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REVIEW ARTICLE (META-ANALYSIS)

Postoperative Rehabilitation Following Thumb Base Surgery: A Systematic Review of the Literature

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Abstract

Objective: To provide an overview of rehabilitation for patients who underwent first carpometacarpal joint (CMC-1) arthroplasty, with emphasis on early active mobilization.

Data Sources: PubMed/MEDLINE, Embase, CINAHL, and Cochrane were searched.

Study Selection: Articles written in English that described the postoperative regimen (including immobilization period/method and/or description of exercises/physical therapy, follow-up 6wk) on CMC-1 arthroplasty were included.

Data Extraction: The Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement was used as guidance in this review, and methodological quality was assessed using the Effective Public Health Practice Project quality assessment tool. Randomized studies were additionally scored using the Physiotherapy Evidence Database scale.

Data Synthesis: Twenty-seven studies were included consisting of 1015 participants, in whom 1118 surgical procedures were performed. A summary of the components of postoperative rehabilitation used in the included studies of CMC-1 osteoarthritis is presented for different surgical interventions. We found that early active recovery (including short immobilization, early initiation of range of motion and strength exercises) provides positive outcomes for pain, limitations in activities of daily living, and grip and pinch strength, but comparative studies are lacking. Furthermore, 3 postoperative exercises/therapy phases were identified in the literature—the acute phase, the unloaded phase, and the functional phase—but again comparative studies are lacking.

Conclusions: Early active recovery is used more often in the literature and does not lead to worse outcomes or more complications. This systematic review provides guidance for clinicians in the content of postoperative rehabilitation for CMC-1 arthroplasty. The review also clearly identifies the almost complete lack of high-quality comparative studies on postoperative rehabilitation after CMC-1 arthroplasty.

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Osteoarthritis (OA) of the first carpometacarpal joint (CMC-1) is a common disorder in the elderly.[1] The prevalence of radiologically diagnosed CMC-1 OA among women aged ≥50 years is 33% to 36%.[2,3] The number of patients with CMC-1 OA is expected to increase because of the aging population.[4] Patients with CMC-1 OA often experience pain; have reduced pinch or grip strength, or both; and report limitations in activities of daily living (ADL).[5]

When conservative treatment fails to reduce pain and limitations in ADL, CMC-1 arthroplasty may be indicated.[6] In the past decades, a variety of surgical techniques have been described.[7,8] When CMC-1 OA is treated surgically, usually a trapeziectomy is performed, with or without ligament reconstruction and/or tendon interposition.[6-8] CMC-1 arthrodesis and implants are also used, but the usage of these techniques has been associated with a higher risk of complications (ie, nonunion or dislocation).[6-8]

Some studies[6,8] emphasize the importance of postoperative rehabilitation for patients who underwent CMC-1 arthroplasty in order to improve pain intensity and limitations in ADL, and improve range of motion (ROM) and grip and pinch strength. However, the lack of consensus on the content of postoperative

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rehabilitation for patients who underwent CMC-1 arthroplasty is mentioned as well.[6,8]

A systematic review by Wolfe et al[9] in 2014 on postoperative rehabilitation after CMC-1 arthroplasty concluded that no recommendations on postoperative rehabilitation could be made because of a large reported variation regarding type and duration of postoperative immobilization, postoperative exercises, and duration before patients returned to full activities. Furthermore, no overview of postoperative rehabilitation and variations as reported in the literature (ie, differences in immobilization period) is presented for different types of surgery. Additionally, their search in 2013 was limited to PubMed and Cochrane, and limited information on the search strings and the inclusion and exclusion criteria is provided.[9] Therefore, an overview of postoperative rehabilitation regimens for CMC-1 arthroplasty reported in the literature remains desirable.

The aim of this systematic review is to describe and to create an overview of the different components and phases of postoperative rehabilitation protocols for patients who underwent CMC-1 arthroplasty, and to quantify how often these are used. Furthermore, we investigated several specific components or variations in postoperative rehabilitation protocols that are presently discussed. Since tensile strength of scar tissue is at 80% of normal tissue at 6 weeks and at 50% at 4 weeks, we specifically studied these time frames.[10] We formulated the following research questions:

1. What type of postoperative rehabilitation (including immobilization period and initiation of ROM and strengthening exercises) is used in the literature for different types of surgery, categorized by used tendon plasty?
2. What are the outcomes of short immobilization (4−6wk or ≤4wk) with regard to pain intensity, limitations in ADL, grip and pinch strength, and complications?
3. What are the outcomes of ROM and strengthening exercises in an early phase (≤4wk) with regard to pain intensity, limitations in ADL, grip and pinch strength, and complications?

Methods

Design

This systematic review was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement as guidance.[11] The inclusion of eligible articles was conducted by 2 reviewers (R.M.W., B.D.); disagreements were resolved in a consensus meeting between the 2 raters.

Search strategy

The electronic databases MEDLINE (PubMed, from 1950), Embase (Elsevier, from 1974), CINAHL (EBSCO, from 1961), and the Cochrane Library (time limit unknown) were searched for eligible articles (search date: June 15, 2017). The references of the included articles were scanned for eligibility after primary and secondary screening.

The following Medical Subject Headings terms and keywords (and their synonyms) were used: "carpometacarpal joint," "thumb," "arthroplasty," "trapeziectomy," "ligament reconstruction and tendon interposition," "rehabilitation," and "hand therapy." The complete search strategy can be found in supplemental appendix S1 (available online only at http://www.archives-pmr.org/). We considered each tendon plasty as ligament reconstruction and tendon interposition, except if the authors specifically stated that only ligament reconstruction or tendon interposition was used.

List of abbreviations:

ADL	**activities of daily living**
CMC-1	**first carpometacarpal joint**
MCP-1	**first metacarpophalangeal joint**
OA	**osteoarthritis**
ROM	**range of motion**
SMD	**scaphometacarpal distance**

Study selection

Articles were eligible for inclusion if they (1) included patients who underwent CMC-1 arthroplasty because of symptomatic CMC-1 OA; (2) included men/women aged ≥18 years; (3) described an intervention with a follow-up of ≥6 weeks postoperatively; (4) provided an adequate description of the postoperative regimen, including immobilization period, immobilization method, or description of exercises/physical therapy treatment; (5) provided a description of the type of surgery performed; (6) described a comparison of results over time (ie, preoperative vs postoperative); (7) included pain intensity and/or limitations in ADL and/or grip and pinch strength as outcome measures; and (8) were written in English.

Articles were excluded when they (1) provided an abstract only, a clinical commentary, a research letter, an editorial note, a review presented at meetings, a preliminary study, case reports with complications/exceptions, or when full texts were unavailable; (2) dealt with revision arthroplasty, external fixation, implant/prosthesis, arthrodesis, osteotomy, structural involvement of the MCP-1 joint (ie, volar capsulodesis), or other procedures; (3) were (systematic) reviews; or (4) were long-term follow-up studies with already included study populations.

Study selection

Initially, articles were screened for eligibility on title and abstract. When titles and abstracts implied that an article was potentially eligible for inclusion, a full-text copy of the report was obtained. Additionally, reference tracking was performed in all included articles (see flowchart in fig 1).

Data extraction

Two reviewers (R.M.W., J.T.) extracted data using a standard extraction form; disagreements were resolved in a consensus meeting between the two. Data extracted from the included articles were as follows: (1) authors, publication year, and study location; (2) study design; (3) study population; (4) surgical intervention; (5) immobilization period; (6) therapy/exercises; (7) outcome measurements; and (8) outcomes. If data were missing or further information was required, serious attempts were made to contact the first 2 authors to request the required information. The rehabilitation protocol of the included studies was identified and summarized.

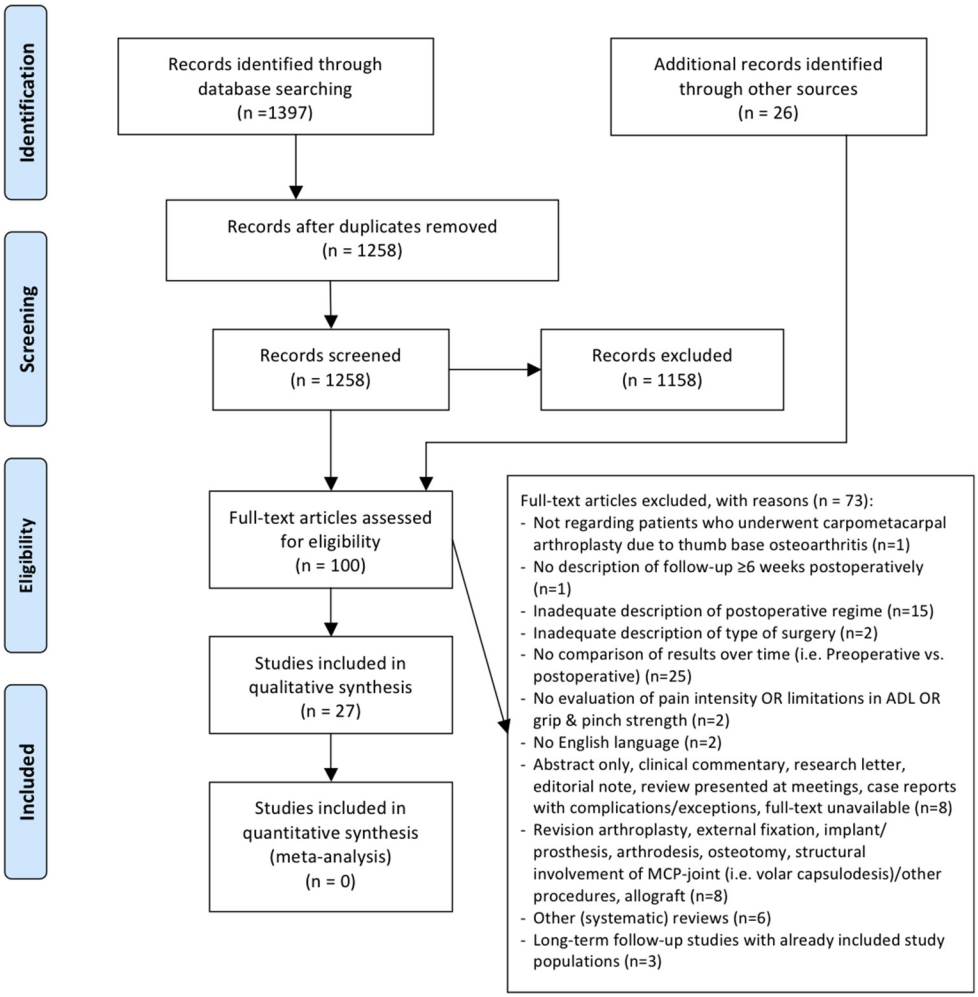

Fig 1 Flowchart of the search process (derived from Preferred Reporting Items for Systematic Reviews and Meta-Analyses[11]).

Assessment of methodological quality (risk of bias)

Two reviewers (R.M.W., J.T.) independently assessed the methodological validity of the included articles. The methodological quality (risk of bias) was scored using the Effective Public Health Practice Project quality assessment tool,[12] and randomized studies were scored using the Physiotherapy Evidence Database scale as well.[13] Disagreements were resolved in a consensus meeting between the 2 raters. The strength of interrater agreement was measured by Cohen's kappa coefficient.[14]

Synthesis of results and data analysis

Effect sizes were calculated for comparative studies included in this review when means and SDs for pre- and posttest outcomes were provided. If data were missing or further information was required, we contacted the first 2 authors to request the required information. When SDs were obtained, the pretest SDs were pooled to calculate effect sizes.[15,16] Cohen[16] defined conventional values for effect sizes, where a value of .20 reflects a small, .50 a medium, and .80 a large effect size. Results of individual studies were not statistically pooled because of a limited number of comparative studies per research question and large heterogeneity.

Results

Study selection and study characteristics

The initial search identified 1397 articles. After applying the inclusion and exclusion criteria, 27 studies were included in this systematic review (see fig 1).

An overview of the included studies, their characteristics, measurements, and outcomes are shown in table 1. The 27 selected studies included a total of 1015 participants, in whom 1118 procedures were performed. Twelve different surgical procedures were performed in the 27 included studies (table 2). In 8 studies, 11 surgical cointerventions were performed (supplemental table S1, available online only at http://www.archives-pmr.org/). Six studies[19,24,38,39,41,43] described that no other cointerventions were performed, and it is unclear whether other cointerventions were performed in the 13 remaining studies.[17,20,23,26,28,30-34,36,40,42]

Table 1 Overview of characteristics, measurements, and outcomes of included studies

Author, Year	Study Design	Study Population (N, F/M, Age [Mean, Range/±SD], Right/Left, Dominance*)	Surgical Intervention	CoInterventions	Postoperative Rehabilitation—Immobilization Period	Postoperative Rehabilitation—Exercises	Measurements (Instruments, Follow-Up)	Outcomes
Abbas et al,[17] 2012	Case series	N=10 F/M: 10/0 Age: 50—60y (n=4), 61—70y (n=3), 71—80y (n=2), 81—90y (n=1) Dominance: 7	Modified LRTI using PL for interposition and FCR for ligament reconstruction	Unknown/not described	0—6wk: Short-arm thumb spica cast, K-wire excision after 6wk	6wk: ROM exercises were begun with gradual progression to resistive pinch and grip strengthening by 12wk postoperatively.	Limitations in ADL (Quick DASH). Measures at: t0 (preoperative), t1 (3mo), t2 (6mo)	Quick DASH score at t0, 58.8; t1, 40.5; t2, 31.3 (P=.005)
Ataker et al,[18] 2012	Retrospective cohort	N=23 consecutive patients, 27 thumbs F/M: 21/2 Age: 63.5y (range, 30—83y) Dominance: 13/27	Modified LRTI according to Burton-Pellegrini using FCR	CTR (n=3), trigger release (n=3), de Quervain tenosynovitis surgery (n=2), and extensor pollicis brevis tenodesis for MCP-1 joint reconstruction (n=1).	0—2wk: Spica plaster cast (wrist in 20° extension, thumb in midway between extension and abduction, and the IP joint of the thumb is free) 2—6wk: CMC butterfly (24h/d), 6—8wk: CMC butterfly (only at night)	Mean of 16.8 therapy sessions 0—4wk: ROM exercises for the unaffected fingers, IP-1, elbow, and shoulder; and flexor and extensor tendon gliding exercises as a home-based program. The home exercise program includes (1) fist/extension and (2) finger abduction and adduction exercises (digitus 2—5) 4 times/d 10 reps. 4—6wk: AROM exercises for CMC-1 and MCP-1 supervised by a physical therapist; no CMC-1 flexion/adduction, opposition. Scar management. 6—8wk: Progressive ROM and strengthening: isometric abduction, extension, and adduction. If patient can perform opposition to Kapandji 6 with no pain, complete flexion can be attempted gradually. AROM IP, MP, CMC-1, and thumb opposition added to the home exercise program 4 times/d, 10 reps. 8—10wk: Isotonic strength, gentle pinch, grip using putties, and power webs; and the resistance is increased gradually. 10—12wk: Strengthening exercises with putty + discharge. ≥12wk: No restrictions.	Pain intensity (VAS, 0—10), limitations in ADL (DASH), ROM, grip and pinch strength, joint imaging (SMD). Measures at: t0 (preoperative), t1 (12wk), and t2 (31.5mo; range, 12—57mo)	VAS at t0, 8; t1, 3; t2, 3 (P<.001). DASH at t0, 56; t1, 29; t2, 24 (P<.001). Increase in palmar and radial abduction, Kapandji score (P<.001). Grip strength (kg) at t0, 12; t1, 18 (P<.001); t2, 13. Lateral pinch at t0, 3; t1, 5; t2, 4 (P<.001). Joint imaging at t0, 11mm; t1, 5mm; t2, 3mm.
Başar et al,[19] 2012	Retrospective cohort	N=19 F/M: 18/1 Age: 55±5.7y Dominance: 18/19	Modified LRTI using full-thickness FCR	None	0—4wk: Thumb spica 4—8wk: Removable splint 8wk: Splint removed	4—8wk: MCP and IP joint exercises and isometric thenar abduction amplification exercises 8wk to 3mo: CMC-1 joint mobilization allowed. Easy grasping exercises and progressive thenar abduction amplification exercises against resistance were started. +3mo: Resistive grasping and gripping exercises were started and increased progressively.	Pain intensity (VAS, range 0—10 + other instruments), ROM (Buck-Gramcko score, Kapandji), grip and pinch (tip pinch and lateral pinch) strength, joint imaging (SMD). Measures at: t0 (preoperative) and t1 (60±15mo)	Pain intensity: t0, 7 (±0.9); t1, 0.9 (±1.4). ROM: Grip and pinch strength: Grip t0, 13.15; t1, 19.28; tip pinch t0, 2.78; t1, 4.45; lateral pinch t0, 4.13; t1, 5.60; all strength measures significant (P<.0001). At t1, 0.2mm height, not significant.

