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Complex motions embedded in a hand exercise regimen – effects on thumb function in participants with carpometacarpal osteoarthritis: A pilot study

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Abstract

Objective: The goal of this pilot study was to identify changes associated with completion of a unique six-week hand exercise program in persons with carpometacarpal osteoarthritis. *Methods:* Twenty-four individuals, aged 55–80, with doctor-diagnosed carpometacarpal osteoarthritis participated in the study. Movement data from standard clinical motions and complex multi-planar motions were obtained using a motion capture system at three-time points: an initial visit, after two weeks of hand exercises, and after completion of the six-week exercise program. *Results:* This exercise program produced trends of improvement in complex multi-planar motions. Specifically, joint angle changes were seen during opposition and the formation of an "okay sign" that was included as part of the exercise program. *Conclusion:* Through the use of motion capture, changes were identified in thumb joint function after exercise. Specifically, motions associated with the more complex multi-planar tasks showed changes in individual joint contributions following the six-week exercise intervention. The results suggest that further exploration of this exercise program, particularly the inclusion of complex multi-planar tasks during osteoarthritis treatment and associated evaluations, should be considered in future clinical studies.

Introduction

Osteoarthritis (OA) is documented as the most common degenerative joint disease and 50% of individuals over the age of 65 have OA in the thumb carpometacarpal (CMC) joint [1]. The CMC joint plays a critical role in hand and arm function and is essential for daily tasks such as holding a pen and turning a key in a lock [2–4]. In severe cases, joint pain and loss of range of motion can become debilitating; affected individuals require assistive devices and may lose their ability to live independently [2,5].

Initial treatment for OA typically includes pain management, joint protection, and exercise or therapy. Although exercise is commonly part of CMC OA treatment, there is a lack of high-quality evidence-based research supporting its benefits [6]. More specifically, the effects of hand exercise on CMC motion and OA symptomology are unclear. Although studies have investigated the effect of hand exercises on qualitative improvements like perceived function and pain, only a few have quantified the ability of hand exercises to change ranges of motion in individuals with CMC OA [7–12]. Of the published literature, data have shown that exercise programs have the greatest pain reduction and improvement in general function when they incorporate multi-modal exercises [13–15].

The gold standard for measuring motion clinically is goniometry. However, goniometry can only be used to measure motion in a single plane. The CMC joint has a complex structure, and in regular daily tasks, it moves in multiple planes simultaneously [16,17]. Goniometry has been shown to have poor inter-rater reliability when measuring motion in the CMC joint [18–22]. Joint deformity, like OA development, may also alter the reliability and variability of goniometry measurements [18,23]. In order to improve CMC OA treatments, the evidence basis for exercise therapy using quantifiable measures to evaluate outcomes like range of motion must be researched. Motion capture is one such method that can be used to measure both standard, clinically measured CMC ranges of motion and more complex multi-planar motions that occur during task completion with greater accuracy than a goniometer [23–27].

Capturing standard clinical and complex multi-planar motion datasets have the potential to reveal new motion trends and provide better understanding of joint function [4,23,28,29]. Motion capture data allow for more advanced assessments, including the calculation of multiple joint angles simultaneously and the evaluation of shape changes in motion patterns. By utilizing a multi-modal exercise regimen that has movements closely related to everyday tasks, we can identify the specific motion benefits of this exercise therapy, thereby increasing the evidence basis for exercise therapy in the treatment of CMC OA. Therefore, the goal of this pilot study was to identify changes in carpometacarpal motions associated with the completion of a six-week hand exercise prescription in persons with carpometacarpal osteoarthritis.

Materials and Methods

Participant Testing

All testing was completed in accordance with the University's Institutional Review Board regulations and all individuals consented to participation. Participants with doctor-diagnosed CMC OA and symptoms in the right thumb CMC joint were recruited for this study. All participants were aged 55–80, right-handed, and their dominant hand was tested. Potential participants with recent history of hand therapy or hand surgery, and those with a history of injury, illness, or disease other than osteoarthritis which affected hand function, were excluded from the study. Participants were tested at three-time points: *week zero* (pre-exercise), *week two* (following two weeks of stretching exercises), and *week six* (following four weeks of stretching and strengthening exercises). At each time point, motion data (using a motion capture system), Visual Analogue Scale (VAS) for pain, and Functional Index of Hand OsteoArthritis (FIHOA) scores were collected from each participant at the same time of day. The VAS used for this study was a 100 mm horizontal line where the participant marked their level of pain on the line and then the distance to the mark was measured in millimeters and reported [30,31]. The order of the motion capture movement testing was randomized.

