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Flexor tendon rehabilitation in the 21st century: A systematic review

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ABSTRACT

Study Design: Systematic review.
Introduction: The rehabilitation of patients following flexor tendon injury has progressed from immobilization to true active flexion with the addition of wrist motion over the last 75 years.
Purpose of the Study: This review specifically intended to determine whether there is evidence to support one type of exercise regimen, *early passive, place and hold,* or *true active,* as superior for producing safe and maximal range of motion following flexor tendon repair.
Methods: The preferred reporting items for systematic review and meta-analysis (PRISMA-P 2015) checklist was utilized to format the review. Both reviewers collaborated on all aspects of the research, including identifying inclusion/exclusion factors, search terms, reading and scoring articles, and authoring the paper. Articles were independently scored by each reviewer using the Structured Effectiveness Quality Evaluation Scale (SEQES).
Results: A total of nine intervention studies that included a rehabilitative comparison group were systematically reviewed: one pediatric, four comparing passive flexion protocols to place and hold flexion, and four comparing true active flexion to passive and/or place and hold flexion.
Discussion: This review provides moderate to strong evidence that place and hold exercises provide better outcomes than passive flexion protocols for patients with two to six-strand repairs. The studies included in this review suffered from methodological limitations including short timeframes for follow-up, unequal group distribution, and limited attention to repair site strength.
Conclusions: Based on a lack of superior benefits following true active motion regimens, there is not sufficient evidence to support true active motion as an effective or preferable choice for flexor tendon rehabilitation at this time.

Introduction

The rehabilitation of patients after flexor tendon repair has been the source of intensive study and heated debate for more than 75 years. Early work by Mason and Allen[1] in the 1940s demanded immobilization during the exudative phase of wound healing, and the underlying concept of extrinsic processes as vital for tendon healing was supported for more than 35 years.[2,3] New frontiers in flexor tendon rehabilitation were pursued in the 1970s, resulting in the Duran[4] and Kleinert[5] regimens, which afforded *early passive flexion* and early active extension of the affected digits. The science of flexor tendon healing advanced soon after, with multiple bench studies supporting the intrinsic healing capacity of flexor tendons and the benefits of early passive motion for increasing repair site strength and tendon excursion.[6-14] It was during this time that the subspecialty of hand therapy was formalized, and the collaboration between hand therapists and surgeons greatly informed the advancement of flexor tendon rehabilitation during the next 40 years.

The next major shift in flexor tendon research focused on the biomechanical benefits of wrist motion related to flexor tendon excursion and force modulation.[15-22] Synergistic motion, defined as the combination of wrist extension with digit flexion, was found to decrease passive tension of the antagonistic extensor musculature, thereby decreasing active tension of the digital flexors.[15-18] In addition, combining wrist and digit motion was reported to yield greater tendon excursion.[19-21] These concepts served as the basis for

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the Indiana Protocol,[22] the first published rehabilitation regimen to include synergistic motion and incorporate the exercise referred to as *place and hold.* According to the protocol, a hinged dorsal blocking orthosis is fabricated for exercise, which includes the following place and hold sequence: passive digital flexion, wrist extension, active hold of the wrist and digit position for 5 seconds, and release to wrist flexion with digit extension.[22] Wrist motion and use of the Indiana Protocol were slow to gain traction in hand therapy practice. In a survey of 165 hand therapists published in 2005, only 23% reported using place and hold exercises, with only 14.5% identifying the use of tenodesis.[23] Comparably, 73.9% reported incorporation of passive flexion and 63.6% active extension.[23]

The years around 2005 were also the advent of articles promoting early active motion, commonly abbreviated EAM.[24-26] The concept of EAM called for *true active flexion* as opposed to early passive or place and hold flexion. Some authors promoted motion through the available range,[24,25] whereas others advocated initiating motion in the first third[26] to midrange[27] to avoid the higher levels of resistance encountered when making a composite fist. These protocols included postoperative positioning of the wrist in extension either immediately[24,25,27] or within 2.5 weeks.[26] Advancing the concept of postoperative positioning, the most recent and progressive protocols by Peck et al[28] and Higgins and Lalonde[29] have decreased the amount of metacarpophalangeal joint flexion to 30° to decrease bias toward the proximal interphalangeal (PIP) joint and decrease work of flexion at the distal interphalangeal (DIP) joint. Both regimens also incorporate hand-based orthoses either immediately after surgery[28] or at the 2-week time frame,[29] radically challenging the notion that patients must be immobilized in wrist flexion after flexor tendon repair.

Considering the historical journey from immobilization to true active flexion and the progressive freeing of the wrist joint over time, the resultant question is whether there is evidence to support the effectiveness or superiority of any of the regimens herein described. With an intent toward evidence-based practice and an emphasis on rehabilitation, the purpose of this study was to complete a systematic review of the flexor tendon literature published since 2000. This review specifically intended to determine whether there is evidence to support 1 type of exercise regimen, *early passive*, *place and hold*, or *true active*, as superior for producing safe and maximal range of motion of the digits after flexor tendon repair.

