Elbow

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ABSTRACT

CONTENT: This course section discusses postoperative management of elbow disorders. The surgical procedures, postoperative guidelines, treatment progression, and expected outcomes are presented based on current evidence. Elbow anatomy, biomechanics, and tissue healing guide interventions, precautions, and treatment progression. The course section also addresses identifying and managing the most common complications of the postoperative elbow. **CASE ANALYSES:** Four case studies are presented. Each case highlights surgical intervention, rehabilitation guidelines, and clinical reasoning. The first case describes a 34-year-old male who presents following open reduction internal fixation of an olecranon fracture. The second case describes a 21-year-old male who underwent an ulnar collateral ligament reconstruction with suture-tape augmentation. The third case describes a 66-year-old female who presents with an anterior transposition of the ulnar nerve following cubital tunnel syndrome. Finally, the fourth case describes the postoperative rehabilitation of a 75-year-old female following an open reduction internal fixation of a distal humerus fracture.

Key Words: humeroulnar, radiocapitellar, postsurgical, rehabilitation

LEARNING OBJECTIVES

Upon completion of this course section, the participant will:

1. Understand the anatomy of the elbow related to surgical interventions, tissue healing, post-operative rehabilitation, and management.
2. Explain the biomechanics of the elbow and the impact on postoperative guidelines, treatment progression, and outcomes.
3. Identify the precautions and contraindications associated with each surgical procedure described for the elbow complex.
4. Describe the most common complications for the post-operative elbow.
5. Discuss the management of the most common complications for individuals following elbow surgery.
6. Design and implement an evidence-based physical therapy treatment plan based on the progression of appropriate interventions.
7. Explain the typical timelines associated with safe loading, return to work, functional activities, or sports.

INTRODUCTION

Effective postoperative care for the elbow joint necessitates physical therapists' knowledge of elbow and forearm anatomy, joint biomechanics, the injury or condition, and an understanding of the specifics of the operative procedure. Clinicians must also have a strong foundational knowledge of the principles of tissue healing to determine appropriate postoperative physical therapy management to ensure optimal outcomes. The elbow's propensity to develop contractures challenges obtaining optimal postoperative results. Physical therapists should have a thorough understanding of surgical procedures to ensure that the postoperative treatment progression strikes the right balance, neither advancing too rapidly to risk injuring the repaired tissue nor proceeding too slowly, which could lead to a loss of motion and, ultimately, function at the elbow.

Non-conservative interventions, including surgical procedures at the elbow, are diverse and continually evolving. Furthermore, biomedical advances in elbow surgery, such as tissue engineering and using stem cells, growth factors, and biomaterials to enhance healing, can change postoperative rehabilitation protocols dramatically compared to years past. Given the multiple factors to consider for any given surgery, guidelines and protocols for the postoperative care of elbow conditions may differ widely. Consequently, physical therapists must gather key information from operative reports, maintain open lines of communication with the operating surgeon, and be aware of advancements in both operative and rehabilitation approaches. To ensure positive patient outcomes, ongoing education and collaboration among medical team members are needed to navigate the complexities associated with postoperative care for the elbow.

CLINICAL ANATOMY

Surface Anatomy

The physical therapist should understand normal surface anatomy at the elbow region to note changes that may indicate a complication after a surgical procedure. The contours of the upper extremity at the elbow are defined by the brachialis and the biceps brachii proximal to the antecubital fossa. The muscle belly of the biceps brachii creates a prominent bulge in the anterior arm. The proximal forearm's shape is characterized by a larger muscle mass on the lateral side. In contrast, the inner side muscle mass is less prominent, making the medial epicondyle more visible when viewing the arm anteriorly. The excess skin on the back of the olecranon, known as "olecranon skin," is essential to allow for the elbow's available range of motion (ROM) in the sagittal plane and to accommodate the underlying olecranon bursa.