Exercise Program

The exercise program utilized stretching and strengthening exercises that were selected to target muscle contracture and joint instability (Figs. 1 and 2). This new program drew from existing literature that supports incorporation of passive range of motion, active range of motion, and strength training exercises together to develop a multi-modal exercise regimen [13–15]. The exercise protocol was developed in conjunction with a hand therapist who has over 43 years of clinical experience and has published literature on hand exercises [32].

In CMC OA development, the first dorsal webspace contracts and the metacarpal is pulled toward the thumb and out of its normal alignment [3]. The tension and support of the soft tissue surrounding the CMC joint becomes imbalanced and the joint loses stability [3]. Thus, an exercise program was designed to (1) stretch and relax the contracted muscles that contribute to thumb malalignment and (2) strengthen and stabilize the supporting soft tissue structures to maintain and improve thumb function. More specifically, the exercise program was designed to relax the contracted adductor pollicis muscle and to strengthen the muscles surrounding the first metacarpal (abductor pollicis longus, abductor pollicis brevis, opponens pollicis, and first dorsal interosseous muscles) that are important for CMC joint function [33–35].

The program not only included complex multi-planar motions, e.g. opposition and retropposition, which engaged the CMC joint and wrist stabilizing muscles which are necessary to effectively use the thumb in a controlled manner, but also exercises closely related to functional tasks, e.g., re-training participants to employ thumb and grasp techniques with a more stable thumb position [36,37]. The "okay sign" exercise was incorporated to re-train the participant to open the first web space and slightly flex the first metacarpophalangeal (MCP) joint to form a reverse "C" shape with their thumb and index finger. This posture moves the CMC joint into a more stable position, similar to the position maintained with protective splinting. From the exercises employed, we hypothesized that the participants would experience increased range of motion, increased strength, improved function, and reduced pain.

Following initial testing, participants completed each of the initial exercises with the instructor. Resources for home exercise completion include exercise handouts with written explanations and illustrations, a DVD of the exercises, and an exercise calendar. Participants were contacted to answer any questions that arose during this period. Following re-testing at two weeks, participants completed the strengthening series of exercises and provided additional resources for home exercise completion (updated handouts, DVD, and exercise calendar). Again, participants were contacted to answer any questions or concerns that arose.

Motion Testing

Motion capture

A seven-camera Qualisys motion capture system (Gothenburg, Sweden) along with reflective markers were used to capture motion data of the thumb and index finger as shown in Fig. 3a and described in the caption [23]. All motions were repeated in triplicate unless otherwise noted. Data collected during replicates of the same motion were averaged. Motion capture was used to compute the standard clinical ranges of motion (radial adduction-abduction and palmar adduction-abduction). Complex motions not typically measured in a clinical setting were also obtained. These complex motions were multi-planar in nature and included: opposition, circumduction area, and an "okay sign." Motion capture data were analyzed with a custom-written code using Matlab (version 2019a, Mathworks, Natick, MA).

Standard clinical ranges of motion

To measure standard clinical ranges of motion, angles were obtained using the inverse cosine of the dot product between two 3D vectors, labeled 1 and 2 (Table 1 and Equation 1) (23). Angles were measured at the start and end of each motion, Fig. 4. For radial adduction-abduction and palmar adduction-abduction, the first metacarpal marker was located on the dorsolateral surface of the first metacarpal rather than the dorsal surface (which is used to measure ranges of motion using a goniometer.

$$\Theta = \cos^{-1}\left(\frac{\mathbf{V_1 V_2}}{|\mathbf{V_1}||\mathbf{V_2}|}\right) \tag{1}$$

