INTRODUCTION

Supracondylar fracture humerus (SCFH) is common pediatric injuries, representing about 3% of all fractures, they are considered as the most frequent fractures in children under 8 years of age, and the most common elbow fracture. Boys have a higher incidence of this type of fracture.[1]

Physiological hyperextension of the elbow is common in the affected age group. When a sufficient load is applied to the hyperextended elbow and transmitted through the olecranon to the thin bone of the olecranon fossa, an extension type SCHF results. [2]

Flexion type is uncommon in children, accounting for only 2–10% of all SCFH. It is usually caused by a direct fall on the posterior aspect of the elbow, resulting in a reverse angulation of that seen in the more common extension type SCFH. [3]

Extension type injuries are classified according to Gartland's criteria [4]

Type I or minimally displaced fractures in young children can potentially be treated with an above elbow cast at 90° of flexion for 4 weeks.[5]

Type II requires reduction. These may become stable after closed reduction and casting at 90° of flexion. [5]

Severely displaced SCFH are challenging injuries to treat and entail technically difficult procedures for orthopedic surgeons. The differences among authors relates mainly to the choice between treatment by closed reduction and percutaneous K-wires fixation or open reduction and wiring under direct vision. [1]

The literature supports closed reduction and percutaneous pinning as the treatment of choice for these fractures. However, this could be associated with various complications, such as neurovascular compromise ranging from 5-30%, skin problems, compartment syndrome, Volkmann's ischemia, and cubitus varus with an incidence as high as 60%.[1]

Open reduction and K-wires fixation is indicated if the brachial artery has been compromised and requires exploration or if the fracture is irreducible by closed methods mostly due to interposition of the brachialis muscle,[5] or in the presence of extensive swelling of the traumatized elbow and recurrent reduction attempts for unstable fractures.[6]

There are three main surgical exposure methods for open reduction and internal fixation. These are: lateral, medial, [7] posterior, [8] and anterior. [9]

Lateral exposure provides alignment by using the anterior cortex of the fracture, and allows the surgeon to visualize and extract the interposed soft tissues. Although lateral exposure has the advantage of protecting the posterior vascular structures nourishing the distal humeral epiphysis, the lateral scar is often found unacceptable. [10]

The anterior approach has the advantage of better decompression of the fracture hematoma, better visualization and control of the fracture line, easy recognition of residual malpositioning and rotation of the fracture and the advantage of recognizing the tissues that prevents proper reduction such as the brachialis muscle, joint capsule, and neurovascular structures. [10]

The posterior approach allows excellent visualization obtained by providing good visualization of the distal humerus especially one with posterior comminution that allows exact anatomic reduction with no resultant angular or rotational deformities. No other approach provides an assured anatomic reduction at all times. [7]

The primary aetiology of cubitus varus deformity is tilting of the distal fragment in the coronal plane. [11]

Remodeling of the angulation in the sagittal plane can occur, but angular deformities in the coronal plane are less likely to remodel resulting in a cubitus varus or valgus deformity. [12]

The posterior approach, while claimed to be advantageous by some authors, has come under criticism because it produces damage in the intact posterior extensor muscles, due to cutting triceps muscle. This can result in the loss of full elbow movement. [13]

Aktekin et al. stated that the retracted scar localized posteriorly could decrease the range of motion. [14]

The posterior approach has been reported to have a high rate of loss of motion and the risk of osteonecrosis secondary to the disruption of the posterior end arterial supply to the trochlea of the humerus. [15]

REVIEW OF LITERATURE

Anatomy and Physiology

The distal end of the humerus

The distal end of the humerus is broadened and flattened anteroposteriorly curving anteriorly with an angle 45 degree to the shaft.

It terminates into an articular portion, the trochlea and capitulum, and non articular portion projecting into medial and lateral epicondyles for attachment of flexor and extensor muscles of the forearm. [16, 17] **(Fig.1)**

The trochlea is pulley shaped, it articulates with the trochlear notch of the ulna. It is separated laterally from the capitulum by a faint groove. [18]

The downward projection of the medial edge of the trochlea and the difference in prominence between it and the lateral ridge gives a tilt to the trochlea and this is the principal factor in determining the angulation which is present between the long axis of the humerus and the long axis of the supinated forearm when the elbow is extended. [17]

The capitulum is nearly half a sphere, convex projection. It articulates with head of the radius. It extends anteroinferiorly but not posteriorly. [17]

Immediately above the articular surfaces there are three concavities; anteriorly the coronoid fossa which receives the coronoid process of the ulna during flexion, the radial fossa which receives the anterior margin of the head of the radius during flexion, and posteriorly the olecranon fossa which receives the olecranon process during extension. These fossae increase the range of flexion and extension at the elbow joint by delaying the moment of impact of coronoid and olecranon processes on the shaft of the humerus. [19] They also allow the trochlear notch of the ulna which has a range of movement of 180 degree to glide over the trochlea for an appreciable distance on either sides of the neutral position. [20]

The compact portions of the distal end of the humerus lie on either side of these fossae forming two divergent pillars each ending at its corresponding epicondyle.From above we see that the lower end of the humerus is forklike structure and this explains why it is difficult to reduce fractures of that part. [21]

Ossification:

Ossification age in girls may exceed that of boys. [20] At birth the lower end of the humerus is cartilaginous, it is ossified from four centers; a center for the capitulum and lateral part of the trochlea appears six months after birth. Another center for the medial epicondyle appears commonly in the fourth year in females and six year in males. A third center for the medial part of the trochlea appears in the twelfth year. The fourth center for the lateral epicondyle appears at the eleventh year. The centers for the capitulum, lateral part of the trochlea, and lateral epicondyle unite to form a single epiphysis which unites with the shaft in the fourteenth year in females and sixteenth year in males. The center for the medial epicondyle forms a separate apophysis which is extracapsular and unites with the shaft at the age of seventeen. [17] **(Fig.2)**

The distal physis of the humerus contributes only 20% of the longitudinal growth of the humerus. This is important information for patients and parents regarding the estimated duration of remodeling process in cases of persistent posterior tilt of the distal fragment in younger children. [22]

