An Exercise Program for Carpometacarpal Osteoarthritis Based on Biomechanical Principles

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ABSTRACT: A review of the literature was performed to design a hand exercise regimen based on biomechanical principles of the carpometacarpal (CMC) joint and the forces that act upon the joint. Sixteen biomechanical studies were included in the review: four studies developed a mathematical model of the thumb and 12 performed cadaveric dissections to study the CMC joint. Clinical application of the biomechanical findings from the studies was synthesized into specific recommendations for a hand exercise program to preserve CMC joint range of motion and increase the strength of the stabilizing muscles of the thumb. The exercise regimen was developed in accordance with recommendations of the American College of Sports Medicine guidelines for the development of individualized exercise prescriptions.

Level of Evidence: 4.

Considerable hand function can be lost as a result of carpometacarpal (CMC) osteoarthritis (OA). Functional limitations can include inability to open jars, turn keys, or perform resistive pinch tasks. In patients older than 75 years, thumb CMC OA has a radiographic prevalence of 25% in men and 40% in women.1 Wilder et al.2 studied the prevalence of hand OA in men and women older than 40 years and found a 21% incidence of first CMC joint OA. Kjeken et al.3 reported that despite the fact that four previously published systematic reviews on conservative interventions for hand OA determined the exercise as efficacious, there are no established or specific recommendations regarding the design of a hand exercise program. Kjeken et al.3 also reported that only one of the reviewed studies justified the design of the exercise program that was prescribed to study participants. Current literature suggests that strengthening the thumb extensors, abductors, and wrist extensors will help to counteract the deforming forces that act on the CMC joint4–8; however, most of the published studies’ exercise programs do not include exercises to strengthen these muscles.

Development of a hand exercise program specific for individuals with CMC OA entails more than specifying the type of exercises provided and the goal of the exercises. Specific dosage, which includes the method for assigning initial load, principles for progression, specifics of dosage (load, repetitions per set, number of sets, sets per day, duration of exercise program, and if exercises are performed to maximal effort or within pain-free limits), and precautions or contraindications is also needed. The American College of Sports Medicine (ACSM) published a position stand with the purpose of providing scientific evidence-based recommendations to health professionals in the development of individualized exercise prescriptions for apparently healthy adults of all ages.9 Most of the studies on which these guidelines were based were done on large muscles acting at large joints. The first CMC joint was not specifically included in the studies on which the guidelines were based. The ACSM guidelines state that the recommendations may also apply to persons with certain chronic diseases or disabilities, with modifications required according to an individual’s habitual physical activity, physical function, health status, exercise response, and stated goals under the direction of a health professional.9 However, these guidelines...
recommend that strengthening exercises should be performed at 40–50% of the individual’s one repetition maximal effort, and prescribing resistive exercises to the CMC joint may cause further joint damage. Therefore, more clinical research is needed to determine the threshold for strengthening without damaging the joint. Thumb strengthening exercise programs should be performed in a pain-free manner.\textsuperscript{10}

Biomechanics is divided into the areas of kinetics (concerning the analysis of the forces acting on the body) and kinematics (concerning the analysis of the movements of the body). Although researchers have studied the CMC joint, their findings have not been synthesized into a sole document. Understanding the scientific research regarding CMC biomechanics can provide a foundation that can benefit the clinician in prescribing a program to best assist their patients in reaching their desired therapeutic goals. The purpose of this review was to provide specific recommendations for a hand exercise program for individuals with CMC OA based on a biomechanical analysis of the CMC joint of the thumb in accordance with ACSM guidelines.

MATERIALS AND METHODS

Before the search was initiated, inclusion and exclusion criteria for articles were identified. Articles were included if they were basic science articles that used mathematical modeling or cadaver dissection to study the thumb. Articles were excluded if they addressed postoperative management of the thumb or conditions other than CMC OA. Case series, review articles, and randomized controlled trials of therapeutic interventions for the thumb were also excluded.

A computer search was conducted using the following databases: PubMed, CINAHL, and MEDLINE. Search words included thumb, biomechanics, CMC, and anatomy. The combined search produced 261 articles (Figure 1). The titles and abstracts were each reviewed to identify those of interest. Out of the 261 articles, 16 studies were included in the review for analysis. Nine of the 16 studies performed cadaveric dissections on thumbs with degenerative changes (Appendix A).

