Primary Flexor Tendon Repair in Zones 1 and 2: Early Passive Mobilization Versus Controlled Active Motion

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Purpose To compare early passive mobilization (EPM) with controlled active motion (CAM) after flexor tendon surgery in zones 1 and 2.

Methods We performed a retrospective analysis of collected data of all patients receiving primary flexor tendon repair in zones 1 and 2 from 2006 to 2011, during which time 228 patients were treated, and 191 patients with 231 injured digits were eligible for study. Exclusion criteria were replantation, finger revascularization, age younger than 16 years, rehabilitation by means other than EPM or CAM, and missing information regarding post-operative rehabilitation. This left 132 patients with 159 injured fingers for analysis. The primary endpoint was the comparison of total active motion (TAM) values 4 and 12 weeks after surgery between the EPM and the CAM protocols. The analysis of TAM measurements under the rehabilitation protocols was conducted using *t*-tests and further linear modeling. We defined rupture rate and the assessment of adhesion/infection as secondary endpoints.

Results There was a statistically significant difference between the TAM values of the EPM and the CAM protocols 4 weeks after surgery. At 12 weeks, however, there was no significant difference between the 2 protocols. Older age and injuries with finger fractures were associated with lower TAM values. Rupture rates were 5% (CAM) and 7% (EPM), which were not statistically different.

Conclusions This study showed a favorable effect of CAM protocol on TAM 4 weeks after surgery. The percent rupture rate was slightly lower in the patients with CAM than in the patients with EPM regime. Further studies are required to confirm our results and to investigate whether faster recovery of TAM is associated with shorter time out of work. *(J Hand Surg Am. 2014;39(7):1344–1350. Copyright © 2014 by the American Society for Surgery of the Hand. All rights reserved.)*

Type of study/level of evidence Therapeutic III.

Key words CAM, early active mobilization, flexor tendon repair, Kleinert protocol, zone 2.

FLEXOR TENDON INJURIES IN ZONE 2 are common, and despite abundant data about surgical approach, rehabilitation protocols are still a current topic of debate. Established rehabilitation regimens of flexor tendon repair are immobilization, early passive mobilization (EPM) and controlled active motion (CAM). The CAM protocol was described by Small et al.[1–3] Whereas immobilization is reasonable in

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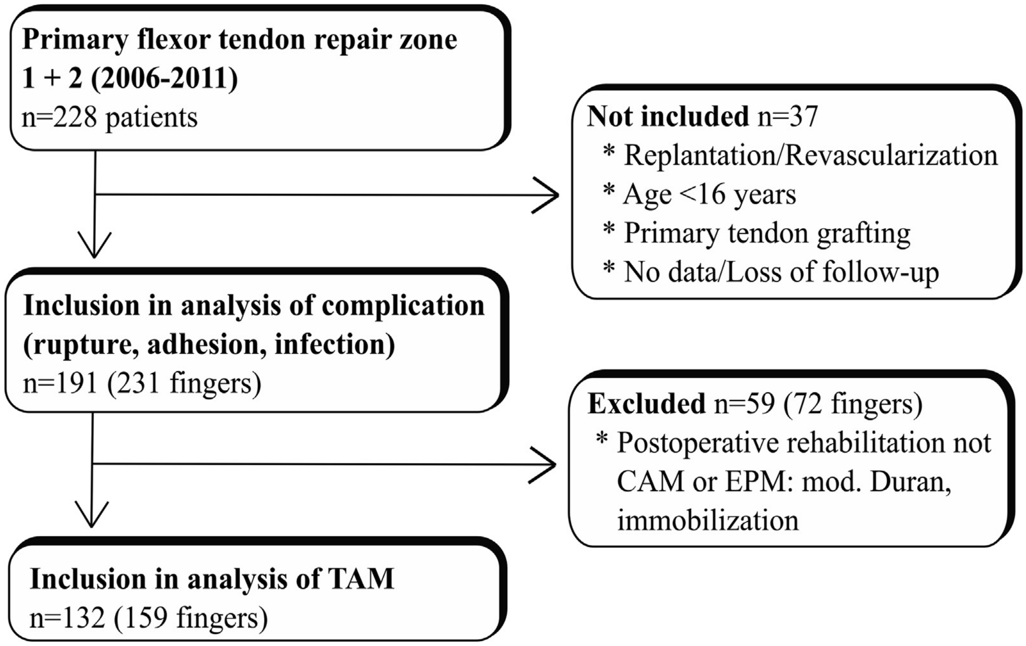