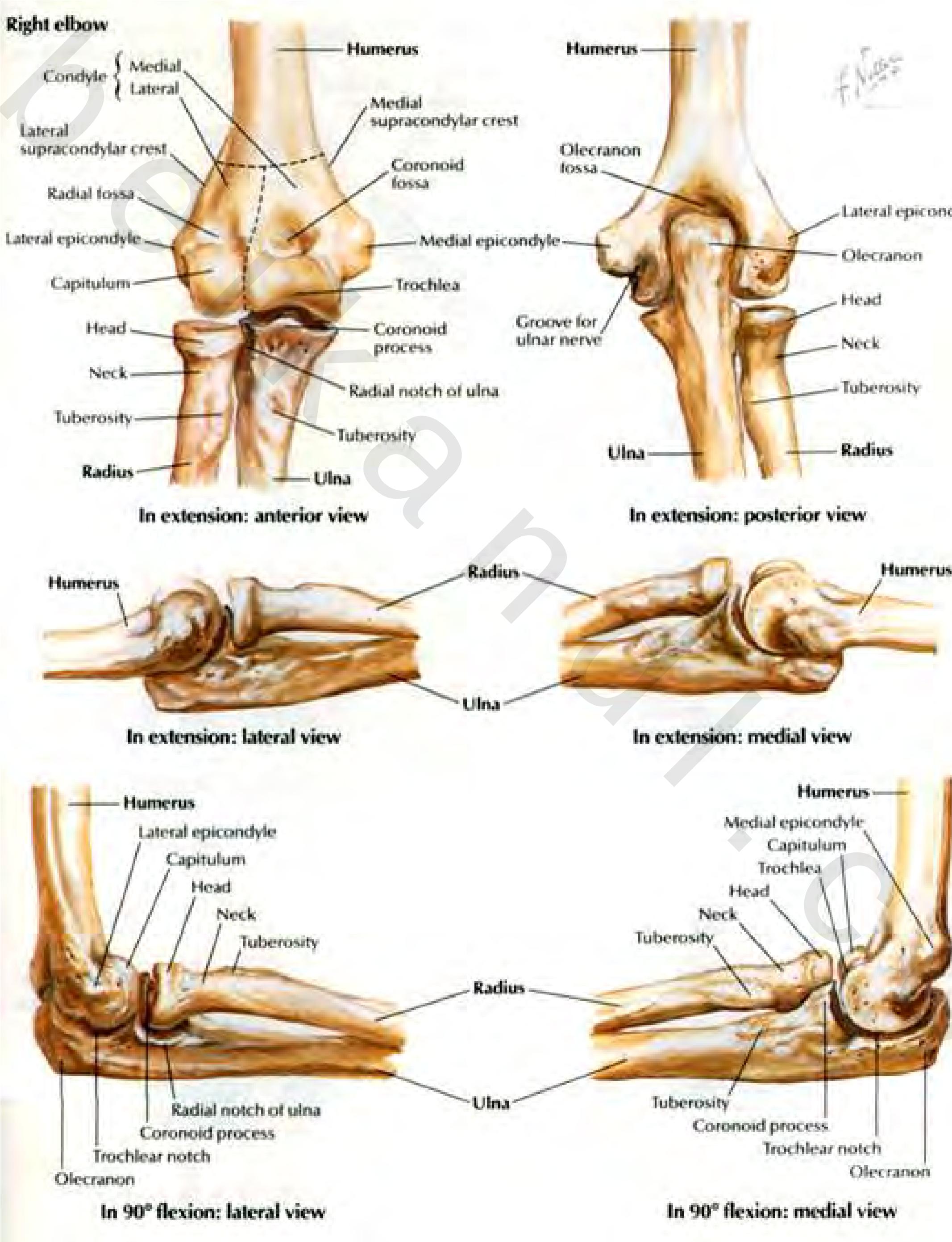

Figure (1): Bones of the elbow. [16, 17]

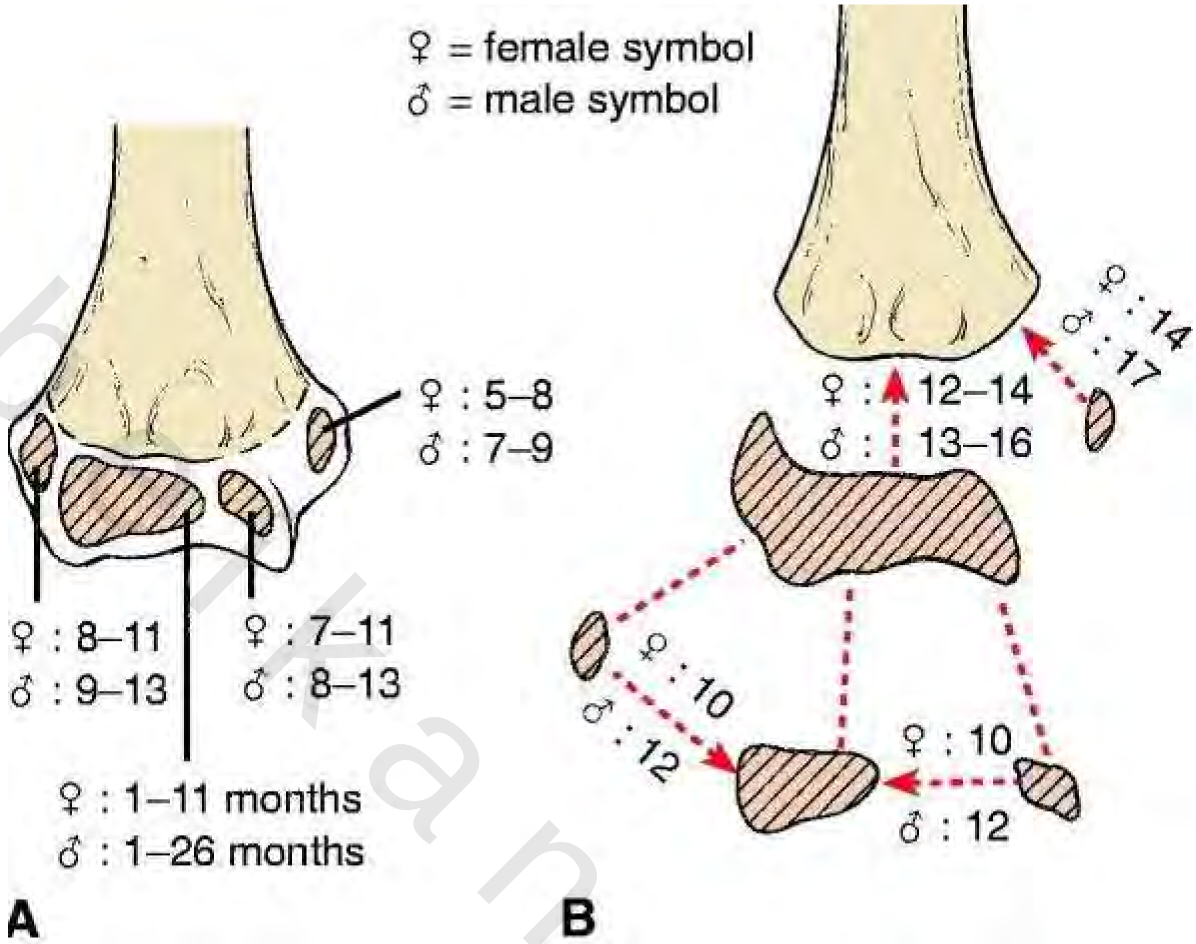

Figure (2): Ossification centres of the distal end of the humerus. [17]

A) Average age for appearance of secondary ossification centres.

B) Average age for fusion of secondary ossification centers.

The elbow joint:

The elbow is a synovial joint of the hinge type. It is formed by two articulations; the first is the humeroulnar between the trochlea and the trochlear notch of the ulna and the second is humeroradial between the capitulum and the upper surface of the head of the radius. [22, 23]

The capsule of the elbow joint:

It is attached to the humerus at margins of the lower rounded ends of the articular surfaces of the capitulum and trochlea but in front and behind it is carried up over the bone above the coronoid, radial and olecranon fossae. Distally the capsule is attached anteriorly to the anterior surface of the coronoid process of the ulna and to the annular ligament. Posteriorly on the medial side it is fixed to the upper and lateral margins of the olecranon, and on the lateral side it is continous with the capsule of the superior radioulnar joint deep to the annular ligament.[24] **(Fig.3)**

It is of importance for the etiology of the supracondylar fractures that the anterior part of the capsule is thick and strong. In hyperextension it becomes taut thus the fulcrum of rotation becomes located at the supracondylar region. [20]

The whole supracondylar region is intraarticular with subsequent haemarthrosis in case of fracture. Two large fat pads anterior and posterior become visible on a lateral X-ray in case of capsular distension. [20]