Observations of the underlying bony structure typically are appreciated through the alignment of the olecranon of the ulna to the medial and lateral epicondyles of the humerus from the posterior aspect.[1] This observation of optimal alignment requires passive ROM. When the elbow is in a 90° flexed posture, these 3 structures (the olecranon and the epicondyles) form an inverted equilateral triangle. With the elbow fully extended, there should be a straight line between the lateral and medial epicondyles at the tip of the olecranon. The anterior elbow crease created when the elbow is flexed aligns with the medial and lateral epicondyles and represents the joint axis. This crease is typically located 1 to 2 cm proximal to the joint line when the elbow is fully extended.[1]

The carrying angle can be observed when the upper extremity is viewed anteriorly, with the elbow extended and the forearm supinated. The typical carrying angle is a slight angle of cubitus valgus in the frontal plane, created by a slight radial deviation of the long axis of the ulna on the long axis of the humerus.[1] The normal carrying angle ranges from 11° to 14° in men and 13° to 16° in women.[1]

Skeletal Anatomy

The elbow is a complex hinge joint consisting of 3 bones that comprise 3 articulations: the humeroulnar, between the humerus and ulna; the humeroradial, between the humerus and radius; and the proximal radioulnar joint, between the radius and ulna. The osseous structures provide the most stability of the joint, further supported by the articular capsule and the ulnar (medial) collateral (UCL) and lateral collateral ligament (LCL) complexes.[2]

Humerus

The humerus, a long bone connecting the glenohumeral joint to the elbow joint, ends distally with the medial and lateral epicondyles. The medial epicondyle is more prominent than the lateral and is the attachment site for the common flexor tendon, pronator teres muscle, and the UCL.[1] The lateral epicondyle is where the supinator, wrist and finger extensor muscles, and the LCL originate. The trochlea is on the posterior-medial aspect of the distal humerus and articulates with the greater sigmoid notch of the ulna. The capitellum and radial fossa are located distally on the lateral aspect of the humerus, while the olecranon fossa is on the posterior surface proximal to the trochlea. During flexion, the coronoid process of the ulna articulates with the coronoid fossa, forming the humeroulnar joint. The radial head articulates with the capitellum and then the radial fossa, forming the humeroradial joint.[1,3]

Radius

The radius is a cylindrical bone that connects to the capitellum of the humerus proximally and to the lunate and scaphoid carpal bones distally.[3] The radial head, located proximally, has a shallow concave shape with a superior depression. Surrounding the radial head is the annular ligament, which holds the head of the radius against the radial notch of the ulna, allowing for pronation and supination of the forearm. The radial head articulates with the ulna over approximately 240° of its margin, leaving a 120° "safe zone" used during surgical techniques for internal fixation devices to maintain the integrity of the articulation of the ulna and the radius.[1] Below the radial head is the radial neck, and further distally is the radial tuberosity, where the biceps brachii muscle inserts.[3]

On the lateral side, the humeroradial articulation includes the radial head, the capitellum of the humerus, and a tubercle or groove on the lateral part of the humerus's trochlea. When the collateral ligaments or distal radioulnar stability is compromised, the radial head becomes a critical stabilizer, especially in resisting valgus stress.[1,2,4]

Ulna

The ulna, one of the long bones in the forearm, along with the radius, is crucial in providing primary bony stabilization at the elbow joint.[1] It is characterized by its trochlear notch, which forms an articulation with the trochlea of the humerus. The coronoid process of the ulna, found on the inferior-anterior medial lip of the trochlear notch, serves as the attachment site for the anterior portion of the UCL. The ulna tuberosity is positioned antero-inferiorly to the coronoid process; it provides an attachment point for the brachialis muscle and serves as the proximal attachment site of the oblique cord. This cord extends distally and laterally to insert inferior to the radial tuberosity, limiting supination. Posteriorly, the olecranon of the ulna serves as the site of attachment for the triceps tendon, the anconeus muscle, and the flexor carpi ulnaris (FCU) muscle.[1,3]

The humeroulnar joint, located on the medial side of the elbow, facilitates movements of flexion and extension and is formed by the medial lip of the trochlea of the humerus and the trochlear notch of the ulna.[3] Additionally, the proximal radioulnar joint (PRUJ), which consists of the radial head, the annular ligament (AL), and the radial fossa of the ulna, allows for optimal motion, including 70° of pronation and 80° of supination.[5] The interosseous membrane (IOM) includes a central band and several accessory bands that extend between the ulna and the radius and offer stability to the PRUJ and the distal radioulnar joint (DRUJ). The central band of the IOM plays a vital role in distributing loads, with the peak strain occurring during neutral forearm rotation.[6]

