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Anatomy and Biomechanics of the Elbow

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A sound understanding of elbow anatomy and biomechanics is necessary to treat common traumatic conditions of the elbow. Combined or isolated injury to vital osseous and soft tissue structures of the elbow joint affects stability. Much work has been accomplished to identify and define the function of the key primary and secondary constraints of the elbow. Biomechanical studies investigating the effect of injury to these structures guide diagnosis and treatment of elbow trauma.

Stability of the elbow is provided by a "fortress" of static and dynamic constraints [1]. The three primary static constraints include the ulnohumeral articulation, the anterior bundle of the medial collateral ligament (MCL), and the lateral collateral ligament (LCL) complex (Fig. 1). If these three structures are intact, the elbow is stable. Secondary constraints include the radiocapitellar articulation, the common flexor tendon, the common extensor tendon, and the capsule. Muscles that cross the elbow joint are the dynamic stabilizers [1]. This article provides a summary of key concepts that are relevant for understanding common elbow injuries. Basic elbow anatomy is presented first, followed by a review of important biomechanical principles.

Elbow anatomy

Osteoarticular anatomy

The articular surfaces of the elbow joint provided by the distal humerus, the proximal ulna, and the proximal radius are highly irregular and congruent providing inherent osseous stability. The elbow has been called the trochleogingylomoid joint for the hinged (ginglymoid) motion in flexion and extension at the ulnohumeral and radiocapitellar articulations and radial (trochoid) motion in pronation and supination at the proximal radioulnar joint [2].

The distal humerus provides the proximal articular surface of the elbow comprising the trochlea and capitellum (Fig. 2A). The spool-shaped trochlea is centered over the distal humerus in line with the long axis of the humeral shaft. The medial ridge of the trochlea is more prominent than the lateral ridge, which causes 6° to 8° of valgus tilt at its articulation with the greater sigmoid notch of the proximal ulna [3]. The hemispheric-shaped capitellum is lateral to the trochlea and articulates with the concave articular surface of the radial head.

The radial head is important as a secondary stabilizer of the elbow (Fig. 2B). The concave surface of the radial head articulates with the capitellum, whereas the rim of the radial head articulates with the lesser sigmoid notch. Articular cartilage covers the concave surface and an arc of approximately 280° of the rim. Displaced fractures of the radial head can be repaired by screw fixation at the remaining 80° of rim not covered by cartilage [3]. The radial head is not perfectly circular and is variably offset from the axis of the neck, which has important implications in reconstruction of the radial head [4,5].

The highly congruent surfaces of the proximal ulna and trochlea form one of the primary constraints of the elbow joint (Fig. 2C). The sagittal ridge of the greater sigmoid notch runs longitudinally and articulates with the apex of the trochlea.

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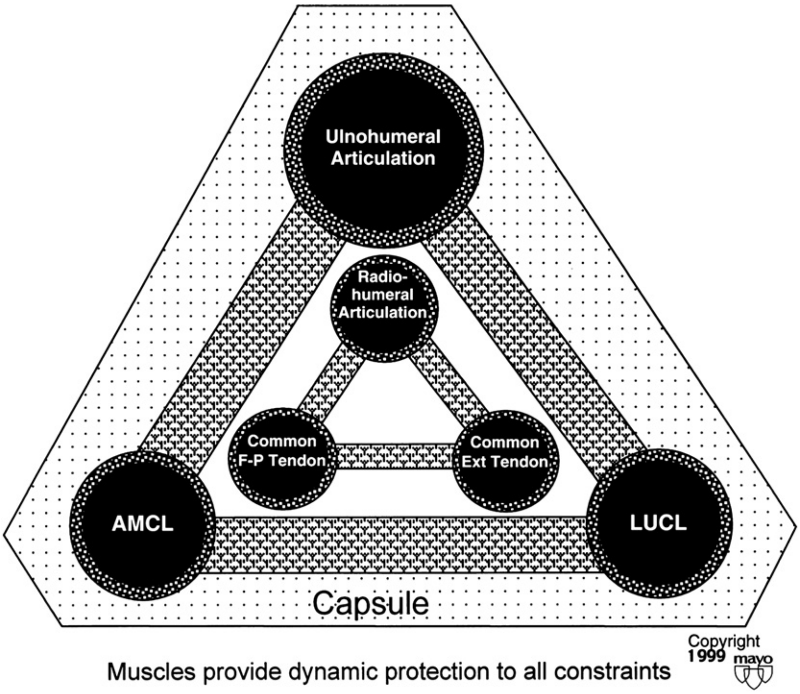

Fig. 1. The "fortress" of static and dynamic constraints to elbow instability. The three primary constraints are the ulnohumeral articulation, the anterior bundle of the medial collateral ligament (AMCL), and the lateral collateral ligament, especially the ulnar part known as the lateral ulnar collateral ligament (LUCL). The secondary constraints are the radiohumeral articulation, the common flexor-pronator (F-P) tendon, the common extensor tendon, and the capsule. The muscles that cross the elbow are the dynamic constraints. (*From* O'Driscoll SW, Jupiter JB, King GJ, et al. The unstable elbow. Instr Course Lect 2001;50:91; with permission.)

The concavities that are medial and lateral to the sagittal ridge complement the convex medial and lateral faces of the trochlea. The lesser sigmoid notch articulates with the rim of the radial head. Osseous stability is enhanced in flexion when the coronoid process locks into the coronoid fossa of the distal humerus, and the radial head is contained in the radial fossa of the distal humerus (see Fig 2A). Osseous stability is enhanced in extension when the tip of the olecranon rotates into the olecranon fossa [6]. The sublime tubercle is the attachment site for the anterior bundle of the MCL.