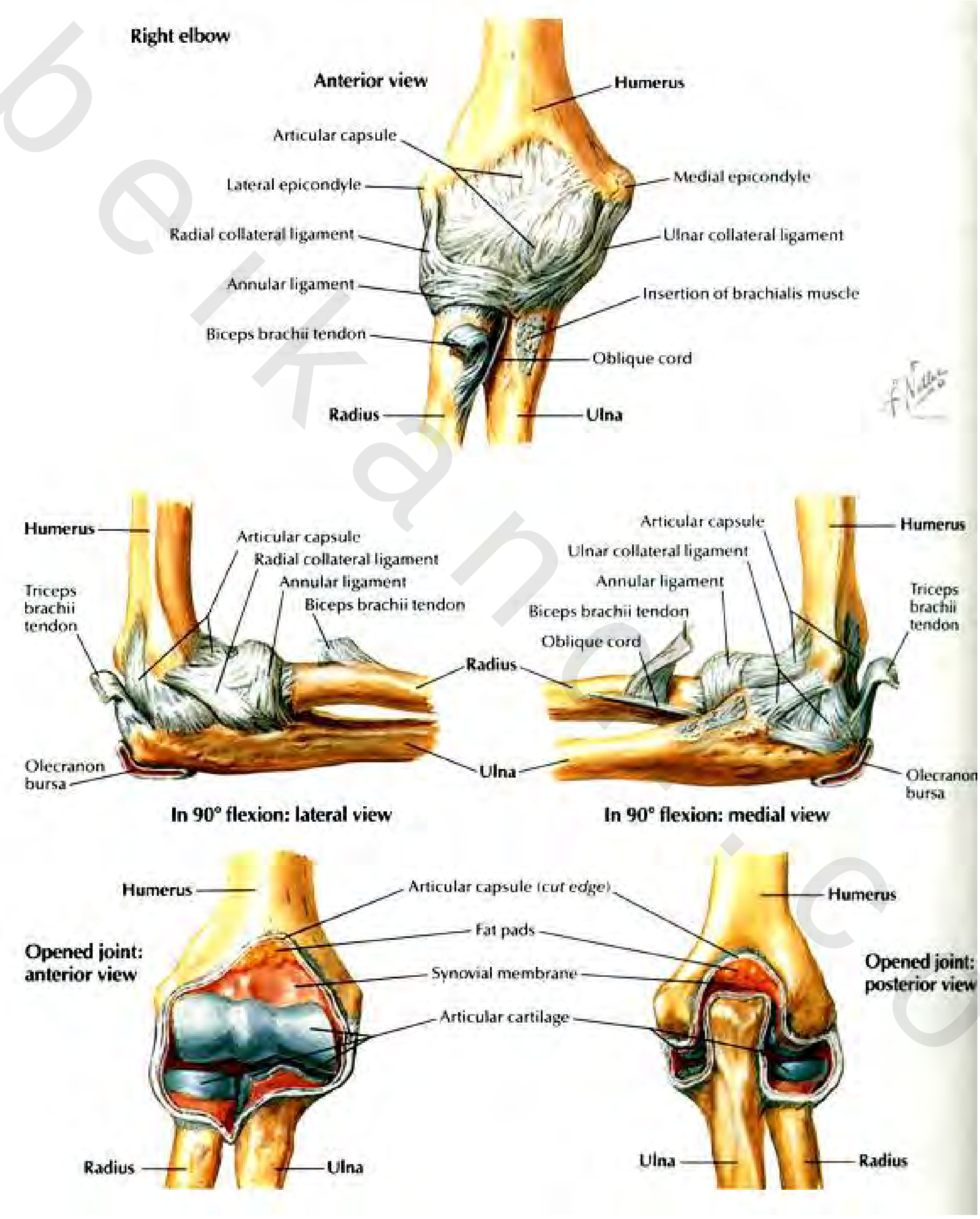

Figure (3): Capsule and ligaments of the elbow joint. [24]

Blood supply and anastomosis around elbow joint:

The brachial artery is the main arterial trunk lies anteriorly in the cubital fossa. It supplies the distal humerus with the help of anastomotic vessels which run posteriorly ;[20]

1. The radial collateral branch of the profunda brachii which passes anterior to the lateral epicondyle to become continous with radial recurrent.

2. The superior ulnar collateral passes behind the medial epicondyle to become continous with the posterior ulnar recurrent.

3. The inferior ulnar collateral passes anterior to the medial epicondyle to become continous with the anterior ulnar recurrent. This vessel also supplies a branch which arches above the olecranon to join the middle collateral branch of profunda.

4. The middle collateral branch of the profunda also sends a branch between the lateral epicondyle and the olecranon to become continous with the interosseus recurrent.

These vessels are small in caliber and will be the only source of nutrition to the arm if the brachial artery is badly damaged. [17, 24] **(Fig.4)**

Nerve supply:

It is derived from the musculocutaneous, median, ulnar and radial nerves (Hilton's law), the capsule and ligaments possess rich nerve supply. [18]

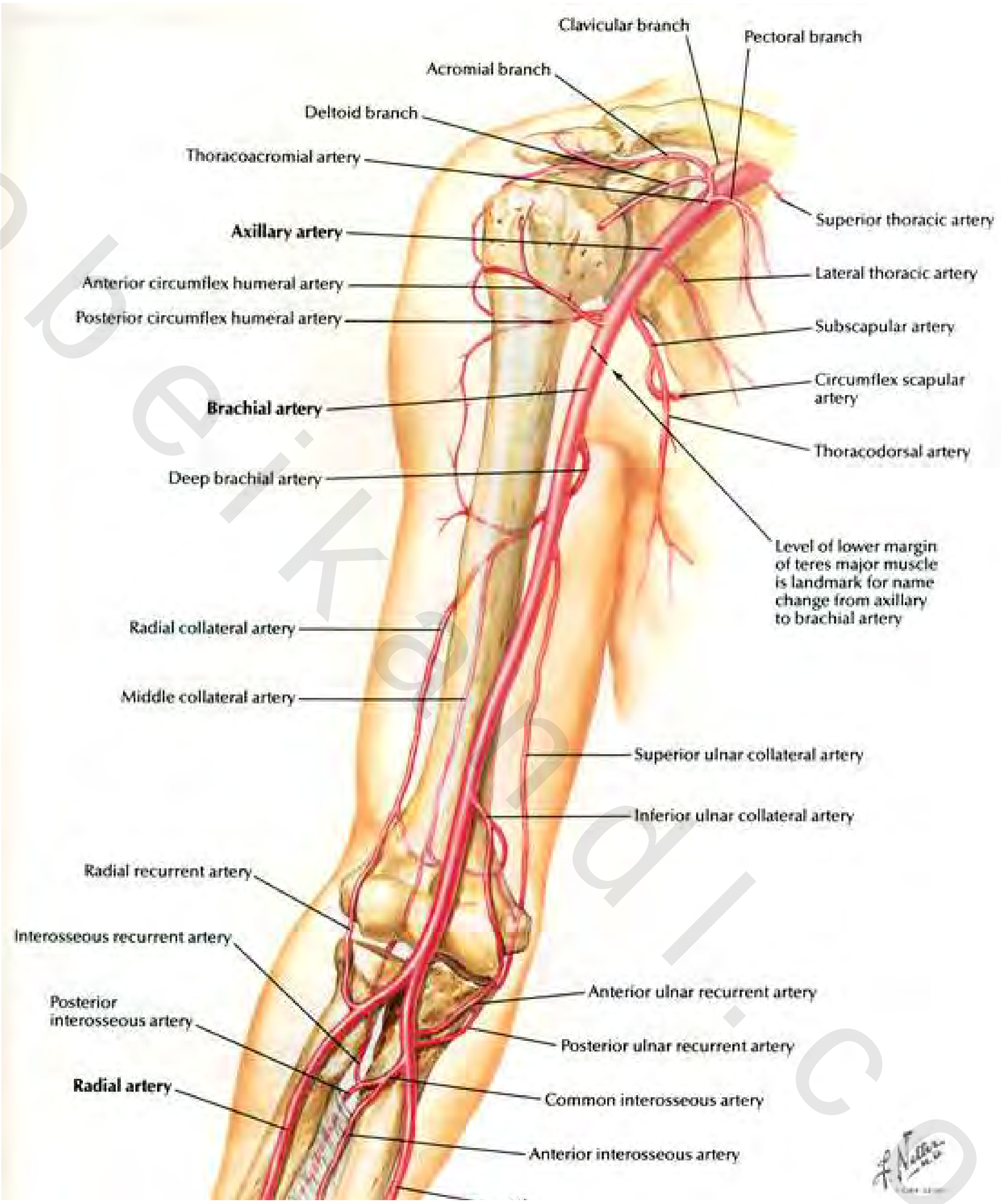

Figure (4): Anastamosis around elbow joint. (17, 24)

Ligaments of the elbow:

The function of these ligaments is to keep the articular surfaces in apposition. They act as two stays located on either side of the joint namely the medial and lateral ligaments. These fan shaped ligaments are inserted proximally on the epicondyles roughly at the level of the transverse axis of the joint and distally around the edge of the trochlear notch. These two lateral stays have a double function; to keep the trochlear notch and radial head fitted well into the distal end of the humerus and to prevent all sideway movements. [19, 21]