Multi-planar ranges of motion

To measure opposition, the ability to reach the base of the fifth finger with the tip of the thumb was measured (Fig. 3b). The minimum distance between the distal-most marker on the tip of the thumb pod (distal phalange pod) and the marker on the dorsal side of the fifth metacarpophalangeal joint was used to calculate the opposition distance. Smaller distances indicated the thumb was

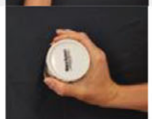
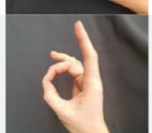
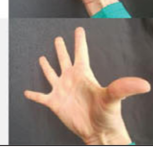
Exercise		Description
1. 1st Web Space Release		With the pinkie side of hand resting on table, the opposite thumb was gently pressed into the web space and the opposite index and middle fingers were wrapped around the palm side of web space.
2. Cone Stretch		The hand was wrapped around a plastic cone to gently relax the muscles in the first web space. A slight flex (bend) was maintained in the distal joints.
3. Passive Palmar Abduction		With the hand resting on a tabletop, the opposite thumb, index, and middle fingers were used to gently stretch the thumb across the body.
4. Passive Radial Abduction		With the hand resting on a tabletop, the opposite thumb, index, and middle fingers were used to gently lift the thumb up and away from the rest of the hand.
5. Bilateral Web Space Stretch		With the first web spaces intertwined between the thumbs and index fingers, the elbows were allowed to gently to fall to participant's sides, stretching the first web spaces.
6. Active Palmar Abduction		With the hand resting on a tabletop, the thumb was gently stretched across the body.
7. Active Radial Abduction		With the hand resting on a tabletop, the thumb was lifted towards the body, so the tip of the thumb pointed towards the ceiling.
8. "Okay Sign"		An "okay sign" was formed by touching the tip of the thumb to the tip of the index finger. Participants focused on making an "O-shape" with each contact while maintaining a slight bend in the thumb joints.
9. Opposition to Base of 5th Finger		The thumb was extended out away from the index finger and the thumb was then swept across palm to reach the base of the 5th finger.
10. Opposition to Fingertips		The tip of the thumb was brought together with the tip of each of the fingers. Participants focused on making an "O-shape" with each contact while maintaining a slight bend in the thumb joints.
11. Finger Spread		Starting with the fingertips together, the fingers were then spread apart as far as possible.

Figure 1. Stretching exercise regimen. Participants were instructed to complete the exercises one to three times daily. Passive range of motion exercises (# 1–5) were held for 30–90 s each and active range of motion exercises (# 6–11) included three sets of 8–12 repetitions for each exercise with each repetition held for 1–3 s.

closer to the fifth MCP joint (better opposition ability). Equation 1 was used to calculate thumb joint angles (vectors shown in Table 1) [23]. The motion capture frame of interest in which the maximum opposition, or minimum distance between the two markers, was identified and the corresponding CMC, MCP, and interphalangeal (IP) joint angles were calculated.

To measure circumduction area, Principal Component Analysis (PCA) was used to determine the area enclosed by the distal-most marker on the first metacarpal [38]. PCA minimized the total distances between the positions of the distal-most first metacarpal marker and a plane in three dimensions. The total area encompassed by the projections of the marker position onto that plane for each thumb revolution was computed and normalized to the respective individual's first metacarpal length [23]. Circumduction was completed five times to calculate the area enclosed.

For the "okay sign" motion, participants were asked to form an "okay sign" with their fingers (thumb and index) gently pressed together (Fig. 3c). To measure adjacent joint angles, the center of each marker pod was calculated. The angle was found between the marker of interest and the two adjacent markers. The area enclosed by all the markers was also calculated. The circularity of the space enclosed by the markers was determined by the center of each marker where circularity is equal to Equation 2; a perfect circle has