While not directly part of the elbow region, the DRUJ is considered a compound joint with the PRUJ. It consists of the distal ends of the ulna and radius, the joint capsule, and the triangular fibrocartilage complex (TFCC).[3] The motion of the DRUJ is essential for achieving the full forearm rotation ROM.[1]

Capsuloligamentous Structures

Capsule

The elbow *joint capsule* encloses all three joints (humeroulnar, humeroradial, and proximal radioulnar), merges with the AL, and forms the collateral ligaments through thickenings on the medial and lateral sides.[3] While the capsule is relatively thin anteriorly and posteriorly, it gains strength from the medial and lateral ligament complexes.[2] The brachialis and anconeus muscles tighten the joint capsule during elbow flexion and extension, respectively, helping to prevent entrapment of the capsule between the articulating surfaces. The anterior capsule is taut during extension, and the posterior capsule is taut during full flexion. The capsule demonstrates its greatest extensibility between 70° and 90° of flexion. The average capsular volume is 25-30 ml but varies depending on the elbow flexion angle.[1]

Ulnar (Medial) collateral ligament complex

The UCL complex at the medial elbow consists of three portions: *anterior, posterior, and transverse*.[1] The positioning of these portions of the ligament determines their tautness during elbow movement, with the complex being slightly behind the elbow joint, creating more tension as the elbow flexes.[7] The *anterior portion* is the strongest of the three and the most resistant to valgus stress. It runs from the anterior medial epicondyle to the medial aspect of the coronoid process. It is taut from full extension to 60° of flexion, and the posterior band is taut from 60° to 120° of flexion.[8] The *posterior portion* of the UCL is most taut at 90° of elbow flexion, acting like a fan from the medial epicondyle to the medial olecranon, particularly effective in preventing excessive gapping during forearm pronation.[9] In contrast, the *transverse portion*, which attaches from the medial olecranon to the inferior medial coronoid process of the ulna, has a lesser impact on elbow stability and is often indistinguishable from the capsule.[1]

Lateral collateral ligament complex

The *LCL complex* consists of (1) the *radial collateral ligament* (RCL), (2) the *annular ligament* (AL), (3) the *lateral ulnar collateral ligament* (LUCL), and (4) an *accessory lateral collateral ligament (ALCL)*.[1] The LCL complex acts as a primary soft tissue stabilizer of the elbow to varus stress and posterolateral instability.[5] The RCL extends from the lateral epicondyle of the humerus to blend into the AL and serves as the origin for a portion of the supinator muscle.[1] The AL encircles the radial head, attaching from the anterior to the posterior portion of the ulna's radial notch; it maintains contact between the radial head and ulna. The LUCL blends with the fibers of the AL as it extends from the lateral epicondyle of the humerus to insert onto the crest of the supinator on the ulna. The LUCL is deficient in cases of posterolateral rotatory instability. Finally, the ALCL portion is a small component of fibers that inserts on the ulnar side at the supinator tubercle to blend proximally with the AL. It is inconsistently present and considered a variant of the LUCL.[1]

Muscles of the Elbow

Elbow flexors

The *biceps brachii muscle* consists of two heads (long and short) with primary functions of elbow flexion and forearm supination.[1,3] The long head originates from the supraglenoid tubercle of the scapula. It travels through the bicipital groove of the humerus, while the short head originates from the coracoid process of the scapula. The distal attachment is the common biceps tendon at the radial tuberosity of the radius. Since it also crosses the shoulder joint, it functions as a secondary flexor of the shoulder. The *brachialis muscle* is located deep in the biceps brachii. Its proximal attachment is the anterior humerus, and the distal attachment is at the ulna's tuberosity and coronoid process. The brachialis has the largest cross-sectional area of the elbow flexors but has a mechanical disadvantage in providing flexion forces due to its proximity to the axis of rotation.[1] The musculocutaneous nerve innervates both muscles. The *brachioradialis muscle* extends from the lateral supracondylar ridge to the radial styloid process. It has the greatest biomechanical advantage of the elbow flexors and is innervated by the radial nerve.[1,3]