The anterior and posterior ligaments are thickened parts of the capsule. The annular ligament is attached to the margins of the radial notch of the ulna and clasps the head and neck of the radius in the superior radioulnar joint. It has no attachment to the radius which remains free to rotate in the annular ligament. The quadrate ligament stretches between the neck of the radius and the upper part of the supinator fossa of the ulna. Its fibers run criss cross so that some are tense while others are relax thus its overall tension remain constant in all positions of pronation and supination. It prevents herniation of synovial membrane between the anterior and posterior free edges of the annular ligament. [19, 21] **(Fig.3)**

Some important structures crossing elbow:

1. The ulnar nerve passes through the lower part of the extensor compartment of the arm and disappears into the forearm by passing between the humeral and ulnar head of the flexor carpi ulnaris. It lies in contact with bone in the groove behind the medial epicondyle, then it lies against the medial ligament of the elbow joint.[17] **(Fig.5)**

2. The radial nerve leaves the extensor compartment of the arm by piercing the lateral intermuscular septum between the middle and the lower third then it enters the cubital fossa lying between the brachialis and the brachioradialis infront of the lateral condyle. Then it divides into two terminal branches; superfacial radial branch, and posterior interosseus nerve.[19] **(Fig.6)**

3. The median nerve lies on the medial side of the brachial artery while crossing the cubital fossa. It enters the forearm between the superficial and deep heads of the pronator teres.[24] **(Fig.7)**

4. The brachial artery is separated from elbow joint by the brachialis. It enters the cubital fossa medial to the biceps tendon by dividing into radial and ulnar branches.[17,24] **(Fig.8)**

Movements of elbow joint:

The elbow joint has two movements physiologically; the first one is flexion extension in the true elbow joint. Which is a simple hinge joint and it does not take place in the line of the humerus because the axis of the hinge lies obliquely. The second is pronation supination in the superior radioulnar joint. [19]

Range of elbow movement

The position of reference is defined as the position achieved when the axes of the forearm and arm are straight in line. Extension is movement of the forearm posteriorly, since the position of reference corresponds to complete extension, the range of elbow extension is zero by definition, except in women and children in whom relative laxity of the ligaments allow hyperextension of 5 to 10 degrees. By contrast relative extension is always possible from any position of flexion. [19]

Flexion is the movement of the forearm anteriorly; active flexion has a range of 145 degrees while passive flexion has a range of 160 degrees with the fist width separating the wrist from the shoulder. [19]

The inclination of the distal end of the humerus anteriorly at an angle of 45 degrees to the shaft of the humerus (shaft condylar angle) together with the inclination of the trochlear notch of the ulna anteriorly and superiorly at an angle of 45 degrees to the ulnar shaft promots flexion of the elbow by delaying contact between coronoid process and humerus till the two bones are almost parallel. [21]

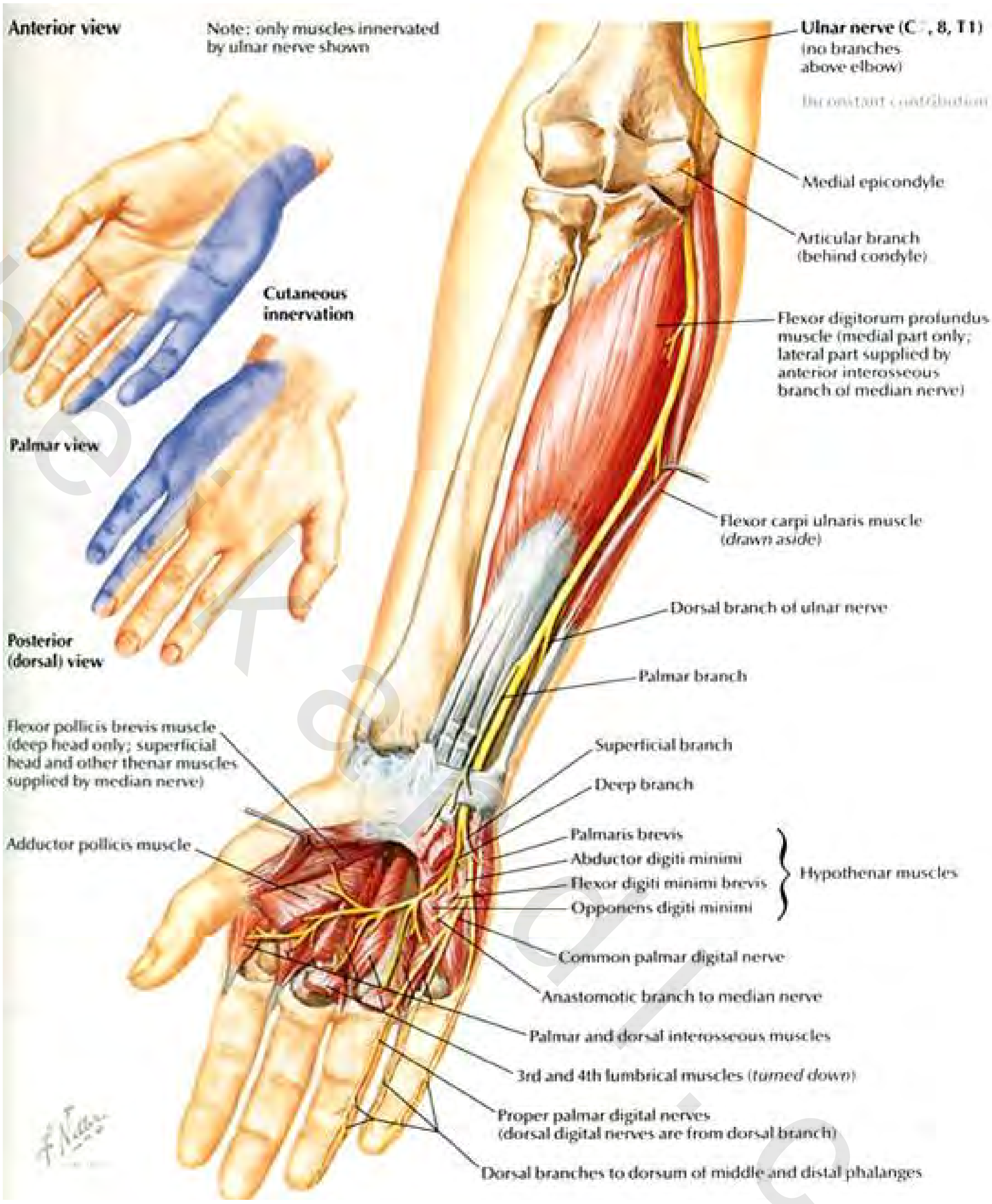

Figure (5): Ulnar nerve crossing elbow. [19]

