Surgical Anatomy, Approaches and Biomechanics of the Elbow

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Abstract

The elbow is a complex anatomical area in which many neurovascular, tendinous, ligamentous and osseous structures are in close vicinity. In order to avoid complications, it is desirable to have a deep knowledge of the anatomy and to be confident with the most commonly-used surgical approaches. Basic understanding of elbow biomechanics can aid the surgeon in understanding the aetiology, pathomechanics and treatment rationale of elbow injuries. The current chapter reviews basic surgical approaches and biomechanics of the elbow.

Keywords

Anatomy • Approaches-lateral, medial, posterior, anterior • Biomechanics • Elbow • Operative techniques

General Introduction

As elbow arthroscopy is gaining popularity, limited exposures of the elbow are less commonly required. When they are indicated, the surgeon should be cautious, and avoid injury to the superficial nerves which may lead to painful neuroma. When dealing with more complex pathology, it is desirable to have the possibility of extending the approach. An extensile posterior cutaneous incision, the so-called "universal approach", allows the surgeon to access to the posterior, medial and lateral compartments of the joint.

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The elbow is not only an intermediate joint that positions the arm in space, but it is also a load-bearing joint which acts as a fulcrum for the forearm and hand, requiring complex interaction between mobility and stability to adequately perform daily activities. Understanding elbow kinematics is crucial to treat injuries affecting the ligamentous and bony structures which have great implications for stability and harmonious motion of the elbow joint.

Anatomy

The elbow contains three separate articulations. The ulnohumeral joint is a modified hinge joint that allows flexion and extension. The radiohumeral joint is a combined hinge and pivot joint that permits flexion and extension as well as rotation of the head of the radius on the capitellum of the humerus. The proximal radioulnar joint facilitates rotation during supination and pronation (Fig. 1).

Osseous stability is re-inforced by the medial and lateral collateral ligament (LCL) complexes. The MCL complex comprises anterior, posterior, and transverse bundles and, especially the anterior bundle, provides valgus stability. The posterior band of the MCL is commonly contracted in post-traumatic elbows, and when dealing with a stiff elbow it may need to be released (Fig. 2). The LCL complex, especially the lateral ulnar collateral ligament, confers rotational and varus stability (Fig. 3).

Four muscle groups act on the elbow. The major flexors are the biceps brachii (which also supinates the forearm when the elbow is flexed), brachioradialis, and brachialis muscles while the extensors are the triceps and anconeus muscles. The supinators consist of the supinator and biceps brachii muscles. Pronation is accomplished by the pronator quadratus, pronator teres, and flexor carpi radialis muscles.

The elbow also has a complex innervation, and all the nerves that cross the elbow may be at risk during certain surgical procedures. The median nerve crosses the elbow medially and passes through the two heads of the pronator teres, a potential site of entrapment (Fig. 4). The ulnar nerve passes along the medial arm and posterior to the medial epicondyle through the cubital tunnel, a likely site of compression (Fig. 5). It is important to recognize that the floor of the cubital tunnel is actually the superficial aspect of the anterior band of the MCL; this anatomic reference should be taken into consideration when dealing with pathology in the medial compartment of the elbow. The radial nerve descends the arm laterally, dividing into superficial (sensory) and deep (motor, or posterior interosseous) branches (Fig. 6). The deep branch must then pass through the arcade of Frohse, a fibrous arch formed by the proximal margin of the superficial

Fig. 1 Anterior aspect of the elbow. Distal humerus (1), proximal radius (2) and proximal ulna (3) (Reproduced by permission of Llusá et al. [1])

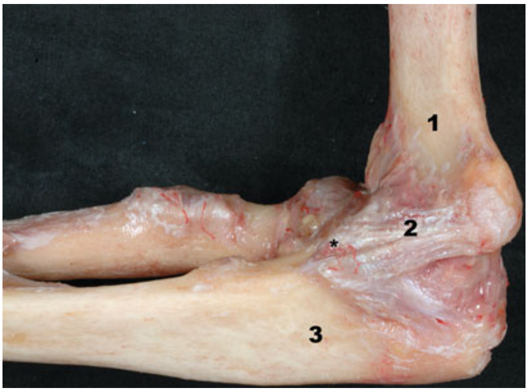


Fig. 2 Medial aspect of the elbow. Distal humerus (1), anterior bundle of the medial collateral ligament (2), and proximal ulna (3). Sublimis tubercle (*) (Reproduced by permission of Llusá et al. [1])

Fig. 3 Lateral aspect of the elbow. Distal humerus (1), proximal radius (2) and proximal ulna (3). Annular ligament (4) and the lateral collateral cubital ligament (5)

head of the supinator muscle, where it is most susceptible to injury, especially when developing lateral approaches to the elbow joint. Proximally, the radial nerve crosses from the posterior to the anterior compartment of the arm at a distance from the lateral epicondyle equivalent to 1.5 times the inter-epicondylar distance. This anatomical reference is also very useful to avoid complications related to this nerve when developing triceps-reflecting approaches.

The functional range of motion of the elbow for activities of daily living is 30–130° of flexion and 50° of supination and pronation. This arc of motion allows independent function but may be very limiting for more specific pursuits.

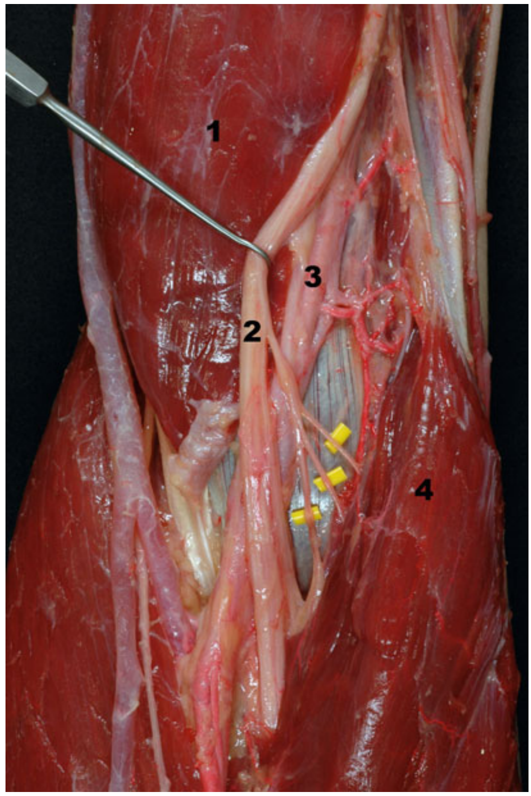


Fig. 4 Anterior aspect of the elbow. Biceps brachii muscle (1), median nerve and its branches for the *pronator teres* muscle (2), humeral artery (3) and flexo-pronator mass (4)

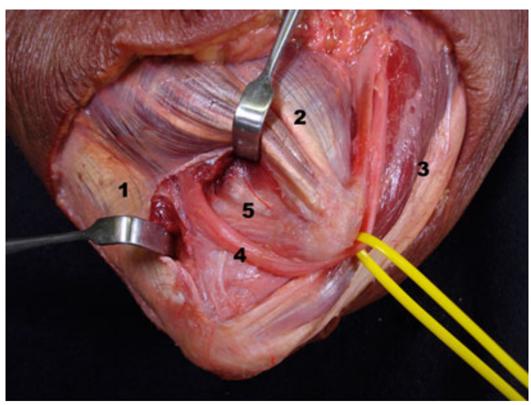


Fig. 5 Medial aspect of the elbow. *Flexor carpi ulnaris* muscle (1). Flexor-pronator mass (2). *Triceps brachii* muscle (3). The intimate relationship between the ulnar nerve (4) and the anterior bundle of the medial collateral ligament (5)

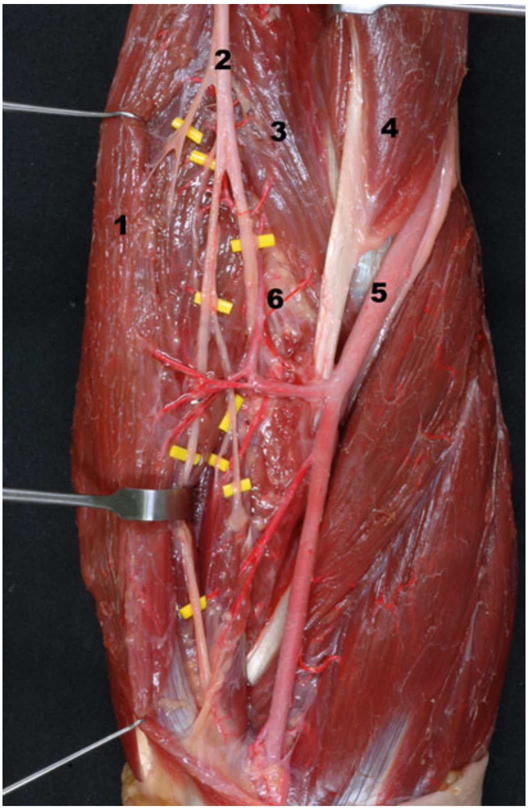


Fig. 6 Anterior aspect of the elbow. *Brachioradialis* muscle (1), radial nerve (2), *brachialis* muscle (3) and *biceps brachii* muscle (4). Humeral artery (5) and the radial recurrent artery (6) ascending between the branches of the radial nerve (2)

Approaches

Superficial osseous landmarks, such as the olecranon, the radial head and both epicondyles, should be identified before any surgical approach is developed. Previous surgical incisions should be considered; particularly those retracted or adherent to the subcutaneous tissue. Utilizing previous scars, when possible, may reduce the risk of skin necrosis. Any approach through anatomical planes of dissection should be prioritized (Fig. 7). Elbow surgery should be routinely done, unless contra-indicated, with the aid of an arm tourniquet.

