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The Role of Active and Passive Mobilization Techniques in Early Recovery After Flexor Tendon Repair: A Systematic Review

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ABSTRACT

Background: Flexor tendon injuries, particularly in Zone II, remain among the most complex challenges in hand surgery. Optimal postoperative rehabilitation is essential to balance tendon protection and early motion. Rehabilitation strategies vary from passive mobilization protocols such as the modified Kleinert and modified Duran, to hybrid techniques like Place-and-Active-Hold (PAH), and fully active regimens such as Controlled Active Motion (CAM). Each technique differs in timing, supervision, and degree of tendon loading, influencing functional recovery and complication rates. This systematic review compares these technique-specific rehabilitation protocols to evaluate their impact on early recovery, complications, and patient-centered outcomes following flexor tendon repair.

Methods: Following PRISMA guidelines, a comprehensive search of PubMed, Embase, Scopus, and CINAHL was conducted. Included studies were RCTs or prospective cohort trials comparing at least two of the following techniques: passive mobilization (modified Kleinert or Duran), hybrid (PAH), or active (CAM) after zone II flexor tendon repair. Data were extracted for functional outcomes (Total Active Motion [TAM], PIP/DIP milestones, grip strength), complications (rupture, adhesions, flexion/extension lag), and patient-centered outcomes (pain, satisfaction, early return to ADLs). Rehabilitation details such as splint design, exercise frequency, and supervision level were analyzed.

Results: Four eligible studies encompassing 215 patients met inclusion criteria. Active (CAM) protocols yielded the fastest early functional recovery, followed by hybrid (PAH) programs, while passive (Kleinert/Duran) techniques demonstrated slower progress. Early TAM, PIP/DIP flexion, and grip strength were highest in CAM groups. Hybrid protocols (PAH) offered a safer middle ground with superior early motion compared to passive regimens and without increased rupture risk. Complications—including adhesions and flexion lag—were reduced in CAM and PAH groups, while rupture rates remained comparable across all methods. Patient satisfaction and early return to ADLs were significantly greater among those undergoing active or hybrid protocols. Long-term results converged across all groups after 12–16 weeks.

Conclusions: Rehabilitation after flexor tendon repair should be viewed as a continuum of motion—progressing from passive to hybrid to active techniques as healing allows. CAM and PAH programs promote earlier tendon glide, improved functional outcomes, and greater patient

satisfaction without compromising safety. Passive regimens remain useful in high-risk repairs but should transition to controlled motion when feasible. These findings highlight the importance of technique-specific protocol selection and individualized rehabilitation planning to optimize early recovery.

Keywords: Flexor tendon repair, Rehabilitation protocols, Controlled Active Motion, Place-and-Active-Hold, Modified Kleinert, Modified Duran, Early functional recovery

INTRODUCTION

Flexor tendon injuries of the hand represent a significant source of disability, particularly when they involve Zone II, an anatomical region historically referred to as "no-man's land." This zone extends from the distal palmar crease to the insertion of the flexor digitorum superficialis and is characterized by a narrow fibro-osseous tunnel containing both flexor tendons and an intricate pulley system. Within this confined space, even minimal edema, hematoma, or scar formation can disrupt tendon gliding, leading to stiffness, adhesion formation, and suboptimal functional recovery.

Despite advances in surgical techniques—including multi-strand core sutures, improved epitendinous repair, and refined suture materials—postoperative rehabilitation remains a critical determinant of outcome following flexor tendon repair. A technically sound repair may still result in poor function if rehabilitation fails to provide adequate tendon excursion or, conversely, if excessive loading leads to repair rupture. Consequently, the balance between protecting the repair and promoting early controlled motion has become a central principle in flexor tendon management.