Capsuloligamentous anatomy

The inherent bony stability together with the capsuloligamentous stabilizers provides the static constraints of the elbow. The static soft tissue stabilizers include the anterior and posterior joint capsule and the medial and LCL complexes. The collateral ligament complexes are medial and lateral capsular thickenings [6].

The capsule attaches along the articular margin of the elbow. The anterior capsule extends proximally above the coronoid and radial fossae, distally to the edge of the coronoid process, and laterally to the annular ligament. The posterior capsule attaches proximally above the olecranon fossa, distally along the medial and lateral articular margins of the greater sigmoid notch, and laterally becomes continuous with the annular ligament. The capsule becomes taut anteriorly when the elbow is extended and posteriorly when the elbow is flexed. Intra-articular pressure is lowest at 70° to 80° of flexion. When fully distended at 80° of flexion, the capacity of the elbow is 25 to 30 mL [7,8]. The capsule provides most of its stabilizing effects with the elbow extended [9].

The MCL complex consists of three components: the anterior bundle or anterior MCL (AMCL), the posterior bundle, and the transverse ligament (Fig. 3). The origin of the MCL is at the anteroinferior surface of the medial epicondyle. The anterior bundle is the most discrete structure

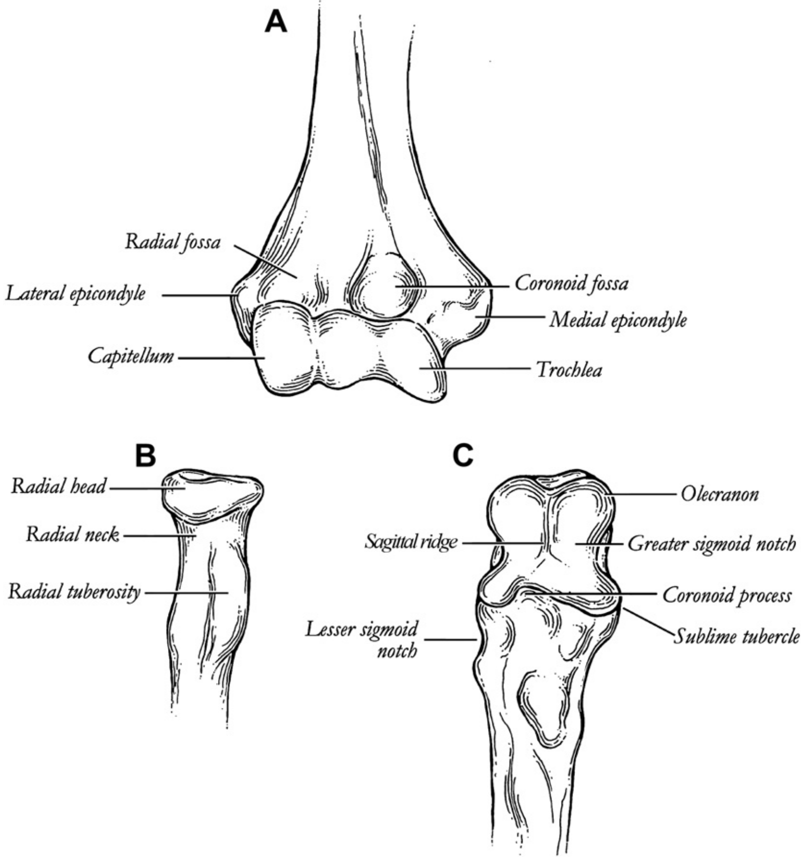

Fig. 2. Osseous elbow anatomy. (*A*) Distal humerus. (*B*) Proximal radius. (*C*) Proximal ulna. (*Adapted from* Armstrong AD, King GJ, Yamaguchi K. Total elbow arthroplasty design. In: Williams GR, Yamaguchi K, Ramsey ML, et al, editors. Shoulder and elbow arthroplasty. Philadelphia: Lippincott Williams & Wilkins; 2005. p. 301; with permission.)

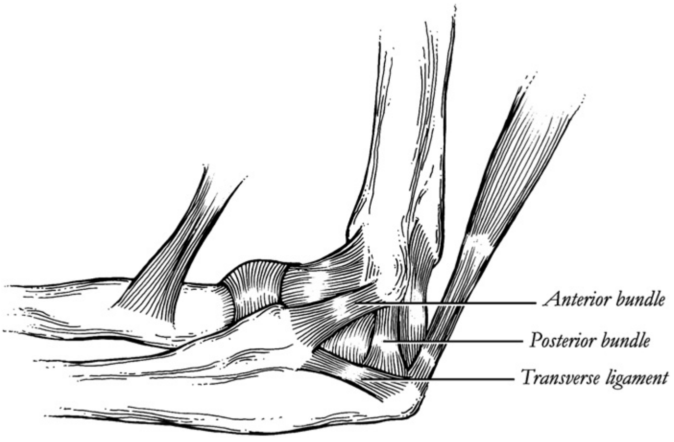

Fig. 3. The medial collateral ligament complex. (*From* Armstrong AD, King GJ, Yamaguchi K. Total elbow arthroplasty design. In: Williams GR, Yamaguchi K, Ramsey ML, et al, editors. Shoulder and elbow arthroplasty. Philadelphia: Lippincott Williams & Wilkins; 2005. p. 303; with permission.)

of the complex and inserts on the anteromedial aspect of the coronoid process, the sublime tubercle. In this position the AMCL is able to provide significant stability against valgus force, making it one of the primary static constraints of the elbow [6]. The anterior bundle is further divided into anterior and posterior bands [10–12]. Some authors include a third central band [13,14]. The posterior bundle is more of a thickening of the capsule rather than a distinct ligament and inserts on the medial olecranon [11]. The transverse ligament runs between the coronoid and the tip of the olecranon and consists of horizontally oriented fibers that often cannot be separated from the capsule. It is believed that the transverse ligament does not contribute significantly to joint stability [12].

