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Role of the anconeus in the stability of a lateral ligament and common extensor origin–deficient elbow: an in vitro biomechanical study

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Background: The role of the anconeus in elbow stability has been a long-standing debate. Anatomic and electromyographic studies have suggested a potential role as a stabilizer. However, to our knowledge, no clinical or biomechanical studies have investigated its role in improving the stability of a combined lateral collateral ligament and common extensor origin (LCL + CEO)–deficient elbow.
Methods: Seven cadaveric upper extremities were mounted in an elbow motion simulator in the varus position. An injured model was created by sectioning of the CEO and the LCL. The anconeus tendon and its aponeurosis were sutured in a Krackow fashion and tensioned to 10 N and 20 N using a transosseous tunnel. Varus-valgus angles and ulnohumeral rotations were recorded using an electromagnetic tracking system during simulated active elbow flexion with the forearm pronated and supinated.
Results: During active motion, the injured model resulted in a significant increase in varus angulation ($P = .0001$ for pronation; $P = .001$ for supination) and external rotation ($P = .001$ for pronation; $P = .003$ for supination) of the ulnohumeral articulation compared with the intact state. Tensioning of the anconeus significantly decreased the varus angulation ($P = .006$ for 10 N pronation; $P = .0001$ for 20 N pronation; $P = .0001$ for 10 N supination; $P = .0001$ for 20 N supination) and external rotation angle ($P = .008$ for 10 N pronation; $P = .0001$ for 20 N pronation; $P = .0001$ for 10 N supination; $P = .0001$ for 20 N supination) of the injured elbow.
Conclusions: In the highly unstable varus elbow orientation, anconeus tensioning restores the in vitro stability of a combined LCL + CEO–deficient elbow during simulated active motion with the forearm in both pronation and supination. These results may have several clinical implications in managing symptomatic lateral elbow instability.
Level of evidence: Basic Science Study; Biomechanics

Keywords: Anconeus; elbow; instability; lateral collateral ligament; PLRI; kinematics

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Lateral collateral ligament (LCL) injuries are common and can occur concomitantly with simple or complex elbow dislocations and with fractures of the radial head, coronoid, capitellum, or olecranon.[7,16,18-20,35] Concomitant injury to the

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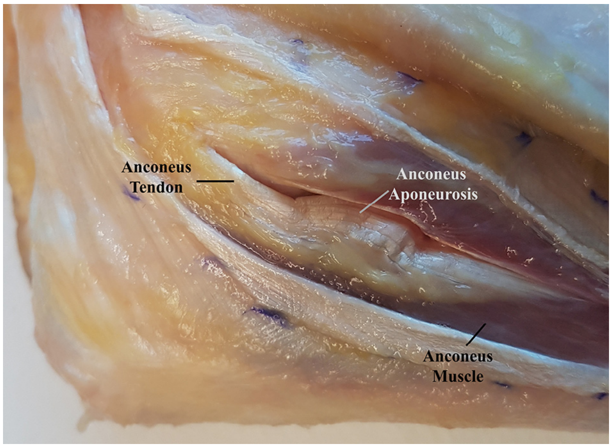

Figure 1 Anconeus tendon/aponeurosis. The anconeus tendon originates from the posterosuperior aspect of the lateral epicondyle and continues as an aponeurosis along the superficial anterior edge of its muscle belly.

common extensor origin (CEO) has been frequently reported in association with elbow dislocations.[23] LCL insufficiency also occurs iatrogenically during surgical procedures on the lateral side of the elbow and as a consequence of repeated steroid injections for the management of lateral epicondylitis.[18] Clinical and biomechanical studies have shown significant varus and posterolateral elbow instability in an LCL-deficient elbow.[5,10,27,29-32] This instability pattern is particularly pronounced with the arm in an abducted (ie, varus) position.[1]

The anconeus is a triangular muscle along the lateral aspect of the elbow. Its tendon arises from the posterosuperior aspect of the lateral epicondyle (Fig. 1).[26,34] This tendon blends into an aponeurosis along the superficial anterior edge of the muscle belly, which continues for approximately 70% of the length of the anterior edge of the muscle.[26,34] Its muscle fibers fan out from the tendon and aponeurosis and attach directly to the posterolateral aspect of the proximal ulna.[26,34]

The role of the anconeus in elbow stability has been a subject of long-standing debate. Anatomic studies have shown that the anconeus aponeurosis runs parallel and adjacent to the LCL and that its muscle fibers are strongly adherent to the lateral joint capsule; thus, suggesting its supplementary role to the LCL in the stabilization of the elbow joint.[26,34] Electromyographic (EMG) studies have also suggested a potential role of the anconeus in elbow joint stabilization.[2,15,33] However, to our knowledge, no biomechanical study has directly investigated the role of the anconeus in the stabilization of a combined LCL + CEO–deficient elbow.