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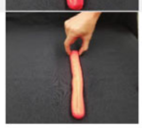
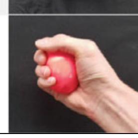
Exercise		Description
1. **Radial abduction with therapy band resistance**		With the hand resting flat on a tabletop, the thumb was stretched away from the index finger, held for one second, then returned to the starting position.
2. **Palmar abduction with therapy band resistance**		With the pinkie side of the hand resting on the table, the thumb was stretched away from the palm, held for one second, then returned to the starting position.
3. **Roll Putty**		Putty was rolled back and forth from the wrist to the fingertips until a putty "tube" with an inch diameter was formed.
4. **Lateral Pinch**		The putty "tube" was pinched along its entire length using the side of the index finger and thumb.
5. **Pinch Grip**		The putty "tube" was pinched along the length bringing the tips of the thumb, index, and middle fingers together, while a "C-shape" at the base of the thumb and a slight bend in the thumb joints was maintained.
6. **"Okay Sign"**		Using the tips of the thumb and index finger, the length of the putty "tube," was pinched by forming an "okay sign" with each pinch. Participants focused on maintaining a "C-shape" at the base of the thumb and a slight bend in the thumb joints during this exercise.
7. **Resisted Finger Spread**		The ends of the putty "tube" were connected to form a "putty doughnut". Then the ends of the fingers were placed into the center of the "doughnut" and spread apart.
8. **Putty Egg**		The putty was formed into an "egg" which was then gently squeezed 5-6 times, without squeezing the putty between the thumb and fingers.

Figure 2. Strengthening exercise regimen. Participants were instructed to complete each exercise resistance band exercise (# 1 and 2) for 3 sets of 5–15 repetitions at least once per day. Exercises were started with 3 sets of 5 repetitions and increased to 10 repetitions, then 15 repetitions, as tolerated. The strengthening exercise regimen was completed 1–3 times daily, beginning two weeks after the stretching exercises were started. Stretching exercises were completed prior to strengthening exercises daily. Putty exercises (# 3–8) were completed three times each. The strengthening regimen was started two weeks after stretching exercises were started.

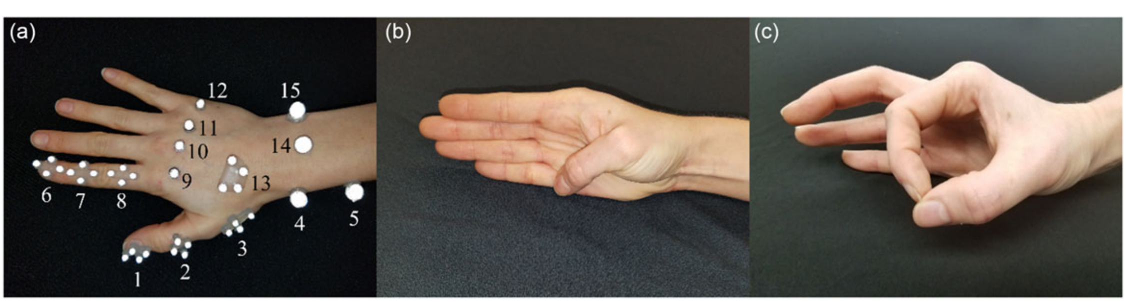


Figure 3. Motion capture marker placement and multi-planar motion tasks. ***a***) rigid four marker pods were placed on each thumb and index segment and single markers were placed on bony landmarks. Markers were denoted by location as follows: 1- thumb distal phalange, 2- thumb proximal phalange, 3-first metacarpal, 4-ulnar side of radial styloid, 5-proximal radius, 6-index distal phalange, 7-index middle phalange, 8-index proximal phalange, 9- the 2nd metacarpophalangeal joint, 10- the 3rd metacarpophalangeal joint, 11- the 4th metacarpophalangeal joint, 12- the 5th metacarpophalangeal joint, 13-palm, 14-mid-wrist (ulnar side of lister's tubercle), and 15-ulnar styloid. For calculations, individual markers on the thumb pods are referred to by their relative location: distal, proximal, radial, and ulnar. Multi-planar motion tasks tested included: ***b***) opposition, and ***c***) "okay sign."

