Radiographic Analysis of Simulated First Dorsal Interosseous and Opponens Pollicis Loading Upon Thumb CMC Joint Subluxation: A Cadaver Study

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Abstract

Background: Therapy programs to treat thumb carpometacarpal (CMC) arthritis may engage selective activation and reeducation of thenar muscles, particularly the first dorsal interosseous (FDI) and opponens pollicis (OP) to reduce subluxation of the joint. We describe the effect of simulated selective activation of the FDI and OP muscles upon radiographic subluxation of the thumb CMC joint. **Methods:** In a cadaver model of CMC subluxation, loads were applied to the FDI, the OP, and then concomitantly at 0%, 25%, 50%, 75%, and 100% maximal loads and radial subluxation of the joint and reduction in subluxation was measured. **Results:** Selective activation of the OP, alone, improved the subluxation ratio (SR) in a dose-dependent manner. Selective activation of FDI, alone, demonstrated minimal effects on SR. Concomitant activation of OP and FDI improved the SR across all loading states, and activation of 75% and greater, when compared with FDI activation alone, resulted in a statistically significant improvement in SR to within 10% of the presubluxed joint. **Conclusions:** Concomitant activation of the FDI and OP acts to reduce subluxation of the thumb CMC joint in a dose-dependent fashion. The OP is likely the predominant reducing force. Hand therapy programs that focus on selective strengthening programs likely function in part to encourage patients to activate the easily palpable and easily understood FDI. Concomitant coactivation of the OP may be the major reducing force to elicit clinical and radiographic reduction of subluxation, improved thumb positioning, and reduction of pain and arthritic symptoms.

Keywords: CMC, carpometacarpal, first dorsal interosseous, opponens pollicis, selective strengthening, trapeziometacarpal, dynamic stability

Introduction

Thumb carpometacarpal (CMC) joint arthritis is common; etiological factors include transmission of forces which are magnified at the basilar joint, small contact areas, and hypermobility of the joint, leading to edge wear.^{2,3,7-10,15,17} Cooney and Chao⁷ described contact forces at the thumb CMC joint and noted transmission of 12 times the forces experienced at the tip to the thumb CMC joint.

Brand and Hollister recognized the importance of the first dorsal interosseous (FDI) muscle to stabilization of the thumb CMC joint and even described the FDI as the “lateral thenar muscle.”⁵ The FDI and its force-couple muscle, the opponens pollicis (OP), are believed to act to center the first metacarpal on the trapezium.⁵ This effectively increases the contact area for the basilar joint of the thumb, and may reduce edge wear and thus development of arthrosis. There is evidence that altering the way pinch occurs, particularly with activation of the FDI and OP, may ameliorate basilar

arthrosis symptoms by reducing subluxation of the basilar joint and potentially altering contact pressures at the CMC joint.^{1,4} Furthermore, it appears that even early thumb CMC arthritis is accompanied by weaker functional pinch strength and changes in kinematics of the thumb over normals.^{11,12,14}

Selective strengthening of the muscles (SSM) around the thumb basilar joint has been used in our clinic since 2005 and

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has early clinical support.^{1,6,16} Albrecht et al¹ described exercises focusing on proprioceptive training and selective activation of the FDI and OP. Our clinic reported reduced pain and improved function in a series of patients treated with these techniques by O'Brien and Giveans.¹⁶ The theorized mechanism of action is that during pinch, grasp, and grip, SSM is intended to have muscular forces alter the joint subluxation of the thumb CMC joint, thereby increasing contact area at the CMC joint and decreasing edge wear and arthritic symptoms. Indeed, a recent radiographic study suggests that activation of the FDI reduces thumb CMC subluxation in normal volunteers.¹³ However, to date, although there are clinical outcomes series supporting the use of SSM, there are little biomechanical data to support these techniques. The purpose of this investigation is to quantify the joint kinematics of a subluxing thumb CMC joint in a simulated pinch with selective loading of the FDI and OP muscles to determine their relative role in reduction. This research aims to test the hypothesis that there exists a muscle loading scheme for the FDI and OP which results in significant reduction in first CMC joint subluxation. It is our contention that this loading scheme should motivate a similar pattern of SSM in thumb CMC joint subluxing patients.