The following approaches are just the most commonly-used in our practice. We tend to favour surgical approaches which are versatile for the whole spectrum of elbow pathology.

Lateral Approaches

Approaches through the lateral aspect of the elbow are probably the most commonly used in elbow surgery and are indicated for fixation of intra-articular fractures, removal of osteophytes, removal of loose bodies, radial head excision, capsulectomy and repair or reconstruction of the lateral ligaments.

If we anticipate that an extensile approach will be required, our preference is to use a straight posterior skin incision. Alternatively, limited

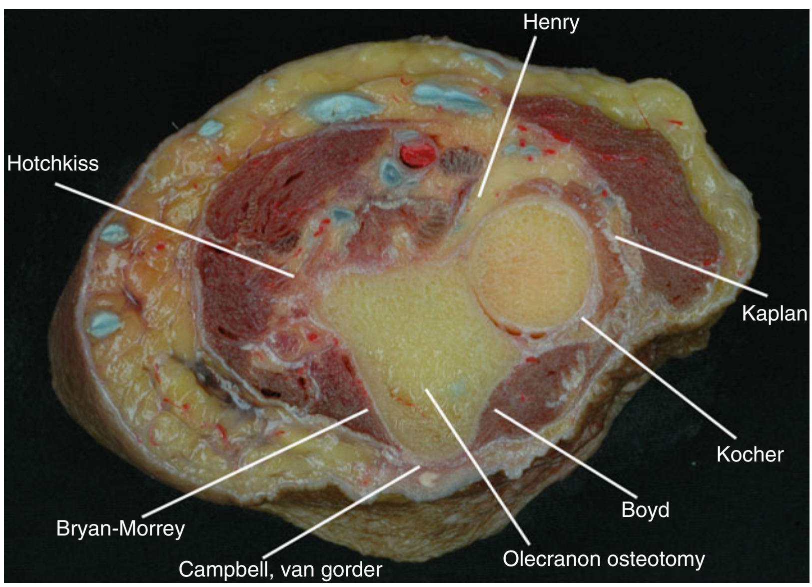


Fig. 7 Coronal section of the elbow showing some of the most commonly-used approaches

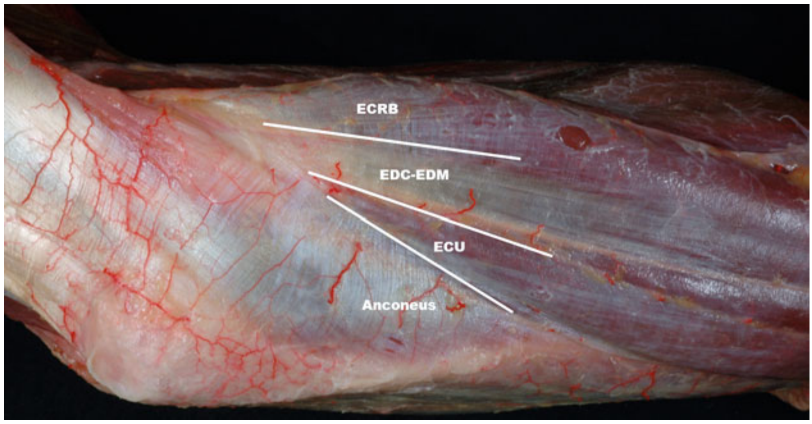


Fig. 8 Lateral view of the superficial muscles of the forearm. *ECRB* extensor carpi radialis brevis, *ED* extensor digitorum, *EDM* extensor digiti minimi, *ECU* extensor carpi ulnaris

incisions proximal or distal to the lateral epicondyle can be utilized depending on the pathology we are dealing with.

Several intermuscular intervals have been described, but Kocher's and Kaplan's approaches remain the most frequently-used. Kocher's approach develops the interval between the anconeus and the extensor carpi ulnaris and can be extended proximally and distally (Fig. 8) [2]. Kaplan described an approach in the interval between the extensor digitorum communis (EDC) and the extensor carpi radialis brevis (ECRB) and longus (ECRL) [3].

The main concern when using lateral approaches is the risk of causing an injury to the radial nerve, particularly with Kaplan's approach, so care must be taken to identify and protect the nerve if necessary. When dealing with a traumatic elbow, the lateral ulnar collateral ligament must be identified and preserved or repair to avoid elbow instability.

Kocher Approach

Kocher's approach utilizes the intermuscular interval between the anconeus and the extensor carpi ulnaris (Fig. 9). This interval permits access to the lateral elbow joint. The radial nerve is relatively safe as it is protected by the extensor carpi ulnaris muscle.

Indications

Fixation of condylar fractures, radial head procedures and repair or reconstruction of the lateral ligaments.

Technique

Our preference is to use a straight posterior skin incision with dissection of a full-thickness lateral fasciocutaneous flap. However, limited distal lateral skin incisions may be used. The interval between the anconeus and extensor carpi ulnaris muscles can be identified by palpation. A thin strip of fat is frequently seen in the interval between these muscles. It is easier to develop the interval in its distal part and then progress proximally as the muscle fibres of the anconeus and the extensor carpi ulnaris muscles tend to blend together towards the insertion. The deep fascia is then opened and the interval is developed by dissecting the anconeus posteriorly. The lateral elbow capsule with the annular ligament is identified and incised anteriorly to the lateral ulnar collateral ligament.

Modifications

When required, this approach can be extended proximally above the lateral epicondyle by developing the interval between the triceps and the brachioradialis. The extensor mass can then be sharply incised from the epicondyle preserving the attachment of the lateral ulnar collateral ligament. Distally, in order to achieve adequate exposure of the crista supinatoris, the anconeus, along with the lateral aspect of the triceps tendon, may be reflected posteriorly [4].

Mansat and Morrey have described the "column procedure" [5], which is a limited proximal lateral approach for capsular release in stiff elbows (Fig. 10). This exposure may

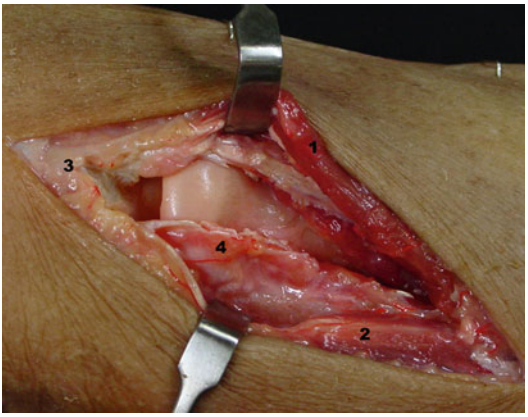


Fig. 9 Kocher approach. *Extensor carpi ulnaris* muscle (1). *Anconeous* muscle (2). Lateral epicondyle (3). Annular ligament (4)

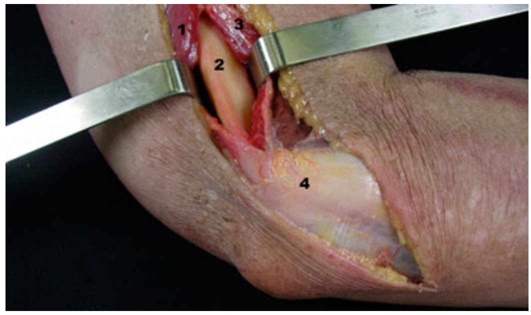


Fig. 10 The "column procedure". The *triceps brachii* muscle (1) has been partially dettached from the posterior aspect of the lateral column. The *extensor carpi radialis longus* and the *brachioradialis* muscle (3) have been retracted anteriorly to expose the capsule and distal humerus (2). Extensor-supinator group (4)

be a proximal extension of the Kocher approach or a focused isolated proximal approach. The exposure is based on dissection made anteriorly and posteriorly to the lateral border of the distal humerus ("the column"). Anteriorly, the distal aspect of the brachioradialis and the extensor carpi radialis longus are elevated from the humerus and the interval between the brachialis and the capsule is developed. Posteriorly, in order to gain access to the capsule, the triceps must be dissected from the posterior part of the humerus.

Kaplan Approach

Indications

Radial head fractures, particularly those involving its anterior half (Fig. 11).

Technique

The skin incision starts on the lateral epicondyle and extends 4 cm distally, through a line running from the lateral epicondyle towards the ulnar styloid process in the wrist. The interval between the EDC and the ECRB and ECRL is developed exposing the underlying capsule, which is incised longitudinally to gain access to the radial head. The radial nerve is at special risk during this approach. Pronation of the forearm and careful use of retractors may diminish the risk of injury to the radial nerve [6].

