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Specimen Specific, 3D Modeling of the Elbow – Prediction of Strain in the Medial Collateral Ligament

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Abstract— **In this project 3D interactive models of twelve cadaver elbows are developed using the author's kinematic simulation software. The effective flexion-extension axes for each specimen's model are iteratively defined based upon congruent joint motion and individual limits in range-of-motion. Origins and insertions of both parts of the medial collateral ligament are digitized following careful dissection of each specimen. Ligament paths are then defined using cubic B-spline models of the principal fibers of each part, flexion extension motion of each elbow is carried out in real-time and the strain of each fiber model is calculated. Results indicate the existence of two distinct populations of medial collateral ligament – one whose anterior part stretches during flexion of the elbow and the other whose anterior part stretches during extension.**

I. Introduction

The medial aspect of the elbow has two ligamentous attachments that are essential for full elbow function, the anterior bundle of the medial collateral ligament (AMCL) and the posterior bundle of the medial collateral ligament (PMCL). These ligaments make up two of the three parts of the medial collateral ligament of the elbow. The AMCL and PMCL have their origins on the medial epicondyle of the humerus and insert on the ulna. The transverse ligament, the third component of the MCL, has no function since its origin and insertion are on the ulna. Due to the position of the MCL, it is the main stabilizer of the elbow along with the ulnohumeral articulation and the lateral collateral ligament.

The AMCL has been determined to be composed of four bundles: anterior, deep, posterior, and superficial. The PMCL has been shown to be composed of three bundles: inferior, medial, and superior. While the anatomy and biomechanics of the elbow have been thoroughly studied and researched, there is limited data on the strain generated throughout the entire range of motion of the elbow.

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II. Procedure

Thirteen cadaver elbows were investigated (specimens were provided by the Texas Willed Body Program). All muscles and tendons were carefully dissected away, leaving only the biceps tendon insertion on the radius and the capsule and ligaments of the elbow intact. After careful dissection, the origin and insertions of five ligaments were determined: AMCL, PMCL, lateral collateral ligament, annular ligament, and oblique cord. The elbows and their ligaments' origin and insertion points were then digitized into a three dimensional model using a digitizer (MicroScribe-3DX Digitizer; Immersion, San Jose, California) and the programs Spider and KinSim (both developed in the UTMB Department of Orthopedic Surgery and Rehabilitation). This specimen specific modeling allows for better analysis between specimens and versus the literature. One elbow was lost due to digitization failure.

The AMCL and PMCL were created for each specimen using four and three bundles respectively, based upon the definitions in the literature and the digitized origins and insertions.[1] Figure 1 is one of the specimens in the study (#53571) in two views to show the use of control and virtual points to create the ligaments using the outlined origin and insertion points. The green regions are the areas for the AMCL while the blue regions are the areas for the PMCL.

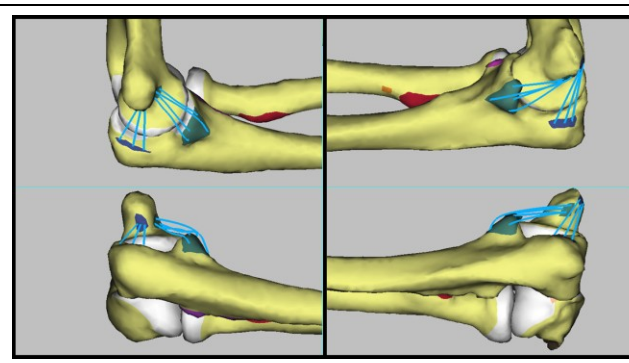

Figure 1. Two views of 2 specimens. On the left a left elbow with an anterior segment that exhibits increasing strain with elbow extension (the ligament path is anterior to the effective axis of motion, thus it lengthens with extension). On the right is a right elbow with increasing strain during flexion (its path is posterior to the effective axis of motion).

Using the KinSim model of each specimen, the effective axis of motion for flexion-extension was adjusted for each specimen by iterative visual positioning during flexion-extension motion (Figure 2). The axis position was optimized based upon congruent motion and limits of range of motion. Each simulated specimen was then rotated through its full range of motion and the fiber lengths for each cubic B-spline path model were recorded. Strain was recorded in percent relative to a reference length when the elbow is at 50^0 (in order to compare with prior work). Data were output to an Excel spread sheet for analysis and **comparison with other results reported in the literature.**

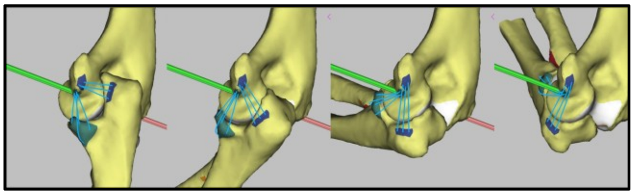

Figure 2. One of the specimens modeled in this study (a right elbow, the specimen on the right in Figure 1) showing four positions from full extension on the left to full flexion after axis identification based upon joint congruence throughout the specimens' range-of-motion. Note that this path is posterior to the effective axis of motion throughout flexion, therefore it undergoes increasing strain as the elbow flexes.