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Table 1 (*continued*)

Author, Year	Study Design	Study Population (N, F/M, Age [Mean, Range/±SD], Right/Left, Dominance*)	Surgical Intervention	CoInterventions	Postoperative Rehabilitation—Immobilization Period	Postoperative Rehabilitation—Exercises	Measurements (Instruments, Follow-Up)	Outcomes
Burton and Pellegrini,[20] 1986	Retrospective cohort	N=24 patients, 25 thumbs (4 revisions, 1 bilateral) F/M: 21/3 Age: 55.4y Dominance: 3/24	Partial (6 cases) or complete trapeziectomy (19 cases) with LRTI using FCR, all with K-wire	Unknown/not described	0—4wk: Thumb spica cast immobilization followed by pin removal 4—6wk: Isoprene thumb spica splint support, worn constantly except for hand exercises and washing. Splinting is stopped when full ROM is attained and thenar strength is improved to a functional level, usually 8—12wk after surgery.	4—6wk: (1) AROM CMC-1 abduction and extension while avoiding flexion adduction position; (2) AROM flexion of the MCP and IP joints with MC1 supported in abduction by the patient's opposite hand. 6wk, continued to 4—6mo: Thenar strengthening is emphasized. 8wk: Grip and pinch strengthening is begun.	Grip and pinch strength, pain relief (self-designed), joint imaging (method not described). Measures at: t0 (preoperative) and t1 (postoperative follow-up at 2y; range, 1—4.5y). Pain relief only measured at t1.	Pain relief: 92% of patients enjoyed excellent pain relief and were satisfied with the thumb. t1 showed an overall improvement in grip and pinch strength of 19% compared with t0 values (no significance mentioned). Average loss of 11% of the initial postoperative arthroplasty space.
Davis et al,[21] 2004	Randomized controlled trial investigating different surgical procedures	N=162 patients, 183 thumbs (trapeziectomy group, 62; PL group, 59; FCR group, 62) F/M: 162/0 Age: Trapeziectomy group: 58y (range, 44—82y), PL group: 60y (range, 41—74y), LRTI group: 59y (range, 40—75y) (3 groups) Dominance: Trapeziectomy group, 34/58; PL group, 38/60; LRTI group, 36/59	Trapeziectomy, trapeziectomy with PL interposition, trapeziectomy with LRTI with 50% FCR	Total group: CTR (n=42), MCP K-wire (n=9), MCP capsulodesis (n=9), MCP arthrodesis (n=4), Quervain release (n=4), trigger thumb release (n=5), trigger finger release (n=2)	0—6wk: Plaster of Paris splint, wrist neutral and thumb abduction 4wk: K-wire excision if applicable	6wk: Physiotherapy was not arranged routinely but when the thumb plaster was discarded, each patient was shown a series of exercises to mobilize and strengthen his/her thumb.	Pain intensity, stiffness, weakness, and restriction of ADL (measured at once in categorical scores, self-designed), grip and pinch strength, ROM. Measures at: t0 (preoperative), t1 (3mo), t2 (12mo)	Pain intensity, stiffness, weakness, and restriction of ADL improved "markedly" at t1 and further at t2 (no significance described). There was no significant difference between the different types of surgery. ROM improved at t2 compared with t0 (no significance mentioned); there was no significant difference between different types of surgery. Thumb key and tip pinch and grip strength in the whole study group at t1 were not different from t0. However, thumb key and tip pinch and grip strength in the whole group at t2 were all significantly stronger compared with t0 ($P<.001$ for all 3 types of surgery).
Eaton et al,[22] 1985	Retrospective cohort	N=21 patients, 25 thumbs (4 bilateral) F/M: 14/7 men Age: 57.3y (range, 31—72y) Dominance of the 17 patients with unilateral involvement: 12/17	Partial trapeziectomy with LRTI using FCR	Stabilization of the MP joint for MP hyperextension >30° (n=5). Advancement or plication of a somewhat lax APL tendon (n=6).	0—4wk: Plaster shell immobilizing CMC-1 and MCP-1, along with K-wire 4wk: K-wire excision	4—6wk: Extension and circumduction of the CMC joint emphasized 6—8wk: Thumb is progressively opposed beginning with Kapandji 3 gradually extended to Kapandji 10. Pinch strengthening is emphasized once full ROM has been achieved.	Pinch strength, clinical results were graded as excellent, good, fair, or failure. Measures at: t0 (preoperative) and t1 (follow-up, 37.5mo; range, 14—60mo).	Pinch strength at t0, 5.5kg; t1, 6.1kg (no significance reported). All patients had "relief of pain" at t1. 55% reported no pain whatsoever, and 44% described "an occasional twinge or rare mild ache." No patient had postoperative pain, even those whose clinical results were graded as fair. According to the grading system, 41.7% of the cases were graded as excellent, 50% were good, and 8.3% were fair.
Horlock et al,[23] 2002	Randomized controlled trial investigating short vs long immobilization	N=39 patients, 40 thumbs (early group, 20; late group, 20) F/M: 30/10 (early group, 14/6; late group, 16/4) Age: Early group, 58±7y; late group, 59±9y Dominance: 20/40	Trapeziectomy	Unknown/not described	Early group: 0—1wk: Scotchcast application 1—6wk: Custom-made Spica only during physical load and night	Early group: ≥1wk: Light use allowed of the hand and were taught active exercises for the thumb	Pain intensity, hand function, opinion about rehabilitation regimen, satisfaction with operation (VAS, 0—100), ROM, grip and pinch strength, and joint imaging (SMD and TMD). Measures at: t0 (preoperative), t1 (6—8mo)	No significant difference in pain intensity decrease. The early group experienced more convenience compared with the late group ($P<.05$). Significant decrease in MCP-1 ROM was found in the late mobilization group but not in the early group (within group, $P<.02$).

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Table 1 (*continued*)

Author, Year	Study Design	Study Population (N, F/M, Age [Mean, Range/±SD], Right/Left, Dominance*)	Surgical Intervention	CoInterventions	Postoperative Rehabilitation—Immobilization Period	Postoperative Rehabilitation—Exercises	Measurements (Instruments, Follow-Up)	Outcomes
					Late group: 0—2wk: Scotchcast application 2—4wk: Custom- made Spica 24/7 4—6wk: Gentle motion aloud out of splint	Late group: 4—6wk: Gentle use and mobilization were then allowed out of the splint.		No significant difference in grip and pinch strength, although the early group performed slightly better when pooling effect sizes of grip, pulp pinch, and key pinch strength. Complications were observed in 15% of the participants in the early group compared with 5% in the late group. No differences between groups in median SMD; 2mm larger decrease in TMD within the early group, but not significant
Kriegs-Au et al,[24] 2004	Randomized controlled trial investigating different surgical procedures	N=43 patients, 52 thumbs. Finally 31 participants/thumbs were followed-up (LR group, 15; LRTI group, 16) F/M: 25/6 (LR group, 13/2; LRTI group, 12/4) Age: LR group, 58.4y; LRTI group, 59y Range/±SD: unknown Dominance: 20/31 (LR group, 9/15; LRTI group, 11/16)	Trapeziectomy with LR with FCR vs trapeziectomy with LRTI with FCR	None	Both groups: 0—3wk: Spica cast immobilization 3—6wk: Individually fitted thumb spica splint that was worn constantly, except during bathing	Both groups: 6wk: Active and active-assisted ROM and thenar muscle—strengthening exercises were performed.	Grip and pinch strength, Buck-Gramcko score, ROM, self-administered questionnaire (pain, strength, daily function, dexterity, cosmetic appearance, willingness to undergo surgery again, overall satisfaction with result), current and past employment status and activity levels, joint imaging (SMD). Measures at: t0 (preoperative), t1 (48.2mo; range. 32—64mo)	All outcomes: Significant improvements, although no differences for different types of surgery mentioned. Proximal migration of the first metacarpal was 37%—42%.
Kuhns et al,[25] 2003	Prospective, single-surgeon study	N=26 F/M: 19/7 Age: 65y (range, 52—82y) Dominance: Unknown	Trapeziectomy with K-wire immobilization	MCP-1 volar plate capsulodesis to correct hyperextension (n=7), CTR (n=4), trigger digit release (n=4 digits in 2 patients), ganglion excision (n=1), lipoma excision (n=1)	0—10d: Short-arm thumb spica splint 10d to 5—6wk: Thumb spica cast 5—6wk: K-wire removal +5—6wk: Elastic roller bandage then was used to protect the thumb from extreme movements (each patient was encouraged to wean use of the elastic bandage during the first week after K-wire removal).	5wk: Warm water soaks with ROM exercises were initiated. 7wk: Those who were not adducting their thumb fully into the plane of the palm and opposing it to the fifth metacarpal head (n=8) were referred for hand therapy for recovery of motion, instructed not to initiate strengthening exercises	Jebsen subtests II and III dexterity tests, AIMS2, pain relief, ROM opposition, grip and pinch strength, joint imaging (SMD). Measures at: t0 (preoperative), t1 (6mo), t2 (24mo)	At final follow-up, 92% were pain free. Significant improvements in 3 subscales of the AIMS2. At t1, 92% adducted fully into the plane of the palm, and 96% opposed to the fifth metacarpal head. Significant improvements in grip (+47%), key pinch (+33%), and tip pinch (+23%) strength at t2. SMD decreased by 51% at t1 compared with t0, no correlation between proximal migration and functional outcomes.
Lee et al,[26] 2015	Retrospective cohort	N=19 F/M: 13/6 Age: 62y (range, 43—82y) Dominance: 11/19	Trapeziectomy with APL sling	Unknown/not described	0—4wk: Thumb spica cast in abduction	4wk +: Activity of the thumb was encouraged.	Pain intensity (VAS, 0—10), limitations in ADL (DASH), patient satisfaction (self-designed), returning to work (self-designed), ROM, grip and pinch strength, joint imaging (SMD). Measures at: t0 (preoperative), t1 (36mo; range, 19—73.7mo)	VAS at t0, 7.2; t1, 1.7 ($P<.05$) DASH at t0, 41; t1, 18 ($P<.05$) Significant improvements in all ROM measurements at t1. Of the working participants, 77% returned to their work or activities without any difficulty or occupation modification; in 23% modifications were required. "All patients expressed their satisfaction for improved postoperative appearance of the hand." Increase of 1.1kg in power pinch ($P<.05$) at t1; no difference in tip pinch and grip strength at t1. SMD decreased 34.3% ($P<.05$).

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Table 1 (*continued*)

Author, Year	Study Design	Study Population (N, F/M, Age [Mean, Range/±SD], Right/Left, Dominance*)	Surgical Intervention	CoInterventions	Postoperative Rehabilitation—Immobilization Period	Postoperative Rehabilitation—Exercises	Measurements (Instruments, Follow-Up)	Outcomes
Lins et al,[27] 1996	Retrospective cohort	N=27 patients, 30 thumbs F/M: 25/2 Age: 64y (range, 43–77y) Dominance: 19/30	LRTI with (partial n=20/whole n=10) FCR and K-wire	CTR (n=4), IP-1 joint arthrodesis (n=1)	0–4wk: Thumb spica cast followed by Kirschner pin removal. Removable thumb spica splint at 4wk until 12wk.	4wk: Gentle ROM exercises 12wk: Unrestricted thumb movement allowed	Pain intensity (self-designed), functional status/satisfaction (self-designed), grip and pinch strength, web space, joint imaging (SMD). Measures at: t0 (preoperative), t1 (42–43mo; range, 14–88mo)	At t1, 85% patients considered the frequency of pain "improved a lot or resolved completely" compared with t0, and 89% considered the duration and severity as "improved a lot or completely" at t1, compared with t0. At t1, 89% of the patients were satisfied with the "relief of pain." Web space increased by 1.09cm ($P<.02$). Grip strength increased with 5.9kg ($P<.001$) and pinch strength increased by 1.4kg ($P<.01$). SMD decreased with 30% ($P<.05$).
Mo and Gelberman,[28] 2004	Case series	N=14 patients, 14 thumbs F/M: 11/3 Age: 59.6y (range, 31–79y) Dominance: 5/11	LRTI with FCR (sometimes scaphotrapeziotrapezoid joint excision) and K-wire	Unknown/not described	0–4wk: Thumb spica cast followed by pin removal at 4wk 4–8wk: Removable spica	4wk: Exercises with emphasis on extension/abduction, on maintaining MCP joint flexion and avoiding hyperextension 8wk: Strengthening exercises	Limitations in ADL (DASH), ROM, grip and pinch strength. Joint imaging (SMD). Measures at: t0 (preoperative), t1 (20mo; range, 12–44mo)	DASH outcomes associated with strength, no results over time reported. Distance from thumb tip to base of small finger during maximum flexion decreased by 0.4cm ($P=.02$). Grip strength improved with 26% at t1 compared with t0 ($P=.01$); pinch strength improved by 11% ($P=.11$). SMD improved by 2.5%; no correlation between proximal migration and functional outcomes.
Nylen et al,[29] 1993	Prospective cohort	N=93 patients, 102 thumbs F/M: 89/11 Age: 59y (range, 40–78y) Dominance: 56%	LRTI with FCR without K-wire	MCP arthrodesis (n=6), MCP-1 temporary pinned (n=13). Four other procedures were performed in the similar hand (procedure unknown).	0–5wk: Plaster spica with thumb in RAB/PAB. An abduction splint was sometimes used intermittently for a few weeks thereafter.	5wk: Physiotherapy was started (therapy content unknown).	Pain intensity (self-designed), limitations in ADL (self-designed), adduction contracture (self-designed: severe, moderate, slight, none), ROM, grip and pinch strength, satisfaction. Return to work, joint imaging (SMD). Measures at: t0 (preoperative), t1 (36mo; range, 24–54mo)	At t1, 49% were "pain free" and 51% had "some pain." Of the patients with limitations in ADL preoperatively, 73% reported no limitations at t1. Adduction contracture "diminished" in 57% of the patients, decrease was not significant. Significant improvements in pinch strength, no significant difference in grip strength. At t1, 88% were satisfied. Average SMD at t1 was 4mm.
Poole et al,[30] 2011	Randomized controlled trial investigating the added value of postoperative exercises/therapy	N=9 participants (splint/HT group, 4; splint/HP group, 5) F/M: 8/1 (splint/HT group, 3/1; splint/HP group, 5/0) Age: 58.0y (splint/HT group, 59.3y [range, 49–68y]; splint/HP group, 58.4y [range, 52–64y]) Dominance: 4/9	Partial trapeziectomy with LRTI using PL, and the joint was pinned in 1cm of distraction with K-wires.	Unknown/not described (first stated excluded, later included)	0–4wk: Bulky dressing and a splint was applied. 3–4wk: K-wire removal. Both groups: 4wk: thumb spica or c-bar splint, no description of discontinuation	Splint/HP group: 4wk postoperatively: 1 consult, which included thumb spica or c-bar splint, and HP (included information regarding splint wear, methods to control edema, AROM exercises, and massage of the hand). Splint/HT group: 4wk postoperatively: Receive a thumb spica or c-bar splint followed by outpatient occupational therapy 1h, 1	Pain intensity (Boston Questionnaire), limitations in ADL (JHFT, AHFT), grip and pinch strength, quality of life (AIMS2). Measures at: t0 (preoperative) and t1 (6mo postoperatively)	Improvements in pain intensity in both groups, although no significant within-group differences due to small sample size. No significant differences between groups, although a larger decrease in symptom severity was found in the HT group (ES=.53). Higher improvements in limitations in ADL in the HT group for both the JHFT (ES=.52) and the AHFT