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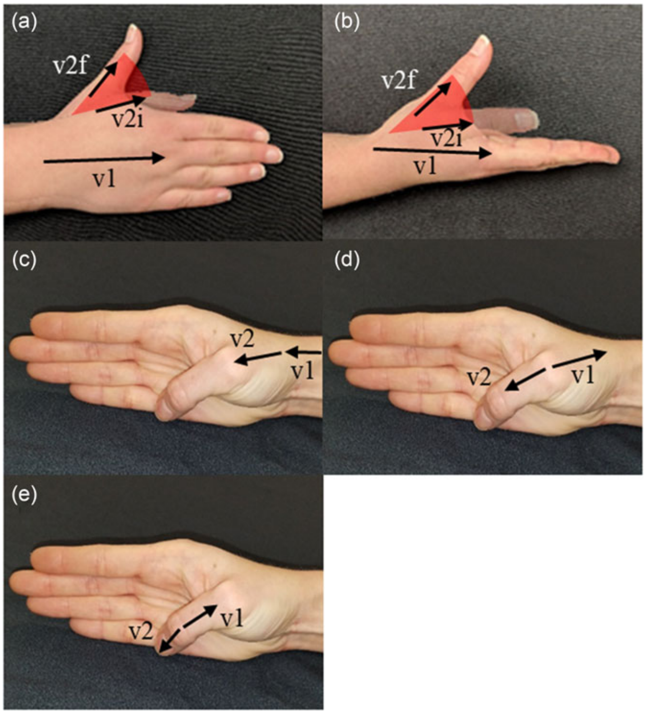

Figure 4. Identification of the vectors used for the motions as defined in Table 1. ***a***) radial adduction-abduction, ***b***) palmar adduction-abduction, ***c***) CMC angle during opposition, ***d***) MCP angle during opposition, ***e***) interphalangeal angle during opposition.

Table 1. Markers identification for range of motion data

Motion/Angle	Vector 1 Markers	Vector 2 Markers
Radial Adduction-Abduction	Third metacarpophalangeal (MCP) joint – midwrist	Thumb proximal phalange (distal marker of pod) – thumb proximal phalange (proximal marker)
Palmar Adduction-Abduction	Second MCP joint – radial styloid	Thumb proximal phalange (distal marker) – thumb proximal phalange (proximal marker)
CMC angle (opposition)	Ulnar side of radial styloid – proximal radius	First metacarpal (distal marker) – first metacarpal (proximal marker)
MCP angle (opposition)	First metacarpal (distal marker) – first metacarpal (proximal marker)	Thumb proximal phalange (distal marker) – thumb proximal phalange (proximal marker)
Interphalangeal (IP) angle (opposition)	Thumb proximal phalange (distal marker) – thumb proximal phalange (proximal marker)	Thumb distal phalange (distal marker) – thumb distal phalange (proximal marker)

This table denotes the motion capture markers and the resultant vectors used to calculate the ranges of motion identified in this study.

a circularity of one. After completing the exercise regimen, increased joint flexibility was anticipated which would lead to an increase in the circularity associated with the "okay sign."

$$\text{Circularity} = \frac{4\pi \cdot Area}{Perimeter^2} \tag{2}$$

Clinical questionnaires

For each time point, participants reported a pain score using a 100 mm VAS for the right thumb. Scores were in reference to the perceived pain levels in the 48 hours prior to testing; a higher score indicated more pain. Participants also completed a modified version of the FIHOA questionnaire score that asked about the level of difficulty for everyday tasks like using a screwdriver [39]. FIHOA is scored from 0 to 30 where higher scores indicated more difficulty completing tasks.

Statistics

To evaluate the effect of exercise, a repeated measures ANOVA with Bonferroni correction for multiple comparisons was used to compare data longitudinally. Comparisons were made for each individual motion within each measurement method (SigmaStat, version 4.0, Systat, San Jose, CA). For all comparisons, a p-value less than 0.05 was considered statistically significant. Effect sizes were calculated using SPSS (version 25, IBM, Armonk, New York). Values greater than 0.26 were designated as large effect sizes and ranges between 0.13 and 0.26 were designated as medium effect sizes.