Elbow extensors

The *triceps brachii muscle*, innervated by the radial nerve, consists of three heads: the *long, lateral*, and *medial heads*.[3] All three heads work together to extend the elbow. The *long head* originates proximally from the infra-glenoid tubercle on the scapula. The *lateral head* originates proximally from the posterior aspect of the humerus, while the *medial head* originates from the posteromedial aspect of the humerus. Despite the medial head being situated beneath the lateral and long heads, all three heads share a distal attachment at the olecranon. The *anconeus muscle* extends from the posterior aspect of the lateral epicondyle and the lateral triceps fascia and inserts into the lateral dorsal surface of the proximal ulna, covering the AL and radial head. It is an important landmark for surgeons for various lateral and posterolateral surgical approaches. Its function is likely related to elbow joint stability rather than serving as a prime mover, and it is also innervated by the radial nerve.[1,3]

Lateral extensor and supinator group

The extensor tendon that starts just distal to the *extensor carpi radialis longus* (ECRL) at the lateral elbow is known as the common extensor tendon.[3] From lateral to medial, this tendon consists of four muscles: the *extensor carpi radialis brevis* (ECRB), *extensor digitorum* (ED), *extensor digiti minimi* (EDM), and *extensor carpi ulnaris* (ECU).[1] Each muscle serves to extend the wrist or digits. The ECRL, which begins above the elbow, plays a minor role in elbow flexion and is primarily responsible for extending the wrist with radial deviation. The function of the ECRB is to assist with radial wrist extension. The ED and EDM extend from the common extensor tendon at the elbow and primarily extend digits 2-5 at the metacarpophalangeal joints. They also assist in wrist extension and, through their attachment to the extensor hood, can assist in the abduction of the fingers. The EDM can extend any joint of the little finger independently.[1,3] The ECU has two attachments: the medial aspect of the lateral epicondyle and the ulnar attachment from the posterior border of the ulna. Its function is to extend and deviate the wrist ulnarly.

The *supinator muscle* lies beneath the extensor muscle group.[3] It is oriented obliquely, running distally and radially to wrap around and attach to the upper lateral part of the radius near the attachment of the pronator teres muscle from the anterior compartment.[1] It has four proximal attachments: the lateral epicondyle, the RCL, the AL, and the supinator crest of the ulna on the olecranon. The radial nerve passes through the supinator during its course through the forearm and emerges from the supinator as the posterior interosseous nerve (PIN).[1,3]

Medial flexor-pronator group

Two muscles acting on the wrist share the common flexor tendon at the elbow: the *flexor carpi radialis* muscle (FCR) and the *flexor carpi ulnaris* muscle (FCU).[3] The FCR lies medial to the pronator with the proximal attachment at the anterior inferior aspect of the medial epicondyle. It is responsible for wrist flexion and radial deviation and is innervated by the median nerve. The ulnar nerve, which innervates the FCU, dives between the muscle's two heads, the humeral and ulnar heads. The FCU performs wrist flexion and wrist ulnar deviation. The humeral head of the FCU originates from the most medial aspect of the medial epicondyle, while the ulnar head originates from the olecranon and posterior border of the ulna. The palmaris longus muscle is absent in approximately 15% of individuals worldwide.[10] When present, it traverses from the medial epicondyle to the palmar aponeurosis of the hand. The palmaris tapers into the tendon proximal in the forearm and is used by surgeons as a donor for reconstructive surgery (eg, ligament and tendon reconstructions).[1,3]

The primary function of the *flexor digitorum superficialis* (FDS) muscle is to flex the proximal interphalangeal joints of the 2nd through 5th digits. It is innervated by the median nerve and has two heads: one arising from the common flexor tendon, the UCL, and the medial coronoid, and the second from the proximal portion of the radius.[3] It runs deep to the wrist flexors and superficial to the *flexor digitorum profundus* (FDP). The FDP has a proximal attachment from the proximal ulna, distal to the elbow joint. The primary function of this muscle is to flex the distal interphalangeal joints. The FDP receives nerve supply from both the median and ulnar nerves. The ulnar half, consisting of the tendons to the 4th and 5th digits, is on the ulnar forearm, and the median half, consisting of the tendons to the 2nd and 3rd digits, is on the radial side of the forearm.[3]