RESULTS

CMC Joint Classification

Three studies classified the CMC joint (n = 3). Cooney and Chao\textsuperscript{11} reported that the CMC joint is a saddle joint composed of two saddle-shaped surfaces, the convexity of one fitting tightly into the concavity of the other. Kovler et al.\textsuperscript{12} reported that the trapezium contains narrow convex regions appearing around the radial and ulnar edges, while both the dorsal and volar aspects of the metacarpal are convex. They also found that the dorsal region consists of two prominences, whereas the volar aspect contains only one.\textsuperscript{12} Cooney and Chao\textsuperscript{11} and Kovler et al.\textsuperscript{12} used three-dimensional (3-D) biomechanical modeling based on cadaver specimens. Doerschuk et al.\textsuperscript{13} used cadaver dissection to determine that

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{quorum_diagram.png}
\caption{Quorum diagram.}
\end{figure}
the first CMC joint is biconcave and saddle shaped. Their findings contribute to the conclusion that the first CMC joint is not a true saddle shape; creating a controversy between the specific joint literature and the textbook classification of the first CMC joint. However, the CMC joint allows extensive mobility, which is required for full opposition. The curved surfaces of the joint provide little intra-articular stability, so stability of the CMC joint is dependent on the surrounding structures.

**Stabilizers of the CMC Joint**

Four studies described the stabilizers of the CMC joint ($n = 4$). Cooney and Chao used 3-D biomechanical modeling based on cadaver specimens to determine that the relationship of the articular structures of the CMC joint, provided by their close-packed structures, limits axial rotation. Constraining collateral ligaments, joint capsule, volar plate, and eight active musculotendinous motor units maintain the stable position of the thumb and resist the external forces of pinch and grasp that tend to produce large rotatory movements. Bettinger et al. reported that the first CMC joint is stabilized primarily and secondarily by 16 ligaments. These ligaments have four specific functions: 1) controlling the extent and direction of joint motion, 2) maintaining normal alignment of the joint, 3) controlling forces, and 4) dissipating forces produced by activated muscles. They reported that the triangular dorsoradial ligament is the strongest and most influential ligament because of its size and bulk and the beak ligament is a poor stabilizer. Doerschuk et al. found that the beak ligament was partially or completely detached from its metacarpal insertion in specimens with OA. Doerschuk et al., and Bettinger et al. limited their analysis to cadaveric dissection.

**Causes of Instability**

Table 1 depicts the studies that describe the causes of CMC instability. Most of the studies used cadaver dissection to study the thumb stabilizers. One study used 3-D biomechanical modeling based on cadaver specimens. The two preeminent theories of CMC-OA etiology are ligamentous laxity and joint impingement. Proponents of ligamentous laxity have observed that CMC OA frequently coexists with degeneration of the palmar or beak ligament, and have proposed that this may result in both abnormal shear stresses and progressive degeneration of the joint along the joint in a dorsoradial direction. Comparatively, other investigators have pointed to the dorsoradial aspect of the trapezium as the initial site of osteoarthritic degeneration. These authors have proposed that rotation of the thumb metacarpal on the trapezium during pinch and grip causes joint impingement that may predispose the CMC to early degenerative changes.

The two divergent theories of abductor pollicis longus accessory tendon etiology debate the

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<tr>
<th>Author, Year</th>
<th>Theory</th>
<th>Consequence</th>
</tr>
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<tbody>
<tr>
<td>Imaeda et al. (1999)</td>
<td>Changes in length of the anterior oblique ligament and the ulnar collateral ligament</td>
<td>Small changes in ligament length affect thumb stability and alter the path of circumduction</td>
</tr>
<tr>
<td>Moulton et al. (2001)</td>
<td>The beak ligament becomes lax, OA initially occurs in the palmar compartment, directly adjacent to the beak ligament insertion where the joint surfaces of the first metacarpal and trapezium primarily contact each other during functional activities</td>
<td>OA then progresses along the joint in a dorsoradial direction</td>
</tr>
<tr>
<td>Bettinger et al. (2000)</td>
<td>The dorsoradial ligament primarily affords CMC joint stability. If this ligament should fail, the primary and preceding site for degeneration is the dorsoradial aspect of the trapezium</td>
<td>As the deterioration progresses within the first CMC joint, the volar region will become affected</td>
</tr>
<tr>
<td>Ateshian et al. (1995)</td>
<td>Excessive contact occurs on the volar–ulnar and dorsal–radial regions of the trapezium during lateral pinch in the presence of metacarpal pronation</td>
<td>Considerable wear on articular surface regions identifies as high load bearing supporting the evidence to the theory that abnormally high stresses may initiate or exacerbate OA progression in articular cartilage</td>
</tr>
<tr>
<td>Koff et al. (2003)</td>
<td>Found cartilage wear patterns occur on both the volar–ulnar and dorsal–radial quadrants of the CMC joint during pronation of the metacarpal (lateral pinch)</td>
<td>CMC OA is likely to be promoted by joint impingement resulting from thumb pronation (lateral pinch)</td>
</tr>
</tbody>
</table>

CMC = carpometacarpal; OA = osteoarthritis.
association between the tendons and the severity of thumb CMC OA (Table 2). All researchers\textsuperscript{20–23} used cadaver dissection to study the abductor pollicis longus accessory tendons.