FIGURE 1: Patient selection process.

treatment of children, noncompliant patients (eg, those with severe dementia) and concomitant intra-articular fracture, EPM and CAM protocols have been used widely for successful rehabilitation of repaired flexor tendons in recent decades.[2] In 2005, Groth[4] showed that Kleinert/Duran EPM protocols were still widespread and used by two thirds of all hand therapists.

CAM was developed in order to improve postoperative range of motion by preventing restrictive adhesions. The CAM regimen requires a strong core suture construct (4 or 6 strands), compliant and motivated patients, and soft tissue coverage that allows for early movement. Rupture rates up to 46% have been reported over the past 20 years for core sutures with 4 or 6 strands with zone 2C repairs being most liable for rupture/adhesion.[5–7] Pulley management has proven to be essential and is challenging, especially in zone 2C where venting of the annular pulleys to prevent impingement of the repaired tendon can be crucial.[8]

Despite the large amount of data about different rehabilitation protocols, there are few studies comparing EPM with CAM protocols. Recent reviews demonstrate favorable effects of CAM on adhesion formation and tensile strength. Rupture rate was highest in Kleinert EPM protocols, and CAM showed the highest proportion of excellent and good results.[9,10] Rubber band traction as used in the Kleinert regimen is one of the causes of proximal interphalangeal joint stiffness related to contraction of the palmar plate.[11] With the goal of improving the results of tendon repair in zone 2, in 2011, we introduced a CAM rehabilitation protocol in our unit.

The aim of this study was to determine results of primary flexor tendon repair in zones 1 and 2 from 2006 to 2011, comparing the effect of EPM and CAM protocols on postoperative recovery of finger motion 4 and 12 weeks after surgery.

MATERIALS AND METHODS

The local ethical committee approved the study protocol.

Study design

Data from patients operated from 2006 to 2011 with fresh traumatic flexor tendon lacerations in zones 1 and 2 were collected retrospectively. Figure 1 shows details of the patient selection process. Complex injuries with crush and/or concomitant fracture were included in this study.

The primary endpoint was the comparison of TAM at 4 and 12 weeks after surgery between the EPM and the CAM protocols. As the secondary endpoint, we defined rupture rate and the assessment of adhesion/infection.

Patients and injury characteristics

We included 191 patients with 231 injured fingers and 349 lacerated tendons. The collective consisted of 56 (29%) women and 135 (71%) men with 94% sharp and 6% crush injuries. The mean age was 40 years (range, 16–71 y) for women and 33 years (range, 16–74 y) for men. Among all, the little finger was affected most frequently with 76 injuries (32%) and 123 lacerated tendons. Sixty-six digits had zone 1 injuries. We observed more zone 1 injuries in the index (33%) than in the little finger (15%). In zone 2 injuries, 67% of the lacerations involved both deep and superficial flexor tendons. The flexor digitorum profundus alone was injured in 30%.

A total of 138 fingers were rehabilitated using an EPM protocol and 21 fingers were treated with a CAM regimen. Seventy-two (31%) fingers were rehabilitated with other protocols because of noncompliance or unstable fractures. Thus, for the comparison of rehabilitation protocols, there were 159 fingers from 132 patients available for analysis (Fig. 1).

Technique of tendon repair

Staff surgeons of our unit were responsible for all surgical procedures. As described by Puippe et al,[12] flexor digitorum profundus and flexor digitorum superficialis tendons were repaired using a 4-strand core suture with locking loops. Suture material was 4-0 or 3-0 polyester braid containing a long chain polyethylene core (FiberWire, Arthrex, Naples, FL). Fifteen percent of the tendons were repaired using other suture technique (2-strand or 6-strand). Circumferential epitendinous locking suture was performed with 6-0 polypropylene (Prolene, Johnson & Johnson Medical, New Brunswick, NJ). In distal flexor digitorum superficialis injuries involving only 1 slip, excision of the slip was the treatment of choice. Injuries of the neurovascular bundle were repaired with 9-0 monofilament polyamide. Before wound closure, free gliding of the tendon under the pulleys and gapping at the repair site were tested performing full extension/flexion of all joints, described as the extension-flexion test by Tang.[13] Venting of the annular pulleys was performed if indicated. A dorsal 4-finger orthosis was applied to protect the repaired tendons (wrist 20° flexion, intrinsic plus position of the finger joints).