The *pronator teres* at the elbow and *pronator quadratus muscles* at the distal forearm are responsible for forearm pronation. The pronator teres also acts as a secondary elbow flexor.[1] The median nerve dives between its two heads: the humeral and ulnar heads. The humeral head originates at the medial epicondyle and the ulnar head originates at the coronoid process of the ulna.[1,3]

Neurovascular Structures

Brachial artery

The *brachial artery* is the primary source of blood flow to the upper extremity.[1] It follows a similar path as the median nerve and is accompanied by the medial and lateral brachial veins. At the antecubital fossa, it lies lateral to the nerve and medial to the biceps tendon. At the level of the radial head, it gives off its terminal branches, the *ulnar artery* and *radial artery,* which provide the vascular supply of the forearm and hand.[1,3]

Median nerve

The *median nerve* (nerve roots, C5-T1) arises from parts of the medial and lateral cords of the brachial plexus. It descends medially in the arm, giving no branches.[3] It lies medial to the brachial artery at the antecubital fossa, underneath the bicipital aponeurosis, and above the brachialis. In the forearm, it passes between the two heads of the pronator teres and dives between the FDS and FDP.[1] The median nerve sends motor branches to all the superficial flexor-pronator musculature except the FCU (innervated by the ulnar nerve). Within the forearm, innervation by the median nerve includes the pronator teres, FCR, and FDS. At the wrist level, the median nerve becomes more superficial and emerges between the tendons of the FCR and the FDS (beneath and just radial to the palmaris longus). It passes underneath the transverse carpal ligament into the palm, providing sensory and motor innervation to the radial aspect of the hand. It innervates the thenar musculature, including the abductor pollicis brevis and opponens pollicis, and innervates the first two lumbricals.[1,3]

The *anterior interosseous nerve* (AIN) branches from the median nerve just past its entrance between the 2 heads of the pronator teres. It travels underneath the aponeurotic origin of the FDS to lie on the anterior interosseous membrane.[3] It sends motor innervation to the deep muscles of the forearm, including the FDP to the index and middle fingers, the FPL, and to the pronator quadratus at its terminal point.[1,3]

Ulnar nerve

The *ulnar nerve* (nerve roots C8 and T1) arises from the medial cord of the brachial plexus and travels on the medial side of the arm, forearm, and hand.[3] It descends medial to the brachial artery to the mid-arm level, giving off no branches. It pierces the intermuscular septum and runs across the medial head of the triceps, then travels to the groove between the medial epicondyle and the olecranon of the humerus.[1,3] It emerges into the forearm between the two heads of the FCU, providing its innervation. It continues to innervate the ulnar half of the FDP, then divides into a dorsal and palmar branch at the distal forearm. The palmar cutaneous branch arises at the middle of the forearm, descends, and ends in the skin of the palm. The dorsal cutaneous branch arises about 6 to 8 cm proximal to the wrist joint and supplies sensation to the dorsoulnar aspect of the hand, as well as the small and ulnar half of the ring finger. At the wrist, the palmar branch of the ulnar nerve enters the hand at a groove formed between the pisiform and the hook of the hamate named Guyon's canal. The nerve lies under the pisohamate ligament and crosses the transverse carpal ligament. It then divides into superficial and deep branches. The superficial branch innervates the palmaris brevis and the skin on the ulnar hand and divides into digital branches. The deep branch innervates the remaining ulnar-nerve-innervated intrinsic muscles, including the abductor and flexor digiti minimi, opponens, all interossei, and the third and fourth lumbricals.[1,3]

Radial nerve

The *radial nerve* (nerve roots C5-8) is the brachial plexus's largest branch and the posterior cord's continuation. In the axilla, it descends anterior to the tendons of the latissimus dorsi and teres major, then travels around from the medial to the lateral side of the arm in the spiral groove of the humerus between the medial and lateral heads of the triceps.[1,3] It then pierces the lateral intermuscular septum into the anterior flexor compartment of the humerus. It passes between the brachialis and the brachioradialis to the front of the lateral epicondyle of the humerus. Muscular branches innervate the triceps, brachialis, brachioradialis, anconeus, and ECRL in the arm. Just distal to the lateral epicondyle, the radial nerve branches into superficial and deep branches. The superficial branch has only sensory fibers and passes along the radial aspect of the forearm just underneath the brachioradialis until it emerges from under the brachioradialis tendon to provide cutaneous sensation to the radial dorsal hand and fingers. The deep branch is called the *posterior interosseous nerve* (PIN) and has only motor fibers. It travels on the dorsal forearm on the lateral side of the radius once it dives between the two heads of the supinator muscle. It descends on the dorsal side of the interosseous membrane. Its branches provide motor innervation to the dorsal radial forearm musculature, including ECRB, supinator, ED, EDM, ECU, abductor pollicis longus, extensor pollicis longus and brevis, and the extensor indicis.[1,3]