The LCL complex consists of four components, including the radial collateral ligament, the lateral ulnar collateral ligament, the annular ligament, and the accessory collateral ligament (Fig. 4). The LCL complex originates along the inferior surface of the lateral epicondyle. The annular ligament attaches to the anterior and posterior margins of the lesser sigmoid notch. The lateral ulnar collateral ligament is one of the primary elbow constraints because it provides varus and posterolateral stability by its insertion distal to the posterior attachment of the annular ligament on the crista supinatoris [15]. The radial collateral ligament inserts into the annular ligament and stabilizes the radial head [6]. The accessory collateral ligament has attachments at the annular ligament and the crista supinatoris.

Muscles

Muscles that cross the elbow joint provide dynamic stabilization to the elbow joint and protect the static constraints. Four groups of muscles cross the elbow: elbow flexors, elbow extensors, forearm flexor-pronators, and forearm extensors. Each muscle that crosses the elbow applies a compressive load to the joint when contracted. Only a few of the muscles that cross the joint act primarily to move the joint, however. The biceps, brachialis, and brachioradialis flex the elbow. The biceps is also the principal supinator of the forearm. The triceps is the main elbow extensor. Although anconeus likely plays a minor role in elbow extension, it is thought to act as a dynamic constraint to varus and posterolateral rotatory instability [6].

Elbow biomechanics

Kinematics

Together with the shoulder, the elbow acts to position the hand in space. Compared to the shoulder, which has a large range of motion in all three axes of rotation, elbow range of motion is relatively constrained.

Flexion-extension

The normal range of elbow motion in flexion and extension is approximately 0° to 140°, with a range of 30° to 130° required for most activities of daily living [16–18]. The flexion-extension axis of the elbow has been described as a loose hinge. Understanding this concept is important in the design and application of endoprostheses, dynamic external fixators, and ligament reconstruction [19–23]. Variation of the flexion axis throughout range of motion is often described in terms of the screw displacement axis (SDA), which shows the

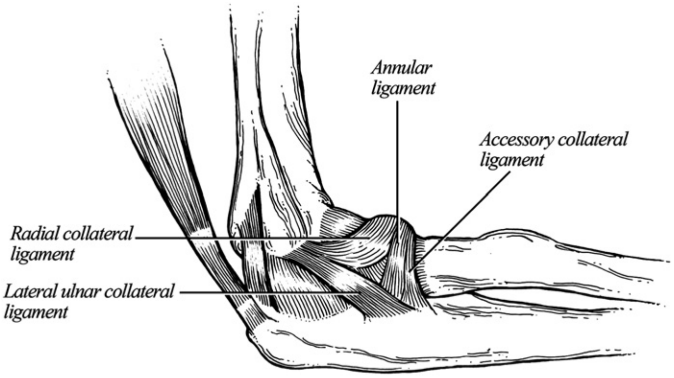

Fig. 4. The lateral collateral ligament complex. (*Adapted from* Armstrong AD, King GJ, Yamaguchi K. Total elbow arthroplasty design. In: Williams GR, Yamaguchi K, Ramsey ML, et al, editors. Shoulder and elbow arthroplasty. Philadelphia: Lippincott Williams & Wilkins; 2005. p. 303; with permission.)

instantaneous rotation and position of the axis throughout flexion. The average SDA has been shown to be in line with the anteroinferior aspect of the medial epicondyle, the center of the trochlea, and the center projection of the capitellum onto a parasagittal plane. One study demonstrated that throughout normal elbow range of motion the instantaneous SDA varies by approximately 3° to 6° in orientation and 1.4 to 2.0 mm in translation [19]. The flexion axis also has been shown to vary with forearm pronation and supination and passive and active movement (Fig. 5) [20]. The average flexion axis of the elbow is oriented at approximately 3° to 5° of internal rotation in relation to the plane of the medial and lateral epicondyles and in 4° to 8° of valgus relative to the long axis of the humerus [6].

Pronation-supination

The radiocapitellar and proximal radioulnar joints of the elbow allow for pronation and supination of the forearm. The normal range of forearm rotation is 180° with pronation of 80° to 90° and supination of approximately 90° [16,24]. Most activities of daily living can be accomplished with 100° of forearm rotation (50° of pronation and 50° of supination) [17]. Although loss of forearm pronation can be compensated to a certain extent by shoulder abduction, there are no effective mechanisms to replace supination [24].

The normal axis of forearm rotation runs from the center of the radial head to the center of the distal ulna [25,26]. It has been stated that axis of rotation is constant and independent of elbow flexion or extension [25]. More recently, however, it