Materials and methods

The Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA-P 2015) checklist was used to format the review.[30] Both reviewers (RLN and RKP) collaborated on all aspects of the research, including identifying inclusion/exclusion factors, search terms, reading and scoring articles, and authoring the article. All work was conducted by 2 certified hand therapists, 1 in an academic setting and 1 in a clinical setting, from November 2016 to August 2017.

Literature search

The following databases were searched using the search terms "flexor tendon repair," "rehabilitation," and "hand:" PubMed, Academic Search Complete, CINAHL, ProQuest Central, and Google Scholar. MeSH headings and alternate terms, such as hand therapy, hand rehabilitation, and occupational therapy, were used to broaden the search and ensure a comprehensive review. Search criteria included articles published between 2000 and 2017, in English, inclusive of all zones of injury and all levels of evidence. Each author independently completed a search, compiling a final list of all articles located in the aforementioned databases. These lists were collaboratively assessed by both authors; articles were excluded if they were duplicates, review articles, surveys of practice patterns, commentaries, case reports, did not report on rehabilitation, focused only on alternative interventions (eg, ultrasound or motor imagery), or studied outcomes other than active range of motion (eg, demographic comparisons). Reports classified as an intervention study[31] were reviewed, including studies categorized as level 1, 2, and 3 evidence.

Scoring and data management

To clarify the review, scoring, and results of each study, 2 grouping strategies were used. Reports were grouped according to age demographic (pediatrics and adults) and the range of motion rehabilitation protocol under study, categorized as *early passive*, *place and hold*, or *true active* for the purposes of this systematic review. Early passive flexion studies included all varieties of Kleinert and/or Duran regimens. Place and hold studies included those that incorporated an isometric hold of digital flexion, regardless of range of motion and not limited to the Indiana Protocol.[22] True active studies included those that incorporated an active arc of flexion within the first postoperative week.

Reports were independently scored by each reviewer using the Structured Effectiveness Quality Evaluation Scale (SEQES).[32] The SEQES is a 24-item tool developed by MacDermid to assist reviewers in critical appraisal of research study methods. Each item is graded 0-2, with a descriptor provided for each option. The highest quality score possible is 48, and scores are graded by strength of the total, with 0-16 graded as low quality, 17-32 as moderate, and 33-48 as high-quality methodology.[32] Before completing independent analyses using the SEQES, the authors pursued inter-rater reliability and concordance of prompt interpretation for all 24 items using a pilot article. The authors then entered scores and comments into separate Excel files for the remaining articles, which were shared on completion. Discrepancies in viewpoint were reviewed until consensus was reached.

Outcomes

The primary outcome of interest was total active motion (TAM), reported either as TAM, Strickland's[33] grade, or Buck-Gramcko[34] grade. Secondary outcomes were rupture rate or any characteristic of function identified by the researchers (eg, grip strength, disabilities of the arm, shoulder and hand (DASH)).

Results

Literature search

Our literature search yielded 241 results. Two hundred six articles were excluded based on title and abstract review (Fig. 1), leaving 35 articles for full-text methodological review. Nine of these were intervention studies on range of motion protocols published between 2000 and 2017,[28,35-42] whereas the other 26 only reported outcomes without a comparison group.[43-68] These outcome studies were not included in our scoring. One intervention study compared pediatric outcomes,[35] with the remaining 8 focused on adult populations.[28,36-42] As previously stated, each article was independently scored using the SEQES, and consensus was pursued for final scores (Table 1).

Pediatrics

Elhassan et al[35] studied pediatric patients aged 2-15 who were either immobilized or treated with passive flexion. Zones 1-2 were