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Table 1 (*continued*)

Author, Year	Study Design	Study Population (N, F/M, Age [Mean, Range/±SD], Right/Left, Dominance*)	Surgical Intervention	CoInterventions	Postoperative Rehabilitation—Immobilization Period	Postoperative Rehabilitation—Exercises	Measurements (Instruments, Follow-Up)	Outcomes
						time a week for approximately 4wk. Therapy included application of a thumb spica or c-bar splint, reduction of edema, instructions in ROM and strength exercises, and ADL.		(ES=.33), although not significant due to sample size. Improvements in grip (+13%) and 3-point pinch strength (+27%) were only found in the HT group, while grip (−8%) and 3-point pinch strength (−6%) decreased in the HP group (ES grip strength, 77; ES 3-point pinch, .95). Significant improvements in several subscales of the AIMS2 for both groups; no between-group differences.
Prosser et al,[31] 2014	Randomized controlled trial investigating partial vs complete immobilization	N=56 (3 lost to follow-up; rigid, 28; semirigid: 28). F/M: 45/11 (rigid, 23/28; semirigid, 22/28) Age: 67.8±8.0y (rigid, 66.9±8.5y; semirigid, 69.6±7.8y) Dominance: 27/56 (rigid, 14/28; semirigid, 13/28)	Trapeziectomy and LRTI using FCR (n=53), or trapeziectomy alone (n=3 [rigid, n=1; semirigid, n=2])	Unknown/not described	Both groups: 0—2wk: Dorsal plaster back slab immobilizing wrist and thumb. Thereafter: randomization. Semirigid group: 2—6wk: custom-made neoprene with a bonded thermoplastic piece from IP-1 to distal 2/3 of the forearm, with thermoplastic piece on radial aspect of thumb extending from midproximal phalanx to just below the wrist and was bonded to the neoprene with thumb in maximal comfortable PAB. Rigid-group: 2—6wk: Thermoplastic custom-made wrist-thumb splint	Both rigid/semirigid: 0—2wk: Composite extension/flexion advised by surgeon 2—3wk: Thumb IP flexion/extension, wrist flexion/extension 4 times/d 10 reps 3—4wk: Isolated AROM MCP flexion/extension to neutral only (0°) out of orthosis. Emphasis placed on flexion. 4—6wk: CMC-1 AROM PAB, no opposition. 6wk: Wean splint, passive exercises, graded strengthening grip and pinch, scar management. Light activity at 6wk upgraded to moderate to heavy activity at 12wk. 0—4wk: Scheduled for weekly visits; 4—10wk: every 2wk	Pain intensity and limitations in ADL (PRWHE, MHQ), and pinch strength. Measures at: t0 (preoperative), t1 (6wk), t2 (3mo), and t3 (1y)	No significant differences in pain intensity and limitations in ADL. No significant differences in pinch strength. Complications were observed in 14% of the participants in the rigid group compared with 7% in the semirigid group.
Roberts et al,[32] 2001	Retrospective cohort	N=23, 25 thumbs F/M: Unknown Age: Median 60y (Q1=53, Q3=65) Dominance: Unknown	Trapeziectomy with LRTI using FCR (n=7) or partial trapeziectomy with LRTI using FCR (n=18)	Unknown/not described	0—10d: Bivalve radial plaster thumb spica splint and ulnar plaster gutter splint. Wrist in ∼15° dorsal flexion, thumb midway abduction and extension, and thumb IP free. 10d: New radial gutter splint fabricated. 3wk: Splint discontinued	3wk: AROM wrist and thumb 3—4 times/d, scar management initiated, swelling and pain modalities (ie, paraffin, Coban, gloves). 6wk: Strengthening exercises begun for patients "who complained of weakness with pinch and grip." Exercises consisted of isometrics and active motion against resistance. Education in joint protection, modification of pinch, and the use of adaptive equipment was provided	Pain intensity (VAS, 0—10), limitations in ADL (self-designed: 15-item daily living checklist). Preoperative pain intensity and limitations in ADL were measured retrospectively, Grip and pinch strength. Measures at: t0 (preoperative), t1 (postoperative: median, 1y11mo; range, 3mo to 11y; Q1=1y, Q3=3y4mo).	Hemitrapezium resections: VAS median improvement: 7.0cm (P=.001, n=12). ADL median improvement: 33% (P=.001, n=13). Grip and pinch strength median improvements between t0 and t1: Grip, 10.2kg (P=.01, n=12); lateral pinch, 2.3kg (P=.01, n=13); tripod pinch, 2.6kg (P=.01, n=8); and tip-to-tip pinch, 1.6kg (P=.03, n=7). Full-trapezium resections: VAS median improvement: 8.0cm (P=.04, n=5). ADL median improvement: 60% (P=0.4, n=5).

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Author, Year	Study Design	Study Population (N, F/M, Age [Mean, Range/±SD], Right/Left, Dominance*)	Surgical Intervention	CoInterventions	Postoperative Rehabilitation—Immobilization Period	Postoperative Rehabilitation—Exercises	Measurements (Instruments, Follow-Up)	Outcomes
								Grip and pinch strength median improvements between t0 and t1: Grip, 13.4kg ($P=.07$, n=4); lateral pinch, 0.9kg ($P=.29$, n=4); tripod pinch, −0.4kg ($P=1.0$, n=3); and tip-to-tip pinch, −0.4kg ($P=1.0$, n=3).
Rocchi et al,[33] 2011	Retrospective cohort	N=50, 8 lost to follow-up F/M: 34/8 Age: 60±9y (range, 49—79y) Dominance: 31/50	Trapeziectomy with LRTI using APL	Unknown/not described	0—1wk: Plaster splint with wrist encompassed, MC1 in slight abduction. 1—4wk: Thermoplastic splint with thumb in incremented abduction and opposition. 4—6wk: Splinting only at night	0—4wk: IP-1 movements prescribed. ≥4wk: Exercises to regain full ability; ie, opposition exercises that gradually progressed from aiming at the tip of the fifth finger, then toward reaching its base. Only for 8 of 42 patients was a rehabilitation program deemed necessary, and exercises of passive, active-assisted, and active ROM were started.	Pain intensity (VAS mentioned, but results expressed as no pain and restriction, mild pain with use and some restriction, pain at rest and some restriction, and pain at rest and severe restriction), satisfaction (VAS), limitations in ADL (DASH), grip and key pinch strength, joint imaging (SMD). Measures at: t0 (preoperative), t1 (3mo), t2 (6mo), and t3 (12mo)	n=42, 8 lost to follow-up At t3, no patients had any pain at rest, only 1 occasional mild pain. No significance mentioned. Satisfaction 9.6, time point unknown. DASH at t0, 43.3; t1, 25.5; t2, 19.1; t3, 14.5, no significance mentioned. Grip strength at t0, 16.0kg; at t3, 19.2kg; key pinch at t0, 3.7kg; at t3, 5.6kg; no significance mentioned. At t3, SMD averaged 6.4mm.
Saehle et al,[34] 2002	Retrospective cohort	N=47, 55 thumbs F/M: 44/3 Age: 58y (range, 44—73y) Dominance: Unknown	Trapeziectomy with LRTI using APL	Unknown/not described	0—4/5wk: Plaster of Paris	Unknown	Pain intensity (VAS, 0—100; only at t1), limitations in ADL (self-designed at t0 and t1 and DASH, only at t1), ROM (only at t1), grip and pinch strength (compared with other hand, only at t1), cosmetics (VAS, 0—100; only at t1), joint imaging (SMD). Measures at: t0 (preoperative), t1 (41mo; range, 16—60mo)	Median VAS pain intensity at t1: 11. ADL function measured with self-designed questionnaire improved in 51% of the patients at t1 compared with t0. Median DASH scores for the disability/symptom and work scales were both 28. The distal phalanx of the 5th finger could be reached by 52 of the 55 operated hands. Average key pinch and grip strengths of the operated hands were reduced by 11% and 22%, respectively, compared with unaffected side. Median VAS score for the cosmetic result at t1: 5. SMD decreased by 55% at t1 compared with t0; no correlation between proximal migration and clinical results.
Sirotakova et al,[35] 2007	Case series	N=74, 104 thumbs F/M: 59/15 Age: 59y (range, 40—82y) Dominance: Unknown	Trapeziectomy with APL sling (around FCR/ECRL)	CTR (n=19) hands in 15 patients (20%)	0—2wk: Plaster of Paris splint. 2—4wk: Thermoplastic splint. ≥4wk: Most remove the splint and only wear it at night. Sometimes during day.	Patient is seen weekly by the therapists. 0—2wk: IP-1 joint flexion and extension exercises, which are performed 5 times on 3 occasions each day 2—6wk: Opposition exercises.	Pain intensity, stiffness, weakness of the hand, functional disability (self-designed), ROM, grip and pinch strength, joint imaging (SMD). Measures at: t0 (preoperative), t1 (6mo), t2 (12mo)	"Excellent" results in terms of pain relief were achieved in 91%. Improvements in all ROM measures at t2 (not statistically tested). Grip and pinch strength improved in all measures at t2 (not statistically tested); SMD decreased by 29% at t2.
Soejima et al,[36] 2006	Prospective cohort	N=18, 21 thumbs F/M: 16/2 Age: 63y (range, 52—77y) Dominance: Unknown	Trapeziectomy with LRTI using APL	Unknown/not described	0—2wk: Short-arm spica splint	2wk: ROM and grip-strengthening exercises were initiated.	Pain intensity (self-designed), ROM, and grip and pinch strength, joint imaging (SMD). Measures at: t0 (preoperative), t1 (33mo; range, 12—71mo)	At t1, 61% had no pain, 24% had mild pain with strenuous activities, and 14% had mild pain with light work.

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Table 1 (*continued*)

Author, Year	Study Design	Study Population (N, F/M, Age [Mean, Range/±SD], Right/Left, Dominance *)	Surgical Intervention	CoInterventions	Postoperative Rehabilitation—Immobilization Period	Postoperative Rehabilitation—Exercises	Measurements (Instruments, Follow-Up)	Outcomes
								ROM radial and palmar abduction increased by 14° ($P=.09$) and 8° ($P=.07$), respectively. Grip and pinch strength increased by 2kg ($P=.18$) and from 1.3kg ($P=.23$), respectively. SMD decreased by 15% ($P<.05$).
Varitimidis et al,[37] 2000	Retrospective cohort	N=58, 62 thumbs F/M: 48/10 Age: 58.4y (range, 28—80y) Dominance: 31/58	Trapeziectomy with LRTI using entire FCR, partial trapeziodectomy in 32 cases	MCP-1 arthrodesis (n=3), CTR (n=4), trigger finger release (n=3), IP-1 arthrodesis (n=2)	0—4wk: Radial thumb spica splint. 4wk: Removable splint is applied. 6wk: Weaning from splint begins. 3mo: Free from immobilization	4wk: Physical therapy is started if significant stiffness exists. 3mo: More intense strengthening exercises are started if necessary. Physical therapy usually is continued until the end of the fourth month, when satisfactory pinch and grip strength have been achieved.	Pain intensity (self-designed), ROM, grip and pinch strength, joint imaging (SMD). Measures at: t0 (preoperative), t1 (42.5mo; range, 21—86mo)	t1: 95% had no pain, compared with 0% at t0. Increase of pain in 0% of participants. An 8% improvement in palmar abduction and a 10% improvement in radial abduction at t1 compared with t0. Significant improvement in strength at t1 in all measurements. SMD decreased by 10%.
Vermeulen et al,[38] 2009	Prospective cohort	N=19, 20 thumbs F/M: 17/2 Age: 58y (range, 51—80y) Dominance: unknown	Trapeziectomy with LRTI (Weilby) using FCR	None	0—4wk: Spica cast. 4wk: Removable protective orthosis	4wk: Physiotherapy was started by a hand therapist (therapy content unknown).	Limitations in ADL (DASH, Specific Personal Questionnaire), grip and pinch strength, ROM. Measures at: t0 (preoperative), t1 (0mo), t2 (3mo), t3 (6mo), t4 (12mo)	DASH score at t0, 51; t2, 36; t3, 30.5; t4, 30 ($P<.001$) Significant improvements in intermetacarpal distance, Kapandji score Significant improvements in 3-point pinch strength and overall grip strength at final follow-up
Vermeulen et al,[39] 2014	Randomized controlled trial investigating different surgical procedures	N=72 (BP group, 36; Weilby group, 36) F/M: 72/0 Age: BP group, 64.7±9.1y; Weilby group, 63.5±8.5y Dominance: 36/72 (BP group, 18/36; Weilby group, 18/36)	Trapeziectomy with LRTI using FCR (BP) vs trapeziectomy with Weilby sling	None	0—4wk: Spica cast 4wk: Removable protective orthosis	4wk: Hand therapist started standardized HT focused on reducing edema and regaining functionality by increasing mobility, stability, and strength of the thumb.	Pain intensity and limitations in ADL (PRWHE, DASH), ROM, grip and pinch strength, complications, joint imaging (SMD). Measures at: t0 (preoperative), t1 (3mo), t2 (12mo)	Pain intensity (PRWHE) decreased significantly for both types of surgery at t2 (Weilby: −17 points vs BP: −18 points [score range, 0—50]). DASH: Significant improvements for both types of surgery (Weilby: −16 points vs BP: −20 points [score range, 0—100]). No differences between different types of surgery, except in CMC-1 extension (decrease in BP group). Increase in grip strength for both types of surgery (Weilby: +3kg vs BP: +4kg). Key pinch decreased 0.1kg for both types

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Table 1 (*continued*)

Author, Year	Study Design	Study Population (N, F/M, Age [Mean, Range/±SD], Right/Left, Dominance*)	Surgical Intervention	CoInterventions	Postoperative Rehabilitation—Immobilization Period	Postoperative Rehabilitation—Exercises	Measurements (Instruments, Follow-Up)	Outcomes
								of surgery, Tip pinch increased 0.4kg for both types of surgery, and 3-point pinch increased for both types of surgery (Weilby: +0.3kg vs BP: +0.5kg). Statistical testing for group differences was not reported. In total, complications were observed in 27.8% of the participants (Weilby: 23.1% vs BP: 32.5%; difference not significant). SMD at t2 during rest in Weilby group decreased by 33%, in BP group by 48%, during pinch in Weilby group: by 66%, BP group: by 57%.
Werthel and Dubert,[40] 2016	Prospective cohort	N=43, 49 thumbs, 4 were lost to follow-up. F/M: Unknown Age: 67y (range, 53—85y) Dominance: 18/39	Trapeziectomy with LRTI using FCR	Unknown/not described	0—5wk: Thumb and wrist immobilized in a cast	Physiotherapy not required on a systematic basis postoperatively	Pain intensity (VAS), limitations in ADL (DASH), grip and pinch strength, ROM. Measures at: t0 (preoperative), t1 (37mo; range, 29—72mo)	VAS during rest at t0, 2.3; t1, 0.3 ($P<.05$); VAS during key pinch at t0, 5.4; t1, 1.3 ($P<.05$). Quick DASH at t0, 49.4; t1, 22.1 ($P<.05$). Significant improvements in all ROM measures, except MCP-1 hyperextension. Pinch strength at t0, 3.3; t1, 5.1 ($P<.05$); no change in grip strength.
Wong and Ip,[41] 2009	Retrospective cohort	N=22 patients, 22 thumbs F/M: 16/6 Age: 50y (range, 43—75y) Dominance: 13/22	Trapeziectomy with LRTI using FCR and PL	None	0—6wk: Thermoplastic removable thumb spica splint	6wk: Gentle thumb and wrist mobilization exercise and control of the swelling immediately after removal of the splint. 8wk: Active thumb and wrist joint mobilization exercise (ie, putty exercise and sandbag). 12wk: Passive thumb and wrist joint mobilization exercise together with vigorous strengthening exercise such as Dexter training and Theraband exercise were started.	Pain intensity (self-designed), grip and pinch strength, ROM, joint imaging (SMD). Measures at: t0 (preoperative), t1 (2wk), t2 (4wk), t3 (8wk), t4 (12wk), t5 (24wk), t6 (52wk), and t7 (final follow-up: average 48mo; range, 12—72mo)	At final follow-up, 82% were "pain free." Kapandji score increased from 4 at t0 to 6 at t7 ($P=.04$). When comparing t0 with t7, differences were found in grip strength (+4kg, $P=.03$), tip pinch (+0.7kg, $P=.04$), and key pinch (+1.0kg, $P=.03$), at t7 SMD space ratio decreased by 9% and SMD in millimeters decreased by 13%
Yang et al,[42] 2014	Retrospective cohort	N=19, 21 thumbs F/M: 18/1 Age: 60y (range, 52—75y) Dominance: Unknown	Trapeziectomy with modified LRTI using FCR	Unknown/not described	0—2wk: Volar plaster splint. 2—6wk: Thumb spica cast with which the thumb is placed in an abducted position. 6—12wk: Patient wears brace intermittently.	6wk: ROM and strengthening exercises are started.	Pain intensity (VAS, 0—10), ROM, grip and pinch strength, joint imaging (SMD). Measures at: t0 (preoperative), further examined at 2wk, 6wk, and 3mo after surgery, then every 3mo for the first year, and every 6mo thereafter. Final follow-up analyzed: t1 (13.9mo; range, 9—28mo).	VAS pain at t0, 6.6; t1, 0.5 ($P<.05$), Improvement in ROM at t1 compared with t0 ($P<.05$). Grip strength at t0, 18.6; t1, 20.5 ($P>.05$). Tip pinch strength at t0, 4.4; t1, 4.5 ($P>.05$). At t1, SMD space ratio decreased by 56% and SMD in millimeters decreased by 55%.