Early mobilization has been shown to enhance intrinsic tendon healing by improving synovial diffusion, stimulating collagen alignment, and reducing peritendinous adhesion formation. However, the optimal method and timing of mobilization remain controversial. Rehabilitation protocols differ substantially in the degree of tendon loading applied, the level of patient participation required, and the intensity of therapist supervision. These differences have important implications for early functional recovery, complication rates, and patient satisfaction.

Contemporary rehabilitation strategies after Zone II flexor tendon repair can be broadly categorized into three biomechanical approaches: passive mobilization, hybrid mobilization, and active mobilization. Passive protocols, such as the modified Kleinert and modified Duran techniques, rely on extrinsic forces or therapist-assisted movement while minimizing intrinsic tendon contraction. Hybrid techniques, most notably Place-and-Active-Hold (PAH), introduce limited intrinsic loading by asking patients to actively maintain a passively achieved flexed position. Fully active regimens, such as Controlled Active Motion (CAM), allow true active flexion and extension within a protected range, typically under the constraint of a dorsal blocking splint.

Although all three approaches aim to optimize tendon healing while minimizing complications, they create distinct mechanical environments at the repair site. These biomechanical differences may influence the rate of functional recovery, the risk of adhesion formation, and the likelihood of tendon rupture, particularly during the early postoperative period when the repair is most vulnerable. Furthermore, patient-related factors—including compliance, access to supervised therapy, and repair strength—play a pivotal role in determining which protocol can be safely implemented.

Given the persistent variability in clinical practice and the lack of universal consensus regarding the optimal rehabilitation strategy for Zone II flexor tendon injuries, a clear synthesis of comparative evidence is needed. This systematic review therefore aims to compare passive, hybrid, and active

mobilization techniques following Zone II flexor tendon repair, with a particular focus on early functional outcomes, complication profiles, and patient-centered measures. By clarifying the relative benefits and limitations of each approach, this review seeks to assist surgeons and therapists in selecting rehabilitation protocols that are both safe and effective.

MATERIALS & METHODS

Study Design: This study was conducted as a systematic review of the literature and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines. The review protocol was developed a priori to minimize selection bias and ensure methodological transparency throughout the study process.

Eligibility Criteria Studies were selected based on predefined inclusion and exclusion criteria. Eligible studies met the following criteria: (1) randomized controlled trials or prospective cohort studies; (2) adult patients (≥18 years) undergoing primary flexor tendon repair involving Zone II; (3) comparison of at least two postoperative rehabilitation protocols, including passive mobilization (modified Kleinert or modified Duran), hybrid mobilization (Place-and-Active-Hold), or active mobilization (Controlled Active Motion); and (4) reporting of at least one clinically relevant outcome, such as early total active motion, joint-specific range of motion milestones, grip strength, complication rates (tendon rupture, adhesion formation, flexion or extension lag), or patient-centered outcomes (pain, satisfaction, or return to activities of daily living).

Studies were excluded if they were retrospective in design, case reports, case series with fewer than 10 patients, animal or cadaveric studies, in vitro biomechanical investigations, or studies involving mixed flexor tendon zones without separable data for Zone II injuries. Articles not published in English or lacking sufficient methodological detail were also excluded.

Information Sources and Search Strategy A comprehensive electronic literature search was performed using PubMed, Embase, Scopus, and CINAHL databases from inception to the most recent available records. The search strategy combined Medical Subject Headings (MeSH) terms and free-text keywords related to flexor tendon injury, Zone II repair, and rehabilitation protocols. Key search terms included combinations of: “Zone II flexor tendon repair,” “early active motion,” “controlled active motion,” “place and hold,” “place and active hold,” “modified Kleinert,” “modified Duran,” and “rehabilitation protocol.” Reference lists of all included studies and relevant review articles were manually screened to identify additional eligible publications.

Study Selection All retrieved records were imported into a reference management software, and duplicate entries were removed. Titles and abstracts were independently screened by two reviewers to assess potential eligibility. Full-text articles were subsequently reviewed for final inclusion. Any disagreement between reviewers regarding study eligibility was resolved through discussion and consensus.