### Joint Stiffness

Wu et al.\textsuperscript{24} analyzed the effects of increased joint stiffness on muscle loading in a thumb using biomechanical modeling. They found that an increase in joint stiffness induced substantial increases in extensor pollicis longus and flexor pollicis longus muscle forces.

### Muscles of the CMC Joint

Smutz et al.\textsuperscript{25} used cadaver dissection to measure the moment arms of the muscles that act on the thumb. A moment arm is defined as the perpendicular distance from the muscle’s force vector to the axis of rotation of the joint that is acted on. A muscle with a large moment arm produces a larger moment than a muscle with a shorter moment arm if both muscles generate equal contractile forces. During key pinch, it was determined the moment arm of the adductor pollicis is 32 mm when compared with 12.9 mm produced by the opponens and 8.07 mm produced by the extensor pollicis longus.\textsuperscript{25} During opposition, the adductor pollicis produces a moment arm of 26 mm compared with 12.8 mm moment arm produced by the opponens and the 9.89 mm moment arm produced by the extensor pollicis longus.\textsuperscript{25} Cooney and Chao\textsuperscript{11} and Giurintano et al.\textsuperscript{26} used biomechanical modeling to determine muscle forces during pinch and grasp. The investigators found that flexor muscle forces are greater than abduction and extensor muscle forces. Giurintano et al.\textsuperscript{26} found the flexor pollicis longus produces 93 Newtons (N) of muscle force during screwdriver gripping compared with 0 N produced by the abductor pollicis longus and 16.9 N produced by the abductor pollicis brevis. It was also found that the extensor pollicis brevis is the most active thumb extensor muscle during key pinch, screwdriver use, and wide grip to stabilize against the applied load.\textsuperscript{26} The strength of the adductor pollicis when compared with the weaker opposing thenar intrinsic and extrinsic extensors and abductors can contribute to CMC deformity.

### Forces that Act on the CMC Joint

Cooney and Chao\textsuperscript{11} and Giurintano et al.\textsuperscript{26} used biomechanical modeling to determine contact forces that act on the CMC joint during pinch and grasp (Table 3). Cooney and Chao\textsuperscript{11} reported that the contact force increases proportionally from distal to proximal as the moment arms of muscles working on the more proximal joints became larger and the number of muscle units acting on the proximal joints increased. There are two muscles that act on the interphalangeal (IP) joint, six muscles acting on the metacarpophalangeal (MP) joint, and eight muscles that act on the CMC joint. They found that extrinsic tendon forces during normal pinch and grasp are four to five times the applied external force and that the intrinsic tendon forces are 1.5 to 3 times the applied force.\textsuperscript{11} The investigators report that typical daily hand function involves pinch forces of 4–5 kg, 10–15 kg in tip pinch, and 30 kg in strong key pinch.\textsuperscript{11} They also determined that during grasp applied forces may reach 20–25 kg.

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### TABLE 2. APL Function

<table>
<thead>
<tr>
<th>Author, Year</th>
<th>Findings</th>
<th>Conclusions</th>
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<tbody>
<tr>
<td>Brunelli and Brunelli (1991)\textsuperscript{20}</td>
<td>APL accessory tendon attaching to the trapezium will increase the stability of the trapezium, decreasing both shearing forces at the first CMC joint and the likelihood of developing first CMC OA</td>
<td>When the accessory tendons are present, a person will pull their metacarpal into radial abduction and the trapezium will follow smoothly because the strength of the muscle is divided between the bones. However, when the accessory tendons are not present, the strength of the muscle is only applied to the first metacarpal. Consequently, when the first metacarpal is pulled into radial abduction, the trapezium is moving indirectly with it, causing the joint to become unstable and eventually cause OA</td>
</tr>
<tr>
<td>Roh et al. (2000)\textsuperscript{21}</td>
<td>No association was found between thenar insertions of the APL and severity of OA in the first CMC joint</td>
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</tr>
<tr>
<td>Schulz et al. (2002)\textsuperscript{22}</td>
<td>No association between first CMC OA and the number of accessory tendons of the APL</td>
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</tr>
<tr>
<td>Roush et al. (2005)\textsuperscript{23}</td>
<td>Hypothesized that the extra tendons would cause an imbalance in joint load and lead to the development of first CMC OA; Their data did not support this idea</td>
<td></td>
</tr>
</tbody>
</table>