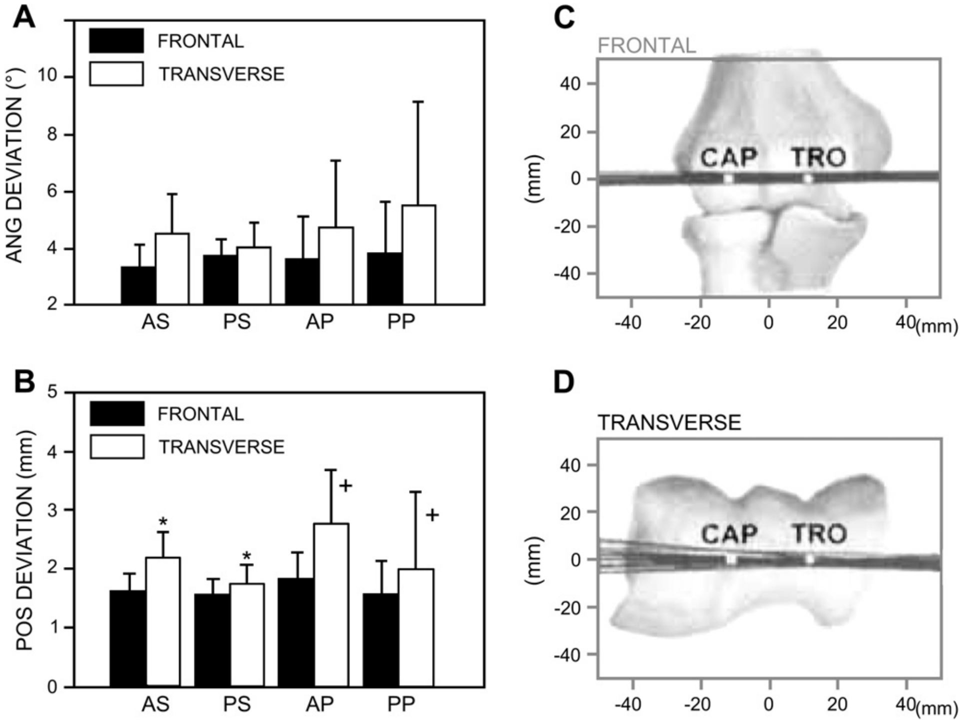

Fig. 5. The flexion axis of the elbow is a loose hinge. The angular (ANG) deviation (*A*) and positional deviation (*B*) for elbow SDAs in the frontal and transverse planes are plotted for the actively and passively flexed elbow with forearm pronation and supination. AS, active supinated; PS, passive supinated; AP, active pronated; PP, passive pronated. Angular deviation is defined as the standard deviation in orientation of all SDAs measured throughout flexion. Positional deviation is defined as the standard deviation in position of all SDAs measured throughout flexion with respect to the humeral origin (the spherical and circular centers of the capitellum and trochlea, respectively). Paired symbols (* and +) represent significant differences. *C* and *D* show the SDAs for a single specimen. CAP, capitellum; TRO, trochlea. (*From* Duck TR, Dunning CE, King GJ, et al. Variability and repeatability of the flexion axis at the ulnohumeral joint. J Orthop Res 2003;21(3):401; with permission.)

was shown that the axis of rotation shifts slightly ulnar and volar during supination and shifts radial and dorsal during pronation [26]. The radius also moves proximally with pronation of the forearm and distally with supination [27].

Forearm rotation plays an important role in stabilizing the elbow, especially when the elbow is moved passively. With passive flexion, the MCL-deficient elbow is more stable in supination, whereas the LCL-deficient elbow is more stable in pronation (Figs. 6 and 7) [28–30]. Research also has shown that the elbow is more stable in supination than in pronation in the setting of coronoid fractures that involve more than 50% of the coronoid with or without an intact MCL [31]. Another study tested valgus laxity with pronated, supinated, and neutral forearm rotation when the AMCL was intact and severed. It was shown that forearm pronation and supination decreased valgus laxity compared with the neutral forearm position. It was postulated that proximal radial head migration with forearm pronation may increase the joint reaction force at the radiocapitellar articulation, thus increasing valgus elbow stability. It was also hypothesized that increased valgus stability with forearm supination may be the result of increased passive tension in the flexor pronator muscles [32].

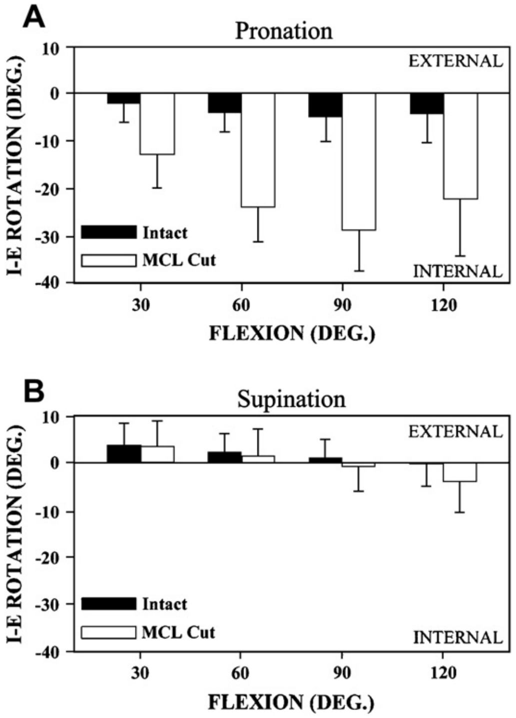

Fig. 6. Passive elbow flexion with the forearm in pronation *(A)* and supination (*B*) for the intact and MCL-deficient elbows. The mean internal-external (I-E) rotation of the ulna with respect to the humerus is plotted for elbow flexion in 30° increments. With the forearm in supination there were no significant differences in I-E rotation between the intact and MCL deficient elbows at 30° and 60° of flexion. There were small but significant differences at 90° and 120°. Overall, for passive flexion of the MCL-deficient elbow there is greater stability with the forearm in supination than in pronation. (*From* Armstrong AD, Dunning CE, Faber KJ, et al. Rehabilitation of the medial collateral ligament-deficient elbow: an in vitro biomechanical study. J Hand Surg [Am] 2000;25(6):1054–5; with permission.)

Osseous stabilization

The importance of osseous stabilization of the elbow joint is illustrated by the simple (no fractures) elbow dislocation. Most simple elbow dislocations are relatively stable once reduced, although the MCL has been reported to be completely ruptured in nearly all cases and the LCL is disrupted in most cases [33–35]. It has been shown that the congruent articulation of the ulnohumeral joint is responsible for as much as 50% of the stability of the elbow [36].