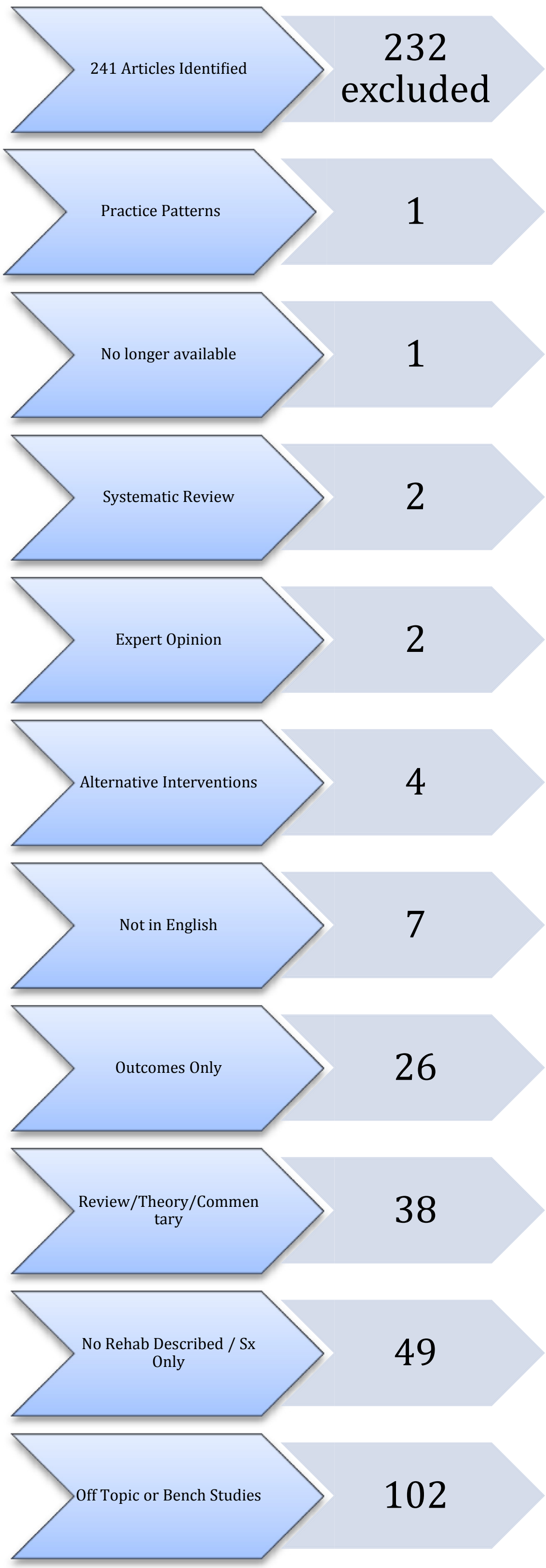

Fig. 1. Results of database search with terms: “flexor tendon repair,” “rehabilitation,” and “hand.”

included, and repairs were of 2 to 4 strands. Zone 1 fared better than zone 2 in both groups, as did patients without nerve involvement. With a SEQES score of 35, this high-quality report provides evidence that children will have comparable TAM at 42 months postrepair with either immobilization or passive flexion during the first 3-4 weeks.

Early passive flexion and place and hold

Four studies compared early passive flexion and place and hold protocols. Farzad et al[36] conducted a randomized controlled trial comparing patients with 2-strand repairs in zone 2 who performed either a modified Kleinert ($n = 26$) exercise program (active extension/passive flexion) or a place and hold ($n = 26$) program (isometric flexion) for 3 weeks (Table 2). Eight weeks after surgery, the place and hold group had statistically significant better TAM than the Kleinert group (77% vs 42% excellent-good). Neither group experienced ruptures. With an SEQES score of 28, this article provides moderate evidence that a place and hold approach yields significantly better TAM at 8 weeks than passive range of motion only in patients with 2-strand zone 2 repairs.

Kitis et al[37] studied 192 patients with zone 2 injuries and 2-strand repairs who were divided into groups of passive range of motion only or a modified Kleinert regimen, including active digital extension (Table 2). Twelve weeks after surgery, the modified Kleinert group had statistically significant better Buck-Gramcko (87% vs 75%) and DASH (29.6 vs 41.7) scores than the passive group. Grip was not significantly different. The passive group had 1 rupture. Limitations of this study include an inequality in the number of treatment sessions per group, with the Kleinert group in supervised therapy sessions 3 times per week for 12 weeks and the passive group with no supervision after the first week. The SEQES score was 28, providing moderate evidence that the Kleinert regimen outperforms passive motion for patients with zone 2 injuries and a 2-strand repair.

Trumble et al[38] conducted a randomized controlled trial of 93 patients with 4-strand repairs in zone 2 who performed either modified Kleinert ($n = 46$) or place and hold ($n = 47$) (Table 2). Range of motion was measured at 6, 12, 26, and 52 weeks. At the final evaluation, dexterity, DASH, and patient satisfaction were also measured. At all time points, the place and hold group had statistically significant better TAM. At 1-year follow-up, patient satisfaction was statistically significantly better in the place and hold group, but there was no statistically significant difference between the 2 groups in dexterity or DASH scores. The SEQES is 37, a high score, demonstrating high methodological quality that place and hold outperforms modified Kleinert protocols in patients with zone 2 injuries and a 4-strand repair.

Yen et al[39] prospectively studied 10 patients with zone 2 injuries and 4-strand repairs who performed place and hold exercises and compared their results to a matched historical control group of 10 patients who had completed a Kleinert protocol (Table 2). The authors reported statistically significant greater active range of motion, grip and pinch in the place and hold group at 12 weeks. Neither group experienced ruptures. Limitations of this study are low sample size and no description of rehabilitation parameters, such as orthosis positioning and exercise frequency. The SEQES is 21, demonstrating moderate strength of the methodology of this study and results.

True active

Frueh et al[40] conducted a retrospective study of 132 patients with zone 1 and 2 injuries and 2, 4, or 6-strand repairs (Table 3).