BIOMECHANICS

Kinematics of the Elbow Complex

The elbow complex, traditionally comprised of the humeroulnar and humeroradial joints, is considered a compound synovial hinge joint with 1 degree of freedom. However, the authors will include the proximal radioulnar joint in the elbow complex discussion because of its close anatomical and functional relationship to the forearm. The normal sagittal plane active ROM of the elbow is 0-150°, while in the transverse plane, pronation and supination are 75° and 85°, respectively. The sagittal plane motion is the most important for function. More specifically, elbow flexion is required for grooming, washing, tying shoes, and communication like sign language. Proper motion in the transverse plane is needed for activities like opening a door, manipulating objects, and holding objects.[11,12]

Motion Restraints

The anatomical contributors of elbow stability include the bony, IOM, and soft tissue stabilizers. The bony interaction for elbow stability plays a larger role at terminal elbow extension (<30°), with the olecranon articulating with the humeral olecranon fossa. During increasing elbow flexion (>100°), the coronoid of the ulna interlocks with the coronoid fossa of the humerus.[13] When moving into extension, at least 50% of the coronoid is needed for joint stability. If 50% of the coronoid is removed and there is a loss of the radial head as a secondary stabilizer, the elbow will be grossly unstable from full extension to 100° of flexion.[5,14] The olecranon is paramount to varus and valgus stability,[15] while the radius plays a role in axial loading and valgus stress.[4] If the elbow joints are intact, the radial head does not contribute significantly to stability in either axial rotation or valgus stress situations.[16] However, in conditions of UCL insufficiency, the radial head plays a vital role as a secondary stabilizer to valgus stresses.

The IOM serves as a bridge between the distal and PRUJ. Ulnar movement is dictated via the tension transmitted through the IOM, thus decreasing the load on the capitellum, transferring more force onto the trochlea, and reducing the risk of humeral fracture.[4] In healthy individuals, the peak strain of the IOM occurs in neutral rotation; however, with injuries to the radial head and decreased stability, peak strain would occur during terminal forearm rotation.[6]

Static soft tissue stability arises from both the medial and lateral ligamentous complex. The medial ligament complex, consisting of anterior, central, and posterior bands, resists valgus and internal rotation forces. The lateral ligament complex consists of the LUCL and RCL. The LUCL is a primary lateral stabilizer and appears to tighten during elbow flexion. Disruption of the LUCL leads to posterolateral rotatory instability. The RCL assists in stabilizing the humeroulnar joint, and its length remains relatively constant during elbow flexion and extension.[13,17]

Axis of Rotation and Motion Excursions

The center of rotation for the elbow in the sagittal plane is thought to be near the anterior medial collateral ligament bundle (AMCLB).[13] However, the center of rotation is not stationary.[18] As a result of the nonstationary nature of the axis, under normal conditions, the AMCLB is thought to change length by as much as 4.8mm throughout the ROM.[19] The normal biomechanical tension placed on the AMCLB during flexion and extension has implications for surgical and postoperative rehabilitation approaches for elbow fracture and UCL repairs.

In addition to the variable tension imparted on the AMCLB with sagittal plane motion, there are other biomechanical components to consider. Pronation occurs at the beginning of flexion,[20] whereas supination and ulnar external rotation occur at the end.[20] Additionally, because the proximal ulna has a dorsal angulation, those with a greater dorsal angulation in the sagittal plane may have a slightly increased terminal extension ROM.[21]