Hence, the purpose of this investigation was to determine whether anconeus loading improves the varus and posterolateral rotatory instability (PLRI) of a combined LCL + CEO–deficient elbow using an in vitro cadaveric elbow motion simulator. We hypothesized that given the anatomic relationship of the anconeus to the LCL, the anconeus loading should improve the varus and posterolateral stability of a combined LCL + CEO–deficient elbow.

Materials and methods

Specimen preparation

Seven fresh frozen cadaveric left upper extremities (mean age at the time of death: 69 ± 8 years) amputated at the forequarter level were used. Computed tomography was performed to rule out preexisting skeletal or articular pathology of the elbow joint. Specimens were stored at –20°C and thawed at room temperature (22° ± 2°C) for 18 hours before testing.

The distal tendons of the biceps brachii, brachialis, brachioradialis, triceps, and pronator teres were sutured in a running locking fashion using braided fishing line (Bravefishermen, Shanghai, China). The distal tendons of the wrist extensors (extensor carpi radialis longus and extensor carpi ulnaris) and the wrist flexors (flexor carpi radialis and flexor carpi ulnaris) were sutured together.

An alignment guide was placed at the medial epicondyle for the passage of the sutures from the pronator teres and wrist flexors. Laterally, an alignment guide was placed at the lateral epicondyle for the suture of the wrist extensors, and an additional alignment guide was secured to the supracondylar ridge to guide the suture of the brachioradialis. The tendon sutures were passed subcutaneously within their respective physiologic compartments to maintain anatomic lines of action of the tendons.

A stainless steel intramedullary humeral mounting rod was inserted into the humeral shaft through the humeral head and cemented with methyl methacrylate bone cement (Stryker, Kalamazoo, MI, USA). This rod was rigidly mounted into a custom clamp on the base of the elbow motion simulator (Fig. 2). All sutures were connected by stainless steel cables to 3 computer-controlled servomotors (for each of biceps brachii, brachialis, and triceps) and 4 pneumatic actuators (for the remaining tendons).

Experimental simulation and testing protocol

A custom-designed LabVIEW program (National Instruments, Austin, TX, USA) was used to control tension and unloading of relevant muscles. Simulated active elbow flexion with the forearm pronated or supinated was prescribed at a rate of 10°/s based on previously established protocols that have been validated with this simulator.[8,9,12,17] During active motion, a 10-N load was applied to the wrist extensors and the wrist flexors to stabilize the wrist in a neutral position. The simulator base was positioned with the arm in the varus position (Fig. 2).

Before testing, 5 simulated active preconditioning cycles of elbow flexion and extension with the forearm maintained in both pronation and supination were performed. During testing, 2 trials were conducted for each active motion, and the average values were used for analysis.

Testing was first conducted for the control state. Dissection was performed through the Kocher interval to expose the anconeus tendon and its aponeurosis. The anconeus tendon was released from its attachment onto the posterior aspect of the lateral epicondyle (Fig. 3). An injured state was then simulated by further sectioning of the CEO and the humeral attachment of the LCL off the lateral epicondyle (Fig. 4). For the anconeus tensioned states, the anconeus tendon and