Table 1
SEQES scores for intervention studies

Authors	Elhassan et al[35]	Farzad et al[36]	Kitis et al[37]	Trumble et al[38]	Yen et al[39]	Frueh et al[40]	Peck et al[28]	Prowse et al[41]	Topa et al[42]
Date	2006	2014	2009	2010	2008	2014	2014	2011	2011
Study question									
1. Was relevant background work cited to establish a foundation for the research question?	2	2	2	2	1	1	2	2	0
Study design									
2. Was a comparison group used?	2	1	2	2	1	1	1	1	1
3. Was patient status at more than 1 time point considered?	0	0	0	1	0	1	1	0	0
4. Were data collection performed prospectively?	0	2	2	2	0	0	0	2	1
5. Were patients randomized to groups?	0	2	0	2	0	0	0	0	0
6. Were patients blinded to the extent possible?	2	1	1	1	1	1	1	1	1
7. Were treatment providers randomized to the extent possible?	2	1	1	1	1	1	1	1	1
8. Was an independent evaluator used to administer the outcome measures?	0	2	0	0	0	0	0	0	0
Subjects									
9. Did sampling procedures minimize sample/collection biases?	0	1	1	1	1	1	1	2	2
10. Were inclusion/exclusion criteria defined?	2	2	2	2	2	2	2	2	0
11. Was an appropriate enrollment obtained?	2	0	0	2	0	0	0	0	0
12. Was appropriate retention/follow-up obtained?	2	2	2	2	2	1	0	2	2
Intervention									
13. Was the intervention applied according to established principles?	2	1	1	1	0	1	1	1	2
14. Were biases due to the treatment provider minimized?	2	1	1	2	1	1	1	1	1
15. Was the intervention compared with the appropriate comparator?	1	2	2	2	2	2	2	2	1
Outcomes									
16. Was an appropriate primary outcome defined?	2	1	1	1	1	1	1	1	2
17. Was an appropriate secondary outcome considered?	2	1	1	1	1	0	0	0	1
18. Was an appropriate follow-up period incorporated?	2	1	1	2	1	1	1	1	1
Analysis									
19. Was an appropriate statistical test performed to indicate differences related to the intervention?	2	1	1	2	1	1	1	1	1
20. Was it established that the study had significant power to identify treatment effects?	0	1	1	2	0	1	1	1	0
21. Was the size and significance of the effects reported?	2	1	1	1	1	1	1	1	0
22. Were missing data accounted for and considered in interpreting results?	2	2	2	2	2	2	2	2	2
23. Were clinical and practical significance considered in interpreting results?	2	1	1	1	1	1	1	1	1
Recommendations									
24. Were the conclusions/clinical recommendations supported by the study objectives, analysis, and results?	2	2	2	2	1	2	2	2	1
Total	35	28	28	37	21	23	23	27	20

SEQES = Structured Effectiveness Quality Evaluation Scale.

Hundred thirty-eight digits were treated with a modified Kleinert protocol, and 21 digits were started on a true active motion (active extension and active flexion) of the fingers within the first 5 postoperative days. At 4 weeks, there was a statistically significant difference in TAM in favor of the EAM group, but there was no such difference at 12 weeks. There was no statistically significant difference between results of zone 1 or 2 or in the rupture rate between groups. The authors did not perform a power analysis, so it is not certain that the sample size was large enough to show statistically significant differences. The SEQES score is 23: moderate.

Peck et al[28] conducted a retrospective study comparing 2 groups of patients with 4-strand repairs and zone 2 injuries (Table 3). The patients wore either a forearm-based orthosis ($n = 62$) with the wrist positioned in neutral or a hand-based orthosis ($n = 40$) that allowed 45° of wrist extension and full wrist flexion. Patients in both groups performed true active motion and were permitted light use of the involved hand, with exclusion of the injured digit. There was no statistically significant difference between the 2 groups in TAM or ruptures at 12 weeks. The group with the hand-based orthosis had statistically significant improvements in DIP flexion and PIP extension as compared with those who wore a forearm-based orthosis. Five of the 121 repaired tendons ruptured, 3 in the forearm-based and 2 in the hand-based groups. The SEQES score for this study is 23, providing moderate support for the hand-based orthosis.

Prowse et al[41] conducted a retrospective case series review of 72 patients with 2-strand repairs in zone 2 who used either the modified Kleinert regimen or true active regimen (Table 3). At 12 weeks after repair, there was no statistically significant difference in TAM when looking at the groups as a whole, but patients older than 30 years in the true active group did have statistically significant greater TAM ($P = .03$). About 11.7% of the true active patients experienced rupture compared with 2.6% of the Kleinert group. This study's SEQES score is 27, demonstrating moderate evidence that patients older than 30 years with 2-strand repairs will have better TAM at 12 weeks if they perform true active motion than if they use a Kleinert regimen.