APL = abductor pollicis longus; CMC = carpometacarpal; OA = osteoarthritis.
which results in tendon forces of 60–70 kg. Intrinsic muscles bear the largest forces per cubic centimeters because of small cross-sectional areas. The larger forces are necessary to maintain thumb-joint stability and provide needed strength. The researchers concluded that the maximum lateral constraints (lateral shear loads) are generally less than 2.1 kg of the applied force. Although larger and potentially harmful forces could occur during vigorous pinch and grasp, strong musculotendinous units assist the ligaments in maintaining equilibrium. Giurintano et al. determined that the force applied to the surface of the trapezium as a result of thumb muscles firing to stabilize the load was between six and 24 times the applied load depending on the posture of the thumb.

CLINICAL APPLICATION OF BIOMECHANICAL FINDINGS

Although there is not a consensus between investigators on the cause of CMC instability, ligaments, muscles, and the forces that act on the CMC joint are potential contributors and must be taken into consideration when designing an exercise program for individuals with CMC OA.

1. The curved surfaces of the CMC joint provide little intra-articular stability. Strengthening the thenar intrinsic muscles, thumb extensors, abductors, and wrist extensors may help maintain the first web space, avoid adduction deformity, and improve thumb stability.
2. Preserving CMC joint passive range of motion (PROM) or restoring lost range of motion (ROM) may limit increased muscle forces and further stress on the joint.
3. Lateral-pincher and key-pincher strengthening exercises should be avoided in patients with advanced CMC OA (Eaton and Littler stages III and IV) who have thumb instability and deformity, as these exercises may result in further joint subluxation and pain.
4. The force applied to the surface of the trapezium as a result of thumb muscles firing to stabilize the load was between six and 24 times the applied load depending on the posture of the thumb. The magnitude of these loads should be considered when performing resistive pinch and grip exercises.

Kjeken et al. reported that there was a lack of consensus regarding the design of exercise programs that were studied in their systematic review. They reported that most programs included an exercise to increase pinch strength and used a device or material to provide resistance and only two of the studies included exercises with the potential of strengthening the extensors and adductors of the thumb. Kjeken et al. also reported that none of the exercise programs as described in the studies met all of the ACSM recommendations concerning warm-up or combination of exercises addressing strength and ROM, and only two had the recommended number of repetitions.

Development of an exercise program for increasing muscular strength and flexibility in older frail adults according to ACSM guidelines, which include:

**Strengthening (further clinical research is needed to determine the threshold for strengthening without damaging the CMC joint. Therapists should judiciously prescribe resistive exercise dosage to a degenerated joint.)**

1. Each major muscle group should be trained on two to three days per week.
2. No specific duration of training has been identified for effectiveness.
3. 10–15 repetitions is effective in improving strength in middle-aged and older persons starting exercise.
4. A single set of resistance exercise can be effective especially among older exercisers.
5. Rest intervals of 2–3 minutes between each set of repetitions are effective.
6. A rest of >48 hours between sessions for any single muscle group is recommended.
7. Progression methods for optimal progression are unknown.

Flexibility.
1. >2–3 days a week is effective in improving joint ROM, with the greatest gains occurring with daily exercise.
2. Intensity: Stretch to the point of feeling tightness or slight discomfort.
3. Time:
   - Holding a static stretch for 10–30 seconds is recommended for most adults;
   - In older persons, holding a stretch for 30–60 seconds may confer greater benefit; and
   - 10- to 30-second assisted stretch is desirable.
4. Pattern repetition of each flexibility exercise two to four times is recommended.
5. Flexibility exercise is most effective when the muscle is warmed passively through external methods such as moist heat packs or hot baths.
6. Progression methods for optimal progression are unknown.