Results

Of the 24 participants with OA that participated in this study (OA; average age 69.4 ± 5.8 years, 18 females, 6 males), 20 completed all three-time points (14 females, 6 males). At baseline, the average VAS score was 20.6 (standard deviation 17.9; range 0–50) and the average FIHOA was 5.9 (SD 3.7; range 0–12).

Ranges of Motion

Six weeks of exercises did not significantly change range of motions associated with standard clinical motions: as radial abduction ($p = 0.193$) or palmar abduction ($p = 0.812$). Although there was a modest increase in palmar abduction following two weeks of exercise, the improvement was not maintained at six weeks.

To evaluate complex multi-planar motion abilities, opposition, repetitive thumb circumduction, and "okay sign" tasks were completed and analyzed (Table 2). Although exercise prescription did not significantly change opposition ability, $p = 0.262$, (measured as the minimum distance between the tip of the thumb and dorsal side of the fifth MCP joint) significant differences were seen in joint contributions toward this movement (Table 2). When comparing the relative contribution of each thumb joint to the opposition task, data showed that exercise significantly decreased the CMC angle and produced an increased IP angle trend (CMC $p = 0.011$; MCP $p = 0.997$; IP $p = 0.545$).

To further evaluate CMC motion in a more comprehensive, multi-directional manner than could be obtained using goniometry or other clinical measures, the ability of participants to enclose the largest area possible using their first metacarpal was measured. Although exercise did not lead to a statistically significant change in the area enclosed by circumduction, 63% of participants showed an increase in their overall area following exercise at two or six

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Table 2. The effect of exercise on multi-planar motions

Action	Week zero	Week two	Week six
Opposition (mm)	55.9 (10.5)	53.5 (9.7)	54.1 (9.7)
Opposition CMC angle (degrees)	21.8 (12.0)	16.4 (11.6)	13.9 (6.9)*
Opposition MCP angle (degrees)	43.8 (9.8)	43.9 (10.3)	42.2 (11.2)
Opposition IP angle (degrees)	38.1 (11.3)	40.1 (13.2)	43.9 (11.8)
Circumduction area (mm^2)	442.7 (261.5)	390.5 (224.7)	444.5 (276.9)
"Okay sign" area (mm^2)	4600.4 (643.8)	4758.2 (619.5)	4743.3 (646.9)
"Okay sign" circularity (unitless; one is a perfect circle)	0.859 (0.051)	0.876 (0.049)	0.872 (0.054)
"Okay sign" CMC angle (degrees)	70.4 (8.7)	72.3 (7.4)	72.5 (9.6)
"Okay sign" MCP angle (degrees)	162.8 (10.6)	154.0 (13.1)*	157.7 (10.9)
"Okay sign" IP angle (degrees)	142.4 (8.4)	138.9 (11.9)	141.3 (7.5)

Data are shown as group average (standard deviation).
*indicates a p-value of<0.05 compared to week zero.

timepoints (Table 2; week zero: 442.7 mm^2 (261.5), week two: 390.5 mm^2 (224.7), and week six: 444.5 mm^2 (276.9); $p = 0.197$).

For the "okay sign" task, the area enclosed, the circularity of the area enclosed, and the relative contribution of each thumb joint were evaluated. Following six weeks of exercise, participants increased the area enclosed and the circularity of area enclosed, although significance was not reached (Table 2; $p = 0.052$ and $p = 0.081$, respectively). Overall, 79% of the participants increased their circularity during the exercise program and had an increase in the overall area enclosed. To determine if the area and circularity trends were due to changes in the posture of the thumb, joint angles were analyzed. Two weeks of exercise significantly increased MCP angle ($p < 0.001$). Although exercise increased the CMC angle and reduced the IP angle during this movement, these changes were not significant ($p = 0.267$ and $p = 0.219$). Additionally, medium to large effect sizes were found for the following additional motions, suggesting that they are likely to achieve statistical significance with larger sample sizes: circumduction area (medium effect size of 0.119) and "okay sign" area (large effect size of 0.132).