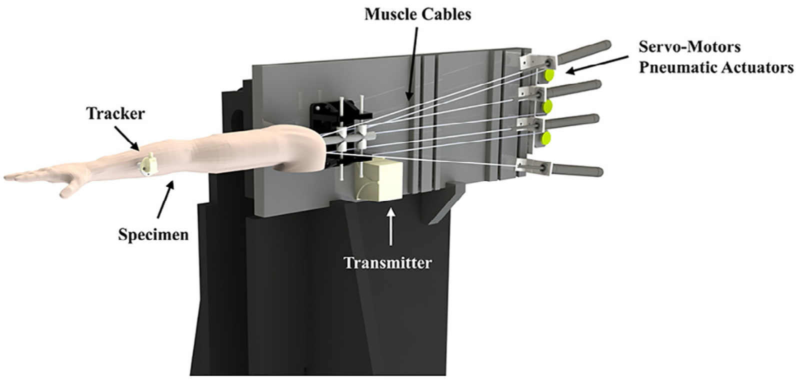

Figure 2 The active elbow motion simulator allows for simulated active elbow flexion-extension using a combination of computer-controlled servomotors and pneumatic actuators. The arm is rigidly connected to the simulator base by a humeral clamp. A transmitter on the humeral base and an electromagnetic tracker fixed to the ulna record ulnohumeral kinematics during elbow motion. The simulator allows placement of the arm in the varus position. Adapted from Ferreira L.M., Johnson J.A., King G.J. Development of an active elbow flexion simulator to evaluate joint kinematics with the humerus in the horizontal position. J Biomech 2010;43:2115.

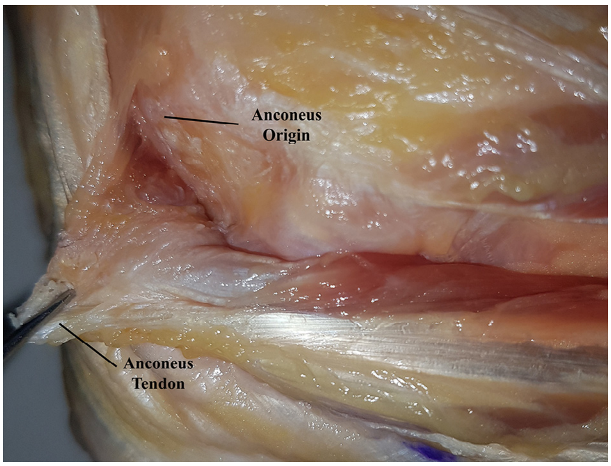

Figure 3 The anconeus tendon was detached from its origin along the posterosuperior aspect of the lateral epicondyle.

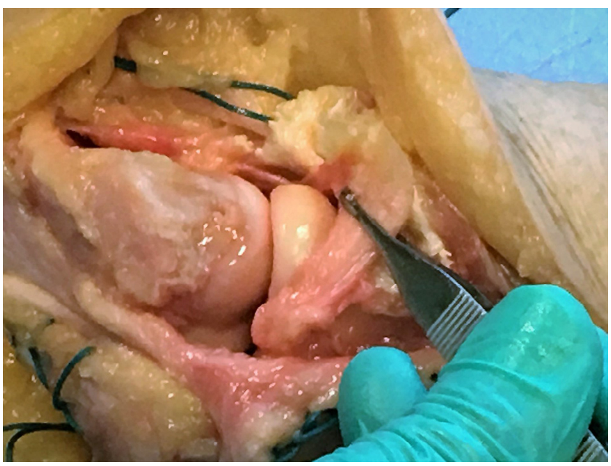

Figure 4 The injured state was created by sectioning of the common extensor origin and the lateral collateral ligament off their origin at the lateral epicondyle.

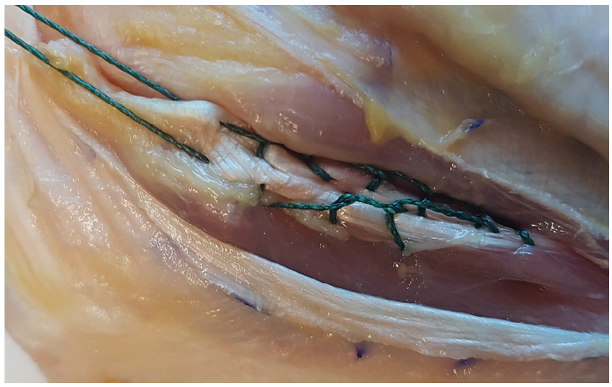

Figure 5 The anconeus tendon and its aponeurosis were sutured in a running locking Krackow fashion.

its aponeurosis were sutured in a running locking Krackow fashion (Fig. 5). A transosseous tunnel was drilled through the lateral epicondyle at the site of origin of the anconeus tendon, and the repair suture was passed through this tunnel (Fig. 6). The repair suture was connected to a load cell. A suture was also tied to the other end of the load cell and manually pulled to the desired tension. Once reached, the suture was locked in place using a custom clamping mechanism. The anconeus tendon was tensioned to 10 N and 20 N.

