weeks, and others. Range of motion in the metacarpophalangeal (MCP), proximal interphalangeal (PIP), and distal interphalangeal (DIP) joints of the injured fingers was measured with a goniometer by specialized hand therapists using a standardized measurement manual. The sum of active flexion at the MCP, PIP, and DIP joints minus any extension deficit was calculated as the total active motion (TAM). Range of motion for injuries to digits 2−5 was also classified according to Strickland and Glogiovac original classification to allow comparison to other studies.[9] According to this classification, patients who regain $< 50\%$, 50%−69%, 70%−84%, and 85%−100% of normal active flexion at the PIP and DIP joints are classified as poor, fair, good, and excellent, respectively.

To identify tendon ruptures, data were cross-checked against a data file containing reoperations in the same HAKIR registry. Unfortunately, data regarding which rehabilitation protocol had been used had not yet been registered as all reoperations following tendon rupture were performed within 3 months, which is the point at which data on rehabilitation protocol is registered in HAKIR.

The Kolmogorov-Smirnov test was used to test normality of data. All data were found to be not normally distributed and the Mann-Whitney U-test was used for comparisons. The chi-squared test was used for categorical data. A P value of $< .05$ was considered statistically significant. Multiple linear

TABLE 1. Patient and Injury Characteristics at 3 and 12 Months After Flexor Tendon Repair in Fingers and Thumbs

Patient and Injury Characteristics		3 mo		12 mo	
		Early Active Mobilization	Passive Flexion, Active Extension	Early Active Mobilization	Passive Flexion, Active Extension
No. of patients		585	152	327	68
No. of injured digits		656	172	373	75
Age, y (mean [SD])		38 (15)	37 (16)	38 (15)	39 (16)
Sex (%)	Male	386 (66)	102 (67)	216 (66)	48 (71)
	Female	199 (34)	50 (33)	111 (34)	20 (29)
Injury to dominant hand (%)	Yes	220 (38)	42 (28)	126 (39)	20 (29)
	No	262 (45)	59 (39)	157 (48)	27 (40)
	Unknown	103 (18)	51 (34)	44 (13)	21 (31)
Injured digit (%)	Thumb	102 (16)	24 (14)	58 (16)	11 (15)
	Index finger	142 (22)	37 (22)	69 (18)	20 (27)
	Middle finger	84 (13)	28 (16)	48 (13)	14 (19)
	Ring finger	89 (14)	28 (16)	58 (16)	9 (12)
	Little finger	239 (36)	55 (32)	140 (38)	21 (28)
Injury to multiple digits (%)	No	526 (90)	136 (89)	289 (88)	62 (91)
	Yes	59 (10)	15 (10)	38 (12)	6 (9)
Injury to digital nerve (%)	No	373 (64)	86 (57)	209 (64)	34 (50)
	Yes	212 (36)	66 (43)	118 (36)	34 (50)

regressions were performed to assess the effect of rehabilitation regimens (EAM or passive flexion, active extension) on TAM. Potential confounding of the variables age, sex (male/female), injury type (flexor digitorum profundus or flexor digitorum profundus and flexor digitorum superficialis), and concomitant nerve injury were defined as a β value change of >10% in the effect of rehabilitation regimen on TAM. Correlations and variance inflation factors were inspected to assess the assumption of independence between variables.

The regional ethics board at Karolinska Institute approved this study.

RESULTS

A total of 737 patients with 702 injured fingers (554 EAM and 148 passive flexion) and 126 thumbs (102 EAM and 24 passive flexion) were available for analysis 3 months after surgery. Twelve months after surgery, 395 patients with 379 injured fingers (315 EAM and 64 passive flexion) and 69 thumbs (58 EAM and 11 passive flexion) were available for analysis. All patients who had a tendon rupture (5.2% at an average of 57 days after the initial surgery) were excluded. In total, 14 thumbs and 73 fingers at 3 months and 24 thumbs and 111 fingers at 12 months were excluded because the rehabilitation regimen used could not be defined as either EAM or passive flexion, active extension. A total of 32 patients (4.8%) in the EAM group and seven patients (4.0%) in the passive flexion, active extension group underwent tenolysis at an average of 384 and 366 days after the initial operation, respectively. The tenolysis surgery was performed after their ROM was registered in HAKIR, and hence after the ROM analysis in this study.