Coronoid

The coronoid process plays a key role in stabilization of the elbow. Coronoid fractures rarely occur in isolation [37–39]. Some authors have said that a coronoid fracture is pathognomonic for an episode of elbow instability [40]. Fractures of the coronoid are commonly associated with injuries to the collateral ligaments and form part of the definition of the ‘‘terrible triad,’’ which is classically defined as an elbow dislocation with associated radial head and coronoid fractures. Isolated fractures that involve the tip of the coronoid do not require fixation if the elbow remains stable. These fractures should not be thought of as simple avulsion fractures, however, based on the fact that there are no soft tissue attachments to the tip of the coronoid seen on arthrotomy, arthroscopy, and an anatomic study [41]. Axial loading that causes shear is the cause for most coronoid fractures [42]. Isolated coronoid fractures are similar morphologically to coronoid fractures seen in elbow fracture dislocations [40].

Fractures that involves more than 50% of the coronoid have been shown to significantly increase varus-valgus laxity, even in the setting of repaired collateral ligaments (Fig. 8) [31,43]. In the setting

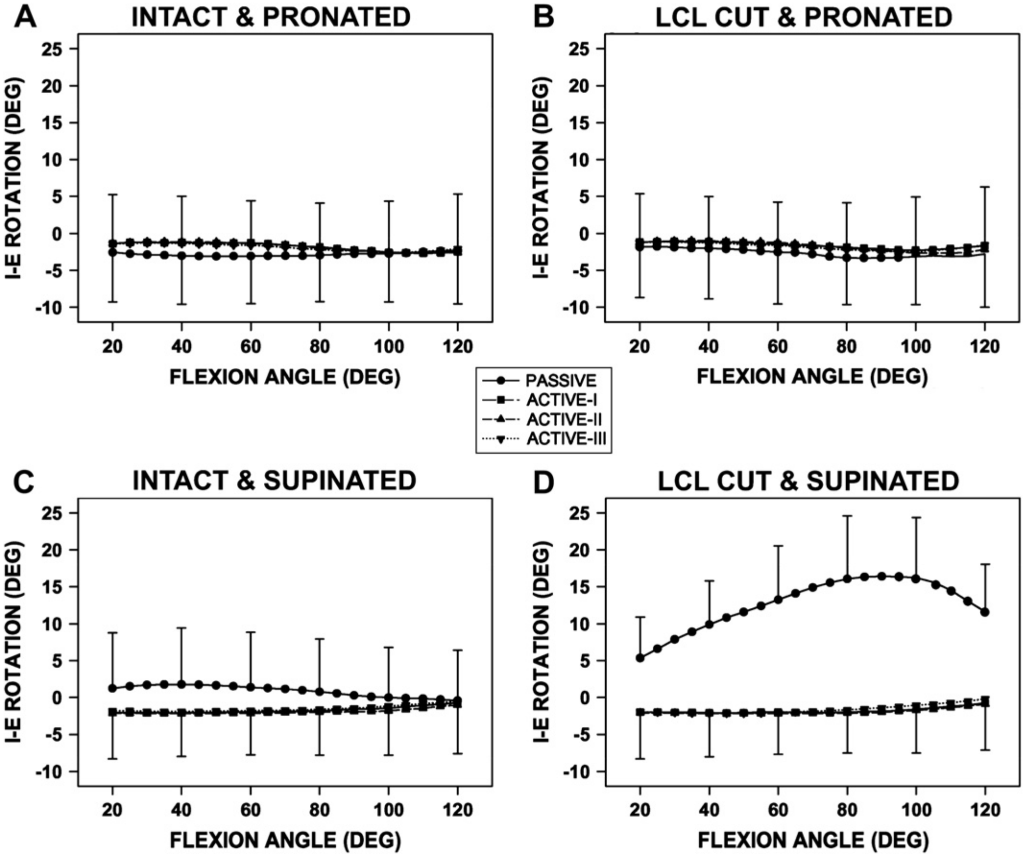

Fig. 7. Mean internal-external (I-E) rotation of the ulna with respect to the humerus is shown for simulated elbow flexion with the forearm in pronation (*A* and *B*) and supination (*C* and *D*) for intact (*A* and *C*) and LCL-deficient (*B* and *D*) elbows (positive = external rotation). Elbow flexion was produced passively and actively. Three different loading combinations (ACTIVE I-III) of the biceps, brachialis, brachioradialis, and triceps were used to generate active flexion. With the forearm pronated, there were no significant differences in I-E rotation between the intact and LCL-deficient elbows with passive or active flexion. With the forearm supinated, however, there was a significant increase in external rotation for passive flexion in the intact and LCL-deficient elbows. The increase in external rotational instability was greatest for the passively flexed LCL-deficient elbow. (*From* Dunning CE, Duck TR, King GJ, et al. Simulated active control produces repeatable motion pathways of the elbow in an in vitro testing system. J Biomech 2001;34(8):1044; with permission.)

of intact ligaments, coronoid fractures that involve more than 50% of the coronoid cause the elbow to became displaced posteriorly more readily than those with less than 50% of the coronoid fractured, especially when the elbow is flexed more than 60° [44]. The coronoid plays a significant role in posterolateral stability in combination with the radial head. With 30% of the coronoid height removed and excision of the radial head, the ulnohumeral joint was shown to dislocate. Stability was restored with replacement of the radial head. With 50% of the coronoid height removed, however, the elbow could not be stabilized with radial head replacement alone. Subsequent coronoid reconstruction restored stability [45]. Soft tissues that attach to the base of the coronoid include insertion of the anterior capsule and brachialis anteriorly and insertion of the MCL medially. Reduction and fixation of coronoid fractures help to restore the actions of these stabilizers [40].