Topa et al[42] compared 94 patients grouped into 4 protocols of early passive (1 protocol), place and hold (2 separate protocols), and true active (1 protocol) motion in patients with zone 2 injuries (Table 3). Repair strength in terms of number of core suture strands was not reported. At 12 weeks, TAM and grip strength were evaluated. The authors report greater TAM and grip strength with the tenodesis place and hold group than other protocols; however, statistical significance was not established. The SEQES score is 20, providing moderate methodological quality to suggest that tenodesis place and hold yields greater TAM and grip strength than modified Kleinert, static wrist place and hold, or true active motion.

Discussion

We found 9 intervention studies that compared range of motion strategies for patients of all ages with flexor tendon repairs published between 2000 and 2017. The SEQES proved helpful as a guide in comparing the studies systematically, using common criteria.

Table 2
Early passive flexion and place and hold studies

Authors	Design	Zones	Repair	Group 1	Group 2	Results	Rupture rate
Farzad et al, 2014[36]	Prospective	2	2-strand	Place and hold $n = 26$ patients, 31 digits Therapy initiated 3 d postsurgery 4-Finger dorsal blocking orthosis with wrist between 0° and 30° flexion, MPs in 70°-90° First 21 d: Passive short arc flexion of digits with wrist in 30° extension; active hold for 3-5 s. 10 repetitions, 4 times per day Active flexion at 3 wk, gliding exercises at 4 wk, resisted and blocking exercises at 6-8 wk	Modified Kleinert $n = 28$ patients, 33 digits Therapy initiated 3 d postsurgery 4-Finger dorsal blocking orthosis with wrist between 0° and 30° flexion, MPs in 70°-90°; elastic traction through palmar pulley First 21 d: Active extension of digits to orthosis 10 repetitions every waking hour Active flexion at 3 wk, gliding exercises at 4 wk, resisted and blocking exercises at 6-8 wk	Measurement of TAM at 8 wk by a blinded evaluator 77% of place and hold and 42% of modified Kleinert group with good or excellent results at follow-up; statistically significant ($P = .001$) Significant differences in TAM based on time frame from injury to surgery in both groups ($P < .001$)	None
Kitis et al, 2009[37]	Prospective	2	2-Strand	Washington regimen (modified Kleinert): $n = 98$ patients, 137 digits Therapy initiated 1-5 d postsurgery Dorsal blocking orthosis (wrist and MP angles not clearly specified), traction applied to all digits via palmar pulley First 3 wk: Controlled active extension with MP joints held in flexion 12 times per hour, passive flexion and extension Orthosis modified to wrist neutral at 3 wk; active finger flexion begun at 5-6 wk *according to tendon gliding.* Active wrist extension at week 5 Orthosis removed after 6 wk, blocking exercises and light functional use initiated. Resistance at 8 wk	Controlled passive motion: $n = 94$ patients, 126 digits Therapy initiated 1-5 d postsurgery Dorsal blocking orthosis with wrist in 20° flexion, MPs in 50° flexion, and IPs in neutral Eight repetitions of full passive flexion and extension for the first 5 wk Week 5: 10 repetitions of active flexion and extension of the wrist and composite active flexion and extension of the digits Orthoses removed at the end of week 5, exercises increased to 12 per hour, and blocking exercises added. Passive wrist extension at week 7 with progressive strengthening and normal hand activities added between weeks 8 and 12 based on individual progress	Measurement of TAM, grip strength, and DASH at 12 wk 119 digits (87%) of Washington regimen and 94 digits (75%) with excellent results as calculated using the Buck-Gramcko classification for TAM of PIP and DIP joints. (significant at $P = .01$) Grip strength recovered to an average of 89% in Washington regimen group and 81% in the controlled passive motion group Significantly lower mean DASH scores for Washington regimen group (29.6) compared with controlled passive group (41.7) ($P = .01$)	Washington regimen group: no ruptures Controlled passive motion group: 1 rupture (<1%)
Trumble et al, 2010[38]	Prospective	2	4-Strand	Place and hold group: $n = 47$ patients, 54 digits Therapy initiated within 72 h postsurgery Hinged exercise orthosis that allowed wrist extension and maintained MPs in flexion; dorsal blocking orthosis donned between exercise. Angles not specified 24-72 h postoperative: passive flexion and extension of digits, active extension of IPs to orthosis 72 h to 4 wk postoperative: place and hold digit flexion with wrist at 30° extension; performed outside orthosis at week 2 Active tenodesis and tendon gliding exercises initiated at week 4; composite wrist/digit flexion/extension at week 5; discontinuation of orthosis with blocking exercises at week 6; light strengthening initiated at week 9	Passive group: $n = 46$ patients, 52 digits Therapy initiated within 72 h postsurgery Dorsal blocking orthosis with injured digit placed in Kleinert traction; angles not specified 24-72 h postoperative: Passive flexion and extension of digits, active extension of IPs to orthosis Orthosis modified to wrist neutral at 3 wk; place and hold exercises initiated Wean from orthosis and begin gentle active motion, passive extension of isolated joints, digit extension with wrist flexed, and light functional activity Blocking and progressive resistive exercises between weeks 9 and 12	Measurement of range of motion at 6, 12, 26, and 52 wk; DASH, Jebsen-Taylor, and Purdue Pegboard at 1 y postsurgery Place and hold group with significantly greater combined PIP and DIP motions at all time points ($P < .05$). Flexion contractures of the PIP and DIP joints greater in the passive group at all time points ($P < .05$) At 1 y, average DASH scores of 2.0 (place and hold group) and 3.1 (passive group). Average satisfaction scores significantly higher for place and hold group ($P < .05$). No significant differences in Jebsen-Taylor or Purdue Pegboard Patients treated by a certified hand therapist with significantly greater active flexion and smaller IP joint contractures	Place and hold group: 2 ruptures (3.7%), both occurred in small digit Passive group: 2 ruptures (3.8%)

