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IN VIVO MODELING OF THE ANTERIOR OBLIQUE LIGAMENT

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INTRODUCTION: The basal joint of the thumb, or the thumb carpometacarpal (CMC) joint (Fig. 1), is a saddle-shaped articulation that gives the human thumb great flexibility. The same articular geometry that allows a wide range of motion, however, provides little bony support – necessitating muscular and ligamentous support for stability[1]. Ligament laxity has been hypothesized to contribute to translational instability, incongruent loading of the joint, and subsequent damage of the articular cartilage that is typical of CMC osteoarthritis (OA).

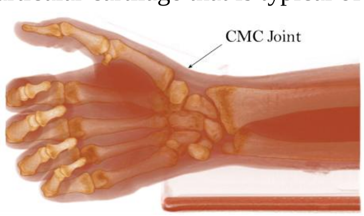

Figure 1. 3D rendering of the hand from a CT scan, indicating the location of the CMC joint.

The anterior oblique ligament (AOL), or the beak ligament, is thought to be particularly implicated in OA pathogenesis[2,3,4,5]. A direct correlation between the stage of OA and the integrity of the beak ligament has been documented[2], but currently there are no *in vivo* data to support hypotheses regarding the mechanism of cartilage degradation and its association with the beak ligament.

Since it is challenging to measure ligament lengths and ligament strains *in vivo*, a computational approximation of beak ligament elongation from CT-derived bone models and joint kinematics can provide valuable insights into the relationship between ligamentous stability and pathomechanics. The purpose of this study was to model AOL elongation from *in vivo* kinematics of the CMC joint[6] during three functional tasks that rely on thumb support and during thumb range of motion positions and to determine if age, gender, and pathology influence elongation.

METHODS: Following IRB approval and informed consents, the dominant hand of 22 healthy subjects (11 young – 5M & 6F – age 23.6±1.5yrs. and 11 older – 5M & 6F – age 52.4±4.4yrs.) and the affected hand of 11 patients (5M and 6F, age 54.1±3.8yrs.) with early stage OA were CT-scanned in a neutral wrist position (Fig. 2A); during three functional task positions: key pinch, jar grasp, jar twist (Fig. 2B-D); and during four maximum active range of motion (ROM) positions: thumb adduction, abduction, flexion, extension (Fig. 2E-H).

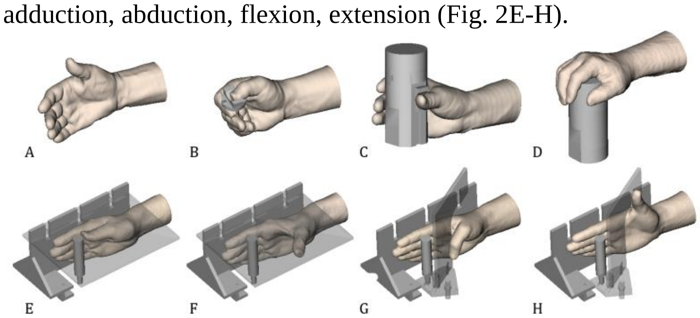

Figure 2. 3D rendering of the hand of one subject and the mechanical jigs used to standardize thumb positions: (A) neutral, (B) key pinch, (C) jar grasp, (D) jar twist, (A) adduction, (B) abduction, (C) flexion, and (D) extension.

An adjustable splint was used to support the wrists and thumbs during the neutral scans and custom-designed polycarbonate mechanical jigs were used to standardize the other positions.
For the functional task positions, subjects were scanned while they applied and maintained 80% of their maximum load for each specific task. A compression load cell was incorporated into the jigs and the front panel of a LabVIEW (National Instruments, Austin, TX) subroutine provided visual feedback to the subjects. CT volume images were generated with a 16-slice clinical CT scanner (General Electric, Milwaukee, WI) at tube settings of 80kVp and 80mA, slice thickness of 0.625mm, and in-plane resolution of ~0.3mm x 0.3mm. 3D bone models were generated by segmenting the neutral CT volume semi-automatically (Mimics, Materialise, Leuven, Belgium) and 6DoF kinematics from the neutral position to the other positions were obtained with a markerless bone registration algorithm[7].

The origin and the insertion sites of the AOL were manually selected in Geomagic Studio (Geomagic®, Research Triangle Park, NC) based on cadaveric studies of the AOL anatomy[3,8]. The ligament was then modeled as a set of 3 fibers (F_1–radial; F_2–central, F_3–ulnar) whose lengths were the shortest distances between three equally distributed points on the origin and the insertion sites, constrained to overcome bone penetrations[6]. The lengths of these fibers in the neutral position were defined as the reference lengths and elongations were computed as the percent changes from the reference lengths.