Questionnaire Results

Six weeks of exercise did not have an effect on pain or function as determined by self-administered questionnaires. Prior to exercise, OA participants had an average VAS pain score of 20.6 (17.9), and following two and six weeks of exercise the average scores were 24.65 (25.1) and 19.5 (17.42), respectively ($p = 0.491$). Similarly, exercise did not increase FIHOA scores (week zero 5.9 (3.7), week two 6.6 (5.5), and week six 5.5 (3.8); $p = 0.688$).

When asked about the perceived benefits of the exercises, 2/3 of participants thought their range of motion increased and 1/2 felt more flexible at the completion of the exercise program.

Discussion

Although hand exercises have been a recommended part of CMC OA treatment plans, few studies have attempted to quantify the effect of exercise on thumb motion abilities in persons with CMC OA. No gold standard exercise program for individuals with CMC OA has been established, therefore we used biomechanical principles, published literature, and our clinical experience to develop a well-rounded, multi-modal exercise regimen and incorporated movements that overlapped with those necessary for everyday activities. The goal of this pilot research was to identify changes in the thumb, particularly in motions at the CMC joint through measurements obtained with a motion capture system before, during, and after completion of this six-week exercise program.

Significant differences in motion abilities were identified during complex multi-planar motions, but not with the standard, single-plane motions. When looking at individualized participant data, we saw improvement in 65%–79% of the participants with at least one complex multi-planar task (circumduction, opposition, "okay sign" area). These pilot data add further evidence to suggest that more complex multi-planar motions may be more sensitive to change. The movements require the joints to move through a larger, more complex range of positions and thus provide an opportunity to detect differences that are not available with the standard planar movements. These complex multi-planar movements may provide better insight into thumb function in daily life. Prior publication in association with strength abilities obtained from this set of participants, showed that this exercise program significantly increased thumb forces of this sample [32]. Taken together, the exercise protocol was able to affect changes in force production in the six weeks, but it may not have been long enough (or sufficiently rigorous) to elicit significant changes in all motions. Based on these findings, the authors believe that this pilot work provides grounds that indicate the need for future studies, particularly around the inclusion of complex, multi-planar, more complex movements into exercise protocols and clinical evaluation methods.

Changes in complex multi-planar movements may have the potential to serve as indicators of OA disease because they appear to be more sensitive measures to evaluate changes. For example, during the opposition task, CMC flexion significantly increased and there was a trend of increased IP angle (flexion) such that the CMC and IP angles post-exercise were more similar to those in young healthy participants [23]. Because the opposition distance was not affected by exercise, this suggests that the IP joint had an increased flexion angle to compensate for the reduced contribution of the CMC joint, or the IP joint increased flexion so the participants did not need to stretch the CMC joint as far to oppose the same distance. A similar situation was seen in the "okay sign" task following exercise; there was a change in the ratio of contribution, the MCP angle decreased, and the CMC angle increased. Although the effect of exercise on the CMC angle did not reach statistical significance, there was a trend of increased CMC angle moving toward the CMC angle found in young healthy participants [23]. Importantly, the motion capture measures described here have the potential to shed light on motion changes occurring at multiple joints simultaneously, which cannot be detected using traditional clinical measurement systems.

Understanding joint alignment is important not only for the movement patterns of the thumb but also for force transmission through the thumb. Joint malalignment alters joint contact forces and increases joint wear [4,40–43]. Research on thumb malalignment is not prevalent in the literature, however, work on the knee shows that joint malalignment plays a role in OA progression [44,45]. When the first webspace contracts and thumb alignment is altered, the joint becomes unstable and thus, cannot sustain the same force transmission without damage. Alignment changes and pain associated with OA progression can lead to reduced hand function and even loss of independence. Although OA treatments (splinting, exercise, and surgery) often aim to improve function and independence through the alteration and maintenance of appropriate joint alignment, to our knowledge, joint alignment during task completion is not objectively measured in a clinical setting. This is an additional avenue for use of motion capture, not only to look at movement patterns but also may lend itself to evaluate intervention associated with alignment. Further studies should investigate the influence of exercise programs on simultaneous joint alignment and force transmission.