Kinematic data were recorded using the Flock of Birds electromagnetic tracking system (Ascension Technologies, Burlington, VT, USA) that has been previously shown to have adequate positional and rotational accuracy with this simulator.[9,12,17,25] The ulnar tracker was mounted on the subcutaneous border of the ulna using 3.5-mm cortical screws. The transmitter on the simulator base recorded the location of the tracker on the ulna throughout testing. Upon completion of the testing protocol, the elbow and wrist were disarticulated for digitization. A Delrin stylus attached to a second receiver was used to determine the humeral and ulnar coordinate systems. The relative motion of the ulna relative to the humerus was established using the Euler *Z-Y-X* sequence. Varus instability was quantified by varus-valgus angulation, and posterolateral instability was quantified by internal-external rotation of the ulna relative to the humerus.

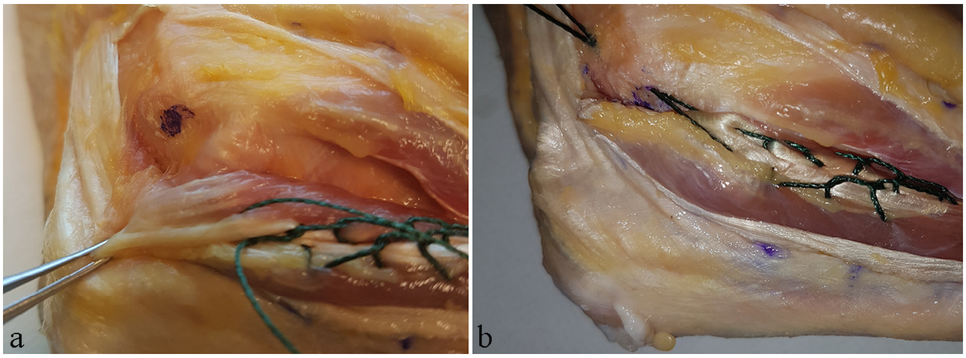

Figure 6 Photographs show (**A**) the site of origin of the anconeus tendon where a transosseous tunnel was drilled and (**B**) the passage of anconeus repair suture through the transosseous tunnel.

Statistical methods

The data were analyzed at 10° increments from 0° to 130° arc of active flexion with the forearm in both pronation and supination. A repeated-measures analysis of variance was performed to compare elbow states (control, injured, 10-N anconeus loading, and 20-N anconeus loading). Statistical significance was set at $\alpha = .05$.

Results

During active motion, the injured model resulted in a significant increase in varus angulation (5.3° ± 2.9°, $P = .0001$ in pronation; 3.5° ± 3.4°, $P = .001$ in supination) and external rotation (ER; 8.6° ± 5.8°, $P = .001$ in pronation; 7.1° ± 6.1°, $P = .003$ in supination) of the ulnohumeral articulation compared with the control state (varus angle: –2.8° ± 3.4° in pronation, –3.3° ± 3.2° in supination; ER angle: 2.1° ± 5.6° in pronation, 1.6° ± 5.8° in supination; Table I, Figs. 7-10).