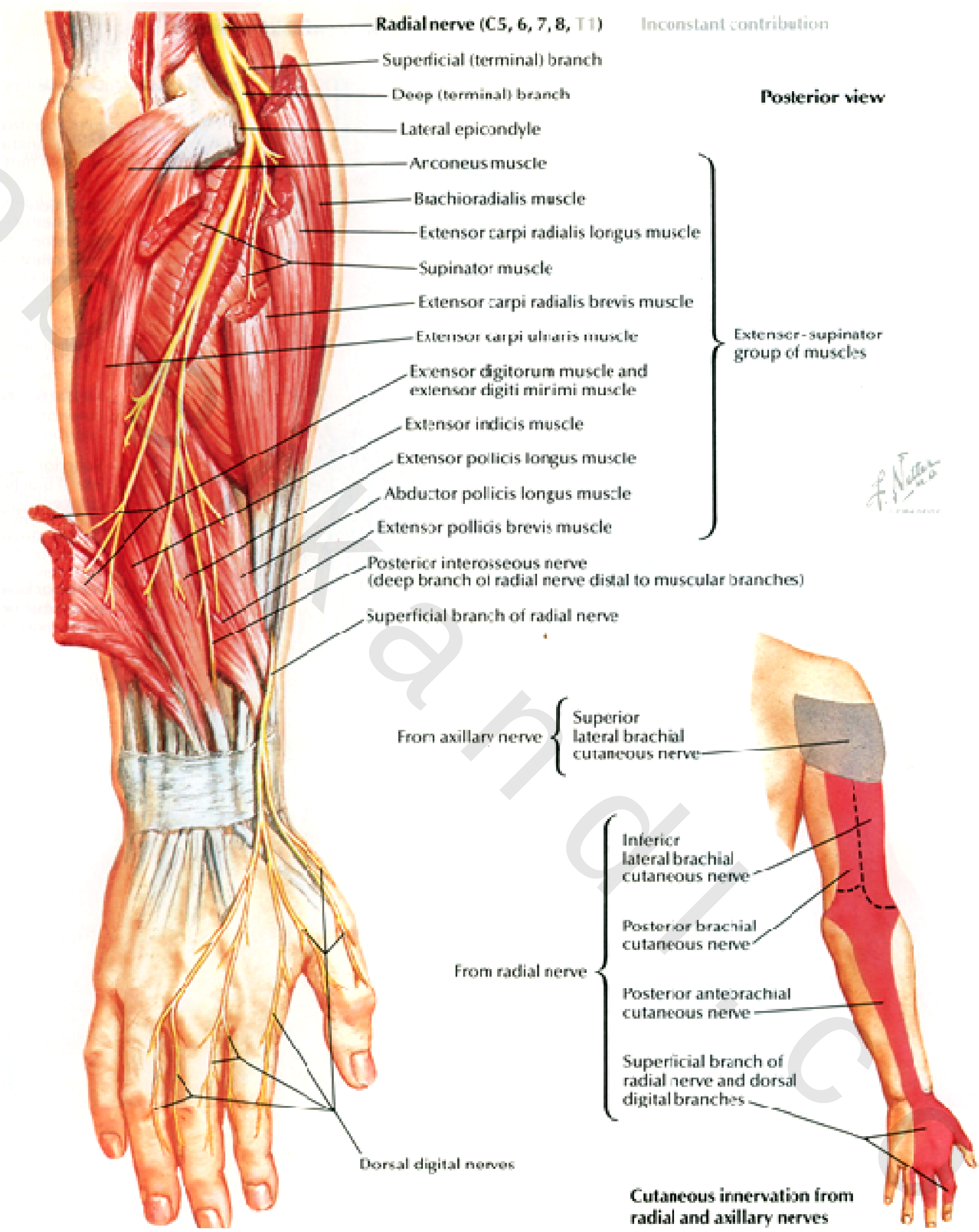

Figure (6): Radial nerve crossing elbow. [24]

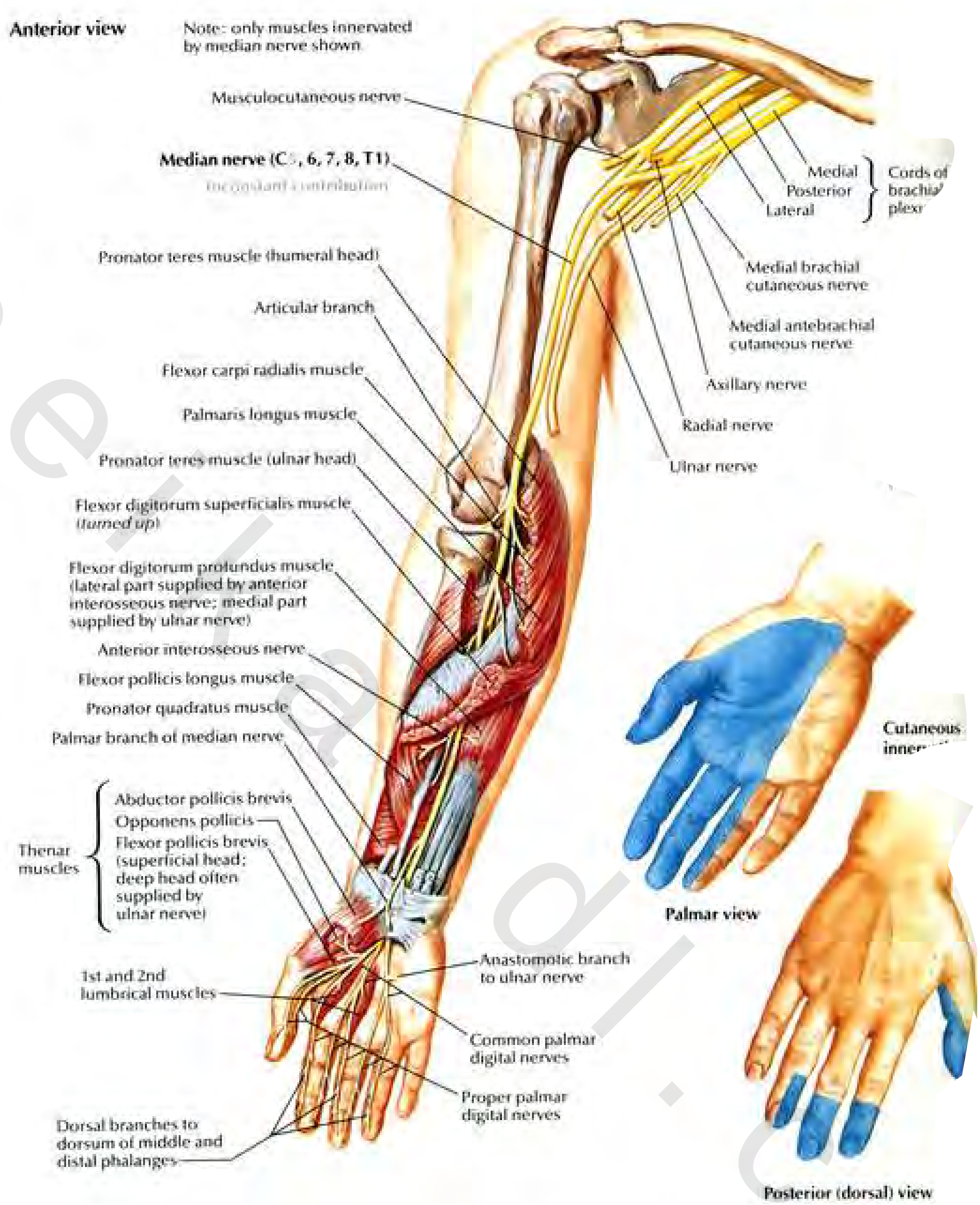

Figure (7): Median nerve crossing elbow. [24]