Kocher Posterolateral Extensile Triceps-Sparing Approach

Indications

Open reduction and internal fixation of fractures, re-surfacing elbow replacement, and interposition arthroplasty.

Technique

This exposure is an extension of the limited exposures described above (Fig. 12). A straight midline posterior skin incision avoiding the tip of the olecranon is used. The triceps is elevated from the posterior aspect of the humerus, and the brachiorradialis and the ECRL are then dissected anteriorly. The Kocher interval is identified and developed to expose the joint capsule, as has been discussed previously. The anconeus is elevated from the ulna and the triceps attachment to the lateral epicondyle is also reflected posteriorly, leaving its insertion to the olecranon intact. At this time, the lateral collateral ligament is released from the humeral origin allowing dislocation of the elbow joint by applying a varus stress.

Modification

This approach was modified in the Mayo Clinic to include complete release of the triceps from the olecranon, reflecting the triceps mechanism and anconeus from lateral to medial by releasing Sharpey's fibers [7].

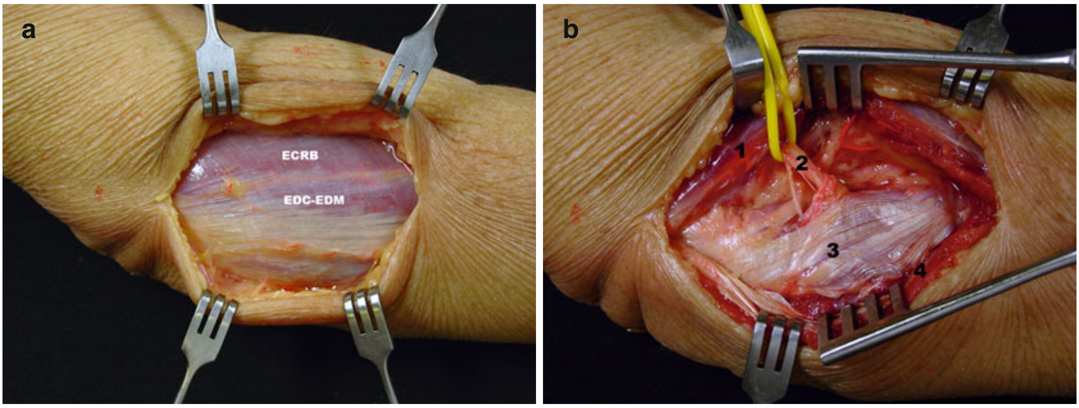


Fig. 11 Kaplan approach. (**a**) The incision is in line with the interval between the *extensor carpi radialis brevis* muscle (1) and the *extensor digitorum* muscle (4). (**b**) After detaching part of the superior origin of both muscles, it is necessary to separate them in order to show the *supinator* muscle (3). The posterior interosseous nerve (2) lies within the *supinator* muscle. With the pronation of the forearm, the posterior interosseous nerve moves medially from the operative field

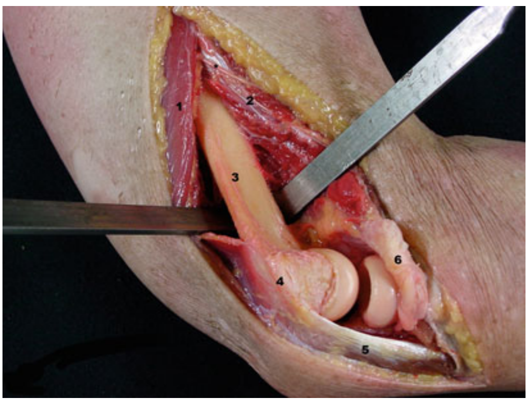


Fig. 12 Kocher posterolateral extensile triceps-sparing approach. Subperiosteal dissection of the *triceps brachii* muscle (1), the *brachioradialis* muscle and the *extensor carpi radialis longus* muscle (2) of the lateral aspect (3) of the distal humerus. It is necessary to detach the *anconeus* muscle (5) off the proximal aspect of the ulna, to expose the interval between this muscle and the *extensor carpi ulnaris* muscle. For complete exposure of the lateral half of the elbow it is necessary to detach the lateral collateral ligament (6) off the lateral epicondyle (4)

Medial Approaches

Medial approaches to the elbow are less frequently-used and have the downside of potential injury to the ulnar nerve. They may be utilized to address pathology of the ulnar nerve, injuries of the MCL, fractures of the coronoid process and contracture release. Less-invasive approaches that do not require detachment of the flexor pronator mass have been described for its use in MCL reconstruction [8].

Extensile Medial Approach

Indications

Hotchkiss initially described this approach for releasing elbow contractures as it provides superb exposure of the medial aspect of the joint with access to the posterior and anterior capsules [9]. It allows treatment of concomitant ulnar nerve pathology and permits access to the coronoid and humeral condyle. The main disadvantage of this approach is the limited access to the lateral aspect of the joint.

Technique

A medial skin incision could be used, but it is our preference, as previously mentioned, to use a straight posterior skin incision for any extensile approach used around the elbow (Fig. 13).

Great care must be taken at the proximal side of the incision to avoid injury to the medial antebrachial cutaneous nerve (Fig. 14). It is usually found lying on top of the superficial fascia and can cause disturbing neuroma if damaged. The ulnar nerve should be identified proximally and dissected from proximal to distal and mobilized as necessary. The medial intermuscular septum should be released for a distance of about

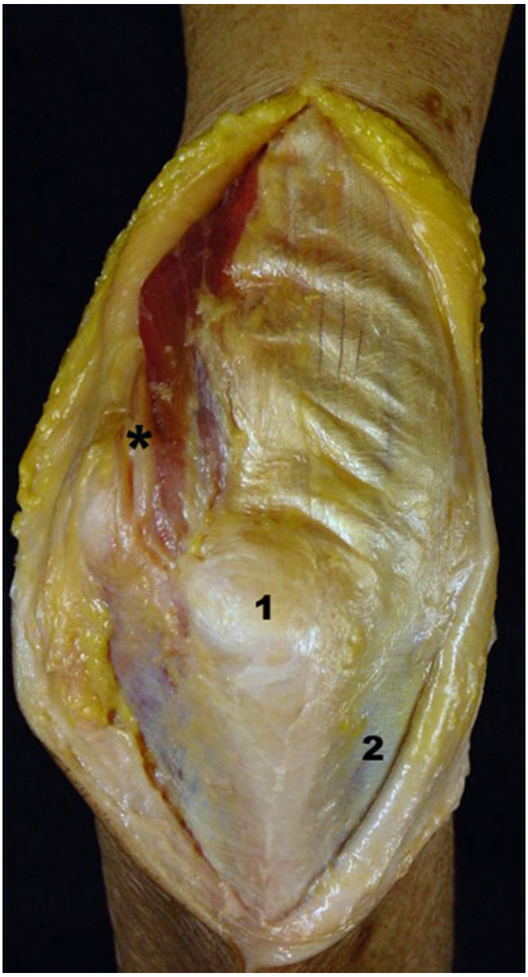


Fig. 13 Universal approach. Full thickness fasciocutaneous flaps are elevated laterally and medially, preserving the subcutaneous arterial plexus and the cutaneous nerves. The ulnar nerve (*) is located and isolated medially to the medial head (deep) of the *triceps brachii* muscle. Olecranon (1) and *anconeus* muscle (2)

5 cm proximally to avoid entrapment. An incision is made on the supracondylar ridge 5 cm proximally to the medial epicondyle and continued distally towards the pronator and a portion of the common flexor tendon. Leaving a portion of flexor carpi ulnaris tendon attached to the epicondyle posteriorly makes closure at the end of the procedure easier. A Cobb elevator can be helpful in elevating the anterior structures from the distal humerus until an appropriate retractor can be introduced. As the dissection proceeds laterally and distally, the brachialis muscle is elevated from the capsule. It is advisable to complete the muscle dissection from the capsule before resecting it.

Another option is to start the dissection distal to the coronoid process and proceed proximally. The flexor tendon can be incised with the knife blade placed almost parallel to the plane of dissection and just distal to the level of the sublime tubercle. This manoeuvre will lead us to the plane between the MCL and the flexor muscle mass, protecting the ligament with the back of the blade. The dissection can be then extended proximally.

The exposure of the posterior capsular can be done safely by mobilizing the ulnar nerve anteriorly. The triceps is then elevated from the capsule with the use of a periosteal elevator. This manoeuvre will allow access to the posterior band of the MCL, should we need its release in stiff elbow surgery.

Posterior Approaches

Posterior skin exposures can be employed for the majority of surgical interventions in the elbow, because the dissection may be easily extended medially or laterally. It is important to dissect full-thickness fasciocutaneous flaps to avoid wound problems. Indications include reconstruction for degenerative diseases or tumours, distal humerus fractures, and elbow stiffness.