EPM protocol

Hand rehabilitation was performed by the hand therapists of our unit (50% of the patients) or by outside hand therapists using our protocol. From 2006 until 2010, a modified Kleinert protocol was the standard rehabilitation for primary flexor tendon repair. Within 3 to 5 days following surgery, the hand therapists adapted a 4-finger thermoplastic dorsal forearm−based orthosis with the wrist in 30° flexion and the finger joints in intrinsic plus position with 70° flexion of the metacarpophalangeal (MCP) joints. A rubber band for passive finger flexion was used for home exercises. During the first 3 weeks, the patient performed passive mobilization in combination with place-and-hold exercises. About 22 days after repair, resistance-free active motion was initiated. Loading exercises started after 8 weeks, and full use was permitted after 12 weeks.

FIGURE 2: Dorsal forearm−based orthosis. Wrist, 10° flexion; MCP joints, 40° flexion; interphalangeal joints, neutral (0°) position.

CAM protocol

In 2011, the CAM protocol was introduced. A dorsal forearm−based orthosis (Fig. 2) was applied within 3 to 5 days after tendon repair. The orthosis was worn day and night for 5 weeks and for 3 more weeks at night. Complete active motion of the fingers was initiated within 3 to 5 days after surgery, depending on the extent of postoperative edema. Active blocking exercises and full passive flexion were started a week after repair (Figs. 3 and 4). Loading exercises and light activities of daily living were initiated after 6 weeks, and full use was permitted after 12 weeks. The patients attended weekly appointments at the hand therapy clinic and were seen by the surgeons 6 and 12 weeks after repair.

FIGURE 3: Full passive flexion/extension (week 1).

FIGURE 4: Early active mobilization with 2-finger blocking exercise. The patient blocks active flexion with 2 fingers, which are placed on the MCP-flexion crease.

Assessment of finger function

The hand therapists assessed postoperative total active motion (TAM) values after 4 and 12 weeks. Motion of the MCP joint was included. To evaluate functional grades, we divided the TAM values of injured fingers by the norm (www.assh.org/Public/HandAnatomy/Anatomy/Pages/Normal-Range-Motion.aspx) and used the American Society for Surgery of the Hand criteria.[14] We did not use contralateral TAM for functional grades, because it was not available for all patients.