(*continued on next page*)

Table 2 (*continued*)

Authors	Design	Zones	Repair	Group 1	Group 2	Results	Rupture rate
Yen et al, 2008[39]	Prospective with historical control	2	4-Strand	Place and hold: $n = 10$ patients Therapy initiated 2 d postsurgery Dorsal blocking cast with wrist in 30° flexion, MPs in 70° flexion, and IPs in full extension First 4 wk: full passive digital flexion with active hold for 5 s and active extension. Two repetitions every 4 h in orthosis; increase to every 2 h in cases of joint stiffness, add passive pressure to proximal phalanx to maximize IP extension in cases of flexion contracture 4-6 wk: continue orthosis if tendon glide good, discontinue if tendon glide poor. Initiate active flexion and extension, progressive light resistance, heavy use of hand at 8 wk and full function at 12	Kleinert: $n = 10$ patients Specifics of this protocol not provided besides the use of a palmar bar for Kleinert traction	Measurement of active motion, grip strength, and pinch strength at minimum of 12 wk Statistically significant difference in joint range of motion (MP: $P = .012$, PIP: $P = .003$, DIP: $P = .004$) favoring place and hold group Place and hold group with significantly greater grip strength ($P = .003$) and pinch strength ($P = .001$)	Place and hold group: no ruptures Kleinert group: 1 rupture (10%)

MP = metacarpophalangeal; TAM = total active motion; IP = interphalangeal; PIP = proximal interphalangeal; DIP = distal interphalangeal; DASH = disabilities of the arm, shoulder, and hand.

Of the 8 adult studies reviewed, 4 compared early passive motion to place and hold (Table 2). Kitis et al[37] offered moderate support for the use of a modified Kleinert regimen over passive flexion and extension for patients with 2-strand repairs. Farzad et al[36] and Yen et al[39] provided moderate evidence for place and hold; however, it is important to note that the former reported outcomes at 8 weeks postsurgery. Trumble et al[38] provided the strongest evidence found in this review to support place and hold as superior to passive flexion for significantly increasing combined PIP and DIP flexion and significantly decreasing flexion contractures.

The remaining 4 studies compared true active motion with at least 1 other range of motion protocol (Table 3). The study by Peck et al[28] was the only study in this review that compared wrist mobilization with immobilization and allowed the patient to use the affected hand for light use in the immediate postoperative phase. With moderate methodological strength, they were unable to demonstrate a significant difference in TAM or rupture rate between the 2 groups.

Prowse et al[41] were also unable to demonstrate a statistically significant difference in TAM or rupture rate between groups who performed early passive flexion vs true active flexion at 12 weeks, unless the patients were 30 years or older, in which case the true active motion group fared significantly better. Two-strand repairs are not generally considered strong enough for true active motion or early use of the involved hand,[69,70] which may have led to the high rupture rate in the true active group of 11.7%.

Frueh et al[40] provided moderate evidence that true active flexion provides better TAM than early passive flexion at 4 weeks but found no difference at 12 weeks in either TAM or rupture rate. This study had 2 major methodological issues that included variety of repair strengths used (2, 4, or 6 strands) and unequal groups, with 138 subjects in the early passive flexion group and only 21 subjects in the true active flexion group. These limitations make it difficult to apply any clinically meaningful information from this study. Finally, Topa et al[42] failed to include information on repair strength, which also makes it difficult to apply their findings clinically.

Based on the methodological limitations and negligible results of the 4 true active motion studies reviewed, there is not sufficient evidence to support true active motion as an effective or superior choice for flexor tendon rehabilitation at this time.

Limitations

The results of this systematic review should be interpreted carefully and with attention to the following limitations. Our search was limited to English language articles published between 2000 and 2017. Although the authors pursued inter-rater reliability for use of the SEQES, scored the articles independently, and pursued consensus in ratings, a weighted kappa statistic was not used to assess agreement. Articles categorized as less than level 3 evidence were not included in this review; a standard that omitted many outcome studies and expert opinions on the topic of flexor tendon rehabilitation.