III. Results

Once each specimen's ligaments were created, each specimen was studied to find comparisons between the elbows. Figure 3 shows the variability of the AMCL's and PMCL's origin, insertion, and position of these areas from specimen to specimen. The sizes and shapes of the areas also vary between specimens. Figure 4 shows the average strain in the seven total bundles of the MCL for all twelve specimens. Figure 5 reinforces the variability between specimens as the strain is shown in all seven bundles for elbow 53571L and 53526R respectively. Figure 6 focuses on the anterior AMCL bundle and displays the strain in that bundle for all twelve specimens as well as strain data from two research studies. [2, 3] (Note that Figures 3 through 6 are included after "References" on pages three and four of this manuscript.)

There were two distinct populations of strain in the anterior bundle – one whose fibers stretched in the direction of extension (average strain 7.5% at full extension, -28.04% at full flexion, N = 7) and the other whose fibers stretched in the direction of flexion (avg strains -10.26% at extension and 3.27% at flexion, N = 5). The differences were significant (p=.0009 at extension, p=.0012 at flexion).

IV. Discussion

The strain for all seven bundles was compared between each specimen and against the literature. The location of the origin and insertion of the MCL differ from specimen to specimen (note two representative specimens in Figure 1 and strain data in Figure 5). The variability in origin and insertion regions is supported by data in Figure 6 showing a large strain range of the AMCL generated over the entire range of motion.

This data supports the existence of two distinct populations that differ in their origin and insertion relative to the rotational axis. One population has an AMCL that shortens when the elbow is flexing (strain decreases as the elbow angle increases); in the other the AMCL lengthens when the elbow is flexing (strain increases as the elbow angle increases). This is further supported from the literature as one study[3] demonstrated increasing strain with flexion while another[2] found the opposite for the AMCL (data with standard deviations from both of these studies are shown in Figure 6).

V. Conclusion

The existence of these two anatomical variations in AMCL architecture could have an important impact upon our understanding and treatment of MCL injuries. One or the other of these intrinsic AMCL structures may predispose a definable population for MCL injury and may explain why athletes of similar training and levels of success experience MCL pain and/or injury.