Specific recommendations regarding design of exercise programs based on biomechanical studies in accordance with ACSM guidelines (Appendix B).
1. All exercises should be performed in periods of no pain and inflammation, and they should not cause pain that persists for more than two hours after the activity.
2. The exercise session may be preceded by a warm-up period of moist heat packs, paraffin bath, or low-intensity aerobic exercise.
3. Active range of motion (AROM) and PROM exercises that preserve or increase CMC web space, thumb IP motion, thumb MP motion, and CMC motion may be performed two to three days a week with at least four repetitions.
4. Each exercise may be held for a period of 30–60 seconds at the point of feeling tightness or slight discomfort.
   - Passive flexion of the thumb to the base of the small finger.
   - Thumb abduction.
   - Thumb opposition.
   - Isolated flexion of the thumb IP and MP joints.
   - Web space stretch performed with caution against hyperextension pressure to the MP joint.
5. Exercises that strengthen the thenar intrinsic muscles (with exception of adductor pollicis), thumb extensors, abductors, and wrist extensors may be performed one set for 10–15 repetitions, two to three days a week with a recovery period of 48 hours between exercise sessions. Initial assignment of the load is based on the patient’s baseline abilities with adherence to the pain-free principle. If the patient reports increased inflammation after performing an exercise, the exercise should be modified. Possible exercises may include:
   - Thumb extension and abduction exercises performed against resistance (i.e., rubber band).
   - Thumb extension and abduction exercise against resistance (i.e., Velcro board or putty).
   - Isometric exercises.
6. Lateral-pinch and key-pincher-strengthening exercises should be avoided in patients with advanced CMC OA who have thumb instability and deformity, as these exercises may result in further joint subluxation and pain.
7. Pinch strengthening exercises may be performed with patients who do not have advanced CMC OA and instability, but the force of pinch applied at the tip of thumb is magnified by six to 24 times the applied load and must be taken into consideration. They may be performed one set for 10–15 repetitions, two to three days a week with a recovery period of 48 hours between exercise sessions. Resistance can be performed as tolerated by the patient while adhering to the pain-free principle. Possible exercises can include:
   - Putty pinch exercises.
   - Putty pinch exercises.
8. Grip strengthening exercises may be performed one set for 10–15 repetitions, two to three days a week with a recovery period of 48 hours between exercise sessions. Resistance may be upgraded as tolerated by the patient while adhering to pain-free principle. Possible exercises can include:
   - Foam wedge squeeze.
   - Putty squeeze.
   - Hand gripper.

DISCUSSION

Education concerning joint protection (how to avoid adverse mechanical factors) together with an exercise regimen (involving both ROM and strengthening exercises) was recommended for all patients with hand OA by the European League of Associations for Rheumatology despite the fact that direct evidence for exercise alone in the treatment of hand OA is lacking. Further clinical research is needed to determine the CMC joint threshold for performing strengthening exercises without causing further joint damage. Clinical research is necessary to compare the efficacy between a standard exercise program and a program that includes resisted thumb extensor and abductor muscle strengthening. Exercise studies should report the intended outcome/goal, the method for
assigning initial load, principles for progression, specifics of dosage (load, repetitions per set, number of sets, sets per day, duration of exercise program, and if exercises are performed to maximal effort or within pain-free limits), and precaution/contraindications to ensure that the study could be replicated and enable the clinician to implement the treatment regimen.

LIMITATIONS

Although this exercise program was based on biomechanical studies and principles, the efficacy of the recommended exercise program has not been established through clinical research.

CONCLUSION

Hand exercises for CMC OA are aimed at maximizing pain-free functional ROM, increasing functional strength, maintaining joint stability, and avoiding fixed deformities of the thumb. This review provides specific recommendations for the development of a hand exercise program for individuals with CMC OA based on the biomechanical analysis of the CMC joint of the thumb.