Recommendations

As a result of this review, the following recommendations are offered for both scholarly and clinical consideration. These recommendations are related to safe regimens based on repair strength, time frames, and variables for outcomes assessment and common language to describe flexor tendon rehabilitation protocols.

Only 1 study clearly stated a repair strength of at least 4 strands used with a true active protocol.[28] Previous work by Strickland[69] on tendon repair strength and by Schuind et al[70] on exercise force demonstrates that a repair strength of at least 4 strands is necessary to withstand the force of true active motion. It would, therefore, be helpful in furthering our understanding of whether true active motion is beneficial or necessary in obtaining greater TAM to have more studies that clearly identify repair strength at 4 strands or greater.

Twelve weeks has been historically identified as a minimal postoperative time frame for comparing results of active range of motion and secondary outcomes, as by 12 weeks even 2-strand repairs are strong enough to allow patients to return to work and the risk of rupture is greatly reduced. Results collected at 6 or 8

Table 3
True active studies

Authors	Design	Zones	Repair	Group 1	Group 2	Results	Rupture rate
Frueh et al, 2014[40]	Retrospective	1 and 2	4-Strand 15% repaired using 2- or 6-strand	EPM $n = 138$ fingers Therapy initiated 3-5 d postsurgery 4-Finger dorsal blocking orthosis with wrist in 30° flexion, MPs in 70° flexion, IPs full extension. Rubber band for passive flexion used for home exercise First 3 wk: Kleinert traction; passive flexion with place and hold Active motion at 22 d; loading exercises at 8 wk	CAM $n = 21$ fingers Therapy initiated 3-5 d postsurgery 4-Finger dorsal blocking orthosis with wrist in 10° flexion, MPs in 40° flexion, IPs full extension Complete active motion initiated 3-5 d postoperatively; active blocking and full passive flexion at 1 wk; loading exercises at 6 wk	Measurement of TAM at 4 and 12 wk Significant difference in TAM between groups at 4 wk ($P < .001$); no significant difference at 12 wk No significant difference in zone 1 vs 2 53% of EPM and 63% of CAM group with good or excellent results after 12 wk	EPM: 10 ruptures (7%) CAM: 1 rupture (5%)
Peck et al, 2014[28]	Retrospective	2	4-Strand	Traditional forearm-based dorsal blocking orthosis, wrist neutral, MPs in 30° flexion, IPs full extension $n = 62$ patients, 76 digits Therapy initiated 4-5 d postsurgery: Full passive flexion Active digital flexion and extension within the orthosis. Flexion initiated at the DIP joint Safe and light use of the hand with exclusion of injured digit(s)	Manchester short splint extends dorsally from proximal wrist crease to fingertips; MPs positioned in 30°, permits up to 45° wrist flexion $n = 40$ patients, 45 digits Therapy initiated 4-5 d postsurgery: Full passive flexion Active digital flexion with wrist extension to 45°, active digital extension with maximal wrist flexion. Flexion initiated at the DIP joint Safe and light use of the hand with exclusion of injured digit(s)	Measurement of TAM at 6 and 12 wk Significantly reduced extension deficit in PIP and DIP joints in Manchester short group at 6 wk ($P = .0003$ and .041); PIP joint at 12 wk ($P = .024$) Total arc of flexion at PIP joint significantly greater in Manchester short group at 6 wk ($P = .010$) Significantly greater improvements in DIP flexion and arc of flexion at 12 wk in Manchester short group ($P < .001$) 29% of traditional forearm-based and 49% of Manchester short groups with good or excellent results after 12 wk	Traditional forearm-based group: 3 ruptures (7%) Manchester short group: 2 ruptures (4%)
Prowse et al, 2011[41]	Retrospective	2	2-Strand	Kleinert regimen: $n = 38$ patients, 42 digits Therapy initiated 3-5 d postsurgery Dorsal blocking orthosis with wrist in neutral, MPs in 50°-70° flexion, traction applied to all digits via palmar pulley that was released overnight Hourly active extension, flexion via pulley with active hold for 2-3 s Orthosis removed completely at week 5	CAM regimen: $n = 34$ patients, 39 digits Therapy initiated 3-5 d postsurgery Dorsal blocking orthosis with wrist in neutral, MPs in 50°-70° flexion Exercises performed every 2 h: Passive flexion of all digits, full active extension to orthosis, gentle active flexion Orthosis removed completely at week 5	Measurement of TAM at 12 wk No statistically significant difference in TAM between groups 42% of Kleinert group and 47% of CAM group with good or excellent results at 12 wk follow-up Patients older than 30 y with significantly worse results; 92% poor or fair results	Kleinert group: 1 rupture (2.6%) CAM group: 4 ruptures (11.7%)
Topa et al, 2011[42]	Prospective	2	Not reported	Kleinert modified: $n = 20$ Dorsal blocking orthosis with wrist in 30° flexion, MPs in 70° flexion, IPs neutral. Traction via pulley at the distal palmar crease. 10 repetitions hourly: active extension, passive flexion Silfverkiold: $n = 22$ Dorsal blocking orthosis with wrist in neutral, MPs in 50°-70° flexion, IPs neutral. All 4 digits included in dynamic flexion. 10 repetitions hourly: active extension, passive flexion, isometric flexion contraction for 2-3 s Strickland: $n = 26$ Dorsal blocking orthosis with wrist in 20° flexion, MPs in 50° flexion. Tenodesis splint with wrist hinge allowing full wrist flexion, wrist extension to 30°, and MPs in 60° flexion. Hourly exercise in tenodesis splint: 15 repetitions of MP and IP passive flexion, 25 repetitions of isometric flexion contraction for 5 s Gratton: $n = 26$ Dorsal blocking orthosis with wrist in 20° flexion, MPs in 80°-90° flexion, IPs neutral 2 repetitions every 2-4 h: passive flexion, active extension, active flexion. Goal of 30° PIP flexion and 5°-10° DIP flexion after 1 wk of exercise		Measurement of TAM and grip strength at week 12 Excellent and good results after 12 wk: Strickland group 88%, Silfverkiold 86%, Gratton 81%, and Kleinert 75%	Not reported