Olecranon

Treatment of displaced olecranon fractures has been controversial. Excision of the fragment and reattachment of the triceps, especially for elderly patients, became popularized in the 1940s. It was

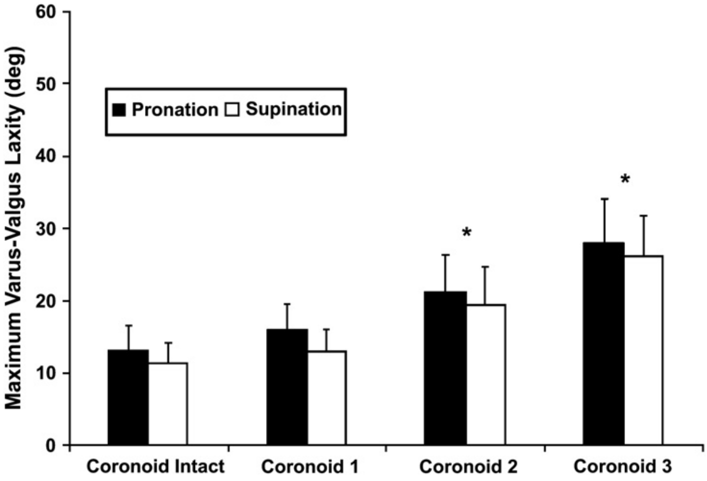

Fig. 8. Average maximum varus-valgus laxity after repair of collateral ligaments with intact coronoid, and simulated coronoid fractures. Coronoid 1 = 10% of bone removed from coronoid tip; coronoid 2 = 50% removed; coronoid 3 = 90% removed. There was significant laxity after 50% of the coronoid was removed. (*From* Beingessner DM, Dunning CE, Stacpoole RA, et al. The effect of coronoid fractures on elbow kinematics and stability. Clin Biomech 2007;22(2):188; with permission.)

stated that as much as 80% of the olecranon could be removed without compromising elbow stability [46]. One study reported that there were no significant differences in elbow extensor power between olecranonectomy with triceps reattachment and open reduction internal fixation of olecranon fractures at an average follow-up time of 3.6 years [47]. In vitro testing of the elbow showed that the constraint of the ulnohumeral joint is linearly proportional to the area of remaining articular surface, from which it was concluded that olecranonectomy is inadvisable in circumstances in which there is instability or an associated coronoid fracture or in a patient with high demands [48]. There are significant increases in joint pressure with excision of 50% of the olecranon, which over time may contribute to elbow pain and arthritis [49].

Proximal radius

The radial head is an important secondary valgus stabilizer of the elbow [36,50,51]. The radial head is responsible for approximately 30% of the valgus stability of the elbow [50]. The radial head becomes more important for valgus stability in the presence of MCL deficiency. When the MCL is transected, replacement of the radial head has been shown to restore valgus stability to a level similar to that of an elbow with an intact radial head [52]. Complete valgus stability is not restored until the MCL is repaired or reconstructed, however [53]. In the presence of an intact MCL, the radial head may be excised without concern for altering the biomechanics of the elbow [51]. This finding has been challenged more recently by demonstration of posterolateral rotatory instability after isolated excision of the radial head, possibly as a result of decreased tension in the LCL [54]. Radial head excision also increases varus-valgus laxity, regardless of whether the collateral ligaments are intact (Fig. 9) [55].

Soft tissue stabilization

Medial collateral ligament complex

Multiple studies have demonstrated that the AMCL is the primary constraint for valgus and posteromedial stability [11,36,50,51,56,57]. The anterior band of the AMCL is more vulnerable to valgus stress when the elbow is extended, whereas the posterior band is more vulnerable when the elbow is flexed. This finding was supported by an in vitro study, which demonstrated that the anterior band was the primary restraint to valgus stress at 30°, 60°, and 90°, and a coprimary restraint at 120°. The posterior band was a coprimary restraint at 120° and a secondary restraint at 30°, 60°, and 90° [10]. A traumatic valgus force with the elbow flexed at 90° or less is more likely to injure only the anterior band, whereas the elbow flexed more than 90° is more likely to injure the complete AMCL. Complete division of the AMCL causes valgus and internal

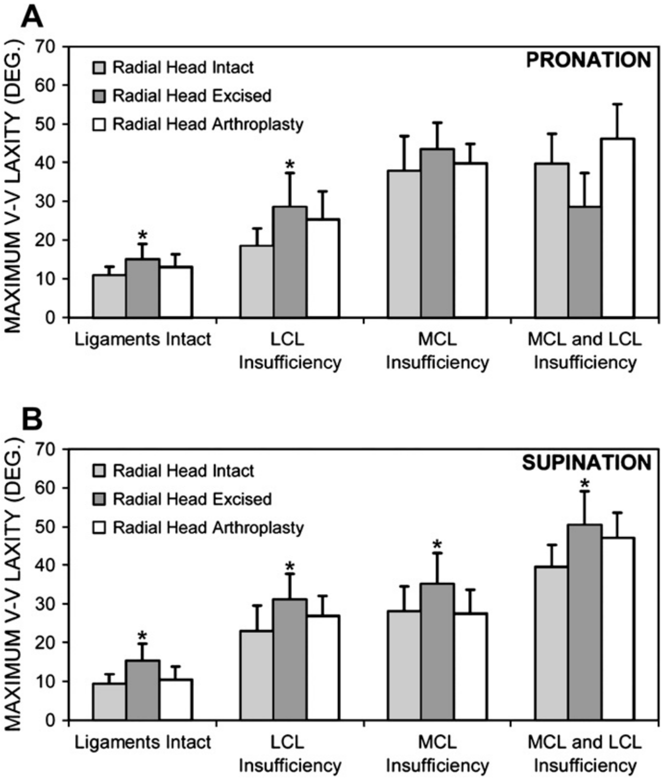

Fig. 9. Maximum varus-valgus laxity plotted for intact and insufficient collateral ligaments with radial head intact, excised, and replaced. Significant increases in laxity after radial head excision are denoted by asterisks. (*From* Beingessner DM, Dunning CE, Gordon KD, et al. The effect of radial head excision and arthroplasty on elbow kinematics and stability. J Bone Joint Surg Am 2004;86(8):1735; with permission.)

rotatory instability throughout the complete arch of flexion with maximal valgus instability at 70° and maximal rotational instability at 60° [11]. The posterior bundle seems to contribute little to valgus stability but does play a role in posteromedial rotatory stability. Severance of the entire posterior band results in only internal rotatory laxity that is maximal at 130° of flexion [11].