Patient and injury characteristics are summarized in Table 1. Three hundred fifty-one patients were available for the analysis at both 3 and 12 months after surgery (Table 2).

Power calculations based on distributions, means, and SDs reported in the data showed that this study had a power of 56% to reveal a difference in TAM between the EAM group and the passive flexion, active extension group at 3 months after surgery, and a power of 83% to reveal a difference in TAM at 12 months after surgery for injuries to the fingers. For

TABLE 2. Total Active Motion, Active Motion at the Proximal and Distal Interphalangeal Joints, Extension Deficits, and Strickland Classification for Injuries to Digits 2–5 at 3 and 12 Months After Flexor Tendon Repair

	3 mo		12 mo	
Range of Motion	Early Active Mobilization	Passive Flexion, Active Extension	Early Active Mobilization	Passive Flexion, Active Extension
TAM, median (IQR)	195 (64)	198 (45)	215 (55)	215 (47)
Active motion at PIP joint + DIP joint, median (IQR)	110 (60)	112 (44)	130 (55)	130 (47)
Extension deficit at PIP joint, median (IQR)	10 (20)	5 (20)	5 (20)	0 (19)
Extension deficit at DIP joint, median (IQR)	0 (10)	0 (10)	0 (10)	4.5 (13)
Extension deficit at PIP joint + DIP joint, median (IQR)	14 (20)	10 (25)	15 (30)	10 (30)

IQR, interquartile range.

injuries to the thumb, the power to show a difference in active motion at the MCP and interphalangeal joints between the two groups was 82 % at 3 months and 76 % at 12 months after surgery.

The power to show a difference between the pooled Strickland classification groups was 81% at 3 months and 77 % at 12 months. Where power calculations reached 80% or more, statistical comparisons were performed.

There was no statistically significant difference in TAM at 12 months after surgery between the EAM group and the passive flexion, active extension group for injuries to fingers.

The distribution between the different groups in the Strickland classification is shown in Figure 1. Pooling the classes into two groups consisting of poor and fair results or good and excellent, as suggested in one of our recent publications, showed no statistically significant difference between these pooled groups at 3 months following flexor tendon repair.[9]

For injuries to the thumb, there was no difference in active motion at the MCP and interphalangeal joints at 3 months after surgery (Table 3).

Adjusting for a possible confounding effect of age, sex, injury type, and concomitant nerve injury did not alter the effect that the different rehabilitation regimens had on TAM in the multiple regression models.

DISCUSSION

In this registry study, we found no difference in TAM between rehabilitation using an EAM regimen compared with passive flexion using rubber bands followed by active extension. Similar results have been shown in previous clinical studies.[5,10–12] Reducing the quantitative data into the Strickland classification risks that minor differences between groups may not be detected. However, it may make the results more relatable and easily comparable with other studies. In this study, there was no difference according to the Strickland criteria when pooling the categories into one poor/fair group and one good/excellent group. The rationale for pooling Strickland classes is that in a previous study, we found that a statistically significant difference between patient-reported outcome measure values for stiffness and satisfaction was only detected between Strickland groups fair and good, but not between poor and fair or good and excellent, according to patients.[13,14] It may therefore be argued that according to the patient's experience of the results, only ROM reaching 70% or more of normal digital motion will be relevant to them. When extrapolated to this study, we find no difference between an EAM and passive flexion using rubber bands followed by active extension. This must, however, be interpreted with caution because other individual factors such as age, sex, and occupation are likely to influence the patient's perceived stiffness and satisfaction.

We believe that the current study, despite the limitation of it being registry-based, adds to knowledge about rehabilitation following flexor tendon injury because it is a large study based on prospectively collected data from a national registry. This study also included thumbs, which were analyzed separately (Table 3).