Materials and Methods

Eleven fresh-frozen hands from eight donors were obtained from the University of Minnesota Bequest Program for the biomechanical testing of the first CMC joint. Seven of the donors were male, and the average donor age at death was 68 years (range, 45-87 years). Specimens had no history of surgery or instrumentation to the upper limb and no clinical history of hand or wrist pathology; specimens were radiographed to confirm that no more than minimal radiographic changes of basilar joint arthritis were present and to exclude other pathology of the hand and wrist. Specimens were harvested from the proximal forearm distally, leaving all distal tissue intact.

Specimens were thawed for 24 hours and were at room temperature before dissection, manipulation, and testing. Each hand was sharply dissected to reveal the musculature and specifically the muscle bellies of the OP, FDI, and the first CMC joint. A 2-0 braided nonabsorbable running locking stitch suture was used for connection and loading of each muscle. These sutures were placed in the tendons of the flexor pollicis longus (FPL), extensor pollicis longus (EPL), extensor pollicis brevis (EPB), abductor pollicis longus (APL), abductor pollicis brevis (APB), flexor digitorum profundus of the index (FDP-II), and adductor pollicis. Due to their lines of action and sizes, the OP, FDI, and flexor pollicis brevis (FPB) had sutures encircling the muscle bellies to ensure an even load distribution to the musculotendon junction.

Pinch simulation was performed on the cadaveric specimens by affixing them to a board which contained pulleys that

Figure 1. Experimental setup demonstrating cadaver preparation and muscle tagging.

support the loading of the muscles via their sutures along their physiologic line of action (Figure 1). A stable test construct was achieved by fixing each wrist supinated in a neutral extension/flexion position. A Steinmann pin was advanced starting between the third and third webspace in a retrograde fashion to cross the carpus into the distal radius. In addition, large Steinmann pins were driven through the proximal and distal radius volarly to dorsally and into the underlying board for fixation. Neutral wrist position and appropriate pin placement were verified grossly and radiographically. Once the hand was fixed to the board, the suture lines for each muscle were pulled through their respective pulleys which maintained the in vivo line of action of the muscle and provided an attachment point for loading. Each muscle was initially loaded in accordance with literature experience,^{3,7} and then the additional muscles were loaded to produce a 25-N pinch in an attempt to create the most physiologic forearm mechanics simulation. The muscle forces utilized herein to produce a 25-N pinch and supporting literature values are found in Table 1.^{3,7} Subsequent pinch simulations herein utilized these loads (via hanging weights) while the values of the OP and FDI were prescribed at 25%, 50%, 75%, or 100% of the maximum load (and verified with a Chatillon force gauge [AMETEK Sensors, Test & Calibration, Largo, Florida]) to examine the role of increased participation of these muscles.

Table 1. Musculotendon Loading for Simulation of 25-N Pinch Mechanics.

Muscle	Force (N)	Cooney and Chao ^{7,a} (N)	Ateshian et al ^{3,b} (N)
Flexor pollicis longus	30	30	45
Flexor pollicis brevis	19	19	22
Abductor pollicis brevis	19	18	22
Adductor pollicis	16	16	23
Abductor pollicis longus	10	23	10
Extensor pollicis longus	20		6
Extensor pollicis brevis	8		
Flexor digitorum profundus II	40		
First dorsal interosseous	30^c		
Opponens pollicis	40^c	19	30

^aPinch form from 10 to 100 N.^bLateral pinch force 25 N.^cPresumptive physiological maximum. **Figure 2.** Fluoroscan demonstrating RS/AW ratio. An RS/AW ratio of 0 is representative of a healthy nondisplaced joint.

Note. RS = radial subluxation; AW = articular width.