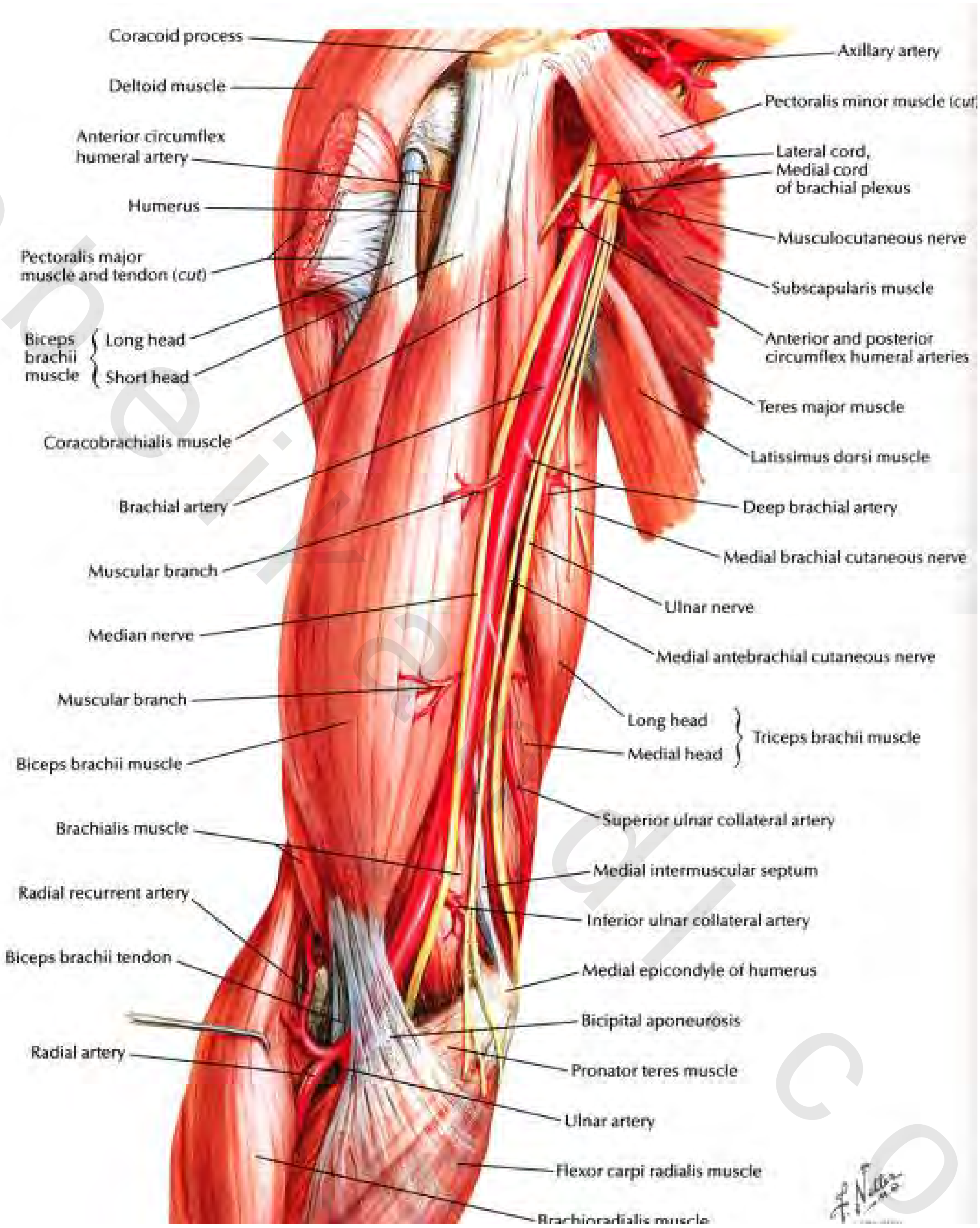

Figure (8): Brachial artery crossing elbow. [24]

Alignment of the lower end humerus

I) Frontal plane alignment

The carrying angle:

It is caused partly by the obliquity or tilt of the lower articular end of the humerus as the medial edge of the trochlea projects about 6 mm below the lateral edge, also the obliquity of the superior articular surface of the coronoid process which is not set at right angle to the shaft of the ulna. [25]-

The carrying angle is made by the intersection of the long axis of the humerus with that of the extended ulna in a supinated forearm. It disappears on full flexion, best visualized when the shoulder is externally rotated, the elbow is completely extended and the forearm is supinated. [19]

This angle varies normally from 163 to 170 degrees. In girls the angle is generally more than boys as regard the broader pelvis in adult life. [26]

The carrying angle fits the elbow into the waist when the arm is at the side and accounts for the outward deviation of the forearm away from the trunk. [17]

It is of particular interest that 9% of normal children have cubitus rectus, and 48% have a carrying angle of 175 degrees or more. [27]

Measurement of carrying angle:

A. Clinically:

The carrying angle can be measured with a goniometer while the elbow is held in full extension. The goniometer is placed with its axis in the center of the humeral antecubital fossa, its proximal arm aligned with the humeral shaft, and its distal arm lying on a line from the center of the antecubital fossa to the center of the wrist; the angle between the long axes of arm and forearm in a fully extended and supinated forearm (humeral ulnar angle). [29]

B. Radiologically:

Different methods have been introduced to measure the carrying angle radiologically as:

1. A central line that bisects the shaft of the humerus and another line that bisects the shaft of the ulna (humeroulnar angle). [29] **(Fig.9 a)**
2. A central line that longitudinally bisects the shaft of the humerus and a metaphyseal line that connects the widest points of the metaphysis of the distal humerus (metaphyseal diaphyseal angle).[30] **(Fig.9 b)**

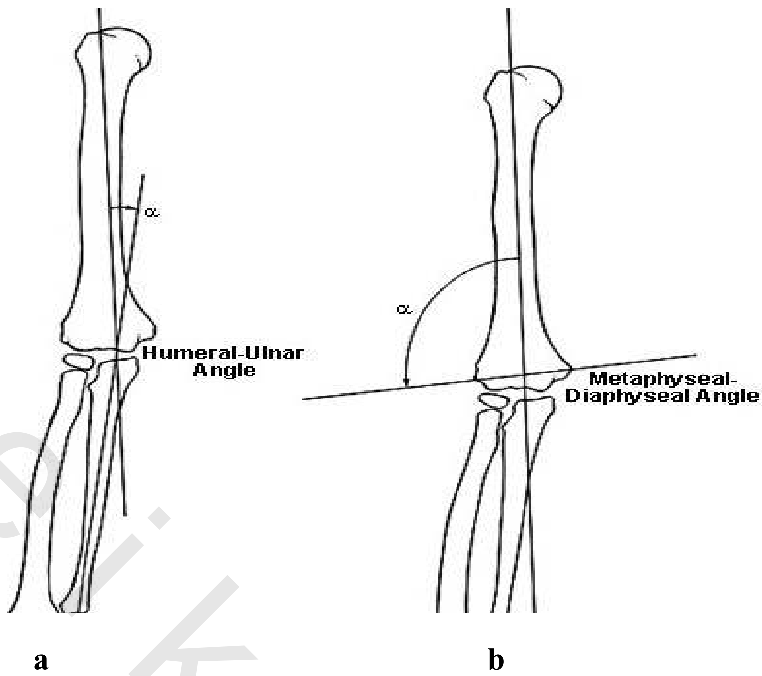

Figure (9):

a) Humeral-ulnar angle. (27, 28)

b) Metaphyseal diaphyseal angle.. (27, 28)

3. Baumann's Angle (BA):

Baumann (1960) described the relation between two important angles; the angle formed by the long axis of the humeral shaft and the axis of the growth plate of the capitulum which is the Baumann's angle. An increase in the Baumann's angle indicates medial tilting of the distal fragment of the humerus and thus decreases in the carrying angle and vice versa. It is normally around 72 degrees (range 64 to 81). (18, 30)

The Baumann's angle is the most frequently cited method of assessing fracture reduction and has been reported to correlate well with the final carrying angle, and not to be obscured or invalidated by elbow flexion or pronation. The common formula is that a change of 5 degrees in the Baumann's angle corresponds to a 2-degree change in the clinical carrying angle. However, orientation of the x-ray beam more than 20 degrees from perpendicular in the cephald-caudad direction invalidates the measurement. (18, 31) **(Fig.10)**

Because Baumann's angle has been shown to vary by 6 degrees for every 10 degrees of humeral rotation on anteroposterior radiographs, it's empirically determined that a difference of 10 degrees represents a meaningful change; this value allowed for minor variations in arm positioning during radiographic evaluations and for measurement variabilities and this also indicates that if the BA on the fractured side can be maintained within a difference of 10^{o} compared with the uninjured side, then a change in the carrying angle of less than 5^{0} is possible. (32)

Marked internal rotation of the distal fragment (> 10°) is expected to produce an apparent increase of Baumann's angle. (27)

The precise margin of the lateral condyle growth plate could not be clearly viewed on X-ray of a lot of children. However, it is difficult to accurately place the line through this physis in children under the age of 3 years, because the lateral condyle is not sufficiently mature to form a straight border. In addition, in many early adolescents, this physis becomes irregular and difficult to follow within 2 years of epiphyseal closure. (32)

II) Saggital plane alignment

Saggital plane alignment is determined by

a. The anterior humeral line (Roger's line) which passes through the middle third of the capitulum in the majority of normal children. In children younger than four years of age, it passes nearly equally through the middle third of the capitulum. (32) **(Fig.11) a**

b. Humerotrochlear angle which consisted of longitudinal lines of the diaphysis of the humerus with the axial line of the condyle and is about 40°.(33) **(fig.11) b**

III) Rotational alignment

Signs of a rotational deformity include a rotation spur or a difference in the AP diameter between the proximal and distal fragment on the lateral x-ray. Rotational deformities persist unchanged, however, the rotation spur as an impediment to flexion remodels even in older children. (34) Even an error of 10 degrees of rotation will not affect the functional or cosmetic result as the shoulder is able to compensate for them. (5) There is a greater capacity of remodeling in the sagittal plane compared with the frontal one, irrespective of Gartland classification. Remodeling has a positive influence on the clinical and functional outcome. However, remodeling can have a role within certain limits. (31)