A three-way (age, gender, pathology) repeated measures (7 positions) MANOVA (3 fibers) was used to determine the effects of gender, age, and pathology on ligament fiber elongation across positions.

RESULTS: The average (±SD) lengths of the F_1, F_2, and F_3 fibers in the neutral position were 4.9±1.0mm, 5.4±1.4mm, 6.4±1.2mm respectively. The F_1, F_2, and F_3 fibers elongated significantly during jar grasp, jar twist, abduction, and extension; they shortened during adduction; and, they did not change significantly during key pinch and during flexion (Fig. 3 & 4).

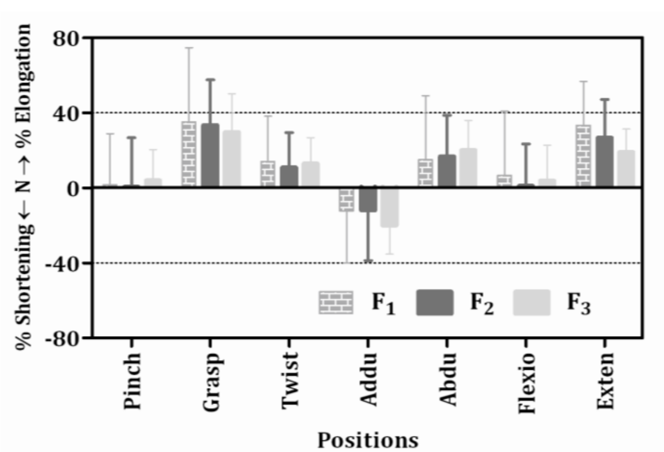

Figure 3. Mean (±SD) AOL fiber (F_1, F_2, F_3) elongations (%) across the three tasks and the four range of motion positions.

Age, gender, and pathology did not have an effect on ligament fiber elongation across positions.

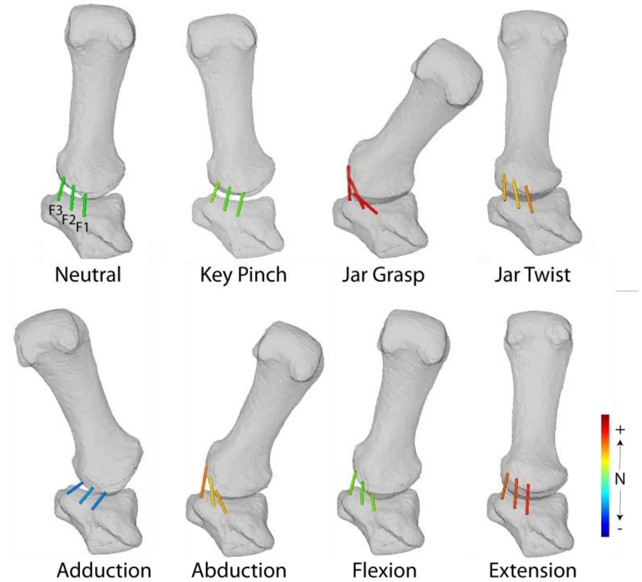

Figure 4. The beak ligament was modeled as three fibers (F_1, F_2, F_3) running from origin of the ligament on the trapezium to the insertion site on the metacarpal. Elongation across range of motion positions is colored according to the color map (+40% to -40%).

DISCUSSION: The purpose of this study was to model the elongation of the beak ligament in the CMC joint during thumb range of motion positions and during three functional tasks. Our findings based on 33 subjects suggest that AOL elongation is not higher in either arthritic individuals or populations that are more predisposed to CMC OA (women and older individuals). Our method is limited by the inability to measure true ligament resting length, which hinders the calculation of true ligament strain. Cadaveric studies[3] have reported mean AOL lengths of 9mm, which may suggest that this ligament is not taut in the neutral position scanned here. While it is difficult to attribute our observed elongation to either slackness in the reference position or true strain, elongation, as defined here, is an insightful metric. The magnitude of elongation that we observed during jar grasp, abduction, and extension may be indicative of ligament slackness and general joint laxity in the other positions. This observation is interesting in that it challenges current beliefs on the role of the AOL as a leading CMC joint stabilizer, at least during precision handling tasks.

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