The origin of the MCL on the medial epicondyle is posterior to the axis of elbow flexion, which creates a cam-like effect with changes in ligament tension throughout flexion and extension of the elbow. The AMCL increases by 18% from 0° to 120° of flexion [12]. In addition to the anterior and posterior bands of the AMCL, a middle or central band of fibers has been identified that has its proximal origin close to the axis of rotation of the ulnohumeral joint. This central band has been called the ‘‘guiding’’ band because it is nearly isometric and close to being taut throughout the full arc of flexion. When sectioned, there is significant elbow instability (Fig. 10A) [13,14,58,59]. Single-strand reconstruction of the central band in the MCL-deficient elbow has been shown to restore valgus stability to the elbow similar to the intact condition (Fig. 10B) [60].

LCL complex

The LCL is the primary constraint of external rotation and varus stress at the elbow. The flexion axis of the elbow passes through the origin of the LCL so that there is uniform tension in the ligament throughout the arc of flexion [12]. It has been stated that damage to the LCL complex is the initial injury seen along the continuum of injuries resulting from elbow dislocation [1]. Instability caused by disruption of the LCL must be considered when treating complex fracture dislocations of the elbow. It has been shown that complete sectioning of the LCL causes varus and posterolateral rotatory instability and posterior radial head subluxation [61]. There is disagreement in the literature regarding the exact

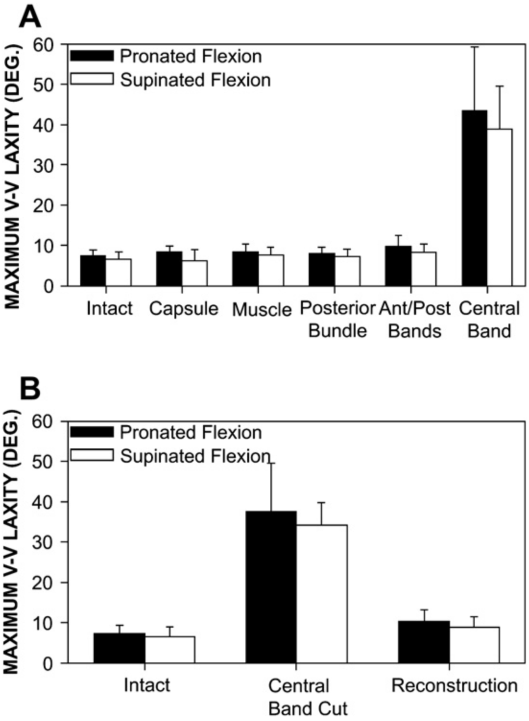

Fig. 10. (*A*) Maximum varus-valgus (V-V) laxity with forearm pronation and supination is plotted for the intact elbow and after sectioning each of the medial elbow stabilizers. The only significant difference in varus-valgus laxity among the structures sectioned occurred after the central band was cut. (*B*) Reconstruction of the central band of the AMCL decreases varus-valgus laxity so that it is not significantly different than the intact elbow. (*From* Armstrong AD, Dunning CE, Faber KJ, et al. Single strand ligament reconstruction of the medial collateral ligament restores valgus elbow stability. J Shoulder Elbow Surg 2002;11(1):69; with permission.)

role of each portion of the LCL complex [62–67]. Recent research has suggested that the LCL complex acts as one functional unit rather than each portion having its own stabilizing function. When the annular ligament and the lateral ulnar collateral ligament are cut in isolation there is only minor laxity [68]. If the annular ligament is intact, the lateral ulnar collateral ligament and radial collateral ligament need to be transected to produce significant posterolateral rotatory and varus-valgus instability (Fig. 11) [63]. This has implications for surgeons who are planning lateral surgical approaches to the elbow for radial head fixation or replacement. As long as the annular ligament is intact, the radial collateral ligament or the lateral ulnar collateral ligament can be cut and repaired without causing instability [63].

When the radial head is excised in the presence of a deficient LCL, there is increased varus and external rotatory instability. Radial head replacement in this setting improves posterolateral instability. Complete stability is not restored until the LCL complex is repaired, however [69]. Although the radial head plays a role in providing stability to the lateral aspect of the elbow, the LCL complex is the primary constraint for varus and external rotatory stability. It is recommended that the LCL complex be repaired after radial head fixation or replacement, particularly in complex elbow fracture dislocation injuries [69].

Muscles

Muscles that cross the elbow joint act as dynamic stabilizers as they compress the joint. Multiple studies have demonstrated the stabilizing effects of loading the muscles that cross the unstable elbow joint [28–30,70,71]. Dynamic compression of the elbow has been shown to decrease the variability of motion pathways of the articulating surfaces at the joint and increases the constraint (Fig. 12) [71].

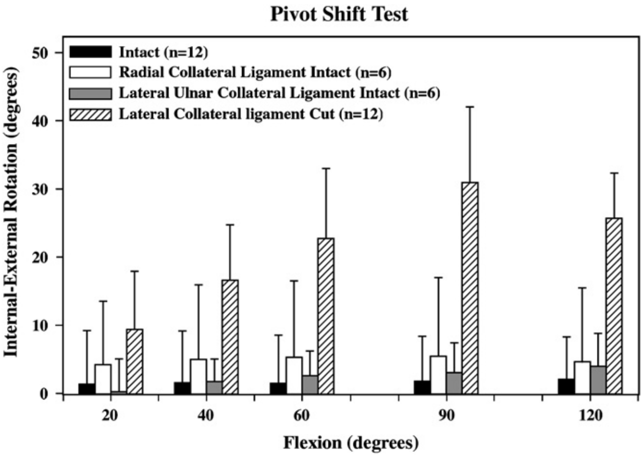

Fig. 11. Mean internal-external elbow rotation during the pivot shift test is plotted for the intact elbow and after sectioning components of lateral collateral ligament. The only significant difference occurred after sectioning of the complete LCL. (*From* Dunning CE, Zarzour ZD, Patterson SD, et al. Ligamentous stabilizers against posterolateral rotatory instability of the elbow. J Bone Joint Surg Am 2001;83(12):1826; with permission.)