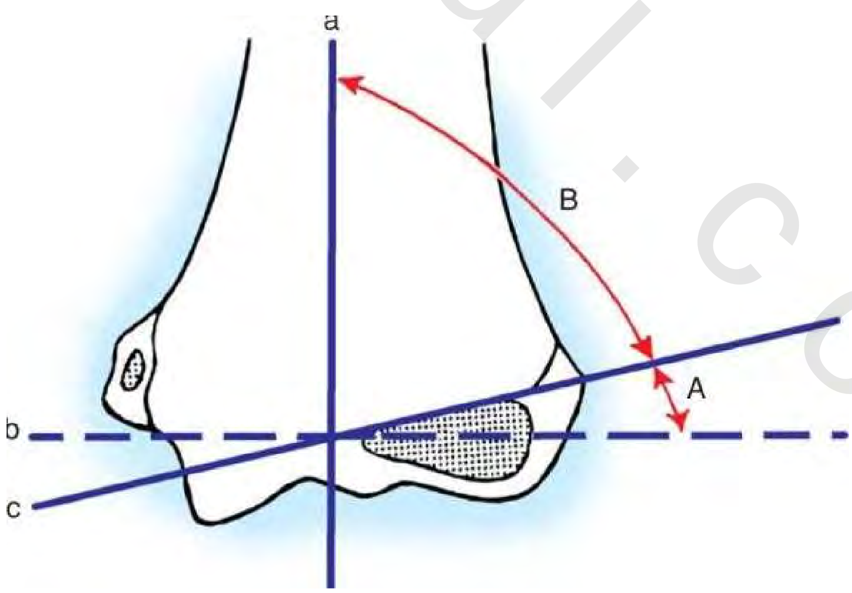

Figure (10): Baumann angle. a, midline diaphysis of humeral shaft. b, Line perpendicular to midline. c, line through physis of lateral condyle. Angle A is original Baumann angle. Angle B is more commonly used currently. (19)

a b

Figure (11) a: Anterior humeral line. [33] **b**: Humerotrochlear angle. [33]

Supracondylar Fracture

Supracondylr fracture of the humerus occurs in the broadened distal end of the humerus just proximal to the condyles; it is not an epiphyseal separation, since there is always part of the metaphysis attached to the distal fragment. (5)

Smith stressed that the level of the fracture line occurs more through rather than above the condyles of the humerus and should therefore be called a transcondylar rather than supracondylar fracture. Dunlop used the terms diacondylar and transcondylar as alternative synonyms with supracondylar fracture but it is not widely accepted in the literature. Fracture may appear to be transcondylar because the medial lateral fracture lines extend to the region of the epicondyles and there is intact bone distal to the thinning of the olecranon and coronoid fossae. (4)

Some authors used the name diacondylar for those fractures in which the fracture line passes through one or both condyles, while others applied it to those cases in which the fracture line lies at the level of the epicondyle and extends round the margin of the olecranon fossa. (3)

Epidemiology:

Supracondylar fractures of the humerus are the second commonest fractures in the children (16.6%) following fractures of distal end radius and the most frequent before seven years. (35-37)

Supracondylar fractures of the humerus are common injuries in the first decade of life. The incidence increases during the first five years and peaks at five to eight years of age. (4, 33, 37)

The fracture is more common in boys than girls, it is almost twice, which may be explained by the fact that boys are more active. (4) There is seasonal peak during summer.(35)

The left side is more affected than the right. This may be due to the fact that in right handed persons the left arm is weaker. (4)

Predisposing factors:

Trauma is the essential factor in the occurrence of the fracture, ligamentous laxity and hyperextensibility and the bony architecture of the supracondylar region in children are predisposing factors for supracondylar fracture in children. (4, 35)

Mechanism of injury:

The vast majority of supracondylar fractures occur after a fall on the outstretched non dominant arm (indirect elbow trauma). Only 1-2% fall on the olecranon with the elbow flexed (direct elbow trauma). Accordingly, extension-type fractures are common; flexion-type injuries are rare. (38) **(Fig.12)**

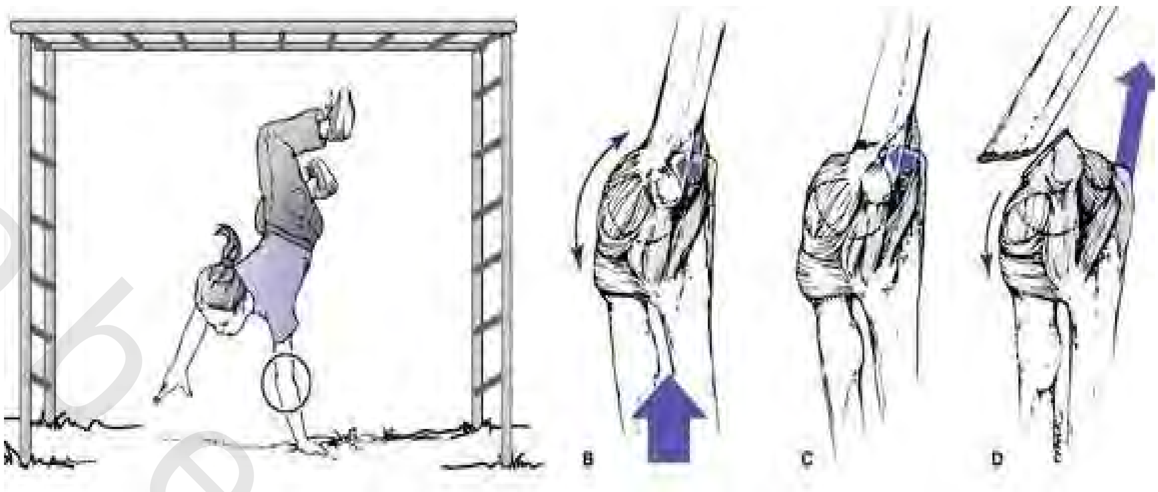

Figure (12): Mechanism of injury in extension type of supracondylar fracture of the humerus. [38]

Because of the ligamentous laxity, the elbow hyperextends allowing the linear force applied along the extended elbow to be converted into a bending force. This bending force is then concentrated by the olecranon into the anatomically weak supracondylar area. The anterior capsule and the anterior portions of the collateral ligaments become taught in hyperextension and reinforce the tension forces anteriorly. In addition as extension of the elbow increases, the two portions of the elbow joint more tightly interlocked by these ligamentous forces. This interlocking of the tip of the olecranon into its fossa concentrates the bending forces in this area when these forces exceed the strength of the bone, a supracondylar fracture is produced in the weak supracondylar area.[4]

Classification:

They have been classified by Gartland as follows:

Type I: Non displaced

Type II: Displaced with intact posterior cortex

Type III: Completely displaced. Posteromedial displacement is more common than posterolateral displacement. [18]

An important variation of the type I fracture is a fracture with subtle medial comminution, which may continue to collapse during the period of immobilization resulting in the gradual development of cubitus varus. Such compression of the medial column of the distal end of the humerus occurring in association with a type I fracture is best identified clinically by inspecting the arm with full elbow extension to compare the carrying angle with that of the normal uninjured elbow. The use of Baumann's angle on an AP radiograph may also be helpful for identifying the varus deformity caused by the medial compression. Early closed reduction and pin stabilization is recommended to prevent this potential outcome in children with this variant of the type I fracture. [38]

The main criteria in deciding to treat type II fracture conservatively are the absence of rotational deformity or medial comminution and the ability to hold the reduction with 90 degrees of flexion. [39]

Leitch et al demonstrated that in rare supracondylar fractures in children, multidirectional instability with a non functional periosteal hinge which can displace into either flexion and/or extension under stress. This fracture can be classified as type IV according to the Gartland system. This instability pattern may be the result of the injury or may occur iatrogenically during attempted closed reduction of an extension-type fracture. Rotational deformity may be corrected by selectively pushing on the lateral or medial condyles. Supination or Pronation doesn't help as there is no periosteal sleeve. This variant frequently needs open reduction. [40]