Tensioning of the anconeus significantly decreased the varus angulation (–1.2° ± 4.5°, $P = .006$ for 10 N in pronation; –3.9° ± 4.0°, $P = .0001$ for 20 N in pronation; –4.3° ± 4.0°, $P = .0001$ for 10 N in supination; –5.3° ± 4.2°, $P = .0001$ for 20 N in supination) and ER angle (2.6° ± 4.5°, $P = .008$ for 10 N in pronation; 0.3° ± 5.0°, $P = .0001$ for 20 N in pronation; 0.1° ± 5.3°, $P = .0001$ for 10 N in supination; –0.8° ± 5.3°, $P = .0001$ for 20 N in supination) of the injured elbow (Table I, Figs. 7-10). Comparing anconeus tensioning to the control state, there was no significant difference in varus-valgus angulation except with anconeus tensioning to 20 N with the forearm in supination, which resulted in less varus angulation ($P = 1.000$ for 10 N in pronation, $P = .267$ for 20 N in pronation, $P = .604$ for 10 N in supination, $P = .030$ for 20 N in supination; Table II, Figs. 7 and 8). Although there were statistically significant differences in ulnohumeral rotation between anconeus tensioning and the control state (except with anconeus tensioning to 10 N with the forearm in pronation, which was not significantly different), anconeus tensioning resulted in decreased external rotation angle compared with the control state ($P = 1.000$ for 10 N in pronation, $P = .020$ for 20 N in pronation, $P = .033$ for 10 N

Table I Impact of anconeus tensioning relative to the injured state on varus and posterolateral elbow stability during active motion with the arm in the varus position

Variable	Forearm position	Angulation, mean ± SD, °				P^*	$P^\dagger$	$P^\ddagger$
		Control	Injured	Anconeus 10 N	Anconeus 20 N			
Varus-valgus angulation[§]	Pronation	−2.8 ± 3.4	5.3 ± 2.9	−1.2 ± 4.5	−3.9 ± 4.0	.0001[¶]	.006[¶]	.0001[¶]
	Supination	−3.3 ± 3.2	3.5 ± 3.4	−4.3 ± 4.0	−5.3 ± 4.2	.001[¶]	.0001[¶]	.0001[¶]
Ulnohumeral rotation[‖]	Pronation	2.1 ± 5.6	8.6 ± 5.8	2.6 ± 4.5	0.3 ± 5.0	.001[¶]	.008[¶]	.0001[¶]
	Supination	1.6 ± 5.8	7.1 ± 6.1	0.1 ± 5.3	−0.8 ± 5.3	.003[¶]	.0001[¶]	.0001[¶]

SD, standard deviation; *ANOVA*, analysis of variance.
* Describes the significance of elbow state (between injured and control state) as the result of a 2-way ANOVA with elbow state and flexion angle.
† Describes the significance of elbow state (between anconeus 10 N and injured state) as the result of a 2-way ANOVA with elbow state and flexion angle.
‡ Describes the significance of elbow state (between anconeus 20 N and injured state) as the result of a 2-way ANOVA with elbow state and flexion angle.
§ Positive values indicate varus angulation and negative values indicate valgus angulation.
‖ Positive values indicate external rotation and negative values indicate internal rotation.
¶ Indicates significance ($P < .05$).