REFERENCES

## APPENDIX

### APPENDIX A. Studies

<table>
<thead>
<tr>
<th>Author (Year)</th>
<th>Method</th>
<th>Study Objective</th>
<th>Findings</th>
<th>Conclusion</th>
</tr>
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</table>
| Cooney and Chao\(^{11}\) (1977) | Mechanical equivalents were determined from five cadaver specimens to create a 3-D mathematical model of the thumb | Present a mechanical analysis of the 3-D static forces during pinch and grasp   | 1. Extrinsic tendon forces during normal pinch and grasp are four to five times the applied force  
2. The joint contact force with 1 kg applied load varies from 6.44 to 13.42 kg at the CMC joint | The large rotational movements during pinch and grasp (especially tip pinch) are responsible for CMC joint subluxation          |
| Giurintano et al.\(^{26}\) (1995) | A virtual five-link mathematical model of the thumb with virtual links connected by hinge joints | Determine muscle-tendon forces of the thumb CMC joint. Determine compressive forces on CMC joint from 10 N (1 kg) of force | Force applied to surface of trapezium to stabilized applied load was between six and 24 times the applied load depending on the posture of the thumb | The reactions at the surface of the trapezium consist of contributions because of shear and compression forces |
| Wu et al.\(^{24}\) (2009) | Mathematical model of the thumb based on a linkage system | Analyze the muscle force in the thumb in response to increased joint stiffness | Increased joint stiffness induces substantial increases in muscle forces, especially in the EPL and FPL | Muscles may not be able to overcome joint resistance if joint stiffness is present in OA |
| Kovler et al.\(^{12}\) (2004) | Creation of 3-D computer models of the articular surfaces of 25 cadaveric CMC joints | To determine the location of joint degeneration to gain insight into the potential mechanical factors in CMC-OA pathogenesis | The dorsoradial trapezial region was found to be significantly more degenerated than other quadrants in both males and females. Mean trapezial articular surface area was 197 mm in males and 160 mm in females; the respective mean areas for the metacarpal were 239 mm in males and 184 mm in females. Joints of females were found to be significantly more concave in radioulnar profile than those of males | CMC OA is likely to be promoted by joint impingement resulting from thumb pronation. For this reason, splinting of the symptomatic thumb should emphasize neutral or slightly adducted and supinated positioning to offload the dorsoradial trapezial region |
| Doerschuk et al.\(^{13}\) (1999) | 18 cadaver hands | Investigate the relationship between degeneration of the palmar beak ligament and articular disease of the CMC joint | 1. Beak ligament degeneration correlated closely with the presence of articular degeneration  
2. All joints with eburnation demonstrated frank detachment of the ligament from its metacarpal insertion site | Findings further support the existence of an anatomically distinct intra-articular beak ligament essential to the normal function of the trapeziometacarpal joint and suggest an etiologic relationship to osteoarthritic disease |
| Koff et al.\(^{19}\) (2003) | 104 cadavers | Cartilage thickness mapping of trapezium and metacarpal using stereophotogrammetry | Cartilage degradation is initiated in radial quadrants of the metacarpal and presses to volar quadrants of articular surface |  
Bettinger et al.\(^\text{15}\) (2000) 20 cadavers
To determine the relative stiffness and strength of the ligaments that stabilize the CMC joint

Dorsoradial ligament demonstrated the greatest ultimate load and toughness (energy to failure)

Trapezio-third MC ligament demonstrated the greatest ultimate stress (normalized failure load) and stiffness

AOL demonstrated the least stiffness and the greatest hysteresis

Dorsoradial and deep AOLs play a substantial role in stabilizing the trapeziometacarpal joint, and the deep AOL may function as a pivot for the first metacarpal during palmar abduction to allow rotation (pronation)

Dorsal trapezio-second metacarpal, volar trapezio-second metacarpal, and T-III MC ligaments were all relatively strong and are anatomically aligned to function as tension bands to restrain the trapezium against cantilever bending forces applied to it by the thumb during key or tip pinch

Dorsal trapezio-second metacarpal, volar trapezio-second metacarpal, and T-III MC ligaments function as tension bands and are required to prevent instability from cantilever bending forces on the trapezium

Imaeda et al.\(^\text{16}\) (1999) 12 cadaver hands
Passive circumduction was measured with a magnetic tracking system. The lengths of the TMC joint ligaments were approximated by measuring the distance between origin and insertion of each ligament

The AOL and the UCL had the greatest effect on TMC joint stability during circumduction of the thumb

Reconstruction of the AOL and UCL ligaments should be considered for treatment of the initial stages of TMC instability

Moulton et al.\(^\text{17}\) (2001) 20 cadaver hands
Each specimen was categorized by its passive range of metacarpophalangeal joint motion, while the hand was in the lateral-pinch mode. Quantitative analysis of the trapezial contact surface at each of the metacarpophalangeal joint positions was performed

In specimens affected by end-stage OA, the center of pressure on the CMC joint moved dorsally by 56.8% of the length of the trapezial surface with metacarpophalangeal joint flexion of 30° (\(p < 0.01\)), whereas the corresponding values were 28.2% and 40.9% in the hyperextended and neutral metacarpophalangeal joint positions, respectively. In specimens with moderate OA, 30° of metacarpophalangeal joint flexion also produced the most dorsal trapeziometacarpal center of pressure (44.8%); however, this center of pressure was not significantly different from the centers of pressure at the other metacarpophalangeal joint positions. In nonarthritic specimens, the center of pressure was again significantly more dorsal with metacarpophalangeal joint flexion of 30° than it was at the other positions