Data Extraction Data extraction was independently performed by two reviewers using a standardized data collection form. Extracted variables included study design, year of publication, sample size, patient demographics, tendon repair characteristics, rehabilitation protocol details (type of splint, timing of mobilization initiation, exercise frequency, duration of active holding, and level of therapist supervision), duration of follow-up, and reported outcomes. When necessary, corresponding authors were consulted for clarification of incomplete or ambiguous data.

Outcome Measures Primary outcomes focused on early functional recovery, including total active motion and proximal and distal interphalangeal joint range of motion within the first 12 weeks

postoperatively. Secondary outcomes included grip strength, complication rates (tendon rupture, adhesion formation, and motion lag), and patient-reported outcomes such as pain levels, satisfaction, and time to return to activities of daily living.

Risk of Bias and Quality Assessment Methodological quality and risk of bias were independently assessed by two reviewers. Randomized controlled trials were evaluated using the Cochrane Risk of Bias tool, assessing domains such as randomization, allocation concealment, blinding, and completeness of outcome data. Prospective cohort studies were assessed using the Newcastle–Ottawa Scale, focusing on selection of cohorts, comparability of groups, and adequacy of outcome assessment. Discrepancies in quality assessment were resolved by consensus.

RESULT

Study Selection and Characteristics The initial database search yielded a total of 412 records. After removal of duplicates and screening of titles and abstracts, 27 full-text articles were assessed for eligibility. Four studies fulfilled all inclusion criteria and were included in the final analysis. These studies specifically evaluated postoperative rehabilitation protocols following Zone II flexor tendon repair and provided comparable outcome measures within the early recovery period.

The four included studies comprised a total of 215 patients, with follow-up durations ranging from 8 to 16 weeks. All studies compared at least two rehabilitation strategies: passive mobilization (modified Kleinert or modified Duran), hybrid mobilization (Place-and-Active-Hold), and active mobilization (Controlled Active Motion). Variability was noted in suture techniques, splint configurations, and therapy supervision intensity; however, all protocols adhered to the principle of early protected mobilization.

Functional Outcomes Across all included studies, early functional recovery consistently favored protocols involving intrinsic tendon activation. Controlled Active Motion demonstrated the highest total active motion within the first 8–12 weeks postoperatively. Patients managed with CAM achieved earlier proximal and distal interphalangeal joint flexion milestones and demonstrated superior grip strength when compared with passive mobilization protocols.

Hybrid Place-and-Active-Hold protocols produced intermediate outcomes. Compared with purely passive techniques, PAH resulted in significantly improved early total active motion and reduced flexion lag, while maintaining a comparable safety profile. Passive mobilization protocols showed slower progression of range of motion and delayed attainment of functional arcs, particularly at the proximal interphalangeal joint.

Complications Tendon rupture rates were low and comparable across all rehabilitation strategies, ranging from 0% to 7%. Importantly, no study demonstrated a statistically significant increase in rupture risk associated with Controlled Active Motion when implemented under supervised conditions. Adhesion formation and motion lag were more frequently observed in passive mobilization groups, whereas both CAM and PAH protocols were associated with lower rates of these complications.

Patient-Centered Outcomes Where reported, patient satisfaction scores and time to return to activities of daily living favored CAM and PAH protocols. Patients undergoing active or hybrid rehabilitation reported greater confidence in hand use and earlier functional independence. Long-term outcomes beyond 12–16 weeks showed convergence across all protocols, with minimal differences in final range of motion.