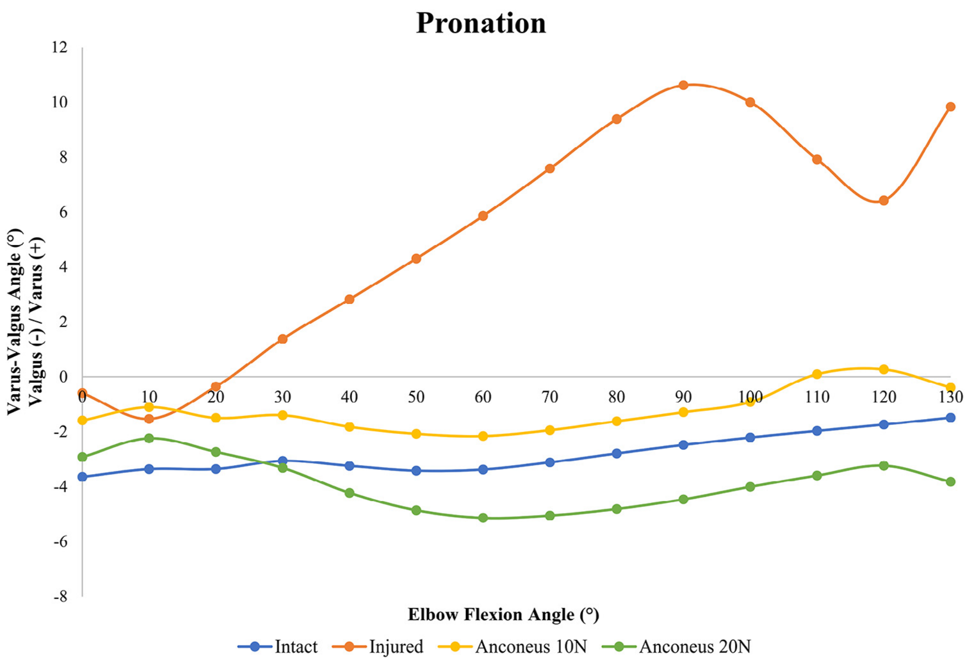

Figure 7 Varus-valgus angulation during active elbow flexion with the forearm in pronation. Positive values indicate varus angulation, and negative values indicate valgus angulation. The standard deviations (omitted from the graph for clarity) ranged from 2.9° to 4.5°.

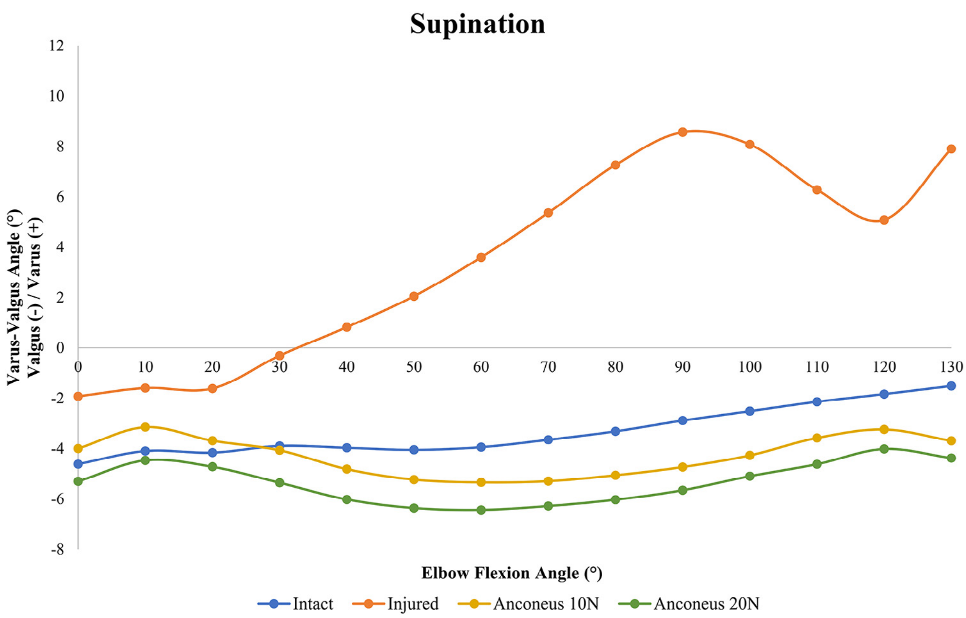

Figure 8 Varus-valgus angulation during active elbow flexion with the forearm in supination. Positive values indicate varus angulation, and negative values indicate valgus angulation. The standard deviations (omitted from the graph for clarity) ranged from 3.2° to 4.2°.

in supination, $P = .001$ for 20 N in supination; Table II, Figs. 9 and 10).

Discussion

Symptomatic lateral elbow instability is an important clinical problem due to the frequency of LCL/combined LCL + CEO injuries as the result of trauma or iatrogenic injuries. This biomechanical investigation demonstrates that anconeus tensioning restores the varus and posterolateral stability of a combined LCL + CEO–deficient elbow in the highly unstable varus arm position during active motion with the forearm in both pronation and supination. Interestingly, there was a significant difference in varus-valgus angulation between 20-N anconeus tensioning with the forearm supinated and the control state, with less varus angulation for the anconeus tensioning, which suggests that loads less