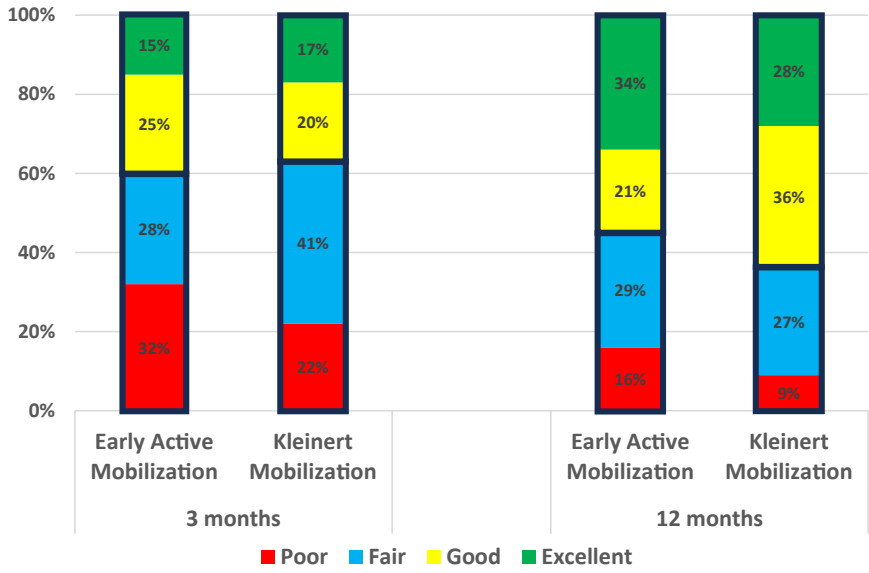

FIGURE 1: Strickland classification at 3 and 12 months after surgery.

TABLE 3. Active Motion at the Metacarpophalangeal and the Interphalangeal Joint and Extension Deficits for Injuries to the Thumb 3 and 12 Months After Flexor Tendon Repair

	3 mo		12 mo	
Range of Motion	Early Active Mobilization	Passive Flexion, Active Extension	Early Active Mobilization	Passive Flexion, Active Extension
Active motion at MCP joint + IP joint, median (IQR)	95 (35)	83.5 (39)	110 (44)	100 (31)
Active motion at IP joint, median (IQR)	39 (25)	37 (50)	52.5 (35)	45 (10)
Extension deficit at MCP joint, median (IQR)	0 (0)	0 (1.5)	0 (0)	0 (0)
Extension deficit at IP joint, median (IQR)	0 (5)	0 (0)	0 (5)	0 (3)
Extension deficit at MCP joint + IP joint, median (IQR)	0 (10)	0 (10)	0 (10)	0 (14)

IP, interphalangeal; IQR, interquartile range.

The reported active ROM in the present study was slightly less, compared with the results of previous studies. In a study by Chevalley et al,[10] 67% of patients who had followed the active mobilization program, and 83% who had followed the passive mobilization program with place and hold were categorized as good or excellent according to Strickland at 3 months after surgery. This rate increased to 81% for the active group and 86% for the passive group by 12 months after surgery. In another study by Rigó et al[11] that included injuries in zones 1−3, the median active ROM at the PIP and DIP joints at 3 months after surgery was 127° for the active group and 125° for the passive motion group. This increased to 150° and 146° at 12 months after surgery, respectively. Using the Strickland classification, 61% of patients who had followed the active mobilization and 52% in the passive motion group were categorized as good or excellent at 3 months after surgery. This number rose to 82% for the active group and 69% for the passive motion group by 12 months after surgery. In a study by Jokinen et al[12] with a mean follow-up of 38 months, the mean TAM was 184° for the active group and 190° for the passive motion group. According to the Strickland classification, 65% of fingers rehabilitated using

active mobilization and 96% rehabilitated with the passive motion regimen were categorized as good or excellent. They included patients with a wider range of injuries, including all zones from zones 1−5. A recent study at our institution also showed no significant difference in median TAM at 3 months (195.5° for the EAM group and 191.5° for the passive motion group) or 12 months (219° for the EAM group and 222.5° for the passive motion group). According to the Strickland classification, 29% of patients following the EAM regimen and 39% of patients following the passive motion regimen were classified as good or excellent at 3 months after surgery. This number increased to 59% for the EAM group and 60% for the passive motion group at 12 months after surgery,[5] which is comparable with 55% for the EAM group and 64% for the passive motion group at 12 months in the current study.

The difference in the results between studies may, in part, be due to different study designs. Also, studies including injuries in zones 3−5 are not directly comparable. The present study reports the results of all flexor tendon repairs in zones 1 and 2, and patients were treated by surgeons and hand therapists of varying levels of experience, including less compliant patients. Patients were followed up according to standard clinical routines. We believe that this adds to the generalizability of the results, representing a true picture of clinical practice.