Skin Incision

A straight skin incision avoiding the tip of the olecranon is advisable, although an “S” incision has also been described. Some surgeons advocate going slightly more laterally to avoid any tenderness of the scar when resting the elbow on the side, and to avoid the risk of damaging the ulnar nerve. Other surgeons have attributed better healing to a medial incision compared to a lateral one [7].

To preserve the subcutaneous arterial plexus and the cutaneous nerves it is critical to dissect full thickness fasciocutaneous flaps, which can be elevated laterally and medially as necessary (Fig. 13). Post-operative seromas have been described as a complication of this approach and applying a compressive dressing at the end of the procedure should aid in preventing them.

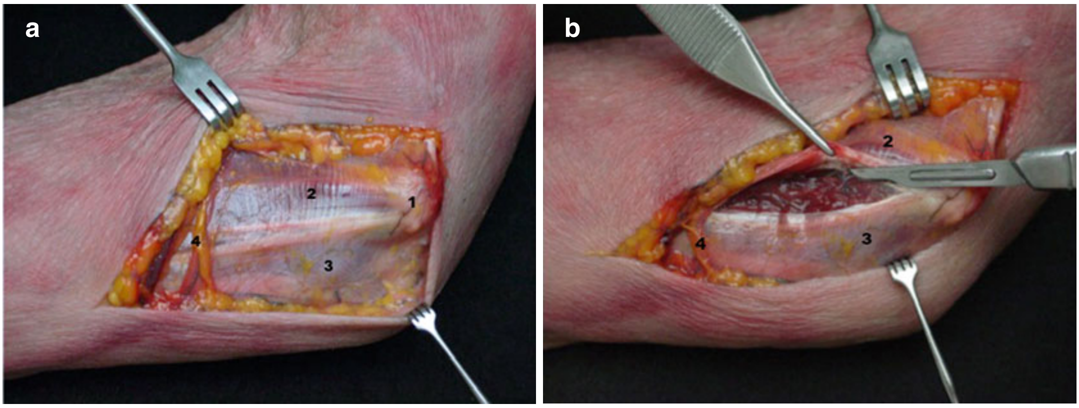


Fig. 14 Extensile medial approach by Hotchkiss. (**a**) Superficial surgical dissection: medial epicondyle (1), flexor-pronator group (2) and flexor carpi ulnaris muscle (3). It is necessary to locate and to preserve the *medial antebrachial cutaneous* nerve (4). (**b**) Location of the interval between the *flexor digitorum superficialis* muscle (2) and the *flexor carpi ulnaris* muscle (3). (**c**) Anterolateral retraction of the *flexor digitorum superficialis* muscle and the rest of the flexor-pronator muscles (2) and posteromedial retraction of the *flexor carpi ulnaris* muscle (3) to expose the anterior bundle of the medial collateral ligament (5), coronoid process (6), the anterior joint capsule (*)

Ulnar Nerve

It is controversial which is the best approach to the ulnar nerve, whether to decompress and protect the nerve throughout the procedure or to transpose it. The final decision regarding the ulnar nerve should be based on pre-operative clinical symptoms, the pathology to be addressed and the surgical approach used.

When performing distal humeral fracture fixation or elbow replacement procedures, our preference is to protect the nerve and to transpose it at the end of the procedure. In cases of releasing a severely contracted elbow, it is systematically transposed, particularly when the elbow has significant flexion deficit.

Once released and mobilized, the ulnar nerve must be protected throughout the procedure avoiding traction manoeuvres. In cases of anterior transposition, the medial intermuscular septum should be excised proximally and the ulnar tunnel retinaculum opened longitudinally between the flexor carpi ulnaris fascia to avoid late entrapment. Meticulous protection and maintenance of the vascular supply to the ulnar nerve should be maximized.

When a submuscular transposition is performed, the nerve is placed under the flexor pronator mass, closing the muscular layer over it. In cases of subcutaneous transposition, the nerve is placed on a subcutaneous pouch. In both procedures impingement of the nerve should be checked both in flexion and extension before final closure.

Triceps

Management of the triceps tendon is a source of disagreement, and multiple approaches may be selected based on the pathology to be addressed. It remains common sense that any disruption of the triceps can increase the incidence of extensor mechanism complications. Several options are available, including approaches in which the triceps attachment is preserved (Alonso-Llames, Patterson, Morrey and Adams) [10–12], where it is reflected from medial to lateral (Bryan and Morrey) [13], reflected from lateral to medial (Kocher posterolateral extensile approach), split in the midline (Campbell, Gschwend, Van Gorder) [14–16] or divided using a triceps tongue (Campbell, Van Gorder, Wadsworth) [14, 17, 18] (Table 1).

The benefit of obtaining an adequate exposure must be weighed against the risk of post-operative triceps insufficiency. In any case, any violation of the extensor mechanism may increase the risk of triceps insufficiency, so a meticulous reconstruction of the tendon at the end of the procedure is a pre-requisite for any of the following procedures.

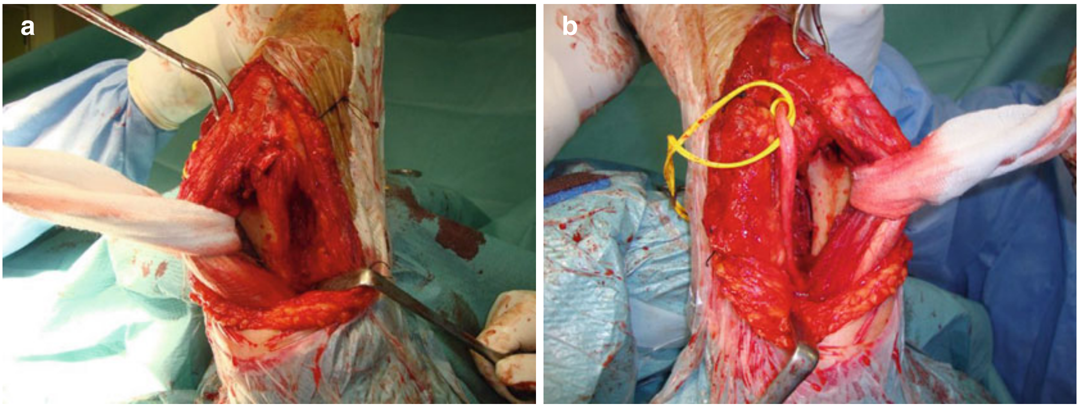


Fig. 15 Triceps-preserving (Alonso-Llames) approach. (**a**) Lateral view. To expose the lateral column and the posterior aspect of the distal humerus, retract the *triceps brachii* muscle medially. (**b**) Medial view. After isolating the ulnar nerve, the *triceps brachii* muscle is retracted laterally, exposing the medial column and the posterior aspect of the distal humerus

Post-operatively, if the triceps insertion has been violated, the surgeon must protect the elbow and delay active extension against gravity for a few weeks to enhance healing of the extensor mechanism.

Triceps-Preserving Approach: Alonso-Llames

Indications

Although initially described for managing pediatric supracondylar fractures, it may also be used for simple distal humeral fractures in adults, non-unions, tumours, and total elbow arthroplasty or hemi-arthroplasty in comminuted distal humerus fractures [10].

The major advantage of this approach is that it preserves the extensor mechanism continuity. The main disadvantage is the limited exposure obtained, which may increase the difficulty of the procedure.

Technique

A posterior skin incision is made medial or lateral to the olecranon and full thickness fasciocutaneous flaps are elevated. The medial and lateral borders of the triceps are incised and elevated from the posterior aspect of the distal humerus with a periosteal elevator. The ulnar nerve must be identified and protected on the medial side of the triceps. The distal humerus can be button-holed medially or laterally, as required, to gain access to the proximal forearm (Fig. 15).

Modifications

Morrey described a variation of this technique indicated mainly for distal humeral non-unions treated with elbow replacement. The extensor origin and the lateral collateral ligament complex are released from the lateral epicondyle. Medially, the common flexor muscle and tendon mass are elevated along with the medial collateral ligament. After resection of the distal humerus non-union, the forearm can be rotated to facilitate exposure of the proximal ulna [7].

A modification of the technique to increase distal exposure was described by Patterson [12]. Laterally, the interval between the extensor carpi ulnaris and the anconeus is developed and, on the medial side, the flexor carpi ulnaris is elevated subperiosteally.

Posterior Triceps-Splitting: Campbell

Indications

Total elbow arthroplasty, distal humeral fractures, sepsis, synovectomy, ulnohumeral arthroplasty, ankylosis and unreduced elbow dislocation [14].

It is a simple exposure which can be easily extended proximally up to the level of the radial nerve and distally along the ulna. Appropriate closure technique is important to avoid button-holing of the olecranon through a defect in the triceps tendon.