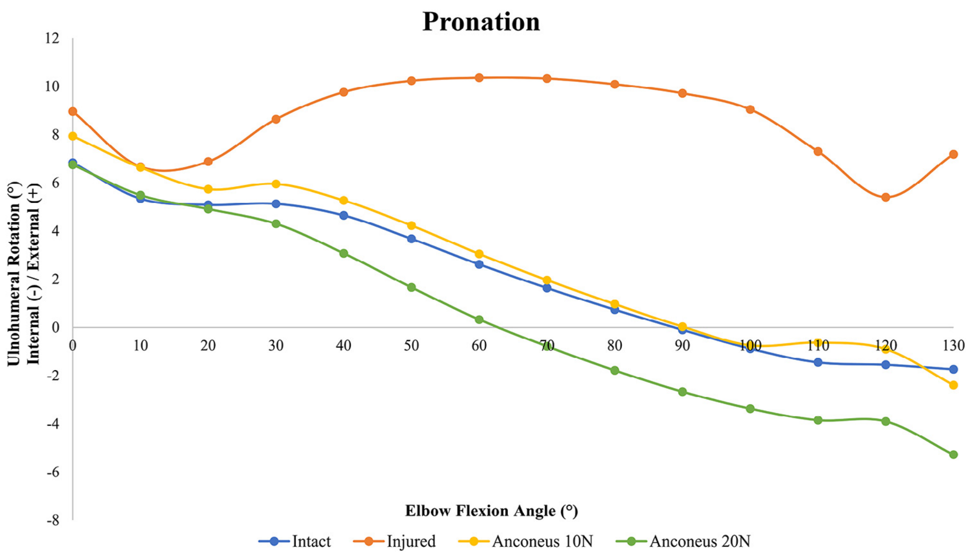

Figure 9 Ulnohumeral rotation during active elbow flexion with the forearm in pronation. Positive values indicate external rotation, and negative values indicate internal rotation. The standard deviations (omitted from the graph for clarity) ranged from 4.5° to 5.8°.

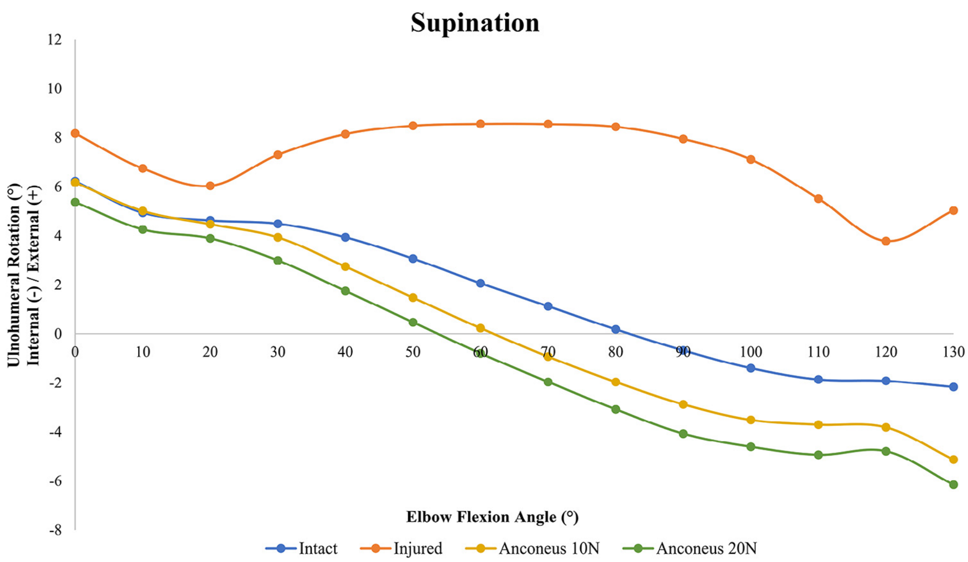

Figure 10 Ulnohumeral rotation during active elbow flexion with the forearm in supination. Positive values indicate external rotation, and negative values indicate internal rotation. The standard deviations (omitted from the graph for clarity) ranged from 5.3° to 6.1°.

than 20 N are sufficient to restore varus stability during active motion with the forearm supinated. Similarly, the significant difference observed in ulnohumeral rotation between anconeus tensioning and the control state suggests that lesser degrees of anconeus tensioning would be sufficient to restore the posterolateral instability of a combined LCL + CEO–deficient elbow.