This study has some limitations. First, as is common in large registry-based studies, we have a high rate of missing final follow-ups. National registries, although valuable for their large and diverse data sets, often have low follow-up rates. This can introduce bias as the patients who do not return for follow-up may differ systematically from those who do, potentially skewing results. For example, patients with better recovery may feel less need for follow-up, leading to an underrepresentation of positive outcomes in the data. Consequently, this limitation must be acknowledged because it can affect the validity and generalizability of the study findings. Perhaps more importantly, missing data can result in a lack of power. In the current study, we have chosen not to report statistical comparisons for any result where the comparison had a power of less than 80%. Since the results between the EAM and passive flexion, active extension group are similar at both 3 and 12 months, it may be hypothesized that even if all comparisons were adequately powered, it is unlikely that we would find a clinically relevant difference. Second, the choice of rehabilitation protocol was not randomized but selected by preference of the surgeon and therapist. There may also be local variations in the rehabilitation protocols, such as minor differences in the design of splints, frequency of therapy visits, etc, between the different hospitals. Therefore, it is impossible to know for certain whether the therapy was uniform beyond the designation of "EAM" or "passive flexion using rubber bands," which are two of the options at the 3-month HAKIR registration. We believe that local tradition was the strongest factor in deciding the surgical technique, suture material, and rehabilitation protocol. However, we cannot completely disregard the possibility of selection bias where, for instance, more severe injuries or noncompliant patients were more commonly chosen for a passive motion regimen. This might mean that the passive flexion, active extension group consists of more seriously injured patients or patients who are more likely to be nonadherent to their rehabilitation. If more severe or noncompliant patients were directed toward the passive motion regimen, the lack of differences observed might underrepresent the true potential of this protocol. The passive regimen group might appear less effective not because the regimen is inferior but because the patients had more challenging recoveries. Although it is difficult to eliminate selection bias entirely in nonrandomized studies, acknowledging and adjusting for potential confounders can mitigate its impact. In this study, multiple linear regressions were used to adjust for age, sex, injury type, and concomitant nerve injury, which helps reduce, but does not entirely eliminate, the risk of bias.

There are also other factors, such as the mechanism of injury, subzone of the tendon injury, surgeon′s experience, repair technique, and time from injury to repair that might have influenced our results. There might also be a difference in the number of therapy visits. Another factor of importance is patient adherence to the rehabilitation protocol, which we had no way of monitoring in the present study. Previous studies have shown that the patient's perception of the injury, the effectiveness of exercises, and social support strongly influence adherence.[15] In another study, similar rates of patients were deemed to be noncompliant both for the EAM and the passive motion protocols; hence, it is possible that both groups in our study were affected equally by nonadherence.[5] Another limitation of this study is that our data did not include risk factors commonly associated with complications and reoperations.[16] Also, the rehabilitation regimens are not registered in HAKIR until the patients come for their 3-month follow-up. As most ruptures happen before this point (on average 57 days in this material), we are unable to analyze if there is a difference in rupture

rate due to different rehabilitation regimens. Traditionally, risk of repair rupture has been regarded as one of the most important topics when comparing active and passive rehabilitation protocols. As we are unable to examine this subject in the current study, it is a major limitation.

Despite these limitations, there is now a growing body of evidence showing that EAM regimens and more passive motion protocols such as passive flexion using rubber bands followed by active extension, lead to similar results with regards to ROM.[5,10–12] There are, however, other aspects to consider when deciding which postoperative rehabilitation regimen should be used. Some studies show a greater incidence of tenolysis following a more passive regimen, and some show a higher tendency toward ruptures when an active regimen is used.[5,17] In this study, the risk of needing tenolysis surgery was similar in both groups (4.8% in the EAM group and 4.0% in the passive flexion, active extension group). There might also be a difference in how quickly patients recover grip strength or pinch strength, favoring EAM.[5,11] Also, the complexity of different rehabilitation protocols may lead to differences in how much time is needed with the hand therapist. It has been shown that passive rubber band rehabilitation increases the health care costs by 4% compared with EAM.[18]

In conclusion, this study adds to the present knowledge that both EAM regimens and passive motion regimens, such as passive flexion using rubber bands followed by active extension lead to similar results regarding ROM following flexor tendon repair. As there are numerous variants of these regimes, a more thorough analysis, preferably as a prospective randomized trial with detailed descriptions of rehabilitation protocols and including measures of adherence, may be needed to detect a possible difference in regained motion after flexor tendon repair.

CONFLICTS OF INTEREST

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

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