Table 1 — Summary of Included Zone II Studies

No	Study	Techniques Compared	Sample	Early Functional Outcomes	Complications	Patient Outcomes	Follow-up
1	Frueh F.S., 2014	CAM vs Passive (Kleinert)	132 fingers	Higher TAM at 4 wks; faster PIP/DIP flexion	Rupture 5% (CAM) vs 7% (Passive)	NR	12 weeks
2	Abdel Sabour H.M., 2018	PAH vs Kleinert	33 tendons	Less tendon lag; higher early TAM; fewer deformities	Similar rupture	Higher satisfaction (PAH)	12 weeks
3	Wang J., 2020	CAM vs Passive (EPM)	36 patients	Higher TAM and grip strength in CAM	No increase in rupture	100% good/excellent (CAM) vs 76% (Passive)	16 weeks
4	Layeghi F., 2012	PAH vs Duran	50 fingers	Higher TAM; earlier PIP/DIP milestones	No ruptures	Higher satisfaction (PAH)	8 weeks

NR = not reported.

Table 2 — Technique Differences and Clinical Impact (Zone II)

Technique	Load on Repair	Effect on Early TAM	Rupture Risk	Adhesion / Lag	Clinical Indication
Passive (Kleinert/Duran)	None (extrinsic only)	Slowest recovery	Low	Highest	Fragile repair, poor compliance
Hybrid (PAH)	Low–moderate (intrinsic hold)	Moderate (recover faster than passive)	Equal to passive	Lower than passive	Bridge to CAM; moderate repair strength
Active (CAM)	Moderate (active within DBS)	Fastest recovery	Equal if supervised	Lowest	Strong multi-strand repair with close therapy

DISCUSSION

Interpretation of Key Findings This systematic review demonstrates a clear hierarchy in early functional recovery following Zone II flexor tendon repair, with Controlled Active Motion providing the most rapid improvement, followed by Place-and-Active-Hold protocols, and finally passive mobilization techniques. These findings were consistent across all included studies despite differences in surgical technique and rehabilitation details.

Biomechanical and Biological Considerations The superior performance of CAM protocols can be explained by their biomechanical and biological effects on tendon healing. Controlled intrinsic loading promotes tendon gliding, enhances synovial diffusion, and facilitates longitudinal collagen fiber alignment, all of which contribute to improved range of motion and reduced adhesion formation. In contrast, passive mobilization relies solely on extrinsic movement and may be insufficient to prevent peritendinous scar formation in the confined Zone II environment.

Hybrid PAH protocols appear to provide a balanced mechanical stimulus by introducing limited intrinsic activation without full tendon excursion. This approach likely explains their favorable safety profile combined with superior early motion compared with passive regimens. PAH may therefore serve as an effective transitional strategy when repair strength or patient compliance precludes immediate initiation of CAM.

Clinical Implications and Protocol Selection The choice of rehabilitation protocol should be individualized based on repair strength, tissue quality, patient reliability, and access to supervised therapy. CAM protocols are most appropriate for multi-strand repairs with strong core sutures and reliable patient compliance. PAH protocols are well suited for moderate-risk repairs and can function

as a bridge toward full active motion. Passive mobilization remains relevant in fragile repairs or in settings where close supervision is not feasible.

Patient-Centered Perspective Beyond objective functional measures, early mobilization strategies have important implications for patient experience. Earlier restoration of hand movement enhances confidence, reduces perceived disability, and facilitates earlier return to daily activities. These patient-centered benefits may improve adherence to rehabilitation programs and indirectly contribute to better long-term outcomes.

Limitations and Future Directions

The limited number of high-quality randomized controlled trials and heterogeneity in rehabilitation protocols restrict the strength of definitive conclusions. Variations in suture technique, therapist supervision, and outcome reporting limit direct comparability. Future studies should aim to standardize hybrid protocol parameters and evaluate long-term outcomes beyond the early postoperative period.

CONCLUSION

For Zone II flexor tendon repairs, early rehabilitation should be individualized along a progressive continuum. Controlled active motion yields the best early functional outcomes when repair integrity and supervision permit. Hybrid PAH protocols offer a safe alternative for moderate-risk cases, while passive mobilization should be reserved for fragile repairs or limited-resource settings.

Declaration by Authors

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Conflict of Interest: No conflicts of interest declared.

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