Compression of the elbow joint by the muscles protects the soft tissue constraints. For example, throwing an object can cause a valgus stress that is greater than the failure strength of the MCL. The flexor-pronator muscle group contracts during the throwing motion and provides dynamic stabilization to the medial aspect of the elbow, which protects the MCL from injury [72].

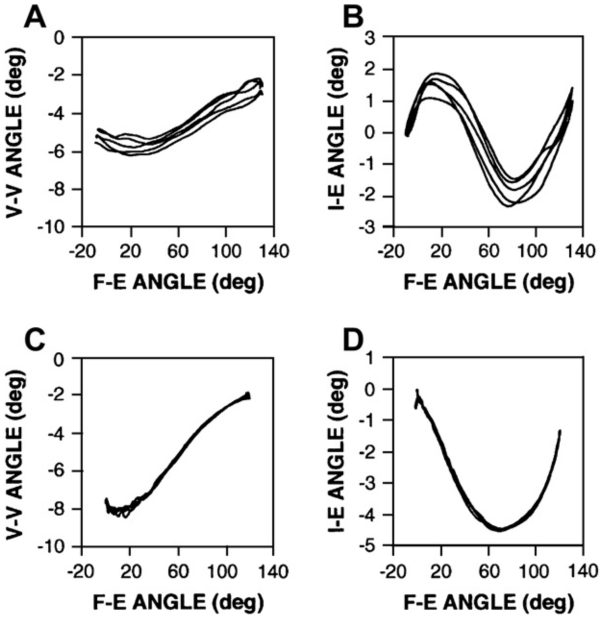

Fig. 12. Motion pathways of the ulna relative to the humerus during repeated flexion of the elbow under passive (*A* and *B*) and active (*C* and *D*) muscle conditions. F-E, flexion-extension; V-V Angle, varus-valgus angulation of elbow during flexion; I-E angle, internal-external rotation of the forearm during elbow flexion. (*From* Johnson JA, Rath DA, Dunning CE, et al. Simulation of elbow and forearm motion in vitro using a load controlled testing apparatus. J Biomech 2000;33(5):637; with permission.)

Joint forces

The compressive and shear forces at the elbow are significant. Given the forces that are generated across the joint under some conditions, some clinicians have said that it is ''erroneous to think of the elbow as 'non weightbearing''' [42]. Most elbow dislocations occur during a fall onto an outstretched hand. A fall onto an outstretched hand from a height of only 6 cm is estimated to create an axial joint compression force at the elbow of 50% of body weight [73]. Falls from a standing height would be expected to create a significantly greater force. Performing push-ups, a common exercise, has been shown to create an average force of 45% of body weight across the elbow joint [74].

Loads across the elbow have been shown to be distributed 43% across the ulnohumeral joint and 57% across the radiocapitellar joint [75]. Joint reaction forces vary with elbow position. Force transmission at the radiocapitellar joint is greatest between 0° and 30° of flexion and is greater in pronation than in supination [76]. When the elbow is extended, the overall force on the ulnohumeral joint is more concentrated at the coronoid; as the elbow is flexed, the force moves toward the olecranon (Fig. 13) [77].

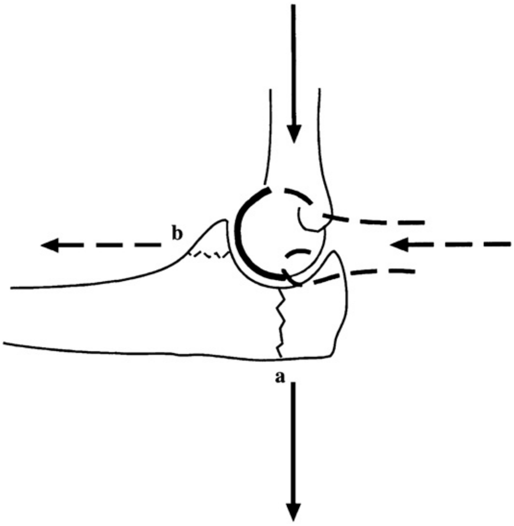

Fig. 13. Concentration of the force at the ulnohumeral joint varies with flexion and extension of the elbow. When the elbow is flexed at 90° (*solid line*), force is concentrated at the olecranon. When the elbow is extended (*dashed line*) the forced is concentrated at the coronoid. The olecranon fracture (a) and coronoid fracture (b) are shown. (*Adapted from* Wake H, Hashizume H, Nishida K, et al. Biomechanical analysis of the mechanism of elbow fracture-dislocations by compression force. J Orthop Sci 2004;9(1):49; with permission.)

Summary

Competent diagnosis and treatment of the injured elbow require a systematic approach and consideration of the anatomy and function of each of the structures that provides stability. Numerous biomechanical studies have contributed greatly to our understanding of elbow motion, forces, and stabilizing factors. Forces across the elbow joint can be significant. Static and dynamic constraints function together to protect the elbow. Each of the three primary constraints must be addressed after elbow trauma for restoration of stability. Secondary constraints, such as the radial head, also play an important role in providing stability. Awareness of the function and likelihood of injury of each stabilizing structure is needed for proficient management of elbow trauma.

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