Metacarpophalangeal joint flexion effectively unloaded the most palmar surfaces of the trapeziometacarpal joint regardless of the presence or severity of arthritic disease in the CMC joint

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<tr>
<td>Ateshian et al.18 (1995)</td>
<td>13 cadaver hands</td>
<td>Determine the contact areas in the CMC joint under the functional position of lateral (key) pinch and in the extremes of ROM of the joint</td>
<td>The lateral-pinch position produced contact areas predominantly on the central, volar, and volar-ulnar regions of the trapezium and the metacarpal</td>
<td>The volar-ulnar, ulnar, and dorsoradial regions of the trapezium were the most common sites of thin cartilage, and these may be the sites of cartilage wear</td>
</tr>
<tr>
<td>Smutz et al.25 (1998)</td>
<td>7 cadaver hands</td>
<td>Measure moment arms of thumb muscles and examine the role of each muscle</td>
<td>It was found that the FPL was a pure flexor, whereas flexor pollicis brevis was an adductor and a flexor, the EPL was an extensor and an adductor, extensor pollicis brevis was an extensor and a mild abductor, the APL was an extensor and an abductor, the abductor pollicis brevis was mainly an abductor, the adductor pollicis was a major flexor and an adductor, and the opponents pollicis was a flexor and an adductor.</td>
<td></td>
</tr>
<tr>
<td>Brunelli and Brunelli20 (1991)</td>
<td>100 cadaver hands</td>
<td>Anatomical dissection of the first dorsal compartment</td>
<td>The first dorsal compartment tendons that insert on the trapezium is present in 71% of the dissected cadaver hands</td>
<td>Instability and arthritis of the trapeziometacarpal joint occur in a higher percentage when the first dorsal compartment tendons are absent</td>
</tr>
<tr>
<td>Schulz et al.22 (2002)</td>
<td>73 cadavers</td>
<td>To determine if accessory APL slips, inserting into the thenar eminence or trapezium influence the incidence and severity of trapeziometacarpal joint OA</td>
<td>The main APL tendon, which inserted at the metacarpal base was accompanied by supernumerary APL slips in 96% of cases. Thenar or trapezial slips occurred frequently but coexisted in only one case</td>
<td>The incidence of trapeziometacarpal arthritis was not influenced by the number of accessory slips or whether they inserted onto the thenar eminence or the trapezium</td>
</tr>
<tr>
<td>Roh et al.21 (2000)</td>
<td>68 cadaver hands</td>
<td>Analyze the relationship between a thenar insertion of an accessory APL tendon and the presence and severity of thumb CMC OA</td>
<td>Thirty-five of 68 specimens (51%) had a thenar insertion, most frequently inserting on either the abductor pollicis brevis or opponens pollicis fascia or muscle belly</td>
<td>No significant association between a thenar insertion and thumb CMC arthritis was observed. Conversely, increasing age was noted to have a significant association with degenerative joint disease</td>
</tr>
<tr>
<td>Roush et al.23 (2005)</td>
<td>61 cadaver hands</td>
<td>Analyze the relationship between supernumerary slips of the APL and increase the risk of trapeziometacarpal OA</td>
<td>Seventy-nine percent of the hands had a digastric-type insertion into the abductor pollicis brevis. Ninety percent had an insertion into the trapezium. All hands possessed an insertion into the base of the first metacarpal. Age and female gender were directly correlated with severity of arthritis. No other correlations existed</td>
<td>Trapeziometacarpal joint arthritis progresses with age and occurs independently of any aspect of APL insertion</td>
</tr>
</tbody>
</table>

EPL = extensor pollicis longus; FPL = flexor pollicis longus; T-III MC = trapezio-third metacarpal; MC = metacarpal; 3-D = three-dimensional; CMC = carpometacarpal; OA = osteoarthritis; AOL = anterior oblique ligament; UCL = ulnar collateral ligament; APL = abductor pollicis longus; ROM = range of motion.
**APPENDIX B. ROM Exercises for the Thumb**

Do the exercises as taught by your therapist
Move the joints as far as you can without forcing them
Always stretch gently. Hold for about 30–60 sec at the point of feeling tightness or slight discomfort
Do not bounce. You should feel a stretch but not pain
Perform each exercise for at least four repetitions
Exercises should be performed 2–3 d per week