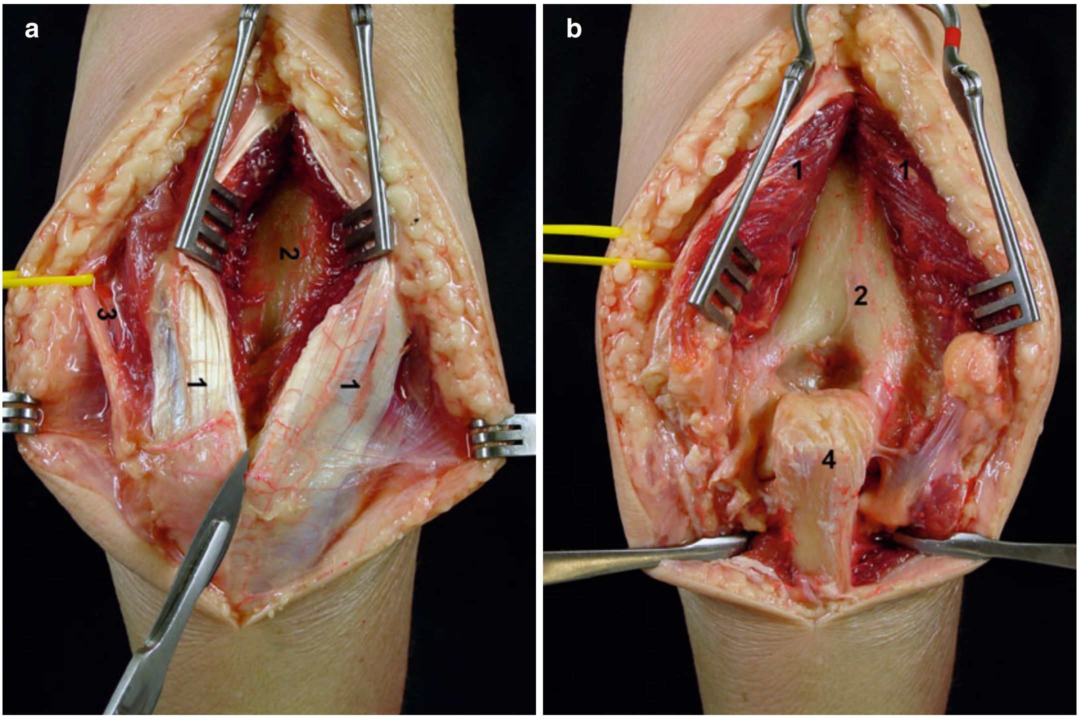


Fig. 16 Posterior triceps-splitting approach. (**a**) The tricipital aponeurosis (1) is incised in line with the skin incision. It is necessary to identify the ulnar nerve (3). (**b**) To gain a better view of the posterior aspect of the distal humerus (2), detach the triceps tendon from the olecranon (4). Distal enlargement of the approach can be accomplished by subperiosteal dissection of the *flexor carpi ulnaris* muscle medially, and the *anconeous* muscle laterally

Technique

The triceps tendon and muscle are longitudinally incised, exposing the distal humerus proximally and proceeding distally by reflecting the anconeus laterally and the flexor carpi ulnaris medially (Fig. 16). Subperiosteal dissection should be done at the level of the olecranon attachment. The ulnar nerve may be visualized medially and protected. Closure of the aponeurosis is done with side-to-side sutures. Transosseous sutures at the triceps insertion may be added to augment the repair.

Modifications

A modification of this approach was reported by Gschwend [15] in which the proximal ulna is exposed with the use of a fine osteotome to create osteoperiosteal flaps, in an effort to promote healing of the extensor mechanism.

Triceps-Splitting-Tendon Reflection: V-Y Approach

This approach was described by Campbell, and later modified by van Gorder and Wadsworth [17, 18], for treating elbow contractures with a scarred and shortened triceps.

Indications

It has the same indications as the previous exposure, but it has been mostly used for chronic elbow dislocations.

The main advantage of this approach is that it gives good exposure, allowing at the same time lengthening of the extensor mechanism by using a V-Y advancement technique. Its main disadvantages are that it weakens the triceps and has a reported infection rate higher than other approaches, due to vascular compromise of the distal flap. For this reason, we prefer a slight modification of this approach in which complete sectioning of the triceps muscle is avoided.

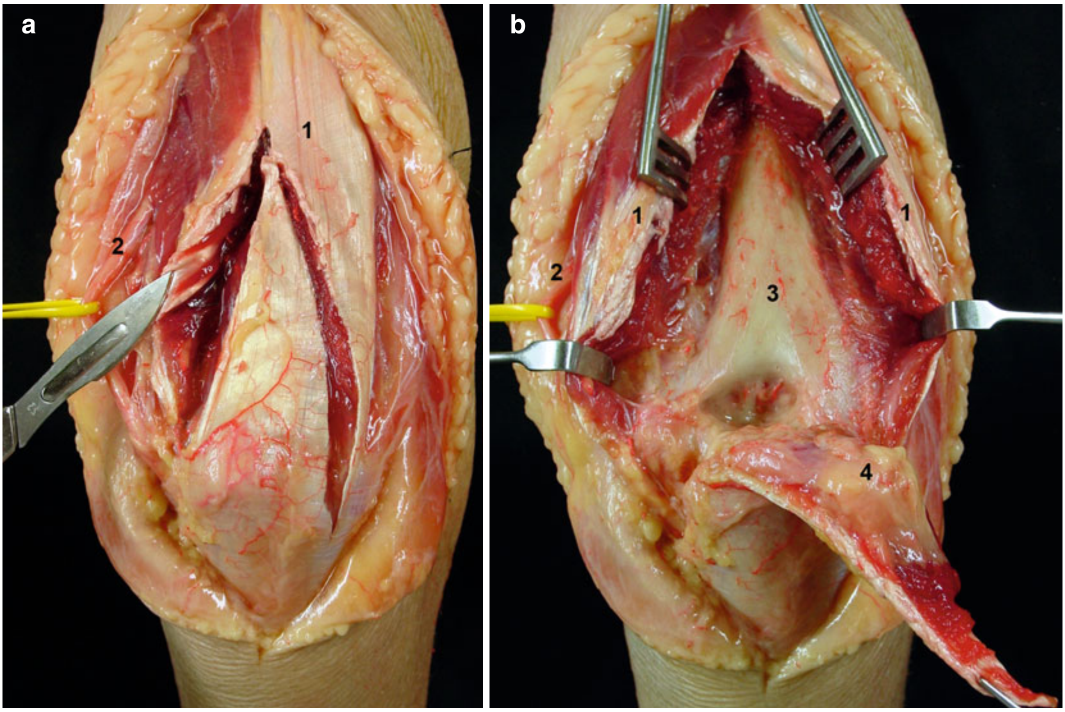


Fig. 17 Triceps-splitting-tendon reflection: V-Y approach. (**a**) After Isolation of the ulnar nerve (2) The tricipital aponeurosis (1) and the medial head of the *triceps brachii* muscle (3) are divided by using a V-Y incision. (**b**) The flap is distally-based and should extend to the outer part of the humeral condyles to gain a good access to the fat pad (*), and the posterior aspect of the distal humerus (3)

Technique

In the original approach, the deep head of the triceps is divided in its mid-line for a length of about 8 cm. The flap is distally-based and should extend to the outer part of the humeral condyles to gain a good approach (Fig. 17). Enough tendon tissue at both sides of the flap must be preserved to obtain a good repair. To advance the flap, the triceps is approximated in the mid-line using sutures for the required length. The rest of the flap is then repaired at its new length to the outer edges of the aponeurosis with interrupted sutures.

The previous approach has an unacceptable rate of infection and triceps disruption. Our preference is to avoid complete triceps disruption by elevating a flap with the superficial triceps aponeurosis and then entering the true triceps tendon longitudinally, through an avascular area (Fig. 18). This approach better preserves the vascularisation of the distal flap and provides a superior repair.

Modifications

Van Gorder [17] described a modification of this technique in which the incision on the medial head of the triceps runs obliquely in order to avoid cutting off the triceps proximally. The incision runs from anterior distal to posterior proximal, leaving the entire thickness of the muscle attached to the base of the flap.

Wadsworth [18] described a modification to enhance the exposure. After creating the flap, the incision is extended distally along Kocher's interval, reflecting the anconeus medially, allowing access to the lateral aspect of the joint.

Posteromedial Extensile: Bryan-Morrey Approach

Indications

Include elbow arthroplasty, distal humerus fractures and elbow stiffness [13].