The contribution of the anconeus to elbow stability has been a long-standing debate. Previous biomechanical studies have demonstrated the importance of the lateral extensor musculature, their fascial bands, and intermuscular septa, in addition to the LCL complex, to lateral stability of the elbow joint.[4,5,11,28] The degree of injury to these secondary stabilizers is correlated with the significance of the elbow instability.[5,20] Although the anconeus has been speculated to play an important role as a dynamic constraint to varus and posterolateral rotatory instability, to our knowledge, this has not been scientifically investigated in any previous publication.[4,5,21] Thus, no data are available for comparison. A recent study using EMG and finite element analysis concluded that the anconeus does not significantly contribute to the kinematic stability of an intact elbow.[24] Although our biomechanical investigation did not directly investigate the contribution of the anconeus to the stability of the intact elbow, we speculate that this role would be negligible because the intact elbow is stabilized by the congruency of the ulnohumeral articulation, collateral ligaments, and dynamic muscle stabilizers.

Table II Impact of anconeus tensioning relative to the control state on varus and posterolateral elbow stability during active motion with the arm in the varus position

Variable	Forearm position	Angulation, mean ± SD, °				P*	P†	P‡
		Control	Injured	Anconeus 10 N	Anconeus 20 N			
Varus-valgus angulation§	Pronation	−2.8 ± 3.4	5.3 ± 2.9	−1.2 ± 4.5	−3.9 ± 4.0	.0001¶	1.000	.267
	Supination	−3.3 ± 3.2	3.5 ± 3.4	−4.3 ± 4.0	−5.3 ± 4.2	.001¶	.604	.030¶
Internal-external rotation‖	Pronation	2.1 ± 5.6	8.6 ± 5.8	2.6 ± 4.5	0.3 ± 5.0	.001¶	1.000	.020¶
	Supination	1.6 ± 5.8	7.1 ± 6.1	0.1 ± 5.3	−0.8 ± 5.3	.003¶	.033¶	.001¶

SD, standard deviation; *ANOVA*, analysis of variance.
* *P* values describe the significance of elbow state (between injured and control state) as the result of a 2-way ANOVA with elbow state and flexion angle.
† *P* values describe the significance of elbow state (between anconeus 10 N and control state) as the result of a 2-way ANOVA with elbow state and flexion angle.
‡ *P* values describe the significance of elbow state (between anconeus 20 N and control state) as the result of a 2-way ANOVA with elbow state and flexion angle.
§ Positive values indicate varus angulation and negative values indicate valgus angulation.
‖ Positive values indicate external rotation and negative values indicate internal rotation.
¶ Indicates significance ($P < .05$).

We are not aware of any clinical study that has investigated the forces that are generated in the anconeus during active motion. However, previous EMG-based studies have estimated the forces that are generated during maximum voluntary contraction.[14,22] Based on these results, generation of 10 N or 20 N of anconeus force is not unexpected.

Our study has some limitations. As mentioned previously, the loads generated in the anconeus muscle during active elbow and forearm range of motion in vivo are unknown. We decided to use 10 N and 20 N of anconeus loading because previous biomechanical studies from our laboratory have shown that LCL loading of less than 20 N was sufficient to stabilize the elbow.[13] Because the anconeus tendon lies adjacent and parallel to the LCL, we assumed that similar anconeus loads may be required in an LCL-deficient elbow. Moreover, previous EMG studies have shown that generation of these loads in the anconeus is not unexpected.

The results of this biomechanical investigation have several clinical implications. Our results suggest that strengthening of the anconeus may play a role in improving the varus and posterolateral instability of a combined LCL + CEO deficient elbow. Previous EMG studies have shown that the anconeus is active during resisted elbow extension and resisted forearm pronation.[3,24,33,36] Thus, isometric elbow extension and forearm pronation exercises may play a role in patients with symptomatic varus and posterolateral instability. These exercises may also play a role in reducing the “sagging” of the elbow joint in patients with radiographic drop sign after an elbow dislocation.[6]

Finally, our results may have implications in the surgical approaches used in the management of patients with preexisting elbow instability secondary to LCL injury. In such cases, the origin of the anconeus tendon and its innervation should likely be protected.

Conclusions

Although previous studies have speculated that the anconeus may play a role in elbow stability, no clinical or biomechanical studies have investigated its role in improving the varus and posterolateral instability of a combined LCL + CEO–deficient elbow. This cadaveric biomechanical study demonstrates that anconeus loading restores the in vitro stability of a combined LCL + CEO–deficient elbow in the highly unstable varus arm position.

Disclaimer

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