<table>
<thead>
<tr>
<th>ROM Exercises</th>
<th>Starting Position</th>
<th>Ending Position</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AROM: Thumb flexion</td>
<td></td>
<td></td>
<td>1. Start with thumb extended as far as possible away from the palm</td>
</tr>
<tr>
<td>PROM: Same as AROM but assist with the other hand</td>
<td></td>
<td></td>
<td>2. Flex the tip of the thumb to the base of the small finger</td>
</tr>
<tr>
<td>AROM: Thumb abduction</td>
<td></td>
<td></td>
<td>1. Start with thumb lying flat against palm in line with the index finger</td>
</tr>
<tr>
<td>PROM: Same as AROM but assist with the other hand</td>
<td></td>
<td></td>
<td>2. Spread thumb as far away from the palm as possible in the same line as the index finger</td>
</tr>
<tr>
<td>AROM: Thumb opposition</td>
<td></td>
<td></td>
<td>1. Touch thumb to the tip of each fingertip alternately</td>
</tr>
<tr>
<td>PROM: Same as AROM but assist with the other hand</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AROM: Thumb CMC extension</td>
<td></td>
<td></td>
<td>1. Spread out thumb as far as possible from palm</td>
</tr>
<tr>
<td>PROM: Same as AROM but assist with the other hand</td>
<td></td>
<td></td>
<td>2. Caution: Do not hyperextend the thumb MP joint</td>
</tr>
<tr>
<td>AROM: Thumb IP flexion</td>
<td></td>
<td></td>
<td>1. Bend just the tip of the thumb (IP joint)</td>
</tr>
<tr>
<td>PROM: Same as AROM but assist with the other hand</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**AROM:** Thumb MP flexion  
**PROM:** Same as AROM but assist with the other hand

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**Resistive exercises**

Exercises should be performed one set for 10–15 repetitions, 2–3 d a week with a recovery period of 48 h between exercise sessions. Isometric exercises can be performed if exercise against resistance causes pain. Lateral-pincho and key-pincho strengthening exercises should be avoided in patients with advanced CMC OA who have instability and deformity. *Exercises should be performed pain free.*

<table>
<thead>
<tr>
<th>Strengthening Exercise</th>
<th>Starting Position</th>
<th>Ending Position</th>
<th>Description</th>
</tr>
</thead>
</table>
| Thumb extension against rubber band or manual resistance | ![Thumb Extension Starting](image1) | ![Thumb Extension Ending](image2) | 1. Wrap rubber band around metacarpals with hand flat on table  
2. Spread rubber band out as far possible |
| Thumb abduction against rubber band or manual resistance | ![Thumb Abduction Starting](image3) | ![Thumb Abduction Ending](image4) | 1. Wrap rubber band around metacarpals with hand resting on small finger  
2. Spread rubber band out as far possible |
| Pinch strengthening | ![Pinch Start](image5) | ![Pinch End](image6) | Pinch object between tip of fingers and thumb  
- Use __________therapy putty  
- Use clothespin  
- Use __________ |
| Grip strengthening | ![Grip Start](image7) | ![Grip End](image8) | Squeeze object as tightly as possible without inducing pain  
- Use foam block  
- Use gripper  
- Use __________therapy putty  
- Use __________ |

ROM = range of motion; PROM = passive range of motion; AROM = active range of motion; CMC = carpometacarpal; IP = interphalangeal; MP = metacarpophalangeal; OA = osteoarthritis.
JHT Read for Credit
Quiz: Article #228

Record your answers on the Return Answer Form found on the tear-out coupon at the back of this issue or to complete online and use a credit card, go to JHTReadforCredit.com. There is only one best answer for each question.

#1. The theoretical goals of the recommended program are to improve CMC
   a. dexterity and manipulation of small objects
   b. grip strength
   c. ROM and stability
   d. pain scores

#2. The program was developed based on
   a. cadaver dissections and published biomechanical studies
   b. clinical assessments and experience
   c. recommendations of the AOTA and ASHT
   d. the DASH and other outcome measures

#3. The exercise program features strengthening of the following
   a. all the muscles of the thumb
   b. thumb extensors, thumb flexors, and thumb abductors
   c. wrist extensors, wrist flexors, and thumb abductors
   d. wrist extensors, thumb abductors, and thumb extensors

#4. The CMC joint is stabilized for the most part by
   a. the unique architecture of the saddle joint
   b. 5 ligaments and 5 muscles
   c. 16 ligaments
   d. 4 muscles

#5. The recommended exercise regime was clinically tested against other traditional regimes and found to be more effective
   a. True
   b. False

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