The advantage of this approach is that it provides great exposure, allowing access to the ulnar

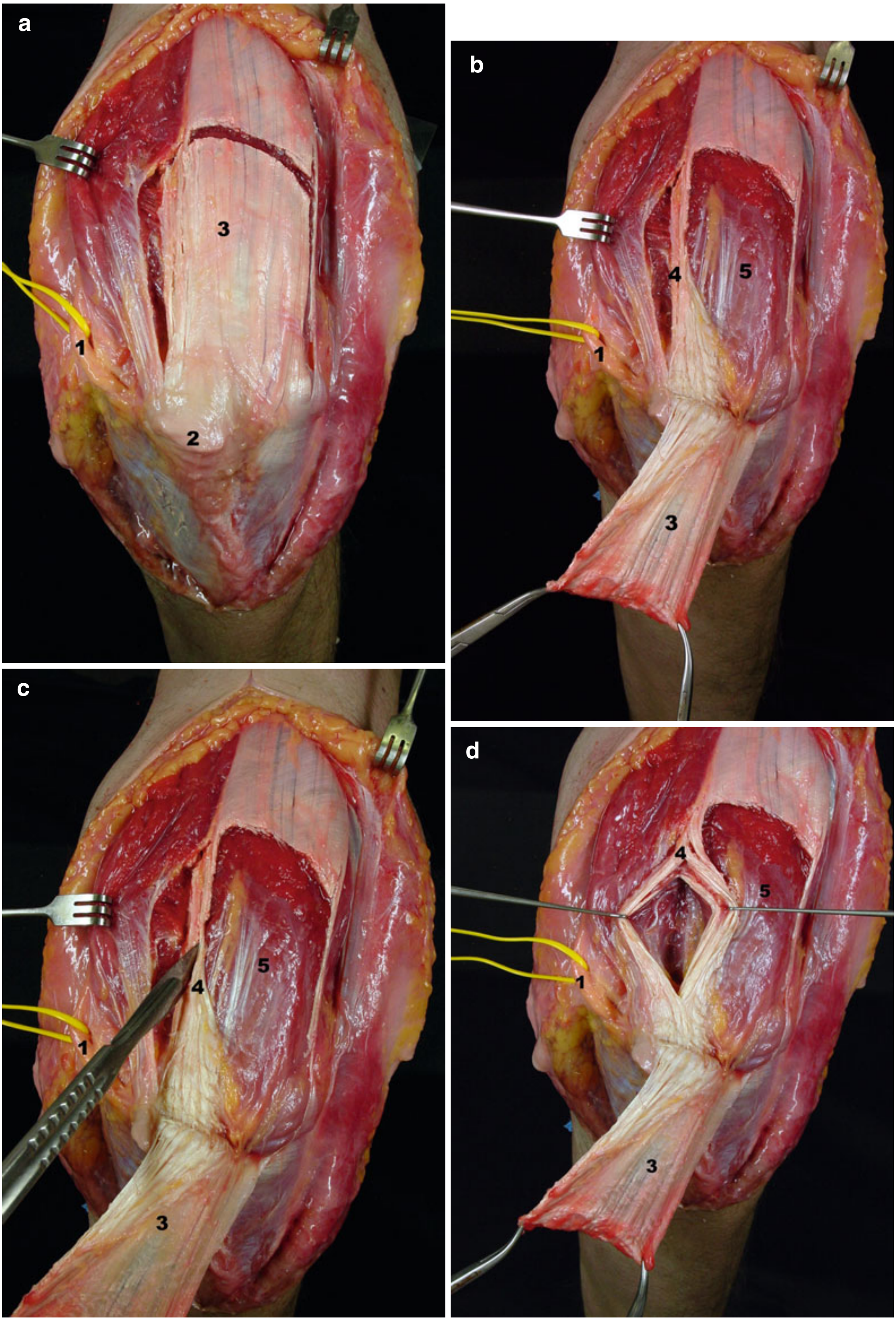


Fig. 18 (continued)

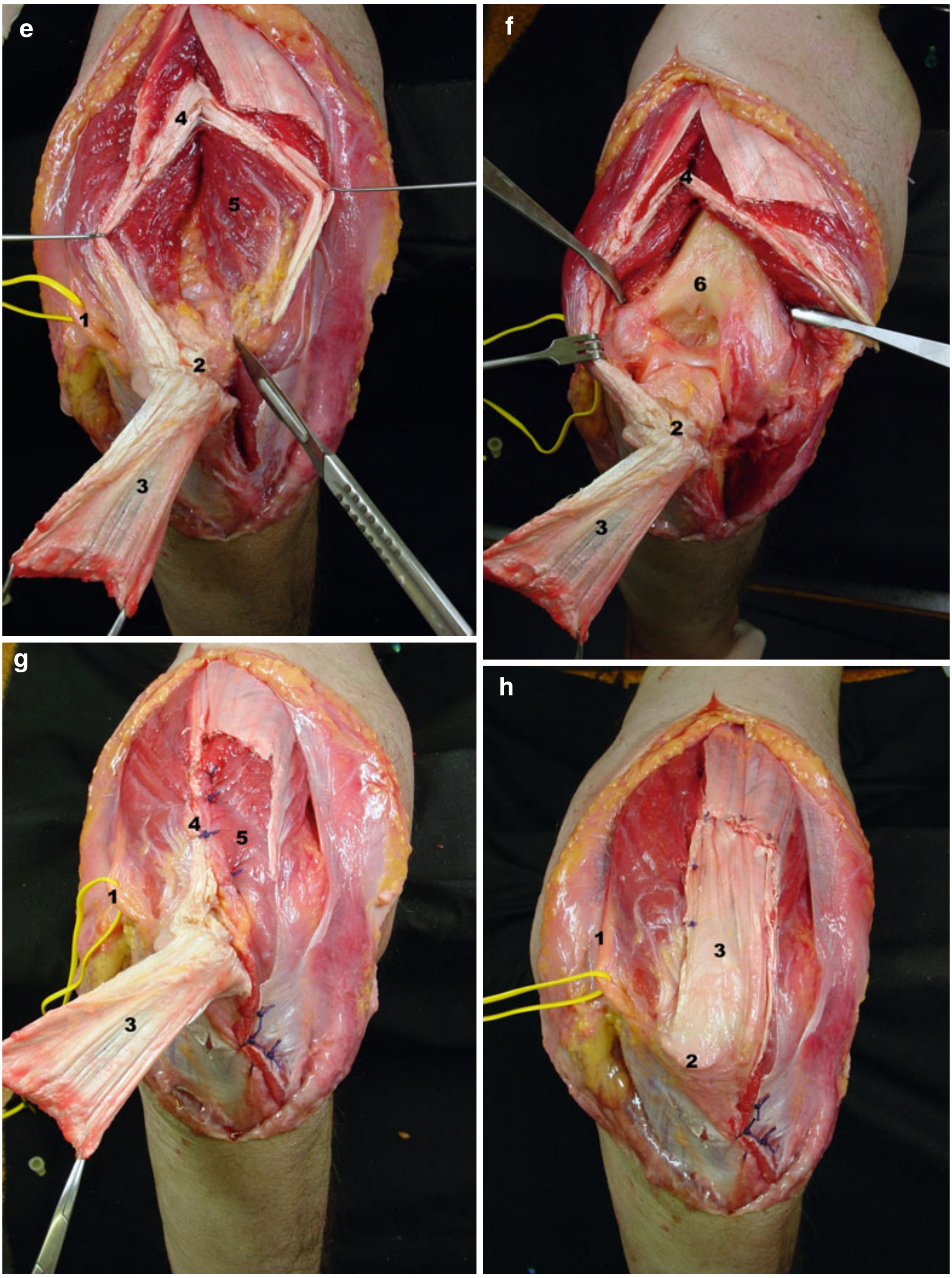


Fig. 18 Campbell approach modification. (**a**) After dissection of the ulnar nerve (1), the tricipital aponeurosis has been carefully incised (3). (**b**) Expose the true, intramuscular and sagittal tendon (4) of the *triceps brachii* muscle (5). (**c**) Make a longitudinal incision in the tricipital tendon. (**d**) After the longitudinal incision is completed, a Z incision of the tricipital tendon is performed (4). (**e**) It may be useful to detach the Anconeus distally. (**f**) Posterior aspect of the distal humerus (6). (**g**) When closing the approach, suturing the tricipital tendon provides resistance. (**h**) Finally, the tricipital aponeurosis will be sutured in its anatomical situation, decreasing the possibilities of adherences

nerve or medial collateral ligament. Anterior transposition of the ulnar nerve is a key step during the approach and should not be avoided. The main disadvantage is the possibility of developing post-operative triceps insufficiency if the tendon repair fails or the tissue quality is poor. Meticulous surgical technique during closure is advisable to prevent complications.

Technique

A mid-line skin incision is used from 8 cm proximal to 8 cm distal to the tip of the olecranon. The ulnar nerve is dissected proximally, where it is easily found medial to the triceps, and followed distally until it gives its first motor branch. The nerve must be protected throughout the procedure, and it is either transposed anteriorly (more commonly) or left in place at the end of the procedure.

The triceps is released from the entire posterior aspect of the distal humerus. The forearm fascia and ulnar periosteum are elevated from the medial margin of the ulna. The triceps tendon is carefully detached from the tip of the olecranon by sharp dissection of Sharpey's fibers (Fig. 19). The lateral margin of the proximal ulna is then identified and the anconeus is elevated from its ulnar bed. Finally, the extensor mechanism is reflected laterally from the margin of the lateral epicondyle.

Modifications

Wolfe and Ranawat [19] described a modification of this approach in which the ulnar nerve is exposed but not transposed and the triceps is released by osteotomizing its attachment on the olecranon through a thin wafer of bone, in an effort to achieve a reliable healing.

Shahane and Stanley [20] reported on a modification of this approach in an attempt to reduce the incidence of ulnar neuropathy. After decompression of the ulnar nerve the triceps is split leaving a quarter of triceps medially and the rest is reflected medially as a single unit.