The outcome measures of this study included radiographic measurements of the degree of subluxation of the proximal metacarpal on the trapezium as a function of different muscle loading. Radial subluxation (RS; Figure 2) was measured on radiographs as the ratio of the distance of joint surface area unapproximated between proximal metacarpal and trapezium divided by the articular width (AW) as described by Wolf et al.¹⁸ Using standard objects in the field, each image and measurement was normalized to account for size variability between fluoroscans. All

measurements and calculations were made using ImageJ software (National Institutes of Health) and performed by one member of the research team to eliminate interrater variability.

Testing involved the acquisition of radiographic measurements for: (1) intact; (2) after subluxation modeling; and (3) after different loading regimes attempting to reduce the subluxation. Subluxation modeling involved dissection of the first CMC joint accompanied with a dorsolateral load. The first CMC joint was sharply dissected and a capsulotomy performed with careful sparing of the intrinsic and extrinsic muscles and tendons. Capsulotomies were complete when the proximal articular surface of the first metacarpal could freely sublux into the incision. A screw eyelet was placed into the dorsolateral aspect of the middiaphyseal region of the first metacarpal with a 50-N load applied to produce a physiologically relevant subluxation during a pinch activity. After subluxation modeling was achieved, the severity was measured using the pinch simulation loading (without loading of the OP and FDI). Finally, the OP and FDI were sequentially and independently loaded up to 100% in 25% increments, and then concomitant loading of the OP and FDI was performed in a similar fashion. The loads for these two muscles were manually applied and measured with an inline force gauge (Chatillon) to ensure repeatability. After each loading step, a fluoroscopic image was taken to produce the outcome measure of subluxation ratio.

The null hypothesis that no difference in the subluxation ratio exists regardless of OP and FDI loading was tested using analysis of variance (ANOVA) techniques. Post hoc *t* test contrasts were also performed to compare the subluxation ratio between specific loading states. Statistical significance was established for $P < .05$.

Results

Seven complete sets of measurements were obtained from the specimens due to the muscle bellies of the OP being irreparably torn during testing in four samples. No evidence of slipping or muscle tearing was found at any other suture loading points for the 10 muscles loaded. Subluxation modeling via capsulotomy resulted in a mean value of the subluxation under pinch muscular loading (except for activation of the FDI and OP) of 44.7% of the AW. This average baseline subluxation ratio was 0.447 ± 0.152 across all specimens, and subsequent data are reported as a within-specimen change in the subluxation ratio.

The null hypothesis was evaluated using ANOVA techniques on the subluxation ratio data, and the null hypothesis was rejected ($P < .001$). Thus, the alternative hypothesis that there exists a loading state for OP and FDI which can produce a significant reduction in the first CMC joint subluxation remains viable to support SSM techniques in these patients. Figure 3 demonstrates the reduction or change in RS/AW

Figure 3. Change in radial subluxation to articular width ratio (RS/AW) with increasing muscle loading.

Note. The whiskers on the plot are the standard error as between-sample variability was large. Loading of the OP alone and OP + FDI produce significantly greater reduction of the joint than the FDI alone at larger levels of activation. * $P < .0455$ for comparisons within a loading level group (eg, at 100%, OP and FDI + OP are significantly greater than FDI alone). RS = radial subluxation; AW = articular width; OP = opponens pollicis; FDI = first dorsal interosseous.

from the initial subluxed position wherein a change in RS/AW of 0.447 represents full reduction of the subluxation.

Selective loading of the OP, alone, improved the subluxation ratio across all loaded states (Table 2). Increasing activation of the OP resulted in an improved subluxation ratio in a “dose-dependent manner” with the average ratio of 0.069 at 100% loading. Thus, OP loading produced a biomechanical response to reduce the subluxation to 6.9% of the AW. Three samples experienced an overreduction at 100% loading indicative of the need for stabilization with OP loading in a subluxation model.

Selective loading of FDI demonstrated a minimal effect on the RS ratio. The greatest reduction in subluxation was seen at 75% loading with an average ratio of 0.409 (range, 0.173-0.974). Increasing loading of FDI alone did not demonstrate a dose-dependent effect as reduction at 75% was greater than 100% (0.409 vs 0.424).