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Table 1 *(continued)*

Author, Year	Study Design	Study Population (N, F/M, Age [Mean, Range/±SD], Right/Left, Dominance*)	Surgical Intervention	CoInterventions	Postoperative Rehabilitation—Immobilization Period	Postoperative Rehabilitation—Exercises	Measurements (Instruments, Follow-Up)	Outcomes
Yao and Lashgari,[43] 2014	Case study	N=1 F/M=1/0 Age: 63y Dominance: Unknown	Trapeziectomy with tightrope suspension	None	0–10d: Plaster thumb spica orthosis. 10–18d: Custom fabrication spica orthosis. 18d to 10wk: Butterfly splint if needed, discontinued after 10wk.	10–18d: AROM exercises (unspecified). 18d to 2mo +18d: Edema control, scar massage, isometric exercises lateral pinch strength, guidance regarding ADL.	Limitations in ADL (DASH). Measures at: t0 (preoperative), t1 (11mo).	DASH at t0, 63; t1, 10.

Abbreviations: AHFT, Arthritis Hand Function Test; AIMS2, Arthritis Impact Measurement Scales 2; APL, abductor pollicis longus; AROM, active range of motion; BP, Burton-Pellegrini; CTR, carpal tunnel release; DASH, Disabilities of the Arm, Shoulder and Hand; ECRL, extensor carpi radialis longus; ES, effect size; FCR, flexor carpi radialis; F/M, female/male; HP, home program; HT, hand therapy; IP-1, thumb interphalangeal joint; JHFT, Jebsen Hand Function Test; LR, ligament reconstruction; LRTI, ligament reconstruction and tendon interposition; MHQ, Michigan Hand Outcomes Questionnaire; N, number of participants; PAB, palmar abduction; PL, palmaris longus; PRWHE, Patient-Rated Wrist and Hand Evaluation; Q1, 1st quartile; Q3, 3rd quartile; RAB, radial abduction; reps, repetitions; SMD, distance between base of first metacarpal and distal end of scaphoid; TMD, distance between base of first metacarpal and radial border of trapezoid; VAS, visual analog scale.

* Dominance, number of treatments of dominant side.

On methodological quality (risk of bias), kappa scores of .84 and .82 were found between the reviewers (R.W., J.T.) with regard to the Effective Public Health Practice Project quality assessment tool and the Physiotherapy Evidence Database scale, respectively; both scores represent very good agreement.[14] Supplemental table S2 (available online only at http://www.archives-pmr.org/) gives an overview of the methodological quality of the included studies.

Results of individual studies and synthesis of results

Six comparative studies were included, of which 3 investigated the research questions of the present study (the other 3 studies compared different surgical procedures). Given the few comparative studies on the research questions, no statistical pooling was performed. A summary of the rehabilitation protocols as used in the included studies (including total immobilization period, initiation of ROM and strengthening exercises) is displayed per surgical intervention (categorized by the tendon plasty used) in figure 2. Figure 2 shows that the most progressive postoperative rehabilitation (including short immobilization and early initiation of ROM and strength exercises) is used in the literature for simple trapeziectomy or for ligament reconstruction and tendon interposition with either a slip, a strip of or the entire abductor pollicis longus tendon.

Postoperative immobilization

An overview of the immobilization periods and methods per study, sorted by year of publication in figure 3, shows that the total immobilization varied substantially, from 2 to 12 weeks. In most studies, emphasis was placed on immobilization in palmar abduction and extension of the CMC-1. The types of immobilization consisted of plaster cast immobilization only,[17,21,22,26,34,36,40,41] or plaster cast immobilization followed by a removable splint that is gradually reduced[18,20,25,27,31,33,35,37,42,43] or completely discontinued at a certain moment.[19,23,24,28,32] Splint usage gradually reduced over time consisted of only night usage,[18,33,35] the use of a butterfly splint if needed,[43] or the splint is stopped when full ROM is attained and thenar strength is improved to a functional level.[20] The discontinuation criterion was not described clearly in 8 studies.[25,27,29,30,37-39,42]

Two comparative studies[23,31] on postoperative immobilization were found (table 3). In these studies, partial immobilization until 6 weeks was compared with complete immobilization until 6 weeks. The authors did not find more complications or worse outcomes at 6 to 12 months postoperatively when partial immobilization was used; on the contrary, the same or better outcomes were found in the groups that used partial immobilization compared with complete immobilization. Insufficient data were provided by Prosser et al[31] to calculate effect sizes. In the study by Horlock et al,[23] effect sizes on pain intensity, satisfaction, ROM, and grip and pinch strength range from −.66 to .66, where positive values indicate superior results for partial immobilization (see table 3).

Table 3 also provides the outcomes for studies using a total immobilization period of either 4 to 6 weeks or ≤4 weeks. Fourteen studies[17,21,23-25,29-31,33,35,38-41] used a total immobilization period of 4 to 6 weeks, and 5 studies[22,26,32,34,36] used a total immobilization period ≤4 weeks. We found similar complications and outcomes in studies using a total immobilization period of 4 to 6 weeks or ≤4 weeks compared with studies that used an immobilization period ≥6 weeks.

Table 2 Types of surgical interventions performed in included studies

Surgical Intervention	N	Reference(s)
Trapeziectomy with LRTI using the FCR	448	18,19,24,29,31,32,37-40, 42
Trapeziectomy with LRTI using the APL	249	26,33-36
Trapeziectomy with LRTI using the FCR and PL	32	17, 41
Trapeziectomy with LRTI using the FCR and Kirschner-wire fixation	125	20, 27, 28, 21
Trapeziectomy with tendon interposition using the PL and Kirschner-wire fixation	59	21
Trapeziectomy with ligament reconstruction using the FCR	15	24
Partial trapeziectomy with LRTI using the FCR	18	32
Partial trapeziectomy with LRTI using the FCR and Kirschner-wire fixation	31	20, 22
Partial trapeziectomy with LRTI using the PL and Kirschner-wire fixation	9	30
Trapeziectomy	43	23, 31
Trapeziectomy with Kirschner-wire fixation	88	25, 21
Trapeziectomy with tightrope suspension	1	43
Total	1118	

NOTE. No distinction was made between half or complete tendon use or the presence or absence of a bone tunnel in this classification.
Abbreviations: APL, abductor pollicis longus; FCR, flexor carpi radialis; LRTI, ligament reconstruction and tendon interposition; N, number of interventions per hand (multiple interventions were performed in several cases because of bilateral disease); PL, palmaris longus.

Postoperative exercises/therapy

Large variations were observed in postoperative exercises/therapy regimens of the included studies. One comparative study[30] investigated the added value of hand therapy compared with a home program only in postoperative rehabilitation. No significant differences were found between the groups because of a small sample size, although higher improvements were found for pain intensity, limitations in ADL, and grip and pinch strength 6 months postoperatively in the group that received hand therapy (table 4). Effect sizes on pain intensity, limitations in ADL, grip and pinch strength, and quality of life ranged from .33 to .95, indicating superior treatment effects of hand therapy compared with a home program only.

Five studies[26,29,34,38,40] did not describe the content of postoperative exercises/therapy. When the other 23 studies are summarized, 3 phases can be identified on postoperative exercises/therapy: (1) the acute postoperative phase (range, 0−6wk postoperatively); (2) the unloaded phase (range, 1−12wk postoperatively); and (3) the functional phase (range, 3wk to 6mo postoperatively). Table 5 provides a summary of the phases and the physical therapy content per phase as used in the included studies, and figure 4 provides an overview of the phases per study. In general, in postoperative exercises/therapy, emphasis is placed on MCP-1 flexion and CMC palmar abduction and extension, while CMC flexion, adduction, and opposition are avoided.

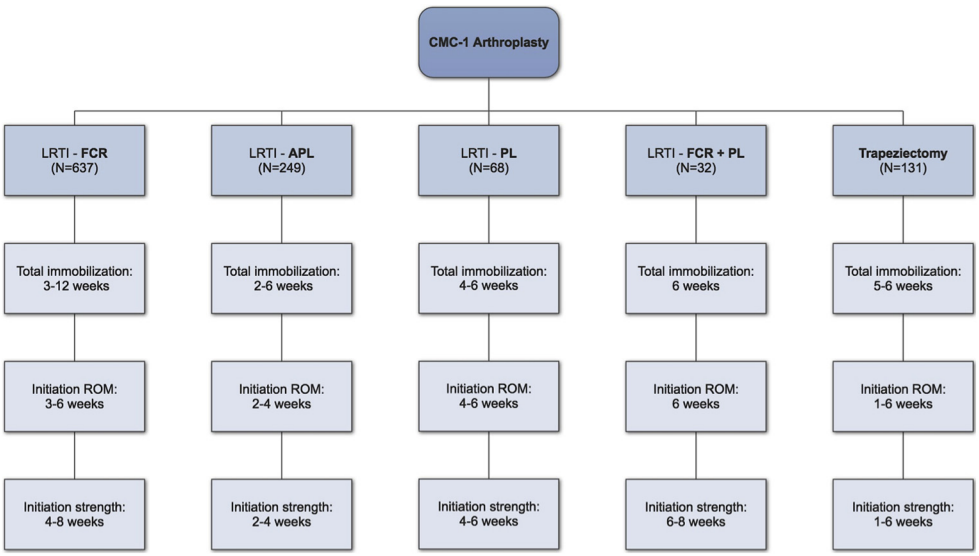

Fig 2 A summary of the rehabilitation protocols used in the included studies regarding total immobilization period and initiation of ROM and strengthening exercises is displayed per surgical intervention (categorized by the tendon used). The displayed time frames indicate the range (minimum to maximum period) of the used period in the literature. Abbreviations: APL, abductor pollicis longus; FCR, flexor carpi radialis; LRTI, ligament reconstruction and tendon interposition; PL, palmaris longus.

Fig 3 Overview of immobilization period per week for individual studies

Year	Author	N	Type Surgery/ Tendon Plasty
1985	Eaton et al[22]	25	FCR
1986	Burton and Pellegrini[20]	25	FCR
1993	Nylen et al[29]	102	FCR
1996	Lins et al[27]	30	FCR
2000	Varitimidis et al[37]	62	FCR
2001	Roberts et al[32]	25	FCR
2002	Saehle et al[34]	55	APL
2002	Horlock et al[23]	40	
	Late group	20	Simple trapeziectomy
	Early group	20	Simple trapeziectomy
2003	Kuhns et al[25]	26	Simple trapeziectomy
2004	Mo and Gelberman[28]	14	FCR
2004	Kriegs-Au et al[24]	52	FCR
2004	Davis et al[21]	62	FCR
		59	PL
		62	Simple trapeziectomy
2006	Soejima et al[36]	21	APL
2007	Sirotakova et al[35]	104	APL
2009	Vermeulen et al[38]	20	FCR
2009	Wong and Ip[41]	22	FCR + PL
2011	Rocchi et al[33]	50	APL
2011	Poole et al[30]	9	
	Home program group	5	PL
	Occupational therapy group	4	PL
2012	Ataker et al[18]	27	FCR
2012	Başar et al[19]	19	FCR
2012	Abbas et al[17]	10	FCR + PL
2014	Prosser et al[31]	53	

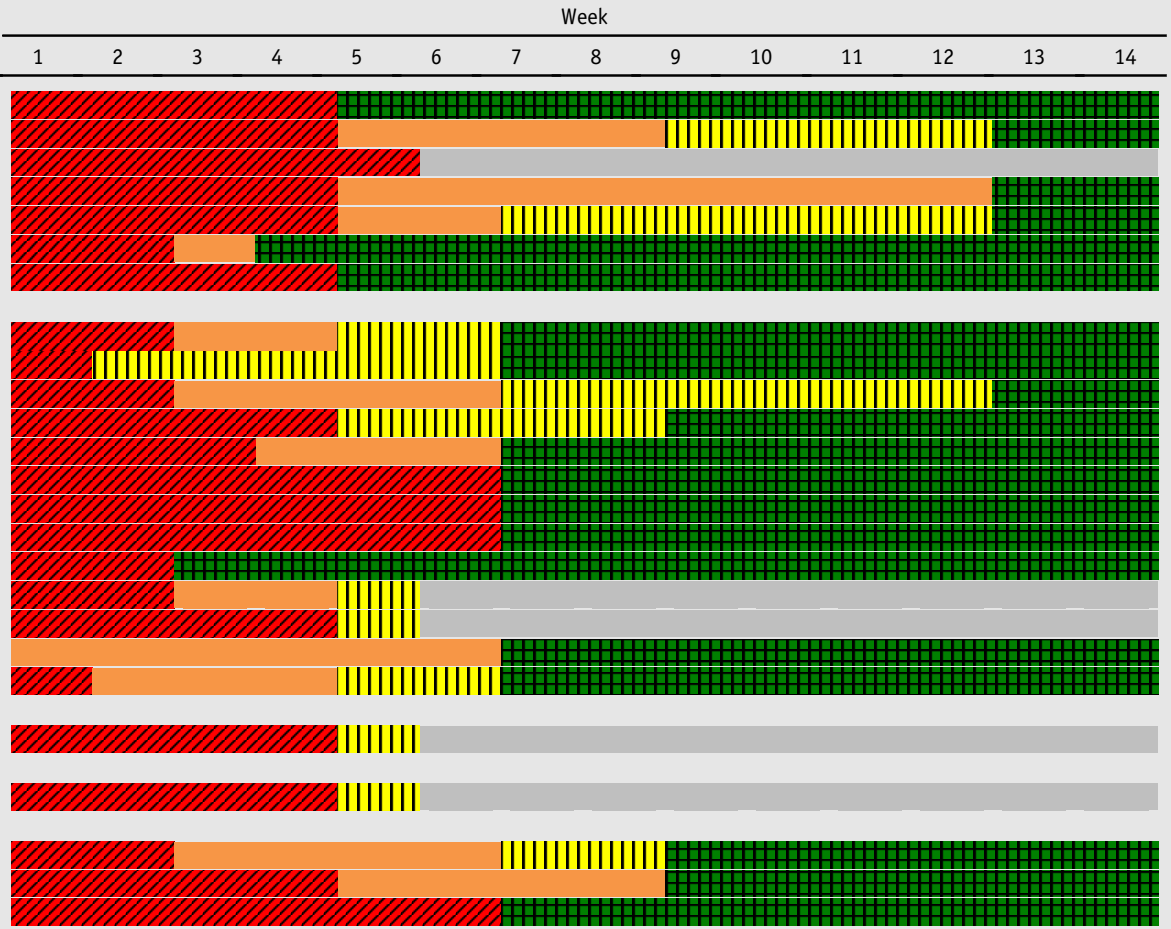

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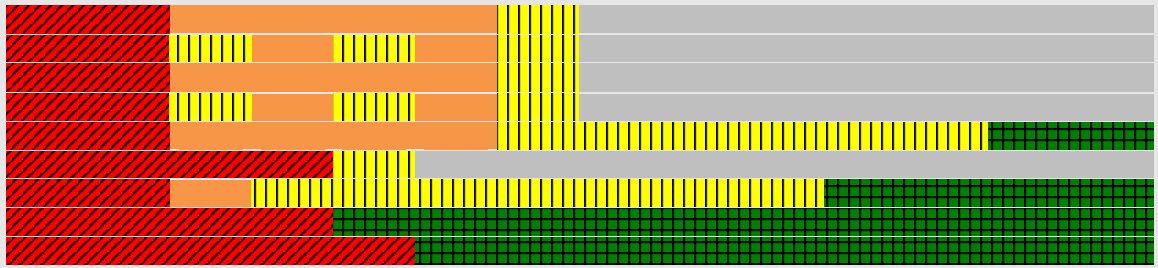
Fig 3 (*continued*)

Year	Author	N	Type Surgery/ Tendon Plasty
	Rigid group	27	FCR
	Semirigid group*	26	FCR
	Rigid group	1	Simple trapeziectomy
	Semirigid group*	2	Simple trapeziectomy
2014	Yang et al[42]	21	FCR
2014	Vermeulen et al[39]	72	FCR
2014	Yao and Lashgari[43]	1	Tightrope
2015	Lee et al[26]	19	APL
2016	Werthel and Dubert[40]	49	FCR



Cast immobilization 24h/d =
Splint immobilization 24h/d =
Splint gradually reduced =
Immobilization completely discontinued =
Immobilization content unknown =

NOTE. In case studies in which a splint was intermittently used from a certain moment but no endpoint of spint usage was described, the first week was considered as gradually reduced splint usage, and the rest is considered unknown.

Abbreviations: APL, abductor pollicis longus; FCR, flexor carpi radialis; PL, palmaris longus.

* After 2 weeks, the semirigid group in this study wore a splint 24h/d that partly immobilized the wrist, instead of complete immobilization (the rigid group). To demonstrate this difference, it is displayed as "splint gradually reduced."

Table 3 Overview of studies comparing different types of immobilization and of studies using a total immobilization period of 4 to 6 weeks or ≤4 weeks

Studies Comparing Immobilization	Immobilization Methods	Measures at	Measurements and Instruments	Outcomes
Horlock et al,[23] 2002	Late vs early mobilization: Cast immobilization for 2wk followed by thermoplastic splint 24h/d until 6wk vs cast immobilization for 1wk followed by thermoplastic splint only during physical load until 6wk	t0 (preoperative) t1 (6–8mo)	1) Pain intensity, hand function, opinion about rehabilitation regimen, satisfaction with operation (VAS, 0–100) 2) ROM 3) Grip and pinch strength 4) Complications 5) Joint imaging (SMD and TMD)	1) No significant difference in pain intensity decrease, although ES = −.66 due to preoperative group differences, but VAS score at t1 for late group, 30; early group, 28. The early group experienced more convenience compared with the late group (ES = .66, $P < .05$). 2) Significant decrease in MCP-1 ROM was found in the late mobilization group but not in the early group (ES = .19, within group $P < .02$). 3) No significant difference in grip and pinch strength, although the early group performed slightly better when pooling effect sizes of grip, pulp pinch, and key pinch strength (ES = .05). 4) Complications were observed in 15% of the participants in the early group compared with 5% in the late group. 5) No differences between groups in median SMD; 2mm larger decrease in TMD within the early group, but not significant.
Prosser et al,[31] 2014	Rigid vs semirigid immobilization: Thermoplastic splint until 6wk with full immobilization of the thumb and wrist vs combined thermoplastic and neoprene splint until 6wk allowing thumb and wrist motion	t0 (preoperative) t1 (6wk) t2 (3mo) t3 (1y)	1) Pain intensity and limitations in ADL (PRWHE, MHQ) 2) Pinch strength 3) Complications	1) No significant differences in pain intensity and limitations in ADL. Insufficient data were provided to calculate ES. 2) No significant differences in pinch strength. Insufficient data were provided to calculate ES. 3) Complications were observed in 14% of the participants in the rigid group compared with 7% in the semirigid group.

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Table 3 (*continued*)

Studies With Total Immobilization Period of 4—6wk	Immobilization Methods	Measures at	Measurements and Instruments	Outcomes
Abbas et al,[17] 2012	Only plaster cast immobilization	t0 (preoperative) t1 (3mo) t2 (6mo)	1) Limitations in ADL (Quick DASH)	1) Quick DASH Score at t0, 58.8; t1, 40.5; t2, 31.3 ($P=.005$).
Davis et al,[21] 2004	Only plaster cast immobilization	t0 (preoperative) t1 (3mo) t2 (12mo)	1) Pain intensity, stiffness, weakness, and restriction of ADL (measured at once in categorical scores, self-designed) 2) ROM 3) Grip and pinch strength	1) Pain intensity, stiffness, weakness, and restriction of ADL improved "markedly" at t1 and further at t2 (no significance described). There was no significant difference between the different types of surgery. 2) ROM improved at t2 compared with t0 (no significance mentioned); there was no significant difference between different types of surgery. 3) Thumb key- and tip-pinch and grip strength in the whole study group at t1 were not different from t0. However, thumb key- and tip- pinch and grip strength in the whole group at t2 were all significantly stronger compared with t0 ($P<.001$ for all 3 types of surgery).
Horlock et al,[23] 2002	Late vs early mobilization: Cast immobilization for 2wk followed by thermoplastic splint 24h/d until 6wk vs cast immobilization for 1wk followed by thermoplastic splint only during physical load until 6wk	t0 (preoperative) t1 (6-8mo)	1) Pain intensity, hand function, opinion about rehabilitation regimen, satisfaction with operation (VAS, 0—100) 2) ROM 3) Grip and pinch strength 4) Complications 5) Joint imaging (SMD and TMD)	1) No significant difference in pain intensity decrease, although ES=−.66 due to preoperative group differences, but VAS score at t1 for late group, 30; early group, 28. The early group experienced more convenience compared with the late group (ES=.66, $P<.05$). 2) Significant decrease in MCP-1 ROM was found in the late mobilization group but not in the early group (ES=.19, within group $P<.02$). 3) No significant difference in grip and pinch strength, although the early group performed slightly better when pooling effect sizes of grip, pulp pinch, and key pinch strength (ES=.05).

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Table 3 (*continued*)

Studies With Total Immobilization Period of 4—6wk	Immobilization Methods	Measures at	Measurements and Instruments	Outcomes
				4) Complications were observed in 15% of the participants in the early group compared with 5% in the late group. 5) No differences between groups in median SMD; 2mm larger decrease in TM within the early group, but not significant.
Kriegs-Au et al,[24] 2004	Plaster cast immobilization + removable splint	t0 (preoperative) t1 (48.2mo; range, 32—64mo)	1) ROM 2) Grip and pinch strength 3) Buck-Gramcko score 4) Self-designed questionnaires: pain, strength, daily function, dexterity, cosmetic appearance, willingness to undergo surgery again, overall satisfaction with result, current and past employment status and activity levels 5) Joint imaging (SMD)	All outcomes: Significant improvements, although no differences for different types of surgery mentioned. Proximal migration of the first metacarpal was 37%—42%.
Kuhns et al,[25] 2003	Plaster cast immobilization + removable splint gradually reduced	t0 (preoperative) t1 (6mo) t2 (24mo)	1) Pain relief (measurement instrument unclear) 2) Limitations in ADL (Jebsen subtests II and III dexterity tests, AIMS2) 3) ROM (descriptive only) 4) Grip and pinch strength. 5) Joint imaging	1) At final follow-up, 92% were pain free. 2) Significant improvements in 3 subscales of the AIMS2. 3) At t1, 92% adducted fully into the plane of the palm and 96% opposed to the fifth metacarpal head. 4) Significant improvements in grip (+47%), key pinch (+33%), and tip pinch (+23%) strength at t2. 5) SMD decreased by 51% at t1 compared with t0; no correlation between proximal migration and functional outcomes.
Nylen et al,[29] 1993	Plaster cast immobilization + removable splint	t0 (preoperative) t1 (36mo; range, 24—54mo)	1) Pain intensity (self-designed) 2) Limitations in ADL (self-designed) 3) ROM: Adduction contracture (self-designed: severe, moderate, slight, none) 4) Grip and pinch strength	1) At t1, 49% were "pain free" and 51% had "some pain." 2) Of the patients with limitations in ADL preoperatively, 73% reported no limitations at t1. 3) Adduction contracture "diminished" in 57% of the patients; decrease was not significant.

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Table 3 (*continued*)

Studies With Total Immobilization Period of 4—6wk	Immobilization Methods	Measures at	Measurements and Instruments	Outcomes
			5) Satisfaction, return to work (self-designed) 6) Joint imaging (SMD)	4) Significant improvements in pinch strength; no significant difference in grip strength. 5) At t1, 88% were satisfied. 6) Average SMD at t1 was 4mm.
Poole et al,[30] 2011	Both groups: Plaster cast immobilization + removable splint	t0 (preoperative) t1 (6mo postoperatively).	1) Pain intensity (Boston Questionnaire) 2) Limitations in ADL (JHFT, AHFT) 3) Grip and pinch strength 4) Quality of life (AIMS2)	1) Improvements in pain intensity in both groups, although no significant within-group differences due to small sample size. No significant differences between groups, although a larger decrease in symptom severity was found in the hand therapy group. 2) Higher improvements in limitations in ADL in the hand therapy group for both the JHFT and the AHFT, although not significant due to sample size. 3) Improvements in grip (+13%) and 3-point pinch strength (+27%) were only found in the hand therapy group, while grip (−8%) and 3-point pinch strength (−6%) decreased in the home program group. 4) Significant improvements in several subscales of the AIMS2 for both groups; no between-group differences.
Prosser et al,[31] 2014	Rigid vs semirigid immobilization: Thermoplastic splint until 6wk with full immobilization of the thumb and wrist vs combined thermoplastic and neoprene splint until 6wk allowing thumb and wrist motion	t0 (preoperative) t1 (6wk) t2 (3mo) t3 (1y)	1) Pain intensity and limitations in ADL (PRWHE, MHQ) 2) Pinch strength 3) Complications	1) No significant differences in pain intensity and limitations in ADL. Insufficient data were provided to calculate ES. 2) No significant differences in pinch strength. Insufficient data were provided to calculate ES. 3) Complications were observed in 14% of the participants in the rigid group compared with 7% in the semirigid group.

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Table 3 (*continued*)

Studies With Total Immobilization Period of 4—6wk	Immobilization Methods	Measures at	Measurements and Instruments	Outcomes
Rocchi et al,[33] 2011	Plaster cast immobilization + removable splint gradually reduced	t0 (preoperative) t1 (3mo) t2 (6mo) t3 (12mo)	1) Pain intensity (VAS mentioned, but results expressed as no pain and restriction, mild pain with use and some restriction, pain at rest and some restriction, and pain at rest and severe restriction) 2) Satisfaction (VAS) 3) Limitations in ADL (DASH) 4) Grip and key pinch strength. 5) Joint imaging (SMD)	1) At t3, no patients had any pain at rest, only 1 occasional mild pain. No significance mentioned. 2) Satisfaction 9.6, time point unknown. 3) DASH at t0, 43.3; t1, 25.5; t2, 19.1; t3, 14.5; no significance mentioned. 4) Grip strength at t0, 16.0kg; t3, 19.2kg; key pinch at t0, 3.7kg; t3, 5.6kg; no significance mentioned. 5) At t3, SMD averaged 6.4mm.
Sirotakova et al,[35] 2007	Plaster cast immobilization + removable splint gradually reduced	t0 (preoperative) t1 (6mo) t2 (12mo)	1) Pain intensity, stiffness, weakness of the hand, functional disability (self-designed) 2) ROM 3) Grip and pinch strength 4) Joint imaging (SMD)	1) "Excellent" results in terms of pain relief were achieved in 91%. 2) Improvements in all ROM measures at t2 (not statistically tested). 3) Grip and pinch strength improved in all measures at t2 (not statistically tested). 4) SMD decreased by 29% at t2.
Vermeulen et al,[38] 2009	Plaster cast immobilization + removable splint	t0 (preoperative) t1 (0mo) t2 (3mo) t3 (6mo) t4 (12mo)	1) Limitations in ADL (DASH, Specific Personal Questionnaire) 2) ROM 3) Grip and pinch strength	1) DASH score: at t0, 51; t2, 36; t3, 30.5; t4, 30 ($P<.001$). 2) Significant improvements in intermetacarpal distance, Kapandji score. 3) Significant improvements in 3-point pinch strength and overall grip strength at final follow-up.
Vermeulen et al,[39] 2014	Plaster cast immobilization + removable splint	t0 (preoperative) t1 (3mo) t2 (12mo)	1) Pain intensity and limitations in ADL (PRWHE, DASH) 2) ROM 3) Grip and pinch strength 4) Complications 5) Joint imaging (SMD)	1) Pain intensity (PRWHE) decreased significantly for both types of surgery at t2 (Weilby: −17 points vs Burton-Pellegrini: −18 points [score range, 0—50]). DASH: significant improvements for both types of surgery (Weilby: −16 points vs Burton-Pellegrini: −20 points [score range, 0—100]).

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Table 3 (*continued*)

Studies With Total Immobilization Period of 4—6wk	Immobilization Methods	Measures at	Measurements and Instruments	Outcomes
				2) No differences between different types of surgery, except in CMC-1 extension (decrease in Burton-Pellegrini group). 3) Increase in grip strength for both types of surgery (Weilby: +3kg vs Burton-Pellegrini: +4kg). Key pinch decreased 0.1kg for both types of surgery, Tip pinch increased 0.4kg for both types of surgery, and 3-point pinch increased for both types of surgery (Weilby: +0.3kg vs Burton-Pellegrini: +0.5kg). Statistical testing for group differences was not reported. 4) In total, complications were observed in 27.8% of the participants (Weilby: 23.1% vs Burton-Pellegrini: 32.5%; difference not significant). 5) SMD at t2 during rest in Weilby group decreased by 33%, in Burton-Pellegrini group by 48%, during pinch in Weilby group, 66%; Burton-Pellegrini group, 57%.
Werthel and Dubert,[40] 2016	Only plaster cast immobilization	t0 (preoperative) t1 (37mo; range, 29—72mo)	1) Pain intensity (VAS) 2) Limitations in ADL (DASH) 3) ROM 4) Grip and pinch strength	1) VAS during rest at t0, 2.3; at t1, 0.3 ($P<.05$). VAS during key pinch at t0, 5.4; at t1, 1.3 ($P<.05$). 2) Quick DASH at t0, 49.4; at t1, 22.1 ($P<.05$). 3) Significant improvements in all ROM measures, except MCP-1 hyperextension. 4) Pinch strength at t0, 3.3; t1, 5.1 ($P<.05$); no change in grip strength.
Wong and Ip,[41] 2009	Only plaster cast immobilization	t0 (preoperative) t1 (2wk) t2 (4wk) t3 (8wk) t4 (12wk) t5 (24wk) t6 (52wk)	1) Pain intensity (self-designed) 2) ROM 3) Grip and pinch strength 4) Joint imaging (SMD)	1) At final follow-up, 82% were "pain free." 2) Kapandji score increased from 4 at t0 to 6 at t7 ($P=.04$).

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Table 3 (*continued*)

Studies With Total Immobilization Period of 4—6wk	Immobilization Methods	Measures at	Measurements and Instruments	Outcomes
		t7 (48mo; range, 12—72mo)		3) When comparing t0 with t7, differences were found in grip strength (+4kg, $P=.03$), tip pinch (+0.7kg, $P=.04$), and key pinch (+1.0kg, $P=.03$). 4) At t7, SMD space ratio decreased by 9%, and SMD in millimeters decreased by 13%.
Studies With Total Immobilization Period of ≤4wk	**Immobilization Methods**	**Measures at**	**Measurements and Instruments**	**Outcomes**
Eaton et al,[22] 1985	Only plaster cast immobilization	t0 (preoperative) t1 (37.5mo; range, 14—60mo)	1) Pinch strength 2) Clinical results graded as excellent, good, fair, or failure	1) Pinch strength at t0, 5.5kg; t1, 6.1kg (no significance reported). 2) All patients had "relief of pain" at t1; 55% reported no pain whatsoever, and 44% described "an occasional twinge or rare mild ache." No patient had postoperative pain, even those whose clinical results were graded as fair. According to the grading system, 41.7% of the cases were graded as excellent, 50% were good, and 8.3% were fair.
Lee et al,[26] 2015	Only plaster cast immobilization	t0 (preoperative) t1 (36mo; range, 19—73.7mo)	1) Pain intensity (VAS) 2) Limitations in ADL (DASH) 3) ROM 4) Grip and pinch strength 5) Patient satisfaction (self-designed) 6) Returning to work (self-designed) 7) Joint imaging	1) VAS at t0, 7.2; t1, 1.7 ($P<.05$). 2) DASH at t0, 41; t1, 18 ($P<.05$). 3) Significant improvements in all ROM measurements at t1. 4) Increase of 1.1kg in power pinch ($P<.05$) at t1; no difference in tip pinch and grip strength at t1. 5) "All patients expressed their satisfaction for improved postoperative appearance of the hand." 6) Of the working participants, 77% returned to their work or activities without any difficulty or occupation modification; in 23% modifications were required. 7) SMD decreased 34.3% ($P<.05$).

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Table 3 (*continued*)

Studies With Total Immobilization Period of ≤4wk	Immobilization Methods	Measures at	Measurements and Instruments	Outcomes
Roberts et al,[32] 2001	Plaster cast immobilization + removable splint	t0 (preoperative) t1 (median, 1y 11mo; range, 3mo to 11y; Q1, 1y; Q3, 3y 4mo)	1) Pain intensity (VAS, 0—10), measured retrospectively 2) Limitations in ADL (self-designed: 15-item daily living checklist), measured retrospectively 3) Grip and pinch strength	1) VAS scores decreased by 8 points ($P=.04$). 2) Limitations in ADL showed 60% improvement ($P=.40$). 3) Significant improvements in grip and pinch strength in group with hemi-resections, except in groups with full-trapezium resections.
Saehle et al,[34] 2002	Only plaster cast immobilization	t0 (preoperative) t1 (41mo; range, 16—60mo)	1) Pain intensity (VAS, 0—100; only at t1) 2) Limitations in ADL (self-designed at t0 and t1 and DASH, only at t1) 3) ROM (only at t1) 4) Grip and pinch strength (compared with other hand, only at t1) 5) Cosmetics (VAS, 0—100; only at t1) 6) Joint imaging (SMD)	1) Median VAS pain intensity at t1: 11. 2) ADL function measured with self-designed questionnaire improved in 51% of the patients at t1 compared with t0. Median DASH scores for the disability/symptom and work scales were both 28. 3) The distal phalanx of the 5th finger could be reached by 52 of the 55 operated hands. 4) Average key pinch and grip strengths of the operated hands were reduced by 11% and 22%, respectively, compared with unaffected side. 5) Median VAS score for the cosmetic result at t1: 5. 6) SMD decreased by 55% at t1 compared with t0; no correlation between proximal migration and clinical results.
Soejima et al,[36] 2006	Only plaster cast immobilization	t0 (preoperative) t1 (33mo; range, 12—71mo)	1) Pain intensity (self-designed) 2) ROM 3) Grip and pinch strength 4) Joint imaging (SMD)	1) At t1, 61% had no pain, 24% had mild pain with strenuous activities, and 14% had mild pain with light work. 2) ROM radial and palmar abduction increased by 14° ($P=.09$) and 8° ($P=.07$), respectively. 3) Grip and pinch strength increased by 2kg ($P=.18$) and by 1.3kg ($P=.23$), respectively. 4) SMD decreased by 15% ($P<.05$)

Abbreviations: AHFT, Arthritis Hand Function Test; AIMS2, Arthritis Impact Measurement Scales 2; DASH, Disabilities of Arm, Shoulder and Hand; ES, effect size (positive scores indicate better performance of experimental treatment compared with control treatment); JHFT, Jebsen Hand Function Test; MHQ, Michigan Hand Outcomes Questionnaire; PRWHE, Patient-Rated Wrist and Hand Evaluation; Q1, 1st quartile; Q3, 3rd quartile; SMD, distance between base of first metacarpal and distal end of scaphoid; TMD, distance between base of first metacarpal and radial border of trapezoid; VAS, visual analog scale.

Table 4 Overview of studies investigating benefits of postoperative exercises/therapy and of studies initiating thumb ROM or strengthening exercises at ≤4 weeks (exercises of other joints [ie, fingers, wrist] not described)

Studies on Benefits of Postoperative Exercises/Therapy	Methods	Measures at	Measurements and Instruments	Outcomes
Poole et al,[30] 2011	Home program group: 4wk: One consult initiating ROM exercises. Hand therapy group: ROM exercises, 1 therapy session every week.	t0 (preoperative) t1 (6mo postoperatively)	1) Pain intensity (Boston Questionnaire) 2) Limitations in ADL (JHFT, AHFT) 3) Grip and pinch strength 4) Quality of life (AIMS2)	1) Improvements in pain intensity in both groups, although no significant within-group differences due to small sample size. No significant differences between groups, although a larger decrease in symptom severity was found in the hand therapy group (ES = .53). 2) Higher improvements in limitations in ADL in the hand therapy group for both the JHFT (ES = .52) and the AHFT (ES = .33), although not significant due to sample size. 3) Improvements in grip (+13%) and 3-point pinch strength (+27%) were only found in the hand therapy group, while grip (−8%) and 3-point pinch strength (−6%) decreased in the home program group (ES grip strength = .77, ES 3-point pinch = .95). 4) Significant improvements in several subscales of the AIMS2 for both groups; no between-group differences.

Studies Initiating CMC-1 ROM at ≤4wk	Description of ROM Exercises Initiated at ≤4wk	Measures at	Measurements and Instruments	Outcomes
Ataker et al,[18] 2012	4wk: AROM exercises for CMC-1 and MCP-1 supervised by a physical therapist; no CMC flexion/adduction, opposition	t0 (preoperative) t1 (12wk) t2 (31.5mo; range, 12—57mo)	1) Pain intensity (VAS) 2) Limitations in ADL (DASH) 3) ROM 4) Grip and pinch strength 5) Joint imaging (SMD)	1) VAS at t0, 8; t1, 3; t2, 3 ($P<.001$). 2) DASH at t0, 56; t1, 29; t2, 24 ($P<.001$). 3) Increase in palmar and radial abduction, Kapandji score ($P<.001$). 4) Grip strength (kg) at t0, 12; t1, 18 ($P<.001$); t2, 13. Lateral pinch at t0, 3; t1, 5; t2, 4 ($P<.001$). 5) Joint imaging at t0, 11mm; t1, 5mm; t2, 3mm.

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Table 4 (*continued*)

Studies Initiating CMC-1 ROM at ≤4wk	Description of ROM Exercises Initiated at ≤4wk	Measures at	Measurements and Instruments	Outcomes
Burton and Pellegrini,[20] 1986	4wk: 1) Active abduction and extension while avoiding flexion and adduction. 2) AROM flexion of the MCP and IP joints with MC1 supported in abduction by the patient's opposite hand.	t0 (preoperative) t1 (2y; range, 1—4.5y).	1) Pain relief (self-designed, only measured at t1) 2) Grip and pinch strength 3) Joint imaging	1) Pain relief: 92% of patients enjoyed excellent pain relief and were satisfied with the thumb. 2) t1 showed an overall improvement in grip and pinch strength of 19% compared with t0 values (no significance mentioned). 3) Average loss of 11% of the initial postoperative arthroplasty space.
Eaton et al,[22] 1985	4wk: Extension and circumduction of the CMC-1 joint is emphasized.	t0 (preoperative) t1 (37.5mo; range, 14—60mo)	1) Pinch strength 2) Clinical results graded as excellent, good, fair, or failure	1) Pinch strength at t0, 5.5kg; t1, 6.1kg (no significance reported). 2) All patients had "relief of pain" at t1; 55% reported no pain whatsoever, and 44% described "an occasional twinge or rare mild ache." No patient had postoperative pain, even those whose clinical results were graded as fair. According to the grading system, 41.7% of the cases were graded as excellent, 50% were good, and 8.3% were fair.
Horlock et al,[23] 2002	Early group, 1wk: Light use of the hand allowed and active exercises for the thumb. Late group, 2wk: Gentle use and mobilization allowed out of the splint.	t0 (preoperative) t1 (6—8mo)	1) Pain intensity, hand function, opinion about rehabilitation regimen, satisfaction with operation (VAS, 0—100) 2) ROM 3) Grip and pinch strength. 4) Complications 5) Joint imaging (SMD and TMD)	1) No significant difference in pain intensity decrease, although ES=−.66 due to preoperative group differences, but VAS score at t1 for late group, 30; early group, 28. The early group experienced more convenience compared with the late group (ES=.66, $P<.05$). 2) Significant decrease in MCP-1 ROM was found in the late mobilization group but not in the early group (ES=.19, within group $P<.02$). 3) No significant difference in grip and pinch strength, although the early group performed slightly better when pooling effect sizes of grip, pulp pinch, and key pinch strength (ES=.05).

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Table 4 (*continued*)

Studies Initiating CMC-1 ROM at ≤4wk	Description of ROM Exercises Initiated at ≤4wk	Measures at	Measurements and Instruments	Outcomes
				4) Complications were observed in 15% of the participants in the early group compared with 5% in the late group. 5) No differences between groups in median SMD; 2mm larger decrease in TM within the early group, but not significant.
Lins et al,[27] 1996	4wk: Gentle ROM exercises	t0 (preoperative) t1 (42–43mo; range, 14–88mo)	1) Pain intensity (self-designed) 2) Functional status/satisfaction (self-designed) 3) ROM (web space) 4) Grip and pinch strength 5) Joint imaging (SMD)	1) At t1, 85% patients considered the frequency of pain "improved a lot or resolved completely" compared with t0, and 89% considered the duration and severity as "improved a lot or completely" at t1, compared with t0. 2) At t1, 89% of the patients were satisfied with the "relief of pain." 3) Web space increased by 1.09cm ($P<.02$). 4) Grip strength increased by 5.9kg ($P<.001$), and pinch strength increased by 1.4kg ($P<.01$). 5) SMD decreased by 30% ($P>.05$).
Mo and Gelberman,[28] 2004	4wk: Exercises with emphasis on extension/abduction, on maintaining MCP-1 joint flexion and avoiding hyperextension	t0 (preoperative) t1 (20mo; range, 12–44mo)	1) Limitations in ADL (DASH) 2) ROM 3) Grip and pinch strength 4) Joint imaging (SMD)	1) DASH outcomes associated with strength; no results over time reported. 2) Distance from thumb tip to base of small finger during maximum flexion decreased by 0.4cm ($P=.02$). 3) Grip strength improved by 26% at t1 compared with t0 ($P=.01$); pinch strength improved by 11% ($P=.11$). 4) SMD improved by 2.5%; no correlation between proximal migration and functional outcomes.
Poole et al,[30] 2011	Home program group, 4wk: One consult initiating ROM exercises. Hand therapy group: ROM 0exercises, 1 therapy session every week.	t0 (preoperative) t1 (6mo postoperatively).	1) Pain intensity (Boston Questionnaire) 2) Limitations in ADL (JHFT, AHFT) 3) Grip and pinch strength 4) Quality of life (AIMS2)	1) Improvements in pain intensity in both groups, although no significant within-group differences due to small sample size. No significant differences between groups, although a larger decrease in symptom severity was

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Table 4 (*continued*)

Studies Initiating CMC-1 ROM at ≤4wk	Description of ROM Exercises Initiated at ≤4wk	Measures at	Measurements and Instruments	Outcomes
				found in the hand therapy group (ES = .53). 2) Higher improvements in limitations in ADL in the hand therapy group for both the JHFT (ES = .52) and the AHFT (ES = .33), although not significant due to sample size. 3) Improvements in grip (+13%) and 3-point pinch strength (+27%) were only found in the hand therapy group, while grip (−8%) and 3-point pinch strength (−6%) decreased in the home program group (ES grip strength = .77, ES 3-point pinch = .95). 4) Significant improvements in several subscales of the AIMS2 for both groups; no between-group differences.
Prosser et al,[31] 2014	Rigid vs semirigid immobilization. Both groups at 4wk: Abduction exercises.	t0 (preoperative) t1 (6wk) t2 (3mo) t3 (1y)	1) Pain intensity and limitations in ADL (PRWHE, MHQ) 2) Pinch strength 3) Complications	1) No significant differences in pain intensity and limitations in ADL. Insufficient data were provided to calculate ES. 2) No significant differences in pinch strength. Insufficient data were provided to calculate ES. 3) Complications were observed in 14% of the participants in the rigid group compared with 7% in the semirigid group.
Roberts et al,[32] 2001	3wk: Thumb ROM exercises	t0 (preoperative) t1 (median, 1y 11mo; range, 3mo to 11y; Q1, 1y; Q3, 3y 4mo)	1) Pain intensity (VAS, 0—10), measured retrospectively 2) Limitations in ADL (self-designed: 15-item daily living checklist), measured retrospectively 3) Grip and pinch strength	1) VAS scores decreased by 8 points ($P = .04$). 2) Limitations in ADL showed 60% improvement ($P = .4$). 3) Significant improvements in grip and pinch strength in group with hemiresections, except in groups with full-trapezium resections.

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Table 4 (*continued*)

Studies Initiating CMC-1 ROM at ≤4wk	Description of ROM Exercises Initiated at ≤4wk	Measures at	Measurements and Instruments	Outcomes
Rocchi et al,[33] 2011	4wk: Exercises to regain full ability; ie, opposition exercises that gradually progressed from aiming at the tip of the fifth finger, then toward reaching its base	t0 (preoperative) t1 (3mo) t2 (6mo) t3 (12mo)	1) Pain intensity (VAS mentioned, but results expressed as no pain and restriction, mild pain with use and some restriction, pain at rest and some restriction, and pain at rest and severe restriction) 2) Satisfaction (VAS) 3) Limitations in ADL (DASH) 4) Grip and key pinch strength 5) Joint imaging (SMD)	1) At t3, no patients had any pain at rest; only 1 occasional mild pain. No significance mentioned. 2) Satisfaction 9.6, time point unknown. 3) DASH at t0, 43.3; t1, 25.5; t2, 19.1; t3, 14.5; no significance mentioned. 4) Grip strength at t0, 16.0kg; t3, 19.2kg; key pinch at t0, 3.7kg; t3, 5.6kg; no significance mentioned. 5) At t3, SMD averaged 6.4mm.
Sirotakova et al,[35] 2007	2wk: Opposition exercises	t0 (preoperative) t1 (6mo) t2 (12mo)	1) Pain intensity, stiffness, weakness of the hand, functional disability (self-designed) 2) ROM 3) Grip and pinch strength 4) Joint imaging (SMD)	1) "Excellent" results in terms of pain relief were achieved in 91%. 2) Improvements in all ROM measures at t2 (not statistically tested). 3) Grip and pinch strength improved in all measures at t2 (not statistically tested). 4) SMD decreased by 29% at t2.
Soejima et al,[36] 2006	2wk: ROM exercises initiated	t0 (preoperative) t1 (33mo; range, 12–71mo)	1) Pain intensity (self-designed) 2) ROM 3) Grip and pinch strength 4) Joint imaging (SMD)	1) At t1, 61% had no pain, 24% had mild pain with strenuous activities, and 14% had mild pain with light work. 2) ROM radial and palmar abduction increased by 14° ($P=.09$) and 8° ($P=.07$), respectively. 3) Grip and the pinch strength increased by 2kg ($P=.18$) and by 1.3kg ($P=.23$), respectively. 4) SMD decreased by 15% ($P<.05$).
Vermeulen et al,[39] 2014	4wk: Standardized hand therapy focused on regaining functionality by increasing mobility	t0 (preoperative) t1 (3mo) t2 (12mo)	1) Pain intensity and limitations in ADL (PRWHE, DASH) 2) ROM 3) Grip and pinch strength 4) Complications 5) Joint imaging (SMD)	1) Pain intensity (PRWHE) decreased significantly for both types of surgery at t2 (Weilby: −17 points vs Burton-Pellegrini: −18 points [score range 0–50]). DASH: significant improvements for both types of surgery (Weilby: −16 points vs

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Table 4 (*continued*)

Studies Initiating CMC-1 ROM at ≤4wk	Description of ROM Exercises Initiated at ≤4wk	Measures at	Measurements and Instruments	Outcomes
				Burton-Pellegrini: −20 points [score range, 0−100]). 2) No differences between different types of surgery, except in CMC-1 extension (decrease in Burton-Pellegrini group). 3) Increase in grip strength for both types of surgery (Weilby: +3kg vs Burton-Pellegrini: +4kg). Key pinch decreased 0.1kg for both types of surgery, tip pinch increased 0.4kg for both types of surgery, and 3-point pinch increased for both types of surgery (Weilby: +0.3kg vs Burton-Pellegrini: +0.5kg). Statistical testing for group differences was not reported. 4) In total, complications were observed in 27.8% of the participants (Weilby: 23.1% vs Burton-Pellegrini: 32.5%; difference not significant). 5) SMD at t2 during rest in Weilby group decreased by 33%, in Burton-Pellegrini group by 48%, during pinch in Weilby group: by 66%, Burton-Pellegrini group: by 57%.
Yao and Lashgari,[43] 2014	10d: Active ROM exercises	t0 (preoperative) t1 (11mo)	1) Limitations in ADL (DASH)	1) DASH at t0, 63; t1, 10 (single case).

Studies Initiating Strengthening Exercises at ≤4wk	Description of Strengthening Exercises Initiated at ≤4wk	Measures at	Measurements and Instruments	Outcomes
Poole et al,[30] 2011	Hand therapy group, 4wk: Strength exercises	t0 (preoperative) t1 (6mo postoperatively).	1) Pain intensity (Boston Questionnaire) 2) Limitations in ADL (JHFT, AHFT) 3) Grip and pinch strength 4) Quality of life (AIMS2)	1) Improvements in pain intensity in both groups, although no significant within-group differences due to small sample size. No significant differences between groups, although a larger decrease in symptom severity was found in the hand therapy group (ES=.53).

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Table 4 (*continued*)

Studies Initiating Strengthening Exercises at ≤4wk	Description of Strengthening Exercises Initiated at ≤4wk	Measures at	Measurements and Instruments	Outcomes
				2) Higher improvements in limitations in ADL in the hand therapy group for both the JHFT (ES=.52) and the AHFT (ES=.33), although not significant due to sample size. 3) Improvements in grip (+13%) and 3-point pinch strength (+27%) were only found in the hand therapy group, while grip (−8%) and 3-point pinch strength (−6%) decreased in the home program group (ES grip strength =.77, ES 3-point pinch=.95). 4) Significant improvements in several subscales of the AIMS2 for both groups; no between-group differences.
Soejima et al,[36] 2006	2wk: strength exercises	t0 (preoperative) t1 (33mo; range, 12—71mo)	1) Pain intensity (self-designed) 2) ROM 3) Grip and pinch strength 4) Joint imaging (SMD)	1) At t1, 61% had no pain, 24% had mild pain with strenuous activities, and 14% had mild pain with light work. 2) ROM radial and palmar abduction increased by 14° (P=.09) and 8° (P=.07), respectively. 3) Grip and pinch strength increased by 2kg (P=.18) and by 1.3kg (P=.23), respectively. 4) SMD decreased by 15% (P<.05).
Vermeulen et al,[39] 2014	4wk: Standardized hand therapy focused on regaining functionality by increasing strength	t0 (preoperative) t1 (3mo) t2 (12mo)	1) Pain intensity and limitations in ADL (PRWHE, DASH) 2) ROM 3) Grip and pinch strength 4) Complications 5) Joint imaging (SMD)	1) Pain intensity (PRWHE) decreased significantly for both types of surgery at t2 (Weilby: −17 points vs Burton-Pellegrini: −18 points [score range, 0—50]). DASH: significant improvements for both types of surgery (Weilby: −16 points vs Burton-Pellegrini: −20 points [score range, 0—100]).

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Table 4 (*continued*)

Studies Initiating Strengthening Exercises at ≤4wk	Description of Strengthening Exercises Initiated at ≤4wk	Measures at	Measurements and Instruments	Outcomes
				2) No differences between different types of surgery, except in CMC-1 extension (decrease in Burton-Pellegrini group). 3) Increase in grip strength for both types of surgery (Weilby: +3kg vs Burton-Pellegrini: +4kg). Key pinch decreased 0.1kg for both types of surgery, tip pinch increased 0.4kg for both types of surgery, and 3-point pinch increased for both types of surgery (Weilby: +0.3kg vs Burton-Pellegrini: +0.5kg). Statistical testing for group differences was not reported. 4) In total, complications were observed in 27.8% of the participants (Weilby: 23.1% vs Burton-Pellegrini: 32.5%; difference not significant). 5) SMD at t2 during rest in Weilby group decreased by 33%, in Burton-Pellegrini group by 48%, during pinch in Weilby group: 66%, Burton-Pellegrini group: 57%
Yao and Lashgari,[43] 2014	18d: Isometric exercises, lateral pinch strength exercises	t0 (preoperative) t1 (11mo)	1) Limitations in ADL (DASH)	1) DASH at t0, 63; t1, 10 (single case).

Abbreviations: AHFT, Arthritis Hand Function Test; AIMS2, Arthritis Impact Measurement Scales 2; AROM, active range of motion; DASH, Disabilities of Arm, Shoulder and Hand; ES, effect size (positive scores indicate better performance of experimental treatment compared with control treatment); IP, interphalangeal joint; JHFT, Jebsen Hand Function Test; MHQ, Michigan Hand Outcomes Questionnaire; PRWHE, Patient-Rated Wrist and Hand Evaluation; Q1, 1st quartile; Q3, 3rd quartile; SMD, distance between base of first metacarpal and distal end of scaphoid; TMD, distance between base of first metacarpal and radial border of trapezoid; VAS, visual analog scale.

Table 5 Summary of phases and content of postoperative rehabilitation after thumb base arthroplasty as reported in the literature

Phase	Weeks Postoperative	Physical Therapy Content
1. Acute	Range: 0—6wk	Composite finger flexion/extension, thumb IP-1 flexion/extension, wrist/elbow/shoulder movements are emphasized, and no CMC-1 or MCP-1 movement is encouraged.
2. Unloaded	Range: 1—12wk	ROM exercises for MCP-1 and CMC-1 are initiated. In general, emphasis is placed on MCP-1 flexion and CMC palmar abduction and extension, while CMC flexion, adduction, and opposition are avoided. The exercises are supplemented with scar management and edema control.
3. Functional	Range: 3wk to 6mo	Progressive ROM of the CMC-1 and MCP-1 is allowed, and strength exercises are initiated.

NOTE. The displayed time frames indicate the range from start to end (minimum to maximum period) of the periods used in the literature.
Abbreviation: IP-1, thumb interphalangeal joint.

Table 4 provides the outcomes for studies initiating ROM or strengthening exercises at ≤4 weeks postoperatively. Thirteen studies[20,22,23,27,28,30-33,35,36,39,43] initiated ROM exercises and 4 studies[30,36,39,43] initiated strengthening exercises at ≤4 weeks. No comparative studies on different regimens of ROM or strengthening exercises were found. We did not find more complications or worse outcomes in studies that initiated ROM or strengthening exercises at ≤4 weeks compared with studies that initiated ROM or strengthening exercises at ≥4 weeks.

Discussion

The aim of this systematic review was to describe the different components of postoperative rehabilitation protocols for patients who underwent CMC-1 arthroplasty, and several components of rehabilitation protocols were specifically investigated. Twenty-seven studies were included with a total of 1015 participants in whom 1118 procedures were performed. This systematic review presents a summary of the postoperative rehabilitation regimens that were used for different surgical interventions (see fig 2). We found positive outcomes of partial instead of complete immobilization until 6 weeks, a total immobilization period of 4 to 6 weeks or ≤4 weeks, and the initiation of ROM or strengthening exercises at ≤4 weeks, but too few comparative studies are available to draw firm conclusions on relative effectiveness. Additionally, we identified 3 phases of postoperative exercises/therapy as used in the included studies: the acute phase, the unloaded phase, and the functional phase (see table 4 and fig 4).

In general in this review, postoperative exercises/therapy emphasizes positioning the CMC-1 in extension and abduction, while flexion and adduction are avoided during rehabilitation.[44,45] Furthermore, MCP-1 hyperextension should be avoided while MCP-1 flexion is encouraged to prevent the development of a Z-deformity.[44] Even though no conclusions regarding effectiveness can be drawn, the presented summary for different surgical interventions and the identification of the aforementioned phases may provide guidance in clinical decision-making for hand therapists and surgeons in the postoperative rehabilitation for patients who undergo CMC-1 arthroplasty. However, there is considerable variation in time frames of the individual phases, possibly since the phases are carried out more quickly over the years in the literature (see fig 4). Hence, further exploration of these phases is needed in future research. Furthermore, these phases should be identified for different surgical procedures specifically.

Wolfe[9] concluded that there was too much variation in the literature to formulate recommendations on postoperative immobilization and exercises. In the present systematic review, we also conclude that there are insufficient comparative studies to draw conclusions regarding the effectiveness of postoperative rehabilitation. However, we do present a more extensive overview of postoperative rehabilitation regimens as reported in the literature compared with the results by Wolfe et al[9] All 19 studies included by Wolfe[9] were identified in the literature search of the present study, but only 4 were included in the present review. For example, Wolfe also included several types of joint prostheses, while we excluded joint prostheses. The inclusion of studies other than those included by Wolfe may have resulted in a different representation of postoperative rehabilitation for patients who underwent CMC-1 arthroplasty.

Two comparative studies[23,31] on postoperative immobilization were included in this review (see table 3). Similar or better outcomes were found when partial instead of complete immobilization was used in the first 6 weeks postoperatively. In the study by Horlock et al[23], where partial instead of complete immobilization was used after simple trapeziectomy, the effect size on pain intensity was −.66, indicating worse outcomes in the early mobilization group. However, the difference was not statistically significant and mostly attributable to a mean difference at baseline between both groups. Furthermore, visual analog scale scores for pain intensity at follow-up were comparable with previously reported outcomes after simple trapeziectomy.[8] Therefore, the effect size of −.66 on pain intensity should be interpreted with caution. For the outcomes of MCP-1 flexion and experienced convenience by the participants, the early mobilization group performed significantly better than the late mobilization group with effect sizes of .19 and .66, respectively, indicating small to large treatment effects.[16] Hence, these studies suggest that partial instead of complete immobilization demonstrates good outcomes, but more randomized controlled trials on postoperative immobilization are needed to confirm this.

The study by Poole et al[30] was the sole study that compared rehabilitation including a home program only with a more extensive rehabilitation program including hand therapy after CMC-1 arthroplasty. No significant between-group differences were found postoperatively, probably because of a small sample size (n=9), although more within-group improvements were found for pain intensity, limitations in ADL, and grip and pinch strength in the group that received hand therapy with effect sizes between .33 and .95, indicating small to large treatment effects.[16]

Fig 4 Overview of the phases on postoperative exercises/therapy per week for individual studies

Year	Author	N	Type Surgery/ Tendon Plasty
1985	Eaton et al[22]	25	FCR
1986	Burton and Pellegrini[20]	25	FCR
1993	Nylen et al[29]	102	FCR
1996	Lins et al[27]	30	FCR
2000	Varitimidis et al[37]	62	FCR
2001	Roberts et al[32]	25	FCR
2002	Saehle et al[34]	55	APL
2002	Horlock et al[23]	40	
	Late group	20	Simple trapeziectomy
	Early group	20	Simple trapeziectomy
2003	Kuhns et al[25]	26	Simple trapeziectomy
2004	Mo and Gelberman[28]	14	FCR
2004	Kriegs-Au et al[24]	52	FCR
2004	Davis et al[21]	62	FCR
		59	PL
		62	Simple trapeziectomy
2006	Soejima et al[36]	21	APL
2007	Sirotakova et al[35]	104	APL
2009	Vermeulen et al[38]	20	FCR
2009	Wong and Ip[41]	22	FCR + PL
2011	Rocchi et al[33]	50	APL
2011	Poole et al[30]	9	
	Home program group	5	PL
	Occupational therapy group	4	PL
2012	Ataker et al[18]	27	FCR
2012	Başar et al[19]	19	FCR
2012	Abbas et al[17]	10	FCR + PL
2014	Prosser et al[31]	53	
	Rigid group	27	FCR
	Semirigid group	26	FCR
	Rigid group	1	Simple trapeziectomy
	Semirigid group	2	Simple trapeziectomy
2014	Yang et al[42]	21	FCR
2014	Vermeulen et al[39]	72	FCR

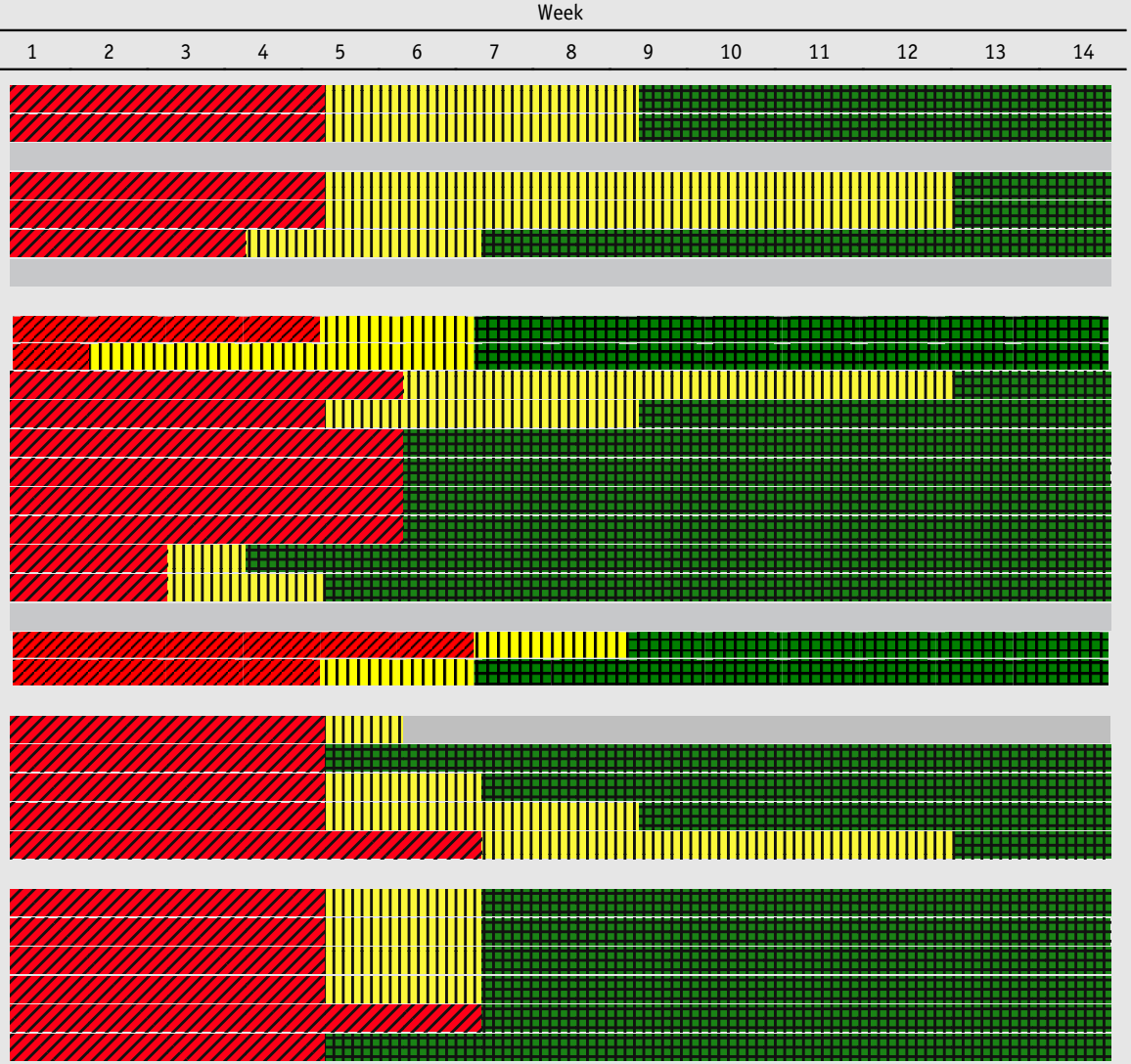

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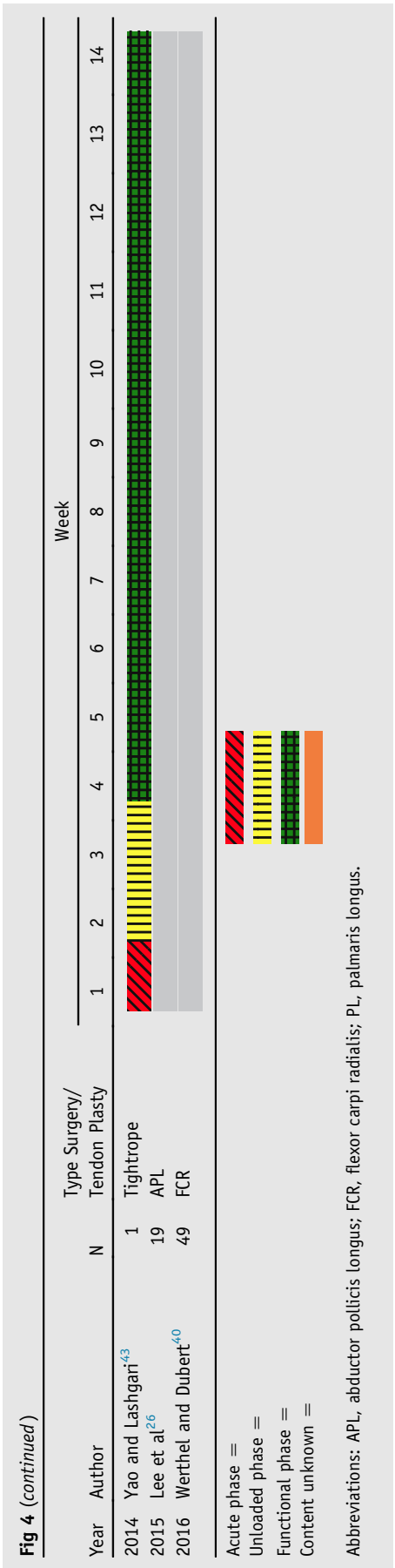
Fig 4 (*continued*)



For example, improvements were found in postoperative grip strength (+13%) and pinch strength (+27%) in the hand therapy group, while a decrease in grip strength (−8%) and pinch strength (−6%) was found in the group that did not receive hand therapy. These findings suggest that additional hand therapy is beneficial in reducing pain intensity and limitations in ADL and improving grip and pinch strength after CMC-1 arthroplasty, but randomized controlled trials with larger sample sizes are needed.

Several studies[23,30,31] investigated the concept of "early active recovery," which includes short immobilization and allows patients to exercise in an early postoperative phase. A trend is identifiable indicating that early active recovery (including short immobilization, early initiation of ROM and strength exercises) provides positive outcomes for pain, limitations in ADL, and grip and pinch strength, but no conclusions about effectiveness can be drawn since comparative studies are lacking. Additionally, figure 4 indicates that according to reports in the literature, a trend has developed over the years to use early active rehabilitation more often. This accelerated type of rehabilitation does not lead to worse outcomes or more complications. Faster recovery may result in a faster return to work, which could be beneficial for patients with CMC-1 OA since aging populations need to participate longer in working life. Hence, future high-quality studies are needed to determine the effectiveness of early active recovery.

Historically, the determination of postoperative scaphometacarpal distance (SMD) by joint imaging has been a particular outcome of interest in many studies on CMC-1 arthroplasty, since the hypothesis is that maintenance of SMD after surgery results in better function and less pain.[8] The sole comparative study on evaluating SMD was by Horlock,[23] in which no difference in SMD was found between the early and late mobilization groups. Additionally, Wajon et al[8] reported that there is no clinically relevant correlation between SMD and pinch strength, and all the studies included in the present review did not find a correlation between SMD and clinical outcomes. Therefore, the influence of different types of postoperative rehabilitation on SMD and the predictive value of SMD on clinical outcomes remain unclear and should be addressed in future research.

Study limitations

A weakness of this systematic review is the large number of low-quality studies included (see supplemental table S2). Even though the findings of the individual studies are in line with each other, no conclusions on the effectiveness of postoperative rehabilitation after CMC-1 arthroplasty can be drawn since comparative studies are lacking and a large heterogeneity in outcome measures and measurement instruments is present. Therefore, we recommend, predominantly in line with Vermeulen[7] and Wajon[8] and colleagues, that future studies report homogenous outcome measures, preferably measured with validated measurement instruments. Additionally, confounding may be present regarding the fulfillment of the different components of rehabilitation. The outcomes of studies without group comparisons are based on an interaction between type of surgery, immobilization type, immobilization period, and postoperative exercises/therapy. Hence, no conclusions can be drawn on the specific effects of one of the aforementioned components of treatment. Therefore, future research should explore different postoperative regimens within the same surgical procedure, which allows researchers to study the effectiveness of specific rehabilitation protocols for individual surgical techniques.

Another limitation is that many studies of CMC-1 arthroplasty provide very little or no information on postoperative rehabilitation.[6,8] This may have resulted in a biased reflection of the actual postoperative regimen for CMC-1 arthroplasty. Therefore, we strongly recommend that future studies on CMC-1 arthroplasty provide an adequate description of the postoperative regimen, including an adequate description of postoperative immobilization and postoperative exercises/therapy.

Conclusions

In conclusion, this review presents an overview of postoperative rehabilitation for different surgical interventions for CMC-1 OA. Furthermore, 3 postoperative phases were identified with regard to postoperative exercises/therapy: the acute phase, the unloaded phase, and the functional phase. In addition, we found that early active recovery (including short immobilization, early initiation of ROM and strength exercises) provided positive outcomes for patients who underwent CMC-1 arthroplasty, and is currently being used more often according to reports in the literature. However, more high-quality studies comparing different postoperative rehabilitation protocols are needed to gain more insight into the effectiveness of postoperative rehabilitation. Additionally, we strongly recommend that future studies on CMC-1 arthroplasty provide adequate descriptions of their postoperative regimen.

Keywords

Arthroplasty; Carpometacarpal joints; Osteoarthritis; Rehabilitation; Thumb

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Supplemental Appendix S1 Final Search Strings (June 15, 2017)

PubMed (MEDLINE) → 227 hits

(((CMC* OR carpometacarp* OR (“basal joint”) OR (“basilar joint”) OR basal OR basilar OR thumb OR (“thumb base”) OR (“Carpometacarpal Joints”) OR trapez* OR trapeziometacarp*) AND (arthroplasty OR "Arthroplasty"[Mesh] OR hemiarthroplasty OR suspen* OR (ligament AND reconstruction) OR (tendon AND interposition) OR stabilization OR prosth* OR arthrodesis OR implant) OR "Trapezium Bone/surgery"[Mesh] OR "Carpometacarpal Joints/surgery"[Mesh] OR Weilby[tiab] OR Burton[tiab] OR “Burton Pellegrini”[tiab] OR LRTI OR (Ligament AND reconstruction AND tendon AND Interposition) OR “Ligament reconstruction tendon Interposition” OR Trapeziectomy OR Sardella OR pyrodisk OR “Pyrocarbon interposition” OR (Eaton AND (littler OR Glickel)))) AND ("Rehabilitation"[Mesh] OR “Physical and Rehabilitation Medicine”[Mesh] OR physioth* OR kinesiotherap* OR "Postoperative Care/rehabilitation"[Mesh] OR "Osteoarthritis/rehabilitation"[Mesh] OR "Physical Therapy Modalities"[Mesh] OR “hand therapy” OR "Occupational therapy"[Mesh] OR "Therapeutics/therapy"[Mesh])

CINAHL → 58 hits

((CMC* OR carpometacarp*l OR (“basal joint”) OR (“basilar joint”) OR basal OR basilar OR thumb OR (“thumb base”) OR (“Carpometacarpal Joints”) OR trapez* OR trapeziometacarp*) AND ((MM "Arthroplasty+")OR hemiarthroplasty OR suspen* OR (ligament AND reconstruction) OR (TI weilby) OR (AB weilby) OR (TI Burton) OR (AB Burton) OR (tendon AND interposition) OR stabilization OR prosth* OR arthrodesis OR implant) OR LRTI OR (Ligament AND reconstruction AND tendon AND Interposition) OR “Ligament reconstruction tendon Interposition” OR Trapeziectomy OR Sardella OR pyrodisk OR “Pyrocarbon interposition” OR (Eaton AND (littler OR Glickel))) AND ((MM "Arthroplasty+/RH") OR (MM "Rehabilitation+") OR (MM "Postoperative Care+/RH") OR (MM "Osteoarthritis+/RH") OR (MM "Physical Therapy+") OR (MM "Hand Therapy") OR (MM "Occupational Therapy+"))

Embase → 1075 hits

((‘carpometacarpal joint’/exp OR carpometacarp* OR CMC* OR ‘basal joint’ OR ‘basilar joint’ OR basal OR basilar OR thumb OR ‘thumb base’ OR trapez* OR (“carpometacarpal joint”) OR trapeziometacarp*) AND (‘arthroplasty’/exp OR hemiarthroplasty OR suspen* OR (ligament AND reconstruction) OR (tendon AND interposition) OR stabilization OR prosth* OR arthrodesis OR implant OR Weilby:ab,ti OR Burton:ab,ti OR “Burton Pellegrini”:ab,ti OR LRTI OR (Ligament AND reconstruction AND tendon AND Interposition) OR ‘Ligament reconstruction tendon Interposition’ OR Trapeziectomy OR Sardella OR pyrodisk OR ‘Pyrocarbon interposition’ OR (Eaton AND (littler OR Glickel)))) AND (‘physiotherapy’/exp OR ‘postoperative care’/exp OR ‘Hand therapy’ OR ‘occupational therapy’/exp OR rehabilita*)

Cochrane → 37 hits

#1: (CMC* or carpometacarp*l or ("basal joint") or ("basilar joint") or basilar or basal or (“carpometacarpal joint”) or thumb or ("thumb base") or trapez* or trapeziometacarp*)

#2: (arthroplasty or suspen* or (ligament and reconstruction) or (tendon and interposition) or stabilization or prosth* or arthrodesis or hemiarthroplasty or implant or Weilby:ti,ab or Burton:ti,ab or "Burton Pellegrini":ti,ab or LRTI or (Ligament and reconstruction and tendon and Interposition) or "Ligament reconstruction tendon Interposition" or Trapeziectomy or Sardella or pyrodisk or "Pyrocarbon interposition" or (Eaton and (littler or Glickel)))

#3: “hand therapy”

#4: MeSH descriptor: [Physical Therapy Modalities] explode all trees

#5: MeSH descriptor: [Rehabilitation] explode all trees

#6: MeSH descriptor: [Postoperative Care] explode all trees

#7: MeSH descriptor: [Occupational Therapy] explode all trees

#8: #1 and #2 and (#3 or #4 or #5 or #6 or #7)

Total: 1397 hits

Supplemental Table S1 Types of surgical cointerventions performed in the included studies

Surgical Cointervention	N	Reference(s)
Carpal tunnel release	76	18,21,25,27,35,37
MCP-1 stabilization	22	18,21,22,25
Temporary Kirschner-wire fixation for MCP-1	22	21, 29
MCP-1 arthrodesis	13	21, 29, 37
Trigger finger release	12	18,21,25,37
Quervain’s release	6	18, 21
Advancement or plication of a somewhat lax APL tendon	6	22
Trigger thumb release	5	21
Unknown procedure	4	29
IP-1 arthrodesis	3	27, 37
Ganglion excision	1	25
Lipoma excision	1	25
Total	171	

Abbreviations: APL, abductor pollicis longus; IP-1, thumb interphalangeal joint; N, number of interventions per hand (multiple interventions were performed in several cases due to bilateral disease).

Supplemental Table S2 Methodological quality (risk of bias), scored using the EPHPP, supplemented with the PEDro scale in randomized studies

Author, Year	A: Selection Bias	B: Study Design	C: Confounders	D: Blinding	E: Data Collection Methods	F: Withdrawal and Dropouts	Global Rating	PEDro
Abbas et al,[17] 2012	Moderate	Moderate	Weak	Moderate	Strong	Weak	Weak	N/A
Ataker et al,[18] 2012	Moderate-strong	Moderate	Weak	Moderate	Strong	Weak	Weak	N/A
Başar et al,[19] 2012	Moderate	Moderate	Weak	Moderate	Moderate	Weak	Weak	N/A
Burton and Pellegrini,[20] 1986	Moderate	Moderate	Weak	Moderate	Weak	Weak	Weak	N/A
Davis et al,[21] 2004	Moderate	Strong	Strong	Moderate	Weak	Strong	Moderate	8/10
Eaton et al,[22] 1985	Weak	Moderate	Weak	Moderate	Weak	Weak	Weak	N/A
Horlock et al,[23] 2002	Weak	Strong	Weak	Moderate	Strong	Weak	Weak	4/10
Kriegs-Au et al,[24] 2004	Moderate	Strong	Strong	Moderate	Moderate	Weak	Moderate	4/10
Kuhns et al,[25] 2003	Moderate	Moderate	Weak	Moderate	Moderate	Weak	Weak	N/A
Lee et al,[26] 2015	Moderate	Moderate	Weak	Moderate	Strong	Weak	Weak	N/A
Lins et al,[27] 1996	Moderate	Moderate	Weak	Moderate	Weak	Moderate	Weak	N/A
Mo and Gelberman,[28] 2004	Moderate	Moderate	Weak	Moderate	Strong	Weak	Weak	N/A
Nylen et al,[29] 1993	Moderate	Moderate	Moderate-weak	Moderate	Weak	Strong	Weak	N/A
Poole et al,[30] 2011	Moderate	Strong	Strong	Moderate	Strong	Strong	Strong	7/10
Prosser et al,[31] 2014	Strong	Strong	Strong	Moderate	Strong	Strong	Strong	8/10
Roberts et al,[32] 2001	Weak	Moderate	Weak	Moderate	Weak	Weak	Weak	N/A
Rocchi et al,[33] 2011	Weak	Moderate	Weak	Moderate	Moderate	Strong	Weak	N/A
Saehle et al,[34] 2002	Moderate	Moderate	Weak	Moderate	Strong	Weak	Weak	N/A
Sirotakova et al,[35] 2007	Moderate	Moderate	Weak	Weak	Weak	Weak	Weak	N/A
Soejima et al,[36] 2006	Moderate	Moderate	Weak	Moderate	Weak	Weak	Weak	N/A
Varitimidis et al,[37] 2000	Moderate	Moderate	Weak	Moderate	Moderate	Weak	Weak	N/A
Vermeulen et al,[38] 2009	Moderate	Strong	Strong	Moderate	Strong	Strong	Strong	9/10
Vermeulen et al,[39] 2014	Moderate	Moderate	Weak	Moderate	Moderate	Weak	Weak	N/A
Werthel and Dubert,[40] 2016	Moderate-strong	Moderate	Weak	Moderate	Moderate	Strong	Moderate	N/A
Wong and Ip,[41] 2009	Moderate	Moderate	Weak	Moderate-weak	Moderate	Moderate	Moderate	N/A
Yang et al,[25,27,29,30,37-39,42] 2014	Moderate	Moderate	Weak	Moderate	Strong	Strong	Moderate	N/A
Yao and Lashgari,[43] 2014	Weak	Weak	Weak	Moderate	Strong	Strong	Weak	N/A

Abbreviations: EPHPP, Effective Public Health Practice Project quality assessment tool; N/A, not applicable; PEDro, Physiotherapy Evidence Database.