In every instance, reconstruction of the extensor mechanism should include a repair with transosseous sutures through drill-holes placed in a cruciate fashion in the olecranon.

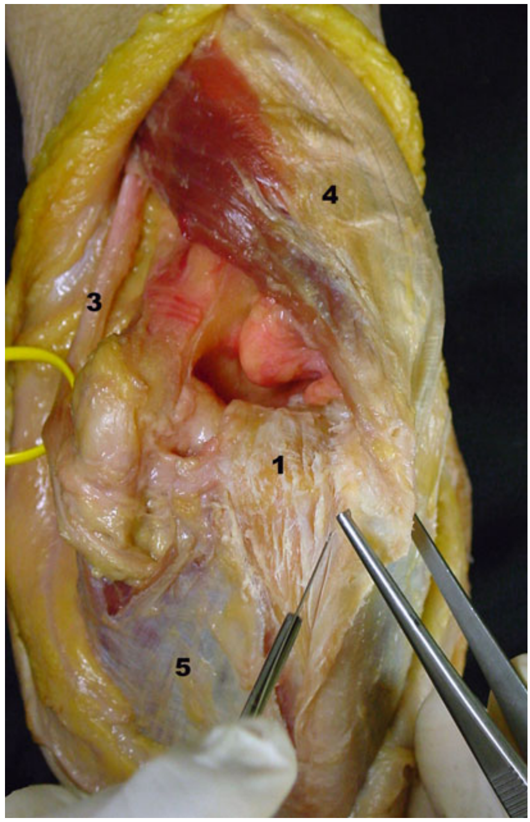


Fig. 19 Posteromedial extensile: Bryan-Morrey approach. (1) olecranon; (2) *anconeus* muscle; (3) ulnar nerve; (4) *triceps brachii* muscle; (5) *Flexor carpi ulnaris*

Olecranon Osteotomy

The transosseous exposure is a very popular way of approaching the elbow joint, and it is probably the most frequently used for the treatment of distal humerus fractures. Healing rates are consistent, and the major concern is related to the fixation method (K-wires, cerclage and plates) which often produces irritation and may require secondary procedures.

The chevron osteotomy is the preferred method of osteotomizing the olecranon in preference to oblique or transverse osteotomies due to its increased intrinsic stability and increased area for bony healing [21].

Indications

This approach was initially described for treating ankylosed joints. Its main indication today is open reduction and internal fixation of distal humerus fractures.

The chevron osteotomy has the advantage over the one originally described by MacAusland of an increased surface area for bony healing and increased stability as described below.

Technique

A posterior mid-line skin incision is used. The ulnar nerve must be located and protected throughout the procedure. A 3.2 mm drill-hole or two parallel Kirschner wires that cross the osteotomy site can be made to achieve perfect reduction at the completion of the procedure. The joint is exposed at the greater sigmoid notch and a sponge may be introduced in the joint to protect the articular surface. The osteotomy is made with a distal chevron and it is started with a saw and finished with an osteotome. This allows the formation of cracks that may facilitate repositioning of the bony fragment. The fragment and the tendon are retracted proximally (Fig. 20). Capsular attachments and the posterior component of the collateral ligaments may need to be divided to gain more access to the joint. At the completion of the procedure the osteotomized fragment is reduced and fixed with a cancellous lag screw, a cerclage with K wires or a plate.

Modifications

Concerns about splitting the anconeus after completing the osteotomy, has prompted the development at the Mayo Clinic of an approach in which the anconeus is sharply dissected distally and reflected proximally respecting its fascial attachment to the triceps. It preserves the anconeus in continuity with the triceps and can be used for later reconstructive procedures, should those be needed.

Anterior Approach

Anterior approaches to the elbow have fallen out of favour due to the proximity of important neurovascular structures, except for biceps tendon reconstruction. The anterior approach is based on the one described by Henry [22].

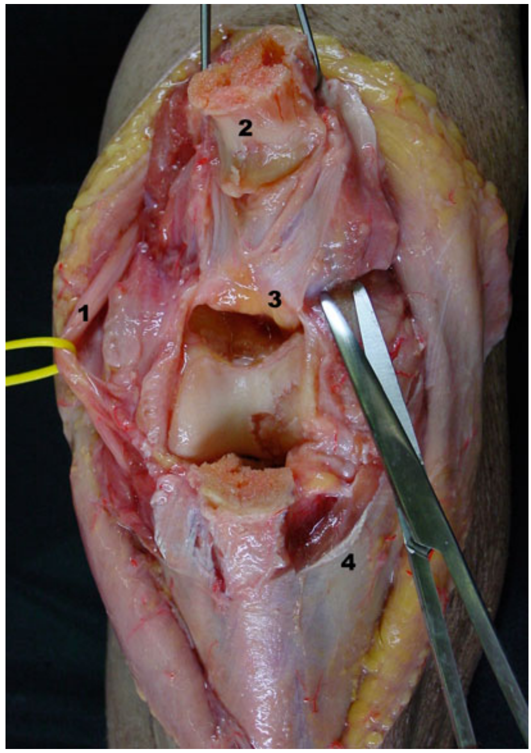


Fig. 20 Olecranon osteotomy approach. After the ulnar nerve (1) is identified, the olecranon (2) is osteotomized, just in the bare area of the greater sigmoid notch. Note that the anconeus (3 & 4) must be disrupted in order to achieve an adequate exposure

Extensile Anterior Exposure of the Elbow

Indications

These include neurovascular exploration in cases of local nerve entrapment, the reconstruction of the distal biceps, the reduction and osteosynthesis of anteriorly displaced fracture fragments and excision of tumours.

Important neurovascular structures, which should be identified and protected if necessary, are in close vicinity with any anterior approach to the elbow. The lateral antebrachial cutaneous nerve in the superficial plane and the median nerve and the brachial artery in the deep plane of dissection are structures at risk during these approaches. The brachialis muscle is between the joint and the median nerve, and the radial nerve is in the interval between the brachialis and the brachiorradialis muscle. These anatomical

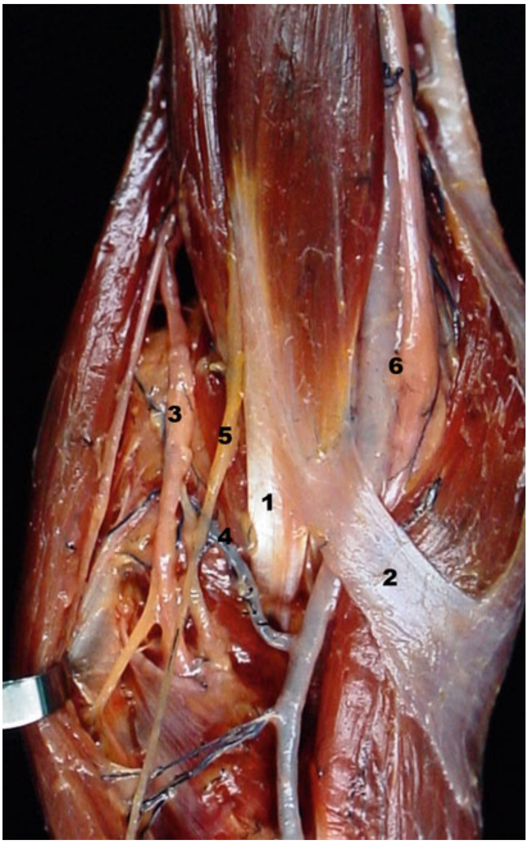


Fig. 21 Bicipital tendon (1); the *lacertus fibrosus* (2); The radial nerve (3); The recurrent radial artery (4); *cutaneus antebrachii lateralis* nerve (5); the brachial artery and the median nerve (6) (Reproduced by permission of Llusá et al. [1])

features must be kept in mind at all times to avoid inadvertent injury (Fig. 21).

Technique

The incision is S-shaped with the transverse arm parallel to the elbow flexion crease. Proximally it follows the medial border of the biceps, and distally it follows the medial border of the brachioradialis. The plane of dissection lies between the brachiorradialis and the brachialis muscle proximally and the brachiorradialis and the pronator teres distally.

During the superficial dissection, the lateral antebrachial cutaneous nerve must be localized and protected. This nerve is found in the interval between the biceps tendon and the brachialis muscle. The aponeurosis is incised with care not to injure the radial artery which runs immediately under it. There are multiple vessels that should be ligated or cauterized. The vein and the median nerve are medial to the artery. If the radial nerve has to be identified, it emerges between the brachialis and the brachioradialis, in front of the joint. The radial nerve can be safely separated laterally along with the brachioradialis, and the pronator teres is retracted medially showing the radial artery, the muscle branch and the recurrent radial artery.

Modifications

Henry's approach can be extended proximally and distally as needed. Likewise, a more limited approach than the one exposed in the technique is currently used for reconstruction of distal biceps ruptures.

Biomechanics

Kinematics of the elbow joint are complex, and may be better understood by clarifying key concepts in motion, stability and force transmission.