Acknowledgment

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References

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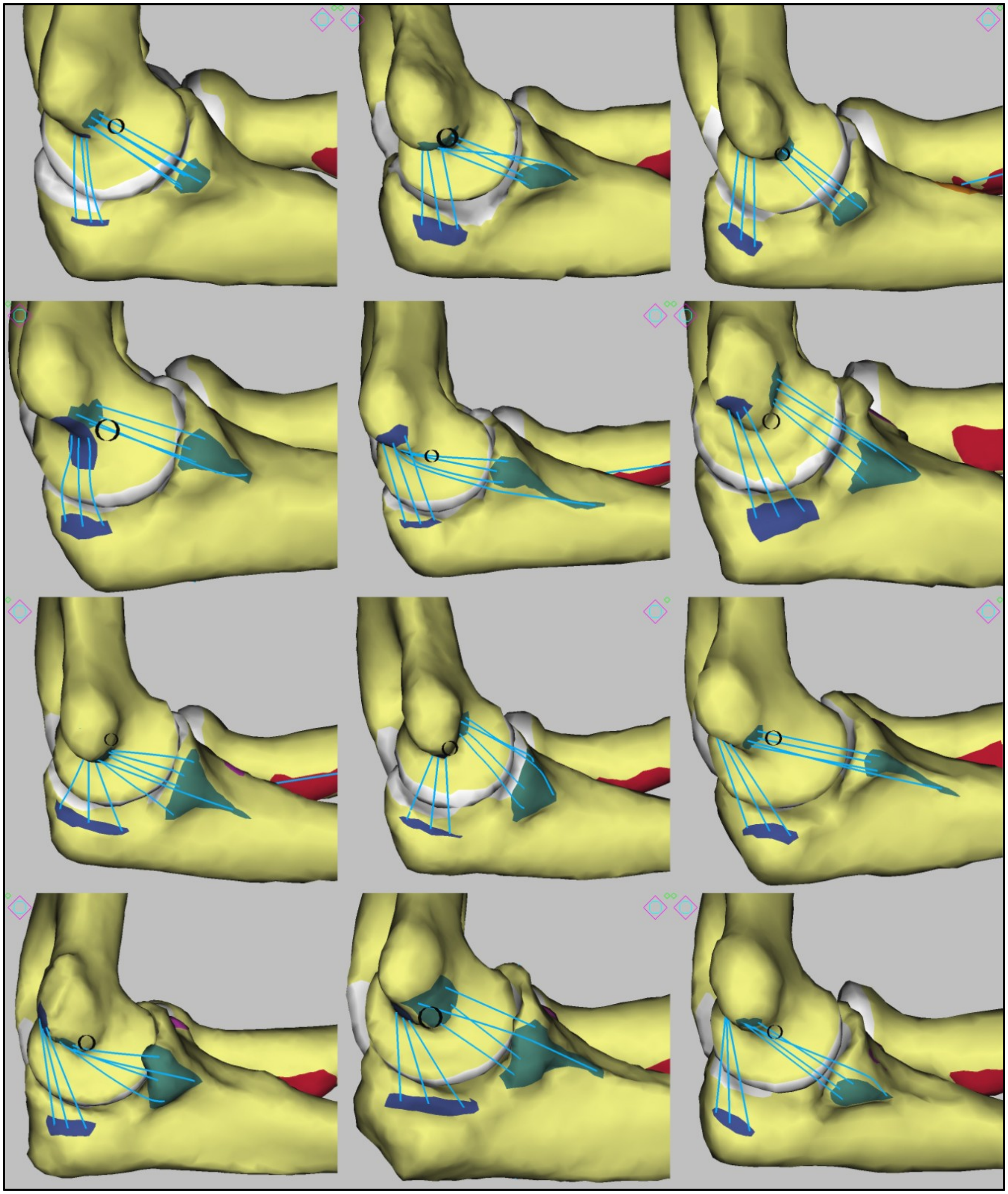

Figure 3, Medial view of all 12 elbows of this study with posterior medial collateral ligament (PMCL) and anterior medial collateral ligament (AMCL) origin and insertion displayed with B-spline ligament models (elbow at 90° and right specimens mirror imaged for comparison). Note the variability in the paths of the AMCL with respect to the effective axis of motion.

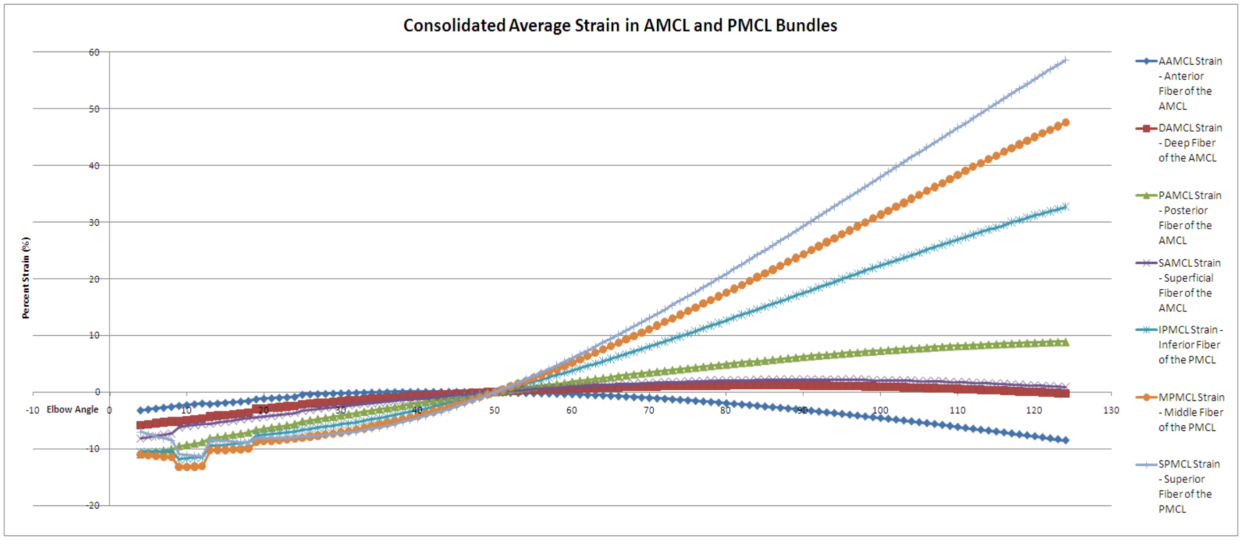

Figure 4. The average strains (n=12) in each bundle of the PMCL and AMCL. The lower three are the strains of the AMCL and are an example of how misleading averages can be (Note especially the tremendous range in individual specimens strain throughout angular range-of-motion indicated in Figures 5 and 6).