Statistical methods

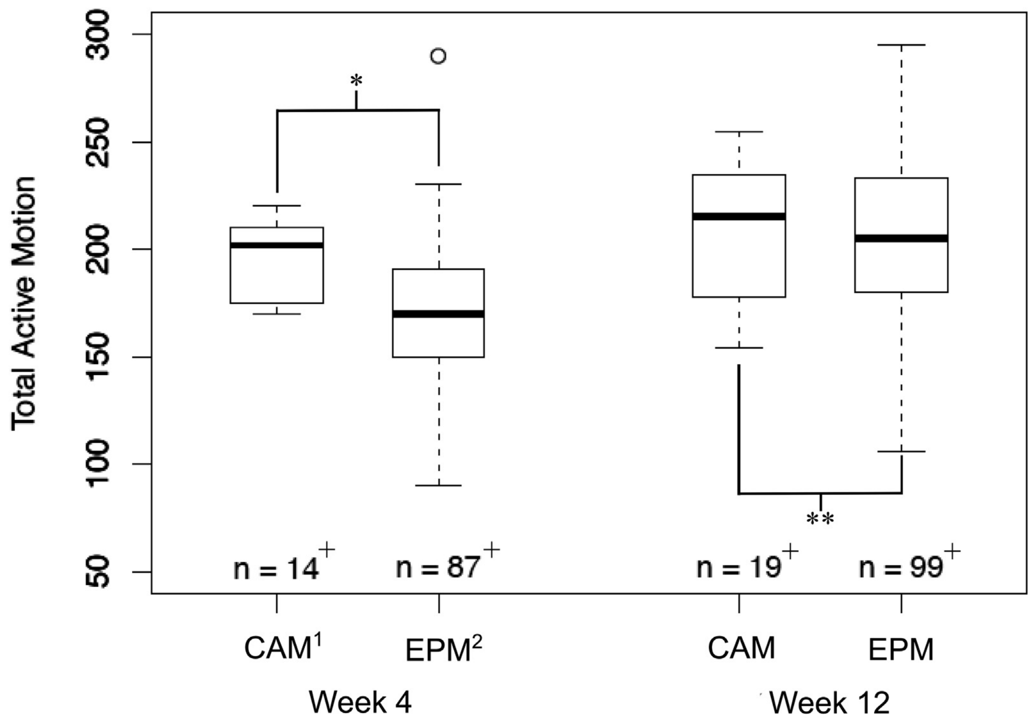
An initial naive analysis of TAM values under the rehabilitation protocols after 4 and 12 weeks was conducted using a t-test with unequal variances. This analysis assumes that all fingers were independent. Because 15% of the patients had multidigital injury, the results were biased. To remove this assumption, generalized estimating equations (GEE) with an exchangeable correlation structure were used to fit linear models for TAM for each time point. Possible confounders were identified using analysis of variance and F-tests of linear models. Age was included because previous studies found an adverse effect on motion outcome.[15] Further univariate GEE linear models were fitted to adjust for confounders.

RESULTS

Total active motion

Motion analysis was performed with 2 groups: 138 fingers (EPM) and 21 fingers (CAM). Fifteen percent of subjects had sustained injury of multiple fingers. There was a marginally significant difference of age distribution between the 2 protocols ($P = .05$). There were 3 fingers in the EPM group with concomitant fractures compared with none in the CAM group. Thirty-eight percent of the CAM group had a digital nerve injury versus 56% in the EPM group.

TAM measurements after 4 weeks showed statistically significant difference between the CAM and the EPM groups ($P < .001$) Twelve weeks after surgery, there was no statistically significant difference between the 2 protocols ($P = .75$). Figure 5 summarizes TAM measurements after 4 and 12 weeks. There was no statistically significant difference between results of tendon repair in zones 1 and 2.



* $P < .001$

** $P = .75$

[1] Controlled active motion

[2] Early passive mobilization

\+ Not all patients had TAM measurements for both time points. To check for bias in the missing observations, models were fitted using only fingers that had all values (n=95). The difference between the protocols remained stable, suggesting that there was no bias due to missing values.

FIGURE 5: TAM at weeks 4 and 12.

Multidigital injuries/confounding factors

The GEE linear models were fitted to incorporate the dependence between fingers from the same patient. The effect of CAM protocol on TAM values after 4 and 12 weeks was stable.

Analysis of confounding factors showed that age ($P = .046$) and concomitant fracture ($P < .001$) were associated with lower TAM values after 12 weeks, whereas after 4 weeks, the rehabilitation protocol was the only statistically significant confounder ($P < .001$).

Functional grades/surgeons' experience

Fifty-three percent of the EPM and 63% of the CAM group showed good or excellent results after 12 weeks. Functional results are shown in Table 1. Attending surgeons (level of experience III[16]) performed 85% of the operations, and residents (level of experience I) did 15% of the repairs. There was no statistically significant association between surgical expertise and the functional results.

Rupture rate

The overall rupture rate was 7%. In the CAM group, there was 1 rupture (5%) compared to 10 ruptures in the EPM group (7%). The group rehabilitated with other protocols (59 patients/72 fingers) showed a rupture rate of 8%.

Analysis of complications across the digits was performed. The lowest rupture rate at 5% (4/76) was recorded for the little finger. Crush injury or multi-digital lacerations were not significantly associated with higher rupture rates.

TABLE 1. American Society for Surgery of the Hand Functional Grades (week 12)

Functional Grade*		EPM (% patients)	CAM (% patients)
Excellent	100%	8	-
Good	> 75%	45	65
Fair	> 50%	43	35
Poor	< 50%	4	-
Worse†		-	-

*(TAM/270) × 100.
†TAM worse than before surgery.