Bahk et al studying obliquity of the fracture line identified 4 coronal (typical transverse, medial oblique, lateral oblique, and high fractures) and 2 sagittal (low sagittal and high sagittal) subtypes with significantly different characteristics and outcome. Compared with fractures with coronal obliquity of less than 10 degrees, fractures with coronal obliquity of 10 degrees or greater were associated with significantly more comminution and rotational malunion. Compared with fractures with sagittal obliquity of less than 20 degrees, fractures with sagittal obliquity of 20 degrees or greater were more unstable and were more likely to result in recurvatum malunion. [41]

Displacement of the distal fragment may be posteromedial which occurs in more than 75% of cases due to pull of triceps which originate more medially or posterolateral which is less common. Rotation of the distal fragment is medial rotation in posteromedial displacement and lateral rotation in posterolateral type. [4]

The type of displacement and direction of rotation has considerable clinical significance; in posterolateral type there is great chance for vascular injury, in posteromedial type there is tendency for internal rotation with higher incidence of varus deformity as a residual deformity. [4, 39]

The injuring force carries the condyles backward and strips the periosteum away from the posterior surface of the proximal fragment, the proximal fragment is carried foreward piercing the anterior periosteum and forcing its way against the soft tissues dividing the brachialis muscle.[4]

In posteromedial type, the spike of the proximal fragment penetrates the brachialis and radial nerve may be tethered. The spike of proximal fragment may continue its way till subcutaneous tissue and become impaled in the dermis leading to puckering of the skin. [4] **(Fig. 13.a)**

The brachialis muscle usually protects the neurovascular structure anteriorly. In posterolateral displacement of distal fragment the medial spike penetrates the subcutaneous tissue and may lead to tethering of the median nerve or brachial artery. [4] **(Fig. 13.b)**

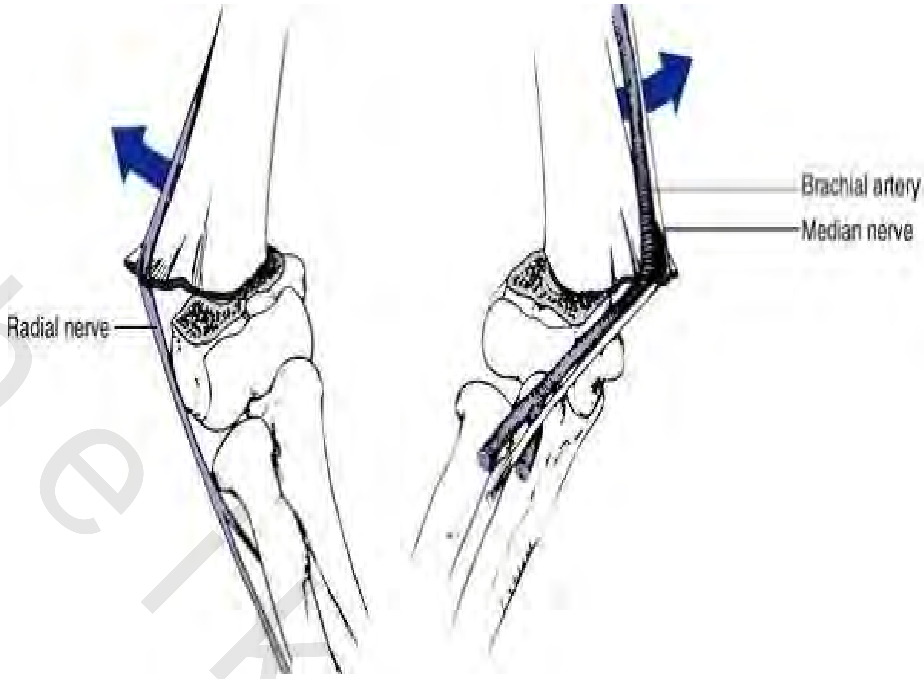

Figure (13): a) Posteromedially displaced distal fragment with liability to radial nerve injury;

b) Posterolaterally displaced distal fragment with liability to medial nerve and brachial artery injury. [4]

Clinical presentation and assessment:

Patients with supracondylar fracture of the humerus clinically present with history of trauma, the elbow shows s-shaped deformity in severe cases (type III) fractures and the skin may show puckering. The patient should be also examined for any ipsilateral associated injuries that may affect the decision for plan of treatment and risk of complications like compartmental syndrome which is increased significantly if there is associated both bone forearm fractures. [4]

The patient should be examined carefully for signs of ischemia and nerve injuries and the findings documented meticulously. An accurate neurological assessment is however not always possible in young children. The radial pulse is absent at presentation in around 12% but vascular insufficiency requiring surgical intervention is relatively rare (2-4%). [18] Nerve injury occurs in at least 7% of cases but fortunately usually transient. [42] Hence radial, anterior interosseous, median and ulnar function should be assessed as far as possible, and documented carefully, particularly as the ulnar nerve is at risk during percutanous pinning from the medial side. Open fractures are not common, but require the standard approach incorporating antibiotics, wound debridement and irrigation and usually an open reduction. [18]

The limb should be immobilized with above elbow back slab in 30-40 degrees of flexion to reduce the risk of neurovascular compromise till the definitive treatment is undertaken. [42]

Radiological assessment:

The ability to correctly asses medial-lateral translation, flexion- extension and rotation of the distal fragment in respect to the humeral shaft is crucial for the choice of the appropriate treatment modality as well as the judgment of the accuracy of reduction via an anteropsterior and a lateral views. [4]

Complications of Supracondylar Fractures of the humerus:

Supracondylar humeral fractures have the highest rates of complications of any pediatric fracture.[41] Some complications occurring after supracondylar fractures are primarily iatrogenic in Origin.[43] Complications of supracondylar fractures of the humerus can be divided into two categories; those that result in an impairment of the function of the extremity, and those that produce a cosmetic problem.[4]

The causes of impairment of function include injuries of the neurovascular structures and conditions that result in loss of the range of motion of the elbow. The major cosmetic problems are cubitus varus or cubitus valgus deformity or hyperextension of the elbow. [4]

(1) Neurologic injuries:

Of all complications associated with supracondylar fractures, nerve injury ranks highest, although reports of the incidence of specific neurapraxia vary. Of nerve injury associated with extension-type fractures, anterior interosseous neurapraxia ranks highest, whereas of flexion-type neuropathy, ulnar nerve injury predominates. The ulnar nerve is at risk of injury in medially pinned patients. Lateral pinning carries neurapraxic risk with respect to the median nerve. [44]

Although radial nerve injury was the most commonly reported in the older literature, more recent investigators have found the anterior interosseous to be the most commonly injured nerve. Because this nerve is purely a motor nerve, diagnosis of injury to it requires specific examination of the flexor pollicis longus and flexor digitorum profundus of the index finger thus it may be overlooked during examination especially if the child experiencing pain.[49] Although the median and anterior interosseus nerves are especially susceptible to injury during posterolateral displacement of the distal fragment and posteromedial displacement is thought to biomechanically increase the risk of radial neurapraxia. Interestingly, posteromedial displacement is reported at a rate of 2 to 3 times that of posterolateral displacement; although it is not uncommon for median and anterior interosseous nerve injury also to occur in conjunction with posteromedial displacement. [44]

Primary injury to brachial artery and the median and radial nerve occurs from stretching, entrapping or disruption of neurovascular structures on the sharp proximal humeral fragment. [45]

Three possible mechanisms of isolated anterior interosseus nerve injuries:

1. The anterior interosseus nerve is injured by traction in the proximal part of the forearm where it passes under pronator teres. A fibrous band holds the distal part of the nerve down tight on the ulna while the usual posterior and radial displacement of the distal fragment places maximum tension on the nerve.

2. Contusion of the posterior aspect of the median nerve occurs at the level of the supracondylar fracture. All anterior interosseous nerve fibres in the median nerve at this level are situated posteriorly. This will also result in some sensory loss, given the intraneural topography of the median nerve at this level.