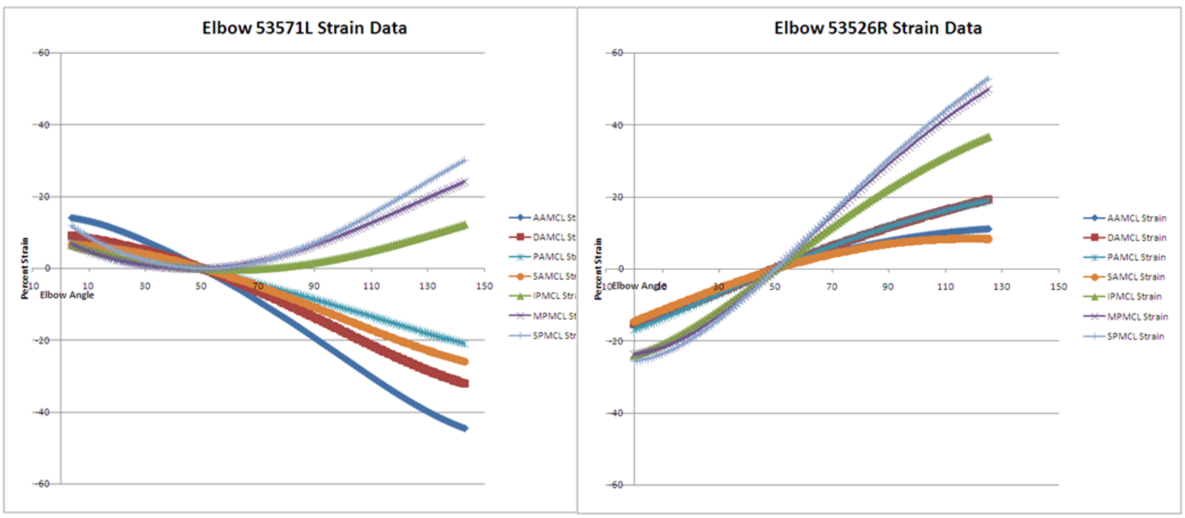

Figure 5. Typical strains in the seven bundles of two elbows illustrating the importance of specimen specific function.

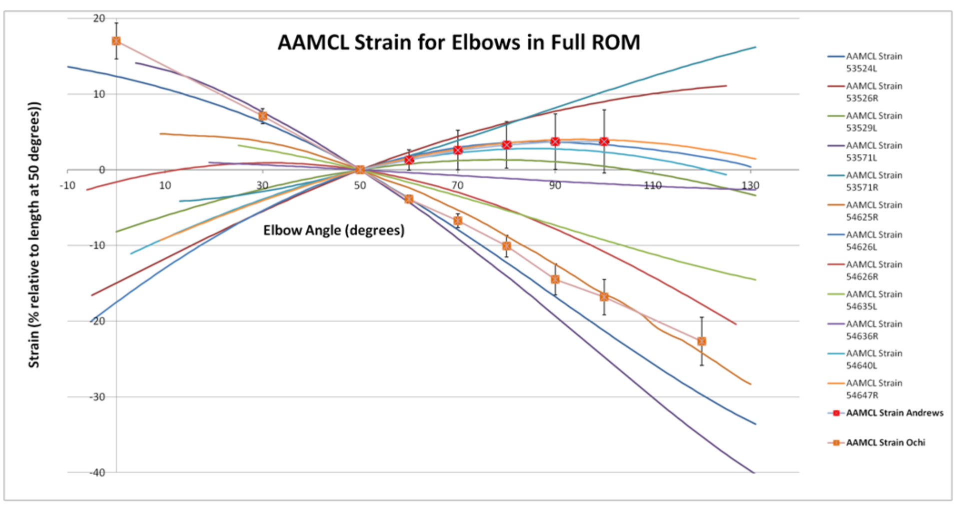

Figure 6. The strain in each of the 12 AMCL ligaments in this study (for each specimen, the four bundles were averaged together) compared to the results of two prior studies in the literature. Taken together the results of the prior two studies and the results reported here support the existence of two distinctly different populations of AMCL.