Other complications

Twenty-nine patients with adhesions and unsatisfactory TAM were reoperated with tenolysis and inpatient hospitalization for immediate hand therapy. There was 1 postoperative infection.

DISCUSSION

Factors affecting the outcome of primary repair are tendon rupture, adhesion formation, contracture of the proximal interphalangeal joint, severity of trauma, surgical skill, and the quality of postoperative rehabilitation.[11] The need for stronger core suture to resist CAM was emphasized over 20 years ago.[17] Since then, several studies have shown about 75% good or excellent results with rupture rates from 2% to 8%. Harris et al[5] identified a strong relationship between rupture rate and the behavior pattern of patients in the early postoperative period. Kitsis et al[18] provided prospective data with multistrand core suture and early active mobilization. They reported good results with a rupture rate of 6%. Trumble et al[19] showed a favorable effect of active place-and-hold therapy compared with passive motion. Level I evidence was achieved by comparing the 2 rehabilitation methods prospectively. Early active motion was associated with greater interphalangeal joint motion, smaller flexion contractures, and higher patient satisfaction. The risk for rupture was not increased in early active regimens. In Starr et al's systematic review,[20] passive motion protocols showed a statistically significantly decreased risk for tendon rupture. On the contrary, range of motion was significantly higher in patients rehabilitated with early active protocols. In our study, The CAM group showed a rupture rate of 5% compared with 7% (EPM) and 8% (other regimens). There was no statistically significant difference between the protocols. The rather high overall rupture rate with 7% is not explained by the inclusion of complex injury (crush). Twenty-nine patients (15%) had to be reoperated because of adhesions and unsatisfactory functional results. Despite early active mobilization, formation of restrictive adhesions still is an unsolved and important issue.

Considering functional results, the total percent of good and excellent rates was about 60%, which was lower than most other reports. This may relate to the fact that 12 weeks is not the endpoint of functional recovery. Furthermore, the rate of good and excellent results might have been higher with the use of individual contralateral TAM because not all patients showed TAM values of 270°. Even though residents performed 15% of the tendon repairs, functional results were not statistically significantly associated with the surgeons' expertise. As with several authors before, we did not find a statistically significant difference in TAM between patients rehabilitated with EPM and CAM protocols after 12 weeks.[7,15] However, after 4 weeks, there was clear evidence for a faster recovery of finger motion in the CAM group. We hypothesize that faster recovery of TAM is advantageous in the process of regaining activities of daily living and might even shorten the time out of work for patients with a sedentary occupation.

Age and concomitant fracture have proven to be relevant confounders of finger motion 12 weeks after surgery. Thus, it is worthwhile but not always possible to achieve stable osteosynthesis for early active motion. However, an associated complicated fracture mostly results in worse outcomes as tissue swelling, pain, and adhesions restrict rehabilitation of finger motion. Severely injured fingers may require temporary immobilization or restrictive mobilization before starting active rehabilitation. Achieving excellent results after primary flexor tendon repair in the little finger is considered difficult.[21,22] The small diameter, a multidirectional moving in the border digit, and a wider structural variation might predispose tendon repair in the little finger to a higher rate of complication. In our study, the little finger was the most frequently injured but was not associated with complication rates above average, and tendon rupture was less frequent in the little finger than in the other digits.

This study has some limitations. Most importantly, it is a retrospective analysis. Hence, loss of follow-up and exclusion of patients reduce its external validity. Because contralateral TAM was not available for all patients, we did not use the zone 2 Strickland and Glogovac[23] criteria for assessment of finger function. Thus, comparison with the results of other flexor tendon studies is difficult. We did not assess subjective results with a scoring tool (ie, Disabilities of the Arm, Shoulder, and Hand score).

The results of CAM following primary flexor tendon repair are encouraging considering the trend to lower complication rates and early recovery of finger motion. Our CAM protocol was equally safe compared with the EPM protocol and easier to perform for both hand therapists and patients. We are well aware that this is not necessarily applicable for other existing early active motion protocols.

Further prospective studies are required to confirm our goal of faster return to work following early active mobilization.

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