Motion

The elbow is described as a trochoginglymoid joint, which provides motion in two planes: flexion-extension and pronation-supination. Basically, it acts as a hinge due to the congruity of the ulnohumeral joint and to the constraints of the surrounding soft tissues. However, we know that it should be better described as a loose hinge, because it allows a varus-valgus laxity of about 4° throughout the range of motion.

In extension, the long axis of the humerus forms a valgus angle with the forearm of about 5° in men and 10º in women (defined as the carrying angle). This valgus alignment diminishes with elbow flexion due to the obliquity of the elbow joint line. The flexo-extension axis of rotation of the elbow goes from a point immediately distal to the lateral epicondyle to a point distal and anterior to the medial epicondyle, a line which can be identified in a lateral view of the elbow as passing through the centre of the arcs formed by the capitellum and trochlear sulcus.

The normal arc of motion in flexion and extension ranges approximately from 0° to 150°. Flexion is limited by the anterior muscles, contraction of the triceps and osseous impingement of both the head of the radius and the coronoid process against the radial fossa and coronoid fossa, respectively. Extension is limited by the impingement of the olecranon process against the olecranon fossa and tautness of anterior muscles, capsule and ligaments.

Forearm rotation is independent of elbow flexion and extension and occurs as the radius rotates around the ulna through an axis which is oblique with respect to the longitudinal axis of the forearm, running from the distal end of the ulna to the centre of the radial head. Pronation/supination motion involves the radiocapitellar and the proximal and distal radio-ulnar joints. The arc of motion in pronation supination is approximately 160°, with slightly more supination than pronation.

Stability (Constraints)

The role of the ligamentous and osteo-articular elements of the elbow on joint stability has been extensively studied using biomechanical and electromagnetic testing.

Varus stability is provided mainly by the joint congruity, and ulnohumeral contact, and this contribution increases with increasing degrees of elbow flexion. However, the capsule and the LCL provide almost half of the stability against varus in extension.

Valgus stress is resisted equally by the joint articulation, the capsule and the MCL. With increasing elbow flexion the role of the MCL, more specifically, the anterior band of this ligament increases (Fig. 22). The proximal half of the sigmoid notch is the osseous articular structure resisting valgus stress, while varus stress is mainly resisted by the coronoid and the distal half of the sigmoid notch.

In a classical article, Morrey et al. [23] studied the contribution of anatomical structures against valgus stress, concluding that the radial head is a secondary stabilizer for resisting valgus stress, with the MCL being the primary stabilizer. This implies that in the presence of a MCL injury all efforts should be made to preserve the radial head. In cases of radial head resection with an intact MCL the stability is slightly impaired although this situation is well tolerated over the long term [24]. Forearm rotation may affect valgus and varus laxity. Pronation may increase valgus laxity of the elbow and this may be especially relevant in throwing athletes and should therefore be considered when performing the clinical exam in these patients.

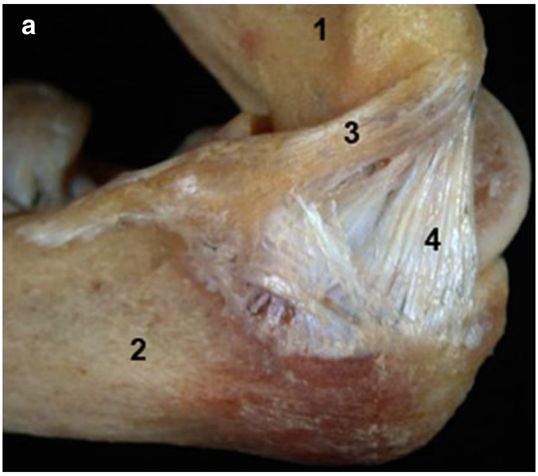
Similarly, when using a radial head implant in the setting of an unstable elbow, it is critical to choose the right size. Over-lengthening or under-lengthening by as little as 2. 5 mm may alter elbow kinematics and increase the rate of complications [25].

Force Transmission

The elbow can be considered a load-bearing joint. The forces that cross the elbow are the resultant of a combination of the loads applied on the hand or forearm balanced by the forces exerted by the musculotendinous units, ligaments and the joint anatomy. When considering the elbow joint as a hinge, the forces exerted by the muscles vary with the range of motion.

The force vector crossing the elbow joint is perpendicular to the flexor-extensor axis of rotation and passes through the centre of the joint line.

Single-muscle analysis is probably a simplistic but quite helpful way to understand how forces act across the elbow. In this type of analysis, changes in the moment arm of the muscle with



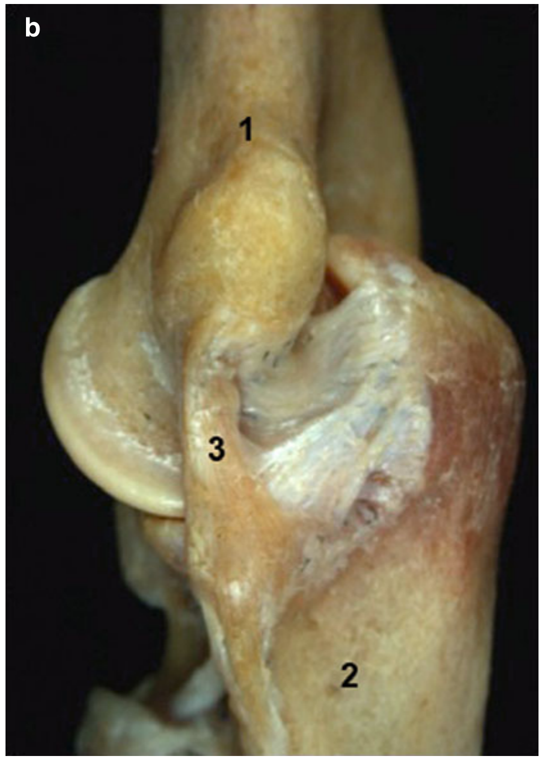


Fig. 22 (**a**, **b**) When applying a valgus stress, the primary stabilizer is the anterior band of the medial collateral ligament, especially in flexion. Distal humerus (1). Proximal ulna (2). Anterior bundle of the medial collateral ligament (3)

respect to the position of the joint are balanced by the magnitude of the muscle force. There is a close relationship between the joint forces and the muscle forces acting through the joint for a particular external load being applied to the hand. Increasing the moment arm of a muscle decreases the joint reaction forces and the muscle forces required to balance them. The position and orientation of the external load on the forearm or hand and the flexion angle of the joint alter the moment arm of the forces and the muscle line of action.

Maximum elbow strength occurs at 90° of flexion when the cross-sectional area of the muscle is largest. With the elbow extended, one-third to one-half of the maximum force can be generated. Forces around the joint are three times the body weight with maximum force at 30° of flexion.

Six muscle groups participate in flexion-extension: brachialis, biceps, brachioradialis, extensor carpi radialis longus, triceps and anconeus [26]. The contribution of forearm muscles to flexion and extension is probably limited. Analysis with surface electrodes has helped to elucidate the function of arm muscles. The brachialis muscle shows activity with elbow flexion, especially with the forearm in neutral rotation or pronation, while the biceps shows activity with flexion of the elbow if there is supination of the forearm, diminishing with forearm pronation.

The medial head of the triceps is most active at both 90° and 120° of extension and is presumed to be the main extensor of the elbow. The lateral and the long head of the triceps act as auxiliary muscles. The anconeus shows activity throughout the arc of motion and is considered a dynamic stabilizer of the elbow. Although forearm muscles were considered stabilizers for lateral ligaments of the elbow, EMG analyses has showed no electrical activity when testing the elbow for stability [27].

Joint compressive forces with the elbow in extension occur 40 % across the ulnohumeral joint and 60 % across the radiohumeral articulation, but varus and valgus alignment can significantly shift these forces to the proximal ulna or to the radiocapitellar joint, respectively [28].

Articular stress forces are equally distributed across the joint, considering the elbow as a rigid-spring model with the line of action of all forces centred at the middle of the articular surface. If the line of action is somewhat translated anteriorly or posteriorly, the bearing surface diminishes and compressive stresses increase, making joint stress distribution uneven.

Summary

The elbow is a complex joint both from the anatomic and biomechanical points of view. A thorough understanding of elbow kinematics will greatly aid the surgeon in dealing with complex elbow pathology. The close vicinity of neurovascular structures should always be kept in mind when selecting a surgical approach.

Any approach to the elbow joint needs to be safe and versatile. Oftentimes we need to extend our surgical field to address unexpected associated pathology. In this regard, a universal posterior approach is recommended, especially for trauma cases. Additionally, it is wise to select an approach which runs through intermuscular and internervous planes. One of the key issues in elbow surgery is the management of the triceps tendon attachment which should be preserved whenever possible. The ulnar nerve may also be a source of complications, and it should be gently handled during surgery. Adequate management of elbow ligaments during trauma and reconstructive procedures will reduce the risk of inadvertent post-operative instability.

In conclusion, any surgeon dealing with elbow pathology should have basic knowledge of elbow anatomy and kinematics in order to improve his/her surgical technique and outcomes.

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