Concomitant loading of OP and FDI improved the subluxation ratio across all loading states. Subluxation ratios improved in a dose-dependent manner with increasing loading with the lowest ratio at 100% of 0.100. The coupled loading of the OP and FDI is not statistically different in the subluxation ratio from the OP loading alone (Figure 2). Concomitant loading also demonstrated overreduction in three specimens but to a lesser degree than the OP-alone loading.

Table 2. Subluxation Ratio for Pinch Simulation Addition of OP and FDI.

% Load (OP, FDI)	RS/AW		Change in RS/AW	
	Mean	SD	Mean	SD
0, 0	0.447	0.152		
25, 0	0.407	0.321	0.084	0.187
50, 0	0.189	0.241	0.312	0.306
75, 0	0.124	0.263	0.368	0.290
100, 0	0.069	0.286	0.473	0.337
0, 25	0.441	0.274	0.005	0.078
0, 50	0.418	0.228	0.025	0.107
0, 75	0.409	0.244	0.034	0.123
0, 100	0.424	0.256	0.015	0.131
25, 25	0.290	0.237	0.204	0.328
50, 50	0.226	0.203	0.255	0.307
75, 75	0.136	0.229	0.360	0.297
100, 100	0.100	0.260	0.397	0.317

Note. OP = opponens pollicis; FDI = first dorsal interosseous; RS = radial subluxation; AW = articular width.

Post hoc contrasts of the results reveal the OP loading and OP + FDI loading at greater than 75% to be statistically larger than the same load percentage of the FDI alone ($P < .014$). Finally, a trend in “dose response” was observed with increasing loading resulting in increased reduction of the joint. Although an absolute dose response is not able to be determined, it appears that greater than 25% of loading (activation) is necessary to significantly affect CMC joint RS reduction.

Discussion

In this cadaver model of pinch mechanics, we investigated the effect of simulated activation of the FDI and OP in affecting (reducing) subluxation of the trapeziometacarpal joint. The rejection of the null hypothesis supports that there exists a muscle loading regime which can produce significant thumb CMC joint reduction in a subluxation model. These results support clinical observations and the selective data which exist on this topic. SSM may provide real benefits to the patient with a first CMC subluxing joint, and the results herein support the combined strengthening of the OP and FDI with a greater emphasis on the OP to produce joint reduction. These benchtop cadaveric model biomechanics results support a starting point in assessing an SSM approach, but clearly this topic needs further investigation and validation prior to widespread prescription of a muscle strengthening approach.

Limitations include those inherent to cadaver studies including the likelihood of altered tissue turgor and stiffness related to age and postmortem changes, the likelihood of early arthritic changes present in these specimens, and the challenges of in vitro physiologic loading of tendons and muscles.

In addition, the laboratory scenario we created to simulate instability of the thumb included a gross capsulotomy of the joint which allowed for subluxation of the joint and is rarely replicated in the clinical setting. Nevertheless, it may be considered perhaps as a “worst-case” scenario. Finally, the sample size was small as typical in cadaveric testing.

These data suggest that concomitant loading of the FDI and OP acts to reduce subluxation of the thumb basilar joint in a dose-dependent fashion. The OP is likely the predominant reducing force. Hand therapy programs which include dynamic thumb stability that focus on selective strengthening programs likely function in part to teach patients to activate the easily palpable and easily understood FDI. However, inherent concomitant coactivation of the OP may be the major reducing force to elicit clinical and radiographic reduction of subluxation, improved thumb positioning, and reduction of pain and arthritic symptoms. Further longitudinal research is warranted on this concomitant activation in persons with thumb pain.

These data provide biomechanical support for use of selective strengthening programs of the OP and FDI to improve thumb CMC joint reduction of subluxation and centering of the joint.

Ethical Approval

This study was approved by our institutional review board.

Statement of Human and Animal Rights

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5).

Statement of Informed Consent

The informed consent is not required as it is a cadaver study.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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