Our findings from this study are promising, and they suggest that daily exercises incorporating complex multi-planar movements are able to influence changes in joints and thumb function. These findings also suggest that complex multi-planar motions, rather than motions solely focused on range of motion, may offer greater benefit to patients and have a potential for an increased sensitivity in evaluation of motion changes. This initial study suggests that further investigation into the utility and clinical significance of complex multi-planar tasks using motion capture methods to evaluate thumb mobility, function, and intervention efficacy is warranted.

Questionnaire Scores

Hand exercises did not improve the average VAS or FIHOA scores. Other-hand exercise studies have shown mixed results [7,9,11,37,46,47]. Clinical questionnaire scores suggested our participants had mild pain and functional loss (average pre-exercise VAS score 20.6 and average FIHOA score 5.9), and thus there was less room for improvement following exercise. Other studies reported pre-exercise VAS scores of 29–54 mm and FIHOA scores of 9–10 [9,48,49]. This suggests that our OA group had better function than participants in some other OA studies. Although many participants expressed a perceived benefit from the exercises including improved range of motion, flexibility, and ability to complete daily tasks, this was not reflected in their FIHOA scores or motion results.

Limitations

One limitation of this work is that CMC OA participants in this study presented with less severe symptomology than those enrolled in other-hand exercise studies. This is illustrated by the lower average VAS and FIHOA scores in our diseased population. This was likely a mechanism of our recruitment criteria; in order to reduce crossover effects from other OA treatments, we recruited participants who had not and were not seeking surgery or therapeutic treatment for their joint pain and had stable medication use. We also recruited individuals with CMC OA symptoms but did not limit enrollment to individuals with a specific stage of OA. Therefore, our results may not reflect the potential for improvement in participants with severe disease; the exercises may have a greater effect on persons with more severe functional deficits, and thus is another area of research that should be investigated.

The results of this pilot study did not demonstrate differences in the standard planar measures associated with the thumb. Although scientific studies on the effect of hand exercises associated with the range of motion, in general, are limited, other researchers have found that hand exercises increased planar ranges of motion [7,50]. Many of the exercises used in this study overlapped with those used in other studies [15,37]. The lack of significant change in standard clinical ranges of motion found in our study may be due to the participant population tested, the overall difficulty level of the exercise, or a combination of these.

Daily exercise compliance in this study (the percentage of total days participants completed the daily exercise regimen as prescribed) was approximately 70 %. Most exercise noncompliance occurred with participants missing 1–2 days of exercises and re-initiating the exercises as prescribed. Although little research has investigated the effect of exercise frequency on the efficacy, previous studies have shown that exercising as little as twice a week can improve flexibility, and exercising as little as twice a week can improve strength [51]. Similarly, it has been shown that hand strength programs offer similar benefits in elderly participants when completed daily or when completed every other day [52]. Therefore, we anticipate that the somewhat imperfect compliance to exercise observed in our study, although possible, is unlikely to have played profound role in our findings. We also acknowledge that all participants received the same exercise regimen and thus the level of difficulty may have differed among participants. In future studies, options to increase difficulty should be offered as each individual progresses in the program.

The authors recognize that motion capture systems are not readily available in a clinical setting, however, motion capture provides the ability to measure and compute both standard clinical ranges of motion and components of more complex movement patterns. This tool allows evaluation of different movements and assessment of functionally relevant tasks. Motion capture can be utilized to explore movement patterns in a research setting, informing the creation of modified data collection protocols (as with this work) and the development of specific measurement methods that can be utilized in larger clinical studies. Additionally, once complex motions are identified, new, clinically friendly instrumentation can be developed to obtain these specific measures in place of a motion capture system. Work along this line has already occurred with other regions of the body like the shoulder [53].

Conclusions

This study explores the therapeutic benefits of exercise for treatment of CMC OA. Although not all the exercises employed here yielded statistically significant differences, they did alter joint positions and thus may alter joint loading. More complex multi-planar movement exercises demonstrated the largest changes in function and provided insights into thumb joint angles and movements; these complex multi-planar tasks may produce greater benefits than those focused solely on planar ranges of motions. Further studies are necessary to elucidate the sensitivity and potential benefits of complex multi-planar movements in the field of hand research. Such studies will better inform the development of future exercise programs and anticipated patient outcomes.

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