Uniaxial rotation of the elbow is achieved by radial motion about the ulna. The axis of rotation is from the center of the radial head to the center of the distal ulna. The radius moves proximally during pronation[18] and translates anteriorly, placing tension on the posterior aspect of the annular ligament. Conversely, the radial head translates posteriorly during supination.[21] There is also a slight counter-rotation of the ulna relative to the humerus and evidence that the ulna internally rotates during pronation.[18] Additionally, there is some evidence for kinematic coupling at the elbow because there is an interconnection between valgus angulation and forearm rotation.[17] For example, as valgus laxity increases, more ulnar internal rotation occurs, thus increasing UCL laxity. Finally, one study has demonstrated that gaining supination results in increased elbow flexion, thus providing preliminary support that motion in one plane can affect motion in another plane.[22]

Kinetics of the Elbow Complex

Muscle torque and production levers

Musculature that crosses the humeroulnar and humeroradial joints also contributes to stability at the elbow complex. Generally, musculature from the forearm and humerus reduce distraction forces during elbow joint motion.[17] The wrist flexor-pronator group and the biceps and triceps contribute to valgus stability during both contracted and resting states.[8,17,23,24] Specifically, the contribution of the flexor-pronator group to stability is greatest when the wrist is pronated and the muscle group is active. There is also evidence that the common wrist extensor groups passively stabilize during varus stress when the wrist is placed in supination. However, stability is greater during muscle activation.[23]

Internal stress and joint reaction forces

Besides providing stability, soft tissue plays a role in joint reaction forces (JRF) about the elbow. Joint reaction forces are joint forces that are generated from muscle activity. Forces are greatest during the cycle of ROM, where there are poor mechanical advantages. For example, the biceps brachii, brachialis, and brachioradialis have a poor mechanical advantage early in the elbow flexion cycle. Joint reaction forces are the largest in the initial stages of flexion and the smallest at the end range of flexion because increased muscle force is required early in the flexion cycle.[25] As a result, loading early in the flexion cycle after biceps repair presents a higher risk of rupture.

Joint reaction forces should be considered along with the external load and lever arm yielding the total load at the elbow joint during rehabilitation. Some activities of daily living (ADLs) using the biceps brachii early during the flexion cycle may generate a JRF of approximately 350N during light (less than 5 lbs) activities, while other ADLs have been shown to generate a JRF of over 1000N.[25,26]

TISSUE HEALING

Background

While comprehensive knowledge of anatomy and biomechanics is vital in rehabilitation, it is equally important for physical therapists to grasp the fundamental principles of tissue healing for effective postsurgical care. Moreover, the physical therapist should recognize the unique characteristics of the healing process for each type of tissue. Each tissue within the body possesses distinct responses to injury, regenerative capabilities, and mechanical properties. Therefore, a comprehensive understanding of the specific healing mechanisms for various tissues is crucial in establishing the plan of care to ensure optimal outcomes for individuals undergoing rehabilitation following surgery.

General tissue healing process

Healing consists of a sequence of overlapping events aimed at repairing or regenerating damaged tissue.[27] Tissue repair involves the formation of scar tissue, which is primarily composed of collagen. Tissue regeneration replaces the damaged tissue close to the original tissue. Regeneration replaces the damaged cells with the proliferation of specialized cells. The general stages of healing include the hemostasis phase (seconds to hours), inflammation phase (hours to days), proliferation phase (days to weeks), and remodeling phase (weeks to months and up to one year).[27] The healing process is complex and is often influenced by numerous factors, including the individual's overall health, age, and the nature and extent of the injury. Additionally, specific comorbidities and medications may significantly impact the healing timeline, necessitating adjustments in treatment progression timelines.

Bone healing

Bone healing occurs through one of two distinct mechanisms after a fracture; these are referred to as primary and secondary healing.[28] Each type of bone healing involves a combination of intramembranous and endochondral ossification. Bone healing consists of a 4-phase process including the inflammatory phase (seconds to days), reparative and revascularization phase (1 to 6 weeks), modeling phase (4 to 6 weeks), and remodeling phase (6 weeks to several months or years).[28,29] Throughout these phases, factors such as proper alignment, stability, and blood supply play crucial roles in successful bone healing. Monitoring patient compliance with post-surgery instructions and providing appropriate rehabilitation are essential for optimal outcomes.

Primary bone healing occurs when the fractured bone segments are rigidly stabilized through surgical fixation using plates and screws.[28] The bone heals through intramembranous ossification with minimal callus formation, and the repair closely