EPM = early passive motion; MP = metacarpophalangeal; IP = interphalangeal; CAM = controlled active motion; TAM = total active motion; PIP = proximal interphalangeal; DIP = distal interphalangeal.

weeks will not account for tendons that may have gapped due to too much force through exercise or activity and go on to later rupture. It is recommended that authors carefully review the literature on repair site strength before initiating regimens that may prove to be unsafe.

There were a variety of secondary outcomes reported in the 9 studies examined, including rupture rate, grip, pinch, and DASH or QuickDASH. Only 1 study by Trumble et al[38] used functional performance tools as an assessment of outcome. Although these assessments can be more time consuming to administer, they provide useful information that neither a self-report measure of function or a grip or pinch test may yield. None of the studies in this review included the patient's ability to return to work as a formal outcome measure. Recent and ongoing changes to our health care system in America are placing a stronger focus on functional outcomes as a key indicator in quality of care. Perhaps this is a good time for research studies on flexor tendon outcomes to include functional performance assessments and return to work status, in addition to impairment measures of range of motion, grip, and pinch.

None of the studies included minimal clinically important differences, which could provide helpful outcome information for clinicians when deciding which motion regimen to use with individual patients. Future studies should consider including this information to assist clinicians in decision making.

It is also recommended that a common terminology be pursued to describe postoperative motion. Analysis of all studies for this review was confounded by the variety of ways authors describe their exercise regimens. For instance, the term *early active motion* is used to describe protocols that used active extension to the dorsal block as the only active component,[37] passive flexion with active hold of the position,[36,38,39] and actively flexing the digits through an arc of motion.[28,40,42] To clarify what was being compared, as well as to bring the comparisons to the level that current repair strengths allow, it was determined that the term *true active flexion* should be used to specifically describe an actual *arc* of motion, and in the study of flexor tendons, it should be a flexion arc. *Early passive flexion* is recommended for those protocols that include passive flexion of the digit regardless of extension, with *place and hold* being specified for those regimens that incorporate passive flexion of the digit with an isometric hold at the end of the range.

Conclusion

This review provides studies with moderate to high methodology that place and hold exercises that provide better outcomes than passive flexion protocols, including Kleinert and modified Kleinert, for patients with 2- to 6-strand repairs. Patients older than 30 years with a 2-strand repair appear to have greater TAM at 12 weeks with a true active protocol than those who perform passive flexion. Further research into the optimal motion protocol after flexor tendon repair needs to use standardized terminology of protocol regimens, report on repair strengths of at least 4 strands to safely study early motion, use a standardized criteria tool such as the SEQES to guide their study design, and include some assessment of active functional performance to evaluate the quality of each rehabilitative approach. Although the literature continues to move toward progressive protocols with true active motion and decreased immobilization of the wrist, it is important to recognize that well-designed intervention studies to support those regimens does not yet exist.

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Quiz: # 604

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#1. The study design is
  a. RCTs
  b. a prospective cohort
  c. a systematic review
  d. a case series

#2. Historically ______________________initially advocated immobilization as the best approach to dealing with flexor tendon injuries
  a. Mason and Allen
  b. Fess and Bell
  c. Hunter and Mackin
  d. Bunnell and Mennell

#3. The following approaches and their relative effectiveness to management of flexor tendon injuries were compared
  a. early passive motion
  b. place and hold
  c. true active ROM
  d. all of the above

#4. There is significant data to suggest that
  a. none of the techniques produce acceptable outcomes
  b. all three techniques produce comparable outcomes
  c. the place and hold technique produces better outcomes than the early passive motion approach
  d. the early passive motion approach produces better outcomes than the place and hold technique

#5. To date there is sufficient evidence to demonstrate the superiority of true active motion as the “best practices model” in the management of flexor tendon injuries
  a. true
  b. false

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