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Effect of a stabilization exercise program versus standard treatment for thumb carpometacarpal osteoarthritis: A randomized trial

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ABSTRACT

Study Design: Randomized, interventional trial with 1 year follow-up.
Introduction: Though recommended, evidence is lacking to support specific exercises to stabilize and strengthen the first carpometacarpal (CMC) joint for cases of osteoarthritis (OA).
Purpose of the Study: To determine in a naturalistic setting, whether standard treatment plus a home exercise program (ST+HEP) is more effective than standard treatment (ST) alone in improving Quick Disabilities of Arm, Shoulder and Hand (qDASH) scores, and secondarily, in other patient-centered (pain, function) and clinical outcomes (range of motion, strength).
Methods: A total of 190 patients from a hand therapy practice in northwestern PA were enrolled by informed consent and randomized into ST or ST+HEP groups. Average age was 60 years, most were female (78%) with sedentary occupations most common (36%). ST group received orthotic interventions, modalities, joint protection education and adaptive equipment recommendations, while the ST+HEP group received a home exercise program in addition to ST for 6-12 months. Follow-up occurred at 3, 6, and 12 months. Outcomes included grip strength, pinch strength, range of motion (ROM), qDASH, Patient Specific Functional Scale (PSFS) and pain ratings. At the 6 month mark, all subjects could change groups if desired. Efficacy data analysis included both parametric and non-parametric tests. The threshold for statistical significance was 0.05 and adjusted for multiple comparisons.
Results: Repeated measures ANOVA failed to show a statistically significant difference in strength and ROM assessments between treatment groups over the 12 month follow-up ($P \geq .398$). Differences between groups did not exceed 13%. Both the ST and ST+HEP groups evidenced improvement over time in most patient-focused assessments ($P \leq .011$), including improvements exceeding reported clinically important differences in pain with activity and PSFS scores. Scores for these measures were similar at each follow-up period ($P \geq .080$) in each group. The presence of CTS exerted no effect on outcomes; longer treatment time was weakly related to poorer qDASH and PSFS scores initially. Of those enrolled, 48% of subjects completed the study.
Conclusions: The addition of a high-frequency home exercise program did not improve clinical or patient-centered outcomes more so than standard care in our sample however, study limitations are numerous. Both groups had decreased pain with activity and improved PSFS scores, meeting the established minimally clinically important difference (MCID) of each at 6 and 12 months. Adherence with the home program was poor and/or unknown.

Introduction

The thumb is vitally important for pinch and grasp activities, as well as overall hand function, largely due to the mobility of the first carpometacarpal (CMC) joint. CMC osteoarthritis (OA), also known as basal joint arthritis (BJA) or trapeziometacarpal

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osteoarthritis (TM or TMC) is common, affecting women more so than men at a prevalence rate of 33% (post-menopausal women).[1] Symptoms of CMC OA can include pain, decreased strength,[2] and decreased overall hand function in older adults.[3] Surgery is the most invasive treatment option, and most physicians begin with conservative approaches that may include steroid injections, non-steroidal anti-inflammatory drugs (NSAIDs), orthoses and/or splinting, thermal modalities, joint protection education, and exercises.[4,5] There is evidence that splinting the CMC joint decreases pain and improves function,[6,7] however, in the literature involving the use of exercises to treat CMC OA, there is a lack of consensus regarding best practices.

Biomechanically, there are several ideas regarding the cause of CMC OA, including genetic predisposition and joint incongruity,[8] joint impingement,[9] decreased neuromuscular control of joint alignment[8] and ligamentous laxity.[8,9] Joint laxity, or subluxation, of the base of the first metacarpal is thought to be due to weakening or laxity of the supporting ligaments of the thumb[10,11] which results in abnormal joint loading,[12] and migration of the base of the first metacarpal in a dorsoradial direction.[8] Treatment of this subluxation is thus a potential target for treatment of CMC OA. Studies have demonstrated that the thumb CMC joint, receives some of its stability from dynamic stabilizing structures via muscles including the opponens pollicis, abductors pollicis, and first dorsal interosseous (DIO).[8,12-15] The dynamic stability approach for CMC OA[13] suggests targeting muscles needed for stability to reduce pain and disability associated with CMC OA. While there are several exercise regimens available for CMC OA, we are not aware of the benefits of other over another.[16-19] Strengthening programs targeting these and other CMC joint stabilizer muscles are currently being included in treatment plans by many therapists.[16] There is much more available literature to support quadriceps strengthening to alleviate pain from knee osteoarthritis,[20] yet in the hand therapy literature there remains limited data to support a specific exercise or set of exercises.

The objective of this pilot study was to investigate the efficacy of a stabilization home exercise program issued in a naturalistic setting, representing the variety of individuals with CMC OA. Using a randomized, interventional design from March 2016 to September 2018, we evaluated whether adding a stretching and/or stabilizing and/or strengthening home exercise program to standard therapy (orthotics, modalities and joint protection education) improves patient-focused outcomes. Clinical outcomes were also evaluated. Our hypothesis was that patients with CMC OA treated with exercise plus standard therapy would improve patients' symptoms and function, evidenced primarily by Quick Disabilities of Arm, Shoulder and Hand (qDASH) scores, at 3 months, 6 months and 12 months after intervention.

Methods

Trial Design

This was a randomized, interventional trial. 190 volunteers, ages 34-88 (mean age 60 ± 9.2 years), were randomized into two groups: standard treatment (ST) or standard treatment supplemented by a 6-12 month, high frequency (2-3 times per day), stretching and/or stabilizing and/or strengthening home exercise program targeting thumb musculature (ST+HEP). Treatment allocation was based on 1:1 block randomization using a computerized random numbers table to establish treatment and control groups. Patient study numbers were first assigned to the ST+HEP Treatment Group listing, based on half of the enrollment target (see below) followed by populating the ST (Control) Group listing. Allocation to a treatment group was based on chronological order of enrollment. The study design was based on a mixed effects model (eg, treatment as fixed, patient variables as random). The random numbers listing and associated treatments were available to therapists with treatment assignment recorded in patients' EMR to ensure untoward events would be identified and corrected. Study duration was 12 months.

Participants

Subjects with confirmed CMC OA as diagnosed by orthopedic surgeons and/or physician assistants were recruited from the Hand and Upper Body Rehabilitation Center in Erie, PA. The practice serves a 350+-bed, Level II Trauma Center and Outpatient Surgery Center in the immediate vicinity. Exclusion criteria were prior hand surgery or the inability to speak or understand written and/or verbal instructions. Inclusion criteria was kept broad to foster sufficient enrollment at this practice. Subjects with unilateral or bilateral CMC OA were included, as well as those who had received cortisone injections, oral steroids, or other medications for symptoms of arthritis, and/or previous therapy interventions for CMC OA. Patients with concomitant pathologic diagnoses (such as carpal tunnel, trigger finger, depression etc.) were also included. Along with demographics, patient medication and treatment history were obtained at enrollment and recorded for latter analysis. Most patients were female (78%), had sedentary occupations (36%), had Eaton Radiographic Scores of 2-3, and were symptomatic for 12 months or more (Table 1).

Interventions

ST consisted of heat modalities, joint protection education, adaptive equipment training, as well as an orthosis. The orthosis was selected from a variety of both custom and prefabricated designs and was based on the treating therapist's evaluation and individual patient needs and therefore was not standardized in this study. The ST group continued to practice these standard of care instructions throughout. The ST+HEP received standard care, as well as a stretching and/or stabilizing and/or strengthening program for the thumbs (Appendix 1). In general, this included exercises to widen a contracted webspace, and activate and strengthen stabilizing musculature. However, each patient's exercise tolerance was taken into consideration per typical hand therapy practice and tailored to meet individual needs and/or abilities (ie, instruction on web stretching was given if a tight webspace was present; an exercise was omitted if too painful). Exercises targeted stabilizing muscles of the thumb including opponens pollicis ("C" contraction), first dorsal interossei, abductor pollicis muscles (APL, APB) and flexor pollicis brevis (FPB). The subject was first shown active motion using these muscles, and if tolerated, was progressed to the addition of resistance. The home program design was largely based on previous work by O'Brien et al[13] and Albrect[21] as well as biomechanical principles described by Mobargha et al,[8] Pellegrini,[22] Valdes et al,[9] and Moulton et al[23]. Total in-clinic treatment time was recorded and later assessed for group bias and effects on patient outcomes.

After initial instruction on their home exercise program in the clinic by a Certified Hand Therapist (CHT), the subjects were instructed to continue to perform the exercises at home, 2-3 times per day, every day, and to keep a log indicating adherence. Each set of exercises took approximately 10 minutes to perform. The subject was instructed to perform only those exercises which could be performed pain-free, and were given instructions on how to progress their home program (ie, adding resistance as tolerated) and encouraged to continue for the duration of the study. Currently prescribed medications along with NSAIDS (as needed for pain

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Table 1
Patient demographics, medical history, orthoses

Variable	ST Group (*n*)	ST+HEP Group (*n*)	*P* Value
Age ± SD[1] Sex[2]	60 ± 8.8 yrs (95)	61 ± 9.6 yrs (94)	0.450
• female	• 80% (76)	• 78% (73)	0.694
• male	• 20% (19)	• 22% (21)	
Hand Affected[2]			0.062
• R	• 28% (27)	• 32%(30)	
• L	• 40% (38)	• 25% (23)	
• B/L	• 32% (30)	• 44% (41)	
Laterality			0.100
• Unilateral	• 68% (65)	• 56%(53)	
• Bilateral	• 32% (30)	• 44% (41)	
Eaton Score[3 4]			~0.185[5]
• ≤1	• 4% (3)	• 12%(8)	
• 2	• 42%(35)	• 31%(21)	
• 3	• 40% (33)	• 43%(29)	
• 4	• 15%(12)	• 13%(9)	
Duration Sx [in months][2]			0.269
• ≤3	• 13%(12)	• 15%(14)	
• 3-5.9	• 14%(13)	• 7% (6)	
• 6-12	• 30%(28)	• 25%(23)	
• >12	• 43%(40)	• 53%(48)	
Medications at Enrollment[2]			
• None	• 36%(33)	• 34%(31)	>0.999
• Cortisone inj	• 34%(32)	• 29%(26)	0.432
• NSAID	• 33%(31)	• 37%(33)	0.646
• Acetominophen	• 1% (1)	• 1%(1)	~0.999[5]
• SSRI, GABA	• 8%(7)	• 9%(8)	0.792
• Nutriceutical	• 9%(8)	• 3% (3)	0.213
• Relaxant	• 4%(4)	• 4%(4)	~0.999
• Narcotic	• 10% (9)	• 10%(9)	>0.999
• DMARD	• 1%(1)	• 3%(3)	~0.363[5]
• SSRI	• 12%(11)	• 14%(13)	0.665
• Oral Steroid	• 1%(1)	• 0	––
No. of Medications at Enrollment[3]			0.883
Median [IQR]	• 1(1)	• 1(1)	
Occupation[2]			~0.703***
• Retired	• 34%(32)	• 33%(30)	
• Office/sedentary	• 38%(36)	• 34%(31)	
• Laborer	• 25%(23)	• 26%(24)	
• Unemployed	• 3%(3)	• 7%(6)	
CTS[2]			**0.008**
• Yes	• 21%(20)	• 39%(36)	
• No	• 79%(74)	• 61%(56)	
Trigger Finger[2]			0.793
• Yes	• 16%(15)	• 17%(16)	
• No	• 84%(79)	• 83%(76)	
Tendonitis[2]			~0.708****
• Yes	• 4%(4)	• 5%(5)	
• No	• 96%(90)	• 95%(87)	
Dupuytren's[2]			~0.166****
• Yes	• 1%(1)	• 4%(4)	
• No	• 99%(93)	• 96%(88)	
DeQuervain Synovitis[2]			~0.983****
• Yes	• 2%(2)	• 2%(2)	
• No	• 98%(92)	• 98%(90)	

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Table 1 (*continued*)

Variable	ST Group (*n*)	ST+HEP Group (*n*)	*P* Value
Orthosis[2]			
• CMC neoprene	• 34%(32)	• 40%(38)	0.368
• CMC custom	• 54%(56)	• 46%(48)	0.308
• CMC MP custom	• 5%(5)	• 5%(5)	~0.999
• CMC MP Wrist custom	• 2% (2)	• 0	~0.497
• Hely & Weber	• 14% (13)	• 17% (16)	0.551
• MP CMC prefab	• 1% (1)	• 1%(1)	~0.999
• CMC MP Wrist prefab	• 0	• 2% (2)	~0.246
Total Treatment Time (in clinic)[3]	85, 30(95)	100, 44 (94)	<0.001

[1] T-Test
[2] Chi-Square Test
[3] Mann Whitney U Test
[4] for B/L cases, worst hand
[5] approximate *P* value

control) were allowed. At the 6-month mark, subjects were given the option to switch groups (into or out of ST+HEP Group) for the second half of their participation if desired. After the initial baseline visit, follow-up occurred at 2-3 months, 6 months, and 12 months.

Assessments were made during each patient's scheduled therapy session, which was typically 1-3 sessions. If patients were discharged from care, they were called back for follow-up; failure to follow-through at an appointment were considered 'Lost-to-Follow-up' and no further action was taken. Subjects did not receive any payments for enrollment in the study but did receive a parking benefit. All procedures as well as the overall study objectives were approved by our local IRB.

Outcomes

Outcomes included both standard clinical assessments and responses to patient-focused questionnaires. Clinical assessments including active and passive range of motion (AROM/PROM) measurements of the thumb, grip (Jamar Dynamometer) and pinch strength measurements. Patient-focused outcomes utilized reliable and validated instruments including the Numeric Rating Scale (NRS) for Pain (based on rest and activity),[24] the Quick Disabilities of Arm, Shoulder and Hand (qDASH)[25] and the Patient-Specific Functional Scale (PSFS)[26]. Additional outcomes focused on potential confounders including rates of steroid injections during study participation, exercise adherence (ST+HEP Group) and rates of withdrawals. The primary outcome of interest was improvement, if any, in qDASH scores. If true, we expected clinical assessments to support the findings.

Sample Size

A minimum sample size of 180 (90/group) was based on Quick DASH data published by O'Brien and Giveans[13] and reflects an 80% certainty of detecting a minimum 18% difference in scores between treatment groups with 20% added to the calculation to account for withdrawals. Enrollment to 190 was implemented to further add study power as well as mitigate against study withdrawals.

Blinding

Neither patients nor therapists and/or assessors were blinded to the type of treatment allocated.

Statistical Methods

An efficacy analysis approach was used to analyze the data. More simply, patient data were analyzed based on initial group enrollment, regardless of withdrawals or crossover to alternative treatment. While similar to Intent-to-Treat Analysis, our approach did not account for incomplete data (patient withdrawals and/or lost-to-follow-up) nor was data imputation involved in the analysis. Summary statistics included rates of occurrence, means with standard deviations, medians with accompanying interquartile ranges, and absolute or percentage differences (using Controls for the denominator). Data normality of scale data was assessed by Shapiro-Wilks Tests, the results thereof dictated the most appropriate summary statistics along with method of analysis. For parametric scale data, t-Tests or repeated measures ANOVA were used (eg, ROM, strength data). For ANOVA modeling, any covariate that evidenced a group bias after initial comparison, was entered into a *per patient* ANOVA (dominant hand for patients with bilateral OA). A second ANOVA was run for all affected thumbs (eg, unilateral + both thumbs for bilaterals). This approach obviated redundant use of covariates for the same patients. Non-parametric methods included Chi-square (for rates and/or proportions), Mann-Whitney (for ordinal or non-normal scale data), Friedman Tests (repeated measures of time course data for patient questionnaires), and Spearman Correlations. Per SAGER guidelines,[27] data were also separately analyzed based on sex using the approach noted above. The threshold for statistical significance was set at 0.05 unless data were used in multiple comparisons, necessitating Bonferroni adjustment which amounted to $P = .025$. SPSS (version 12.0, Chicago, IL) was used for this analysis. Finally, as a superficial attempt to uncover bias in patient withdrawals, three variables were compared (age, duration of symptoms and Eaton score) between patients who completed the study vs those who withdrew or were lost-to-follow up. Data were first screened with the Shapiro-Wilk Test followed by the appropriate comparison tests.

Results

Enrollment

One hundred ninety consecutive patients were enrolled (Fig. 1) from March 2016 to September 2017. Of these, 96 were randomized to standard treatment, 94 to the standard treatment plus exercise intervention. Over the course of study, 48 and 59 study subjects, respectively, either formally withdrew or were lost to follow-up and a resultant 48 and 35 subjects, respectively, were available at the study's conclusion.

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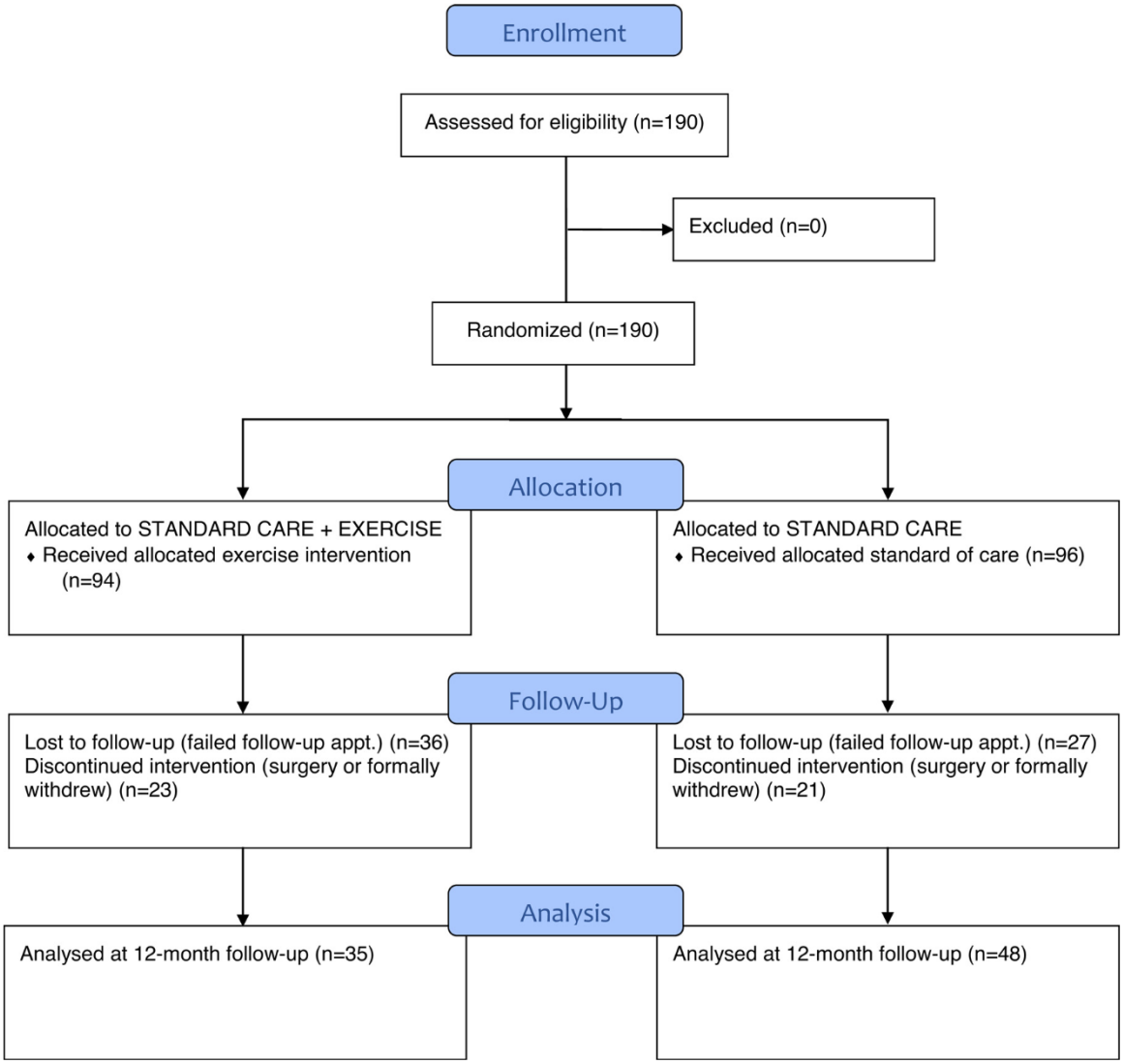

Fig. 1. Enrollment Flow Chart.

Comparison of patient demographics, medical history, disease radiographic stage, and total time in clinical treatment (Table 1) suggests similarity across categories and treatment groups. Prevalence of Carpal Tunnel Syndrome was an exception, the proportion of which was 18% greater in the ST+HEP Group (Chi-Square Test, $P = .008$). This covariate was entered into ANOVA modeling. Absence of medication use aside, cortisone injections and NSAIDs were the most common drugs received prior to study enrollment with rates were similar across groups (28%-30%). 'Other' meds included Serotonin and norepinephrine reuptake inhibitors (SNRIs), Selective serotonin reuptake inhibitors (SSRIs), gamma-Aminobutyric acid (GABA) derivatives, muscle relaxants, Disease-modifying antirheumatic drugs (DMARDs), nutraceuticals, and narcotics. Of this latter category, only 4 patients were taking DMARDs. CMC custom orthoses were most commonly used in this study, representing nearly half the patients in either group, followed by neoprene 'Comfort Cool CMC' and 'Hely & Weber Controller Plus' types. Usage rates were similar across groups. Rates of the other categories of orthoses were so low that exact P values could not be obtained. Total time in clinical treatment was significantly different between groups. For the ST group, the median was 85 minutes (IQR: 30) vs 100 minutes (IQR: 44) for the ST+HEP Group ($P < .001$). Given this disparity, this confounder, along with concurrent carpal tunnel syndrome (CTS), was further analyzed for effects on both clinical assessments as well as patient-focused outcomes (below).

Of the 190 subjects enrolled in the study, 72% (69/96) of the ST group and 49% (46/94) of the ST+HEP group completed the 6-month follow-up. Crossover rates at 6 months were 68% (43/63; 6 cases missing) for the ST group and 24% (9/37; 9 cases missing) for the ST+HEP group ($P < .001$, Chi-Square). At study conclusion, completion rates dropped to 50% (48/96) for the ST group and 37% (35/94) for the ST+HEP group (Table 2). Most patients who did not complete the study were either lost to follow-up (LTF) or formally withdrew (45% ST group, 57% ST+HEP group). Reasons for patient attrition included surgery and unwillingness to travel the distance to the clinic but were largely unknown. However, there was no statistical evidence that study withdrawals were linked to age (mean 59.8 ± 10.46 yrs vs 60.7 ±7.43 yrs. those who completed study, $P = .496$), duration of symptoms(median of 3.0 yrs vs 2.0 yrs., $P = .135$) or Eaton Score at enrollment (2.0 vs 3.0, $P = .054$). Rates of surgery for those who withdrew were identical between groups (5%). The 12% disparity in LTF/withdrawal rates between groups did not reach statistical significance (p approximately = 0.331, Chi-

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Table 2
Follow up

Outcome	ST Group (*n*)	ST+HEP Group (*n*)	*P* Value
Completed Study	50% (48)	37% (35)	0.331*
Withdrew	7% (15)	19% (18)	
Lost-to-Follow-up	28% (27)	38% (36)	
Surgery	5% (5)	5% (5)	
Total Counts	96	94	

* approximate *P* value

Table 3
Range-of-motion outcomes*

Outcome (ST n/ST+HEP n)	ST Group	ST+HEP Group	% Diff
MP ROM			
• Baseline (121/134)	• 56.0 ±15.09 [53.1-58.9]	• 56.5 ± 14.78 [54.0-59.0]	• 0.9
• 2-3 mo. (101/81)	• 58.4 ± 15.10[55.5-61.3]	• 56.5 ± 16.16[53.0-60.0]	• -3.3
• 6 mo. (90/58)	• 57.6 ± 14.93[54.7-60.7]	• 60.9 ± 16.07[56.8-65.0]	• 5.7
• 12 mo. (64/48)	• 55.1 ± 13.79[51.7-58.5]	• 60.1 ± 18.66[54.8-65.4]	• 9.1
IP ROM			
• Baseline (121/133)	• 83.3 ± 19.90[79.8-86.9]	• 82.0 ± 19.42[78.7-85.3]	• -1.6
• 2-3 mo. (101/81)	• 83.4 ± 21.09[79.3-87.5]	• 81.7 ± 21.75[77.0-86.4]	• -2.0
• 6 mo. (90/58)	• 85.5 ± 19.14[81.6-89.5]	• 85.7 ± 23.03[79.8-91.6]	• 0.2
• 12 mo. (64/48)	• 84.2 ± 19.42[79.4-89.0]	• 85.9 ± 25.53[78.7-93.1]	• 2.0
Active Palmar ABD			
• Baseline (121/135)	• 42.2 ± 9.08[40.6-43.8]	• 43.0 ± 10.48[41.2-44.8]	• 1.9
• 2-3 mo. (105/83)	• 42.6 ± 9.04[40.9-44.3]	• 43.7 ± 10.02[41.5-45.9]	• 2.6
• 6 mo. (89/59)	• 41.5 ± 8.86[39.7-43.3]	• 42.7 ± 10.80[39.9-45.5]	• 2.9
• 12 mo. (62/45)	• 40.7 ± 9.77[38.3-43.1]	• 43.7 ± 10.24[40.7-46.7]	• 7.4
Passive Palmar ABD			
• Baseline (121/130)	• 45.8 ± 9.75[44.1-47.5]	• 46.6 ± 9.90[44.9-48.3]	• 1.7
• 2-3 mo. (104/83)	• 46.3 ± 9.26[44.5-48.1]	• 47.6 ± 9.25[45.6-49.6]	• 2.8
• 6 mo. (88/59)	• 44.9 ± 9.64[42.9-46.9]	• 45.8 ± 8.87[43.5-48.1]	• 2.0
• 12 mo. (62/44)	• 44.6 ± 11.18[41.8-47.4]	• 46.6 ± 10.44[43.5-49.7]	• 4.5
Active Radial ABD			
• Baseline (123/135)	• 42.0 ± 9.17 [40.4-43.6]	• 42.5 ± 10.54[40.7-44.3]	• 1.2
• 2-3 mo. (105/83)	• 42.6 ± 9.77[40.7-44.5]	• 43.8 ± 10.32[41.6-46.0]	• 2.8
• 6 mo. (89/58)	• 42.7 ± 9.56[40.7-44.7]	• 43.7 ± 9.23[41.3-46.1]	• 2.3
• 12 mo. (62/45)	• 40.9 ± 10.35[38.3-43.5]	• 42.7 ± 10.15[39.7-45.7]	• 4.4
Passive Radial ABD			
• Baseline (123/130)	• 44.6 ± 9.87[42.9-46.3]	• 45.5 ± 10.40[43.7-47.3]	• 2.0
• 2-3 mo. (104/83)	• 44.9 ±10.28[42.9-46.9]	• 46.9 ± 9.84[44.8-49.0]	• 4.5
• 6 mo. (88/57)	• 44.9 ± 10.24[42.8-47.0]	• 46.9 ± 8.96[44.6-49.2]	• 4.5
• 12 mo. (62/44)	• 43.8 ± 12.03[40.8-46.8]	• 45.3 ± 10.22[42.3-48.3]	• 3.4

* All affected thumbs' mean ± SD [95% CI]. $P > .05$ for all group differences

Square). No observable adverse events were noted at each follow-up time. However, information on adverse events for LTF patients is not available.

Clinical Outcomes

RANGE OF MOTION (ROM)

ROM remained essentially unchanged over the 12 month course of study for both groups (Table 3), whether the analysis was *per patient* (overall Group differences: $P = .304$; Group x Time interaction: $P = .480$) or for all affected thumbs (overall Group differences: $P = .065$; Group x Time Interaction: $P = .573$). For the *per patient* ANOVA, CTS and Total Treatment time were the only covariates entered into the model (see Demographics above). Neither represented a confounder either overall ($P = .742$, $P = .331$, respectively) nor exerted an interaction over time ($P = .768$, $P = .361$, respectively). Overall differences between groups throughout the course of the follow-up was less than 10%.

Segregation of the data by Sex (Appendix Table 1) revealed group differences of <12% for females throughout the course of study (Group *P* value: 0.371; Group x Time interaction *P* value: 0.171). Group differences for males were more pronounced, up to 26%. However, baseline differences of roughly 10% existed and contributed to the magnitude of the difference. Despite this, the overall Group difference p value was not significant ($P = .676$; Group x Time interaction could not be calculated due to small number).

STRENGTH

Strength outcomes did not change significantly throughout the study for either group (Table 4), whether per patient analysis (overall Group difference: $P = .501$; Group x Time interaction: $P = .957$) or for all thumbs (overall Group difference: $P = .719$; Group x Time interaction: $P = .398$). Neither presence of CTS nor Total Treatment Time exerted a significant effect on this outcome either as a global, between subjects factors ($P = .376$, $P = .519$, respectively) or over the course of follow-up ($P = .466$, $P = .726$,

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Table 4
Strength outcomes*

Outcome (ST n/ST+HEP n)	ST Group	ST+HEP Group	% Diff
JAMAR			
• Baseline (122/135)	• 55.3 ± 28.17 [50.3-60.3]	• 52.4 ± 25.70 [48.1-56.7]	• -5.2
• 2-3 mo. (106/83)	• 59.6 ± 25.29 [54.8-64.4]	• 55.6 ± 26.22 [50.0-61.2]	• -6.7
• 6 mo. (91/60)	• 59.6 ± 26.68 [54.1-65.1]	• 61.4 ± 27.05 [54.6-68.2]	• 3.0
• 12 mo. (66/48)	• 61.0 ± 27.22 [54.4-67.6]	• 61.8 ± 26.94 [54.2-69.4]	• 1.3
Key Pinch			
• Baseline(122/135)	• 12.6 ± 5.80 [11.6-13.6]	• 12.0 ± 5.28 [11.1-12.9]	• -4.8
• 2-3 mo. (106/83)	• 12.8 ± 5.32 [11.8-13.8]	• 13.1 ± 4.81 [12.1-14.1]	• 2.3
• 6 mo. (91/60)	• 13.3 ± 5.41 [12.2-14.4]	• 14.0 ± 5.47 [12.6-15.4]	• 5.3
• 12 mo. (66/47)	• 14.2 ± 5.49 [12.9-15.5]	• 14.0 ± 4.96 [12.6-15.4]	• -1.4
3-Point Pinch			
• Baseline(122/133)	• 10.1 ± 5.55 [9.1-11.1]	• 9.5 ± 4.53 [8.7-10.3]	• -5.9
• 2-3 mo. (106/83)	• 10.8 ± 4.65 [9.9-11.7]	• 10.8 ± 5.10 [9.7-11.9]	• 0
• 6 mo. (91/60)	• 11.2 ± 4.54 [10.3-12.1]	• 11.2 ± 4.71 [10.0-12.4]	• 0
• 12 mo.(66/47)	• 12.0 ± 4.90 [10.8-13.2]	• 11.8 ± 4.84 [10.4-13.2]	• -1.7
Tip Pinch			
• Baseline(122/133)	• 8.5 ± 4.35 [7.7-9.3]	• 7.9 ± 3.79 [7.3-8.5]	• -7.1
• 2-3 mo. (106/83)	• 8.7 ± 3.52 [8.0-9.4]	• 8.6 ± 3.77 [8.0-9.4]	• -1.1
• 6 mo. (91/60)	• 9.0 ± 3.66 [8.3-9.8]	• 9.0 ± 3.99 [8.0-10.0]	• 0
• 12 mo. (66/47)	• 9.8 ± 4.18 [8.8-10.8]	• 9.1 ± 3.84 [8.0-10.2]	• -7.1

* Unilateral and bilateral cases (both thumbs); means ± SD[95%CI]; $P > .05$ for all group differences

respectively). Overall, the magnitude of differences between groups did not exceed 7.1% for either JAMAR or pinch strengths.

Data segregated by sex (Appendix Table 2) reveals strength differences of up to -11% for females in the ST+HEP group versus the ST group. This difference was not significant, especially over the course of follow-up (Group difference *P* value: 0.780; Group x Time interaction: 0.554). Males in the ST+HEP Group evidenced improvements of up to 16% in strength, but this was inconsistent and nullified by variability (Group *P* value: 0.383; Group x Time interaction: 0.590).

Patient-focused Outcomes

Patient perception of pain at rest was similar between treatment groups at each follow-up time throughout the course of study (Table 5, $P \geq .136$). The ST group evidenced a 2 point improvement in resting pain from baseline to final follow-up, but this change failed to reach statistical significance ($P = .091$). For the ST+HEP Group, pain scores improved by 1 point for the 12 month interval ($P = .227$). While there was no difference between treatment groups for pain with activity scores; both groups improved by 2 scale points at the 6 month time point and 3 scale points by the close of the study ($P < .001$ for each), meeting the clinically important difference of 2 points as reported by Farrar et al.[28] Similarly, median qDASH scores were no more than 10% different between groups at each assessment ($P \geq .164$). However, both treatment groups evidenced significant improvement over time with score reductions of between 40% and 45% ($P \leq .003$). The ST group improved 7 points at 6 months and 12 points at 12 months ($P < .003$), while the ST+HEP group improved 12 points at 6 months and 15 points at 12 months ($P < .002$). All values fell short of the established minimally clinically important difference (MCID) range for this instrument (15.9 to 19).[29,30] Finally, median PFSF scores were identical between groups at each assessment ($P \geq .230$) while both groups demonstrated score increases of 2 points at 6 months and 3 points over the 12 month follow-up ($P \leq .011$), a value in excess of reported minimal important difference.[31]

Based on contingency table analysis and/or Chi-square Tests, the effect of CTS on patient-focused outcomes was not significant for any of the four metrics throughout the study period ($P \geq .051$, data not shown). For Total Treatment Time, Spearman Correlations revealed sporadic weak-to-moderate coefficients (Table 6, $P \leq .047$). Baseline and first follow-up (2-3 month) were the time periods most affected for both qDASH and PFSF, suggesting that longer total treatment was related to poorer scores initially. However, final follow-up for PFSF showed the strongest relationship to treatment time ($r = -0.325$, $P = .004$).

Segregation of this data by sex (Appendix Table 3) suggests some distinctions. Improvements in pain at rest were small across groups and sex (0.5-2 points, $P \geq .061$). Pain with activity in males in the ST group improved significantly (4 points, $P = .005$); the ST+HEP group showed a small, non-significant improvement. In females, 2-4 point improvements were observed across groups ($P \leq .016$). The small number of males in the study mitigated a large improvement in DASH scores, magnitudes of roughly 60% ($P \geq .118$). Females demonstrated between a 30% and 40% improvement across groups with the ST+HEP Group evidencing significant change ($P < .001$). Finally, PFSF scores showed a 2.5 -3 point improvement across groups and sex with females in the ST group showing a significant improvement ($P = .001$). Overall, these results mirror the global assessment shown in Table 5. Given that the study was not designed to specifically address differences in sex response, the absence of statistically significant p values in the face of large-scale changes is not unexpected.

Additional Outcomes

Steroid Injections During the Study

Overall, steroid injections were statistically similar in frequency between groups. 64% ($n = 45$) of the ST group and 57% ($n = 29$) of the ST+HEP group received one or more steroid injections at some point within their 12 month study participation ($P = .408$). The effect was globally not evident in clinical outcomes (differences of ≤10%, $P \geq .057$; data not shown). Sporadic cases of significant effects on patient-focused outcomes (Table 7) suggest that patients who did not receive an injection had a slightly better outcome. For Pain at Rest, differences of 1-2 points were evident at 3 months and 12 months ($P \leq .039$) while DASH score at 6 months reflected a 9-point difference ($P = .017$).

Exercise Adherence

For patients randomized to the ST+HEP Group, 19% (18/94) completed 50% or more of the exercises and 10% (9/94) completed less than 50%. The remaining 71% (67/94) either failed to document their exercise adherence or were lost to follow-up. The median

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Table 5
Patient-focused outcomes*

Outcome (ST n/ST+HEP n)	ST Group	ST+HEP Group	Median Score Difference	Group *P* value**
Pain at Rest				
• Baseline (95/92)	• 2.0[3](2.2 ±2.10)	• 2.0[(3] (2.1 ±2.03)	• 0	• 0.995
• 2-3 mo (74/57)	• 1.0[3](1.9 ± 2.08)	• 2.0[3] (2.1 ±2.28)	• 1.0	• 0.618
• 6 mo. (67/45)	• 1.0[2](1.5 ±1.85)	• 2.0[3] (1.9 ±1.83)	• 1.0	• 0.136
• 12 mo.(48/36)	• 0[2] (1.2 ±1.82)	• 1.0[2] (1.3 ±1.79)	• 1.0	• 0.561
Median F/U Difference	2.0	1.0	–-	–
P value*** (41/40)	0.091 (41)	0.227 (40)		
Pain, Activity score				
• Baseline (95/94)	• 7.0[4](6.8 ±2.34)	• 7.0[3](6.9 ±2.18)	• 0	• 0.730
• 2-3 mo.(75/57)	• 5.0[3](5.5 ±2.37)	• 7.0[4] (6.2 ±+/-2.56)	• 2.0	• 0.080
• 6 mo. (67/44)	• 5.0[5] (4.8 ±2.50)	• 5.0[4] (5.7 ±2.51)	• 0	• 0.103
• 12 mo.(48/36)	• 4.0[4] (4.5 ±2.81)	• 4.0[5] (4.4 ±2.77)	• 0	• 0.561
Median F/U Difference	**3.0**	**3.0**	–	–
P value***(41/40)	**<0.001**	**0.001 (40)**		
PSFS				
• Baseline (91/92)	• 5.0[3] (5.4 ±+/-2.24)	• 5.0[3] (5.1 ±+/-2.09)	• 0	• 0.311
• 2-3 mo. (75/55)	• 6.0[3] (6.3 ±+/-2.06)	• 6.0[3] (6.2 ±+/-2.27)	• 0	• 0.924
• 6 mo. (66/40)	• 7.0[3] (6.6 ±+/-2.20)	• 7.0[4]) (7.1 ±+/-1.99)	• 0	• 0.288
• 12 mo.(44/32)	• 8.0[2] (7.6 ±/-1.94)	• 8.0[3] (7.3 ±+/-1.55)	• 0	• 0.230
Median F/U Difference	**3.0**	**3.0**	–	–
P value***(41/26)	**<0.001 (41)**	**0.011 (26)**		
qDASH				
• Baseline (94/92)	• 30.0[20](32.4 ±16.57)	• 33.0[22] (36.3 ±19.86)	• 3	• 0.164
• 2-3 mo. (79/60)	• 30.0[21] (27.9 ±13.79)	• 28.0[27] (30.4 ±19.39)	• -2.0	• 0.748
• 6 mo. (69/44)	• 23.0[21] (25.5 ±17.22)	• 21.0[24] (23. ±717.53)	• -2.0	• 0.608
• 12 mo. (47/35)	• 18.0[18] (20.8±7.47)	• 18.0[22] (20.4 ±18.13)	• 0	• 0.840
Median F/U Difference	**12.0**	**15.0**		
P value***(46/31)	**0.003**	**0.002**		

* Median[Interquartile Range](Mean+/-SD)
** *P* value for group comparisons at specified follow-up based on Mann Whitney U Test
*** temporal *P* value for treatment group over the course of follow-up, Friedman Test

Table 6
Relationship* between total treatment time (In-clinic) and patient-focused outcomes

Pain at rest (n)		
• Baseline (187)	• 0.056	• 0.446
• 2-3 mo. F/U (131)	• 0.063	• 0.476
• 6 mo. F/U (112)	• 0.178	• 0.061
• 12 mo. F/U (84)	• 0.148	• 0.179
Pain w/Activity (n)		
• Baseline (189)	• 0.018	• 0.805
• 2-3 mo. F/U (132)	• 0.120	• 0.170
• 6 mo. F/U (111)	• 0.132	• 0.168
• 12 mo. F/U (84)	• 0.217	• 0.047
DASH (n)		
• Baseline (186)	• 0.183	• 0.012
• 2-3 mo. F/U (139)	• 0.176	• 0.038
• 6 mo. F/U(113)	• 0.167	• 0.077
• 12 mo. F/U (82)	• 0.157	• 0.158
PSFS (n)		
• Baseline (183)	• -0.219	• 0.003
• 2-3 mo. F/U (130)	• -0.244	• 0.005
• 6 mo. F/U (106)	• -0.163	• 0.095
• 12 mo. F/U (76)	• -0.325	• 0.004

* Spearman correlation coefficients and *P* values listed

baseline resting pain levels were significantly higher for the more adherent patients (Table 8, 3.0 vs 0.5, $P = .019$); other patient-focused outcomes were unaffected.

Discussion

This study of a stabilization home exercise program did not reveal evidence that exercise improved clinical or patient-centered outcomes greater than standard treatment without exercise in our population, though numerous limitations were present.

The issue of exercise adherence, or lack thereof in the present study, is particularly relevant. While other studies have used a home program design for arthritis and had positive outcomes,[3,32] it is known that many patients do not do this well, with 40-70% of people not performing their home programs.[33,34] Although patients may have demonstrated proficiency in an exercise during the first session, they could have been doing exercises incorrectly at home due to the complexity and/or high degree of freedom involved in the CMC joint. Likewise, in completing the exercise program the patient could have been inadvertently strengthening a muscle that applies a destabilizing force on the CMC joint. Consistent with the current study, Duong et al[35] found that median baseline pain levels were higher for more adherent patients with thumb OA. This may point to the need for therapists to examine ways to increase adherence for individuals with less reported pain at baseline, especially. Promoting self-efficacy through positive encouragement, incorporating learning principals such as goal-setting and problem solving, ensuring sufficient time for skill practice, or adding booster sessions may improve adherence to an upper limb program.[35]

The effect of exercise on thumb OA remains an open area for research. There are several studies that have reported improvements in strength, function, and/or pain levels following exercise,[19,32,36-43] however direct comparisons across studies are dif-

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Table 7
Effect of study-based steroid injections on patient-focused outcomes

Outcome	(+)Steroid Injection	(-)Steroid Injection	Abs Diff	*P* value
Pain at Rest				
• Baseline	• 1.0 (3) [71]	• 2.0 (4) [47]	• -1.0	• 0.187
• 2-3 mo F/U	• 2.0 (4) [57]	• 0 (2) [39]	• 2.0	• 0.029
• 6 mo F/U	• 1.5 (3) [52]	• 1.0 (2) [41]	• 0.5	• 0.080
• 12 mo F/U	• 1.0 (2) [38]	• 0 (1) [42]	• 1.0	• 0.039
Pain w/Activity				
• Baseline	• 7.0 (4) [73]	• 7.0 (4)[47]	• 0	• 0.126
• 3 mo. F/U	• 6.0 (3) [58]	• 5.0 (3) [39]	• 1.0	• 0.004
• 6 mo /FU	• 5.5 (4) [52]	• 4.0 (5) [41]	• 1.5	• 0.062
• 12 mo F/U	• 4.0 (4) [38]	• 4.0 (5) [42]	• 0	• 0.752
DASH				
• Baseline	• 34.0 (18) [72]	• 30.0 (23) [47]	• 4.0	• 0.075
• 2-3 mo F/U	• 30.0 (20) [58]	• 24.0 (27) [46]	• 6.0	• 0.054
• 6 mo F/U	• 27.0 (23) [51]	• 18.0 (20) [44]	• 9.0	• 0.017
• 12 mo F/U	• 20.0 (23) [38]	• 14.0 (20 [40]	• 6.0	• 0.115
PFSF				
• Baseline	• 5.0 (4) [72]	• 5.0 (3) [46]	• 0	• 0.165
• 2-3 mo F/U	• 6.0 (3) [56]	• 7.0 (3) [43]	• -1.0	• 0.542
• 6 mo F/U	• 6.0 (3) [51]	• 7.0 (4) [41]	• -1.0	• 0.501
• 12 mo F/U	• 8.0 (4)[35]	• 8.0 (2)[38]	• 0	• 0.092

Table 8
Effect of exercise adherence on patient-focused outcomes*

Outcome	≤50% Compliance	>50% Compliance	Score Difference	*P* Value
Pain at Rest				
• Baseline	• 0.5(2.0)[10]	• 3.0(3.0)[15]	• 2.5	• 0.019
• 2-3 mo F/U	• 1.5(3)[10]	• 3.5(5.0)[12]	• 2.0	• 0.050
• 6 mo F/U	• 0 (1.0)[9]	• 2.0(1.0)[11]	• 2.0	• 0.010
• 12 mo F/U	• 1.0(1.0)[7]	• 3.0(4.0)[10]	• 2.0	• 0.133
Pain w/activity				
• Baseline	• 7.5(4.0)[10]	• 6.5(4.0)[16]	• -1.0	• 0.979
• 2-3 mo F/U	• 6.0(3.0)[10]	• 7.0(3.0)[12]	• 1.0	• 0.923
• 6 mo F/U	• 5.0(4.0)[9]	• 5.0(3.0)[11]	• 0	• 0.710
• 12 mo F/U	• 7.0(3.0)[7]	• 6.0(5.0)[10]	• -1.0	• 0.962
DASH				
• Baseline	• 21.5(33.0)[10]	• 35.0(19.0)[16]	• 13.5	• 0.109
• 2-3 mo F/U	• 22.5(18.0)[10]	• 36.0(8.0)[13]	• 13.5	• 0.002
• 6 mo F/U	• 18.0(9.0)[9]	• 26.5(26.0)[10]	• 8.5	• 0.156
• 12 mo F/U	• 14.0(23.0)[7]	• 26.0(35.0)[10]	• 12	• 0.055
PSFS				
• Baseline	• 6.5(3.0)[10]	• 5.0(3.0)[15]	• -1.5	• 0.367
• 2-3 mo F/U	• 7.0(2.0)[10]	• 5.0(4.0)[13]	• 2.0	• 0.313
• 6 mo F/U	• 7.0(4.0)[9]	• 7.0(3.0)[11]	• 0	• 0.656
• 12 mo F/U	• 8.0(3.0)[7]	• 7.75(3.0)[10]	• -0.25	• 0.740

* group values represent the median (IQR)[n]

ficult given the varied inclusion criteria, diversity of treatments, varied outcome measures used and specific anatomical site of the hand examined. Several of the aforementioned studies (Stamm[32], Garfunkel[36], Rodgers Wilder[37], Henning[38] and Lefler Armstrong[39]) included subjects with general hand OA as well. Exercise selection in particular looms large. Wouters et al[41] found decreased pain with the addition of exercise, including that of extensor pollicis brevis and resistive tip pinch, among others, for the treatment of CMC OA. These exercises were not part of the current study design. In the context of exercise frequency, the same study[28] utilized a home program performed 2-6 times per day. This suggests that other high-frequency exercise programs can be tested for effectiveness. Based on strong biomechanical principles[9,12,13] and moderate evidence showing its benefits,[17] additional study of hand exercise therapy is warranted.

Limitations of the present study cannot be ignored. A so-called 'Efficacy Analysis' (Lachin, 2000) was used to determine treatment effects. This analysis was not based on complete data nor did it involve imputation (which presumes data that are missing completely at random). We considered this the best approach to account for the inability to strictly observe compliance and/or patients who decided to crossover to the alternative treatment. Assessor blinding was not performed simply due to the limited number of available staff and subjects were not blinded to the intervention received. While 12 month (or longer) studies of exercise for CMC OA are limited (other than that of Tsehaie et al),[42] our follow-up was poor, especially at the 6 and 12 outcome timeframes. While there is little doubt that attrition in this study was *not* a random event, study withdrawals did not appear to be driven by age, duration of symptoms or Eaton Score prior to enrollment. Given our

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clinic's population in the northeast, inclement weather may have influenced withdrawal decisions, as some of our clients live a distance from the clinic. It is notable that in the present study, the ST group had a 13% higher rate of study completion than the ST+HEP group. It may have been the case that the individuals in the ST group, who were not blinded to the intervention, were eager to return to the clinic at 6 months to learn exercises. Alternatively, the higher number of dropouts from the ST-HEP group may have been because the subjects had already demonstrated proficiency with their exercises and may not have felt the need to return to the clinic. Some patients who were classified as "lost to follow-up" or "withdrawn" may have gone on to surgery, so the 5% surgical cases may have been higher. Overall, the large proportion of patients who failed to complete the study severely limits the generalizability of our data. Additionally, subjects may have had other treatments, diagnoses and medications or medication changes which contributed to their improvement or lack thereof while participating in the study. Although this reflects a typical clinical situation, it poses uncontrolled or unaccounted for confounders. In bilateral cases, the side receiving cortisone or a certain splint type varied. However, patient-focused outcomes reflect overall pain and function.

Future Research

Future research should focus on larger, multi-center studies to examine whether there are specific and individualized exercises and/or directions and/or loads and/or doses that are the most beneficial in cases of CMC OA, as well as to account for the 3:1 ratio of female:male disease occurrence. There is a need to stratify by sex to more definitively reveal differing responses to exercise. Questions remain regarding which stage(s) of CMC OA may benefit the most from an exercise program.

Clinical Considerations

- Patients can expect continued improvement over the course of a year in pain and hand function from standard therapy with or without the addition of a CMC stabilization exercise program.
- Because no apparent increased pain was noted with >50% adherence to a high-intensity (2-3x/day) home exercise program, it may be beneficial for clinicians to prescribe individualized stabilization exercises, while devoting more time in sessions to review and progress exercises.

Conclusion

A higher frequency home exercise program for CMC OA did not improve clinical or patient outcomes above standard care, although adherence with exercises was poor and/or unknown. Increasing frequency of exercise did not cause greater pain or reduce function in this patient group. Standard care with and without the addition of exercise provided continued improvement in pain levels and measures of hand function. The role of exercise (including exercise selection and dose) in CMC OA is still being explored across many centers and optimal protocols remain to be determined.

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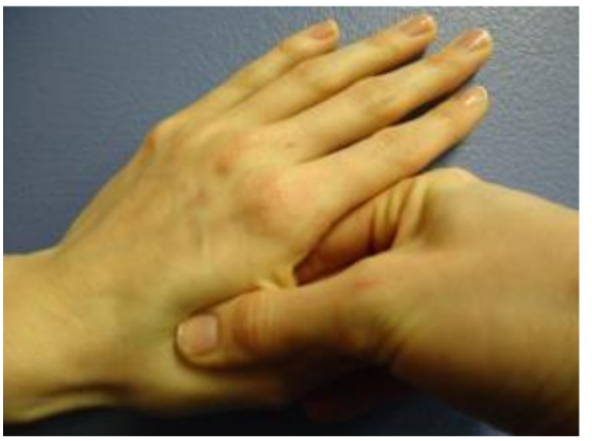
APPENDIX 1

Home Exercise Stabilization Program for Thumb Carpometacarpal Osteoarthritis

The rationale of this program was to restore the webspace as well as to activate and strengthen stabilizing musculature of the CMC joint including the opponens pollicis (OP) and first dorsal interossei (1stDI), and to educate the patient to avoid over-activation of muscles which act as destabilizers to the CMC joint including the flexor pollicis longus (FPL). A handout with photos of each exercise was provided to the patient and included instructions. Exercises were to be performed in a pain-free range and with specific frequency and duration as described below. These exercises were administered by a licensed CHT, individually, in an outpatient clinic. The duration of face-to-face treatment was approximately 30-60 minutes, and each patient had typically 1-3 sessions. During subsequent sessions, the patient was asked to return demonstration of all exercises as a review. The treating therapist used their clinical judgement when administering these exercises (e.g. if an exercise was too painful, it was not issued as part of the HEP). These exercises were continued for 6 months. At the 6 month point, subjects could choose to continue their HEP for an additional 6 months, or to stop the exercises and continue with other conservative treatments (eg, an orthosis).

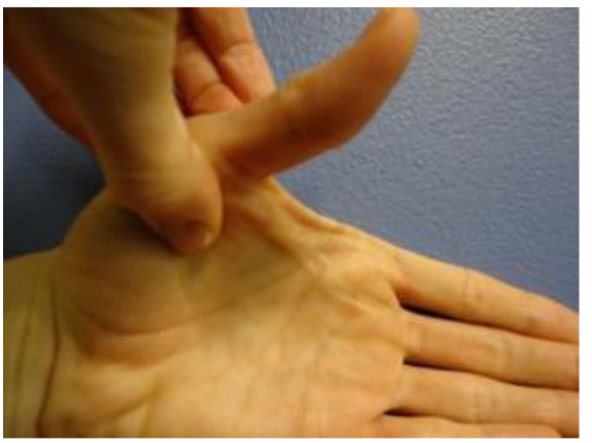
Webspace massage (O'Brien[13], Abrect[21])

3-minute massage to webspace. If bilateral thumbs were involved, the patient interlaced their webspaces to complete.



Webspace stretch (O'Brien[13])

If upon evaluation the webspace was decreased, this stretch was given. Instructions were to gently pull the thumb away from the palm to increase motion and restore joint balance. It was held for 30 seconds and completed 2-4 times per session.



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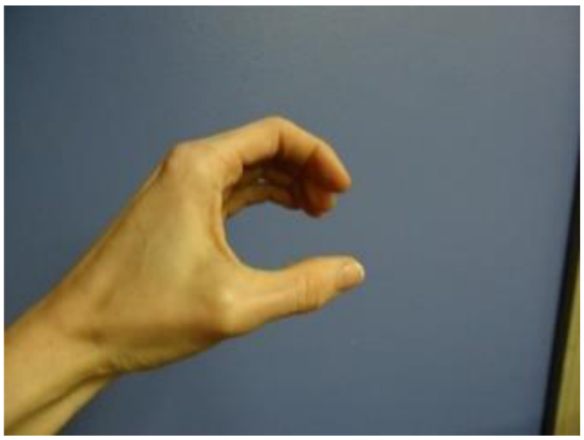
"C" contraction (O'Brien[13], Albrect[21])

This exercise was given as part of neuromuscular re-education to engage the opponens and/or FPB muscles and to avoid over-activation of the FPL. This exercise often took time to instruct and practice, and cues were often required to take some effort away ("pretend like you are holding an egg"). The goal was to achieve 30 degrees of MCP flexion while maintaining a wide webspace ("as if wrapping your hand around a large can"). If MP collapse persisted, a "place and hold" version of this exercise was issued. If the patient was unable to complete this exercise without MCP joint collapse, it was not assigned. Otherwise, it was completed for 10 repetitions.

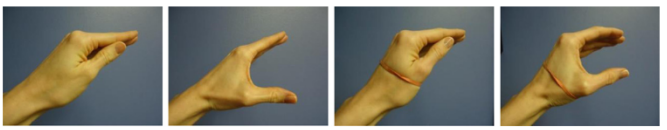


First Dorsal Interosseous (DI) AROM (Mobargha[8], O'Brien[13], Albrect[21])

Active index finger radial deviation was instructed. Cues were given to avoid EIP/EDC activation and to not lift the index finger off the table. If the subject was able to complete 10 repetitions pain-free, they were advanced to performing this exercise with resistance (either manual or via use of a rubber band). The subject was instructed to gradually increase the size and/or strength of the rubber band as able. If this exercise was at all painful, they were instructed to return to active motion only.

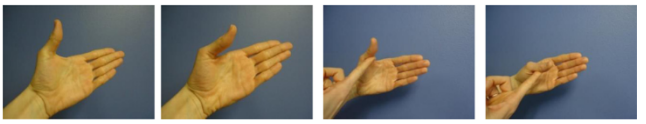
APL/APB (Valdes[9], O'Brien[13], Albrect[21], Pellegrini[22])

Active thumb abduction was first instructed to maintain and/or increase webspace. If the subject was able to complete 10 repetitions pain-free, they were advanced to performing this exercise with resistance (either manual or via use of a rubber band). The subject was instructed to gradually increase the size and/or strength of the rubber band as able. If this resistive exercise was at all painful, they were instructed to return to active motion only.



FBP (Albrect[21], Moulton[23])

Active MP flexion was issued, but only if the subject was able to stabilize the CMC joint and IP joint and isolate only the MP joint. This exercise was very challenging for most people and if it was unable to be completed successfully after instruction, it was not issued. If the subject was able to complete 10 repetitions with good technique, resistance was added manually, or with rubber bands. If this exercise was at all painful, they were instructed to return to active motion only.



Appendix Table 1
Range-of motion by sex.

	Males (Unilateral, B/L)				Females (Unilateral, B/L)			
	ST Group	ST+HEP Group	% Diff	*P* Value*	ST Group	ST+HEP Group	% Diff	*P* Value*
MP ROM								
• Baseline(n)	51.2±13.51(24)	52.9±13.41 (30)	+3.3%	0.655	57.2±16.51 (97)	57.5±15.05 (104)	+0.5%	0.888
• 2-3 mo. F/U(n)	53.2±14.38 (22)	55.8±11.74 (19)	+4.9%	0.533	59.9±15.06 (79)	56.7±17.36 (62)	-5.3%	0.254
• 6 mo. F/U (n)	48.4±13.23 (18)	59.2± 14.98 (17)	+22.3%	**0.030**	59.9±14.52 (72)	61.6±16.63 (41)	+2.7%	0.584
• 12 mo. F/U(n)	52.6 ±15.13 (12)	64.9±19.81 (14)	+4.3%	0.748	55.7±13.55 (52)	62.2±18.03 (34)	+11.7%	0.059
IP ROM								
• Baseline(n)	75.7±26.09 (24)	83.2±27.29 (29)	+9.9%	0.317	85.2±17.72 (97)	81.7±16.74(104)	-4.1%	0.144
• 2-3 mo. F/U(n)	77.5±22.13 (22)	83.7±24.26 (19)	+8.0%	0.391	85.0±20.63 (79)	81.1±21.10 (62)	-4.6%	0.269
• 6 mo. F/U (n)	79.8±22.30 (18)	90.8±29.11 (17)	+13.8%	0.220	86.9 ±18.17 (72)	83.6±20.03 (41)	-3.8%	0.377
• 12 mo. F/U(n)	83.3±17.82 (12)	92.7± 32.66 (14)	+11.3%	0.380	84.4±19.93 (52)	83.1±21.92 (34)	-1.5%	0.781
Act. Palmar ABD								
• Baseline(n)	39.8±9.64 (24)	44.5±10.95 (30)	+11.8%	0.107	42.8±8.90 (97)	42.5±10.35 (105)	-0.8%	0.850
• 2-3 mo. F/U(n)	41.3±8.88 (24)	47.5±9.59 (19)	+15.0%	0.033	43.0±9.10 (81)	42.6±9.94 (64)	-0.9%	0.800
• 6 mo. F/U (n)	36.9±8.62 (18)	46.8± 11.14 (17)	+26.8%	**0.006**	42.7±8.59 (71)	41.1±10.35 (42)	-3.7%	0.368
• 12 mo. F/U(n)	36.7±8.12 (12)	46.5±10.71 (13)	+26.7%	**0.017**	41.6±9.96 (50)	42.5±9.97 (32)	+2.2%	0.691
Pass. Palmar ABD								
• Baseline(n)	43.9±10.08 (24)	48.1±10.38 (29)	+9.6%	0.148	46.2 9.66 (97)	46.2±9.77 (101)	0	0.999
• 2-3 mo. F/U(n)	45.5±9.08 (24)	50.2±9.53 (19)	+10.3%	0.109	46.5±9.36 (80)	46.8±9.09 (64)	+0.6%	0.858
• 6 mo. F/U (n)	40.2±8.43 (18)	48.9 10.27 (17)	+21.6%	**0.010**	46.1±9.62 (70)	44.6±8.04 (42)	-3.3%	0.403
• 12 mo. F/U(n)	40.8±8.56 (12)	49.9±8.50(13)	+22.3%	**0.014**	45.4±11.62 (50)	45.2±10.97 (31)	-0.4%	0.925
Act. Rad. ABD								
• Baseline(n)	41.3±11.44 (24)	44.2±10.61 (30)	+7.0%	0.339	42.2± 8.59 (99)	41.9±10.51 (105)	-0.7%	0.871
• 2-3 mo. F/U(n)	40.7±11.00 (24)	48.7± 8.79 (19)	+19.7%	**0.013**	43.2±9.37 (81)	42.4±10.36(64)	-1.9%	0.647
• 6 mo. F/U (n)	39.3±9.36 (18)	48.1±7.96 (17)	+22.4%	**0.005**	43.6±9.47 (71)	41.8±9.18 (41)	-4.1%	0.340
• 12 mo. F/U(n)	38.8±8.48 (12)	46.2±7.72 (13)	+19.1%	**0.032**	41.4±10.76 (50)	41.3±10.78 (32)	-0.2%	0.965

(*continued on next page*)

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Appendix Table 1 (*continued*)

	Males (Unilateral, B/L)				Females (Unilateral, B/L)			
	ST Group	ST+HEP Group	% Diff	*P* Value*	ST Group	ST+HEP Group	% Diff	*P* Value*
Pass. Rad. ABD								
• Baseline(n)	44.2±12.01 (24)	46.8±10.45 (29)	+5.9%	0.406	44.7±9.35 (99)	45.1±10.41 (101)	+0.9%	0.747
• 2-3 mo. F/U(n)	43.8±11.23 (24)	51.4±9.22 (19)	+17.4%	**0.021**	45.3±10.02 (80)	45.6±9.69 (64)	+0.7%	0.864
• 6 mo. F/U (n)	40.9±9.65 (18)	50.4±8.54 (17)	+25.7%	**0.004**	45.9±10.21 (70)	45.4±8.80 (40)	-1.1%	0.792
• 12 mo. F/U(n)	42.3±9.85 (12)	49.0 ±6.39 (13)	+15.8%	0.052	44.2±12.55 (50)	43.7±11.17 (31)	-1.1%	0.850
P Value, F/U**	Group: 0.676; Group xTime not computed				Group: 0.371; Group x Time: 0.171			

*T-Test
**Repeated Measures ANOVA

Appendix Table 2
Grip & pinch strengths by sex

	Males				Females			
	ST Group	ST+HEP Group	% Diff	*P* Value*	ST Group	ST+HEP Group	% Diff	*P* Value*
Ave. JAMAR								
• Baseline (n)	74.8±38.35 (24)	77.3±26.64 (30)	+3.3%	0.476	50.6±23.81 (98)	45.2±20.54 (105)	-10.7%	0.088
• 2-3 mo. F/U (n)	77.4±30.98 (24)	78.8±26.00 (19)	+1.8%	0.874	54.3±20.83 (82)	48.7±22.15 (64)	-10.3%	0.119
• 6 mo. F/U	78.6±32.85 (18)	84.0±27.42 (17)	+6.9%	0.606	54.9±22.85 (73)	52.5±21.30 (43)	-4.4%	0.572
• 12 mo. F/U	84.8±33.56 (12)	81.3±27.21 (14)	-4.1%	0.769	55.7±22.75 (54)	53.8±22.70 (34)	-3.4%	0.709
Key Pinch								
• Baseline (n)	15.7±7.75 (24)	16.2 ±5.53 (30)	+3.2%	0.773	11.8±4.98 (98)	10.8±4.55 (105)	-8.5%	0.113
• 2-3 mo. F/U (n)	14.6±6.72 (24)	17.0±4.14 (19)	+16.4%	0.187	12.2±4.76 (82)	11.9±4.40 (64)	-2.5%	0.687
• 6 mo. F/U	15.7±6.50 (18)	17.7±5.26 (17)	+12.7%	0.330	12.7±4.99 (73)	12.6±4.91 (43)	-0.8%	0.849
• 12 mo. F/U	19.2±5.11 (12)	17.5±4.56 (13)	-8.9%	0.409	13.1±4.97 (54)	12.7±4.46 (34)	-3.1%	0.697
point Pinch								
• Baseline (n)	13.0±7.53 (24)	13.0±5.09 (30)	0	0.985	9.3±4.73 (98)	8.5±3.82 (103)	-8.6%	0.156
• 2-3 mo. F/U (n)	12.5±6.18 (24)	14.4±5.19 (19)	+15.2%	0.308	10.3±4.01 (82)	9.8±4.61 (64)	-5.9%	0.447
• 6 mo. F/U	12.6±5.69 (18)	13.8±5.20 (17)	+9.5%	0.536	10.9±4.81 (73)	10.2±4.15 (43)	-6.4%	0.433
• 12 mo. F/U	16.4±5.47 (12)	15.6±4.61 (13)	+5.9%	0.695	11.0±4.21 (54)	10.3±4.10 (34)	-6.4%	0.465
Tip Pinch								
• Baseline (n)	10.8±5.46 (24)	11.1±4.24 (30)	+2.8%	0.797	8.0±3.86 (98)	6.9±3.07 (103)	-13.8%	0.042
• 2-3 mo. F/U (n)	10.1±4.79 (24)	11.2±3.36 (19)	+10.9%	0.407	8.2±2.96 (82)	7.8±3.55 (64)	-4.9%	0.408
• 6 mo. F/U	11.1±5.04 (18)	11.0±4.06 (17)	-0.9%	0.943	8.5±3.06 (73)	8.3±3.72 (43)	-2.4%	0.679
• 12 mo. F/U	13.8±4.43 (12)	12.0±3.44 (13)	-13.0%	0.279	9.0±3.62 (54)	8.0±3.41 (34)	-11.1%	0.218
P Value, F/U***	Group: 0.383; Group x Time: 0.590				Group: 0.780; Group x Time: 0.554			

*T-Test
**Repeated Measures ANOVA

Appendix Table 3
Patient-focused questionnaires by sex

	Males				Females			
	ST Group	ST+HEP Group	Score Diff	P Value*	ST Group	ST+HEP Group	Score Diff	P Value*
Pain at Rest								
• Baseline (n)	• 2.0 [2](19)	• 1.0 [3 (21)	• -1.0	• 0.452	• 2 [3] (76)	• 2 [3] (71)	• 0	• 0.716
• 2-3 mo. F/U (n)	• 1.0 [5] (17)	• 0 [3] (12)	• -1.0	• 0.140	• 1 [3] (57)	• 2.0 [4] (45)	• 1.0	• 0.158
• 6 mo. F/U	• 1.0 [3] (14)	• 0.9 [2] (12)	• -0.1	• 0.667	• 1 [2] (53)	• 2 [3] (33)	• 1.0	• **0.038**
• 12 mo. F/U	• 0 [1] (9)	• 0.5 [2 (10)	• 0.5	• 0.497	• 0 [2] (39)	• 1 [2] (26)	• 1.0	• 0.713
P Value, F/U**	0.061	0.919	–	–	0.428	0.268	–	–
Pain w/Activity								
• Baseline (n)	• 7.0 [4] (19)	• 6.0 [4] (21)	• -1.0	• 0.436	• 7 [3] (76)	• 8.0 [3] (73)	• 1.0	• 0.334
• 2-3 mo. F/U (n)	• 6.0 [5] (17)	• 5.5 [4] (12)	• -0.5	• 0.556	• 5 [3] (58)	• 7.0 [3] (45)	• 2.0	• **0.013**
• 6 mo. F/U	• 3.5 [3] (14)	• 4.5 [4] (12)	• 1.0	• 0.297	• 5 [4] (53)	• 5.5 [4] (32)	• 0.5	• 0.140
• 12 mo. F/U	• 3.0 [2] (9)	• 4.5 [6] (10)	• 1.5	• 0.113	• 5 [5] (39)	• 4.0 [4] (26)	• -1.0	• 0.443
P Value, F/U**	**0.005**	0.285	–	–	**0.016**	**<0.001**	–	–
DASH								
• Baseline (n)	• 32.0 [23] (19)	• 25.0 [31] (21)	• -7.0	• 0.282	• 30.0 [18] (75)	• 34.0 [23] (71)	• 4.0	• 0.023
• 2-3 mo. F/U (n)	• 31.0 [25] (18)	• 14.0 [24] (13)	• -17.0	• 0.258	• 27.0 [20] (61)	• 32.0 [23] (47)	• 5.0	• 0.271
• 6 mo. F/U	• 17.0 [17] (14)	• 11.5 [17] (12)	• -5.5	• 0.212	• 23.0 [21] (55)	• 24.0 [26] (32)	• 1.0	• 0.761
• 12 mo. F/U	• 12.5 [10] (8)	• 8.0 [17] (10)	• -4.5	• 0.633	• 18.0 [21] (39)	• 23.0 [28] (25)	• 5.0	• 0.847
P Value, F/U**	0.118	0.511	–	–	0.030	<0.001	–	–
PSFS								
• Baseline (n)	• 5.5 [4] (18)	• 5.0 [4] (21)	• -0.5	• 0.494	• 5.0 [3] (73)	• 5.0 [3] (71)	• 0	• 0.120
• 2-3 mo. F/U (n)	• 5 [4] (17)	• 8.0 [4] (12)	• 3.0	• 0.059	• 6.0 [3] (58)	• 6.0 [4] (43)	• 0	• 0.219
• 6 mo. F/U	• 6.0 [5] (13)	• 8.0 [3] (10)	• 2.0	• 0.232	• 7.0 [3] (53)	• 7.0 [3] (30)	• 0	• 0.705
• 12 mo. F/U	• 8.0 [3] (6)	• 8.0 [3] (10)	• 0	• 0.635	• 8.0 [2] (38)	• 8.0 [3] (22)	• 0	• 0.304
P Value, F/U**	0.035	0.122	–	–	**<0.001**	0.054	–	–

*Mann Whitney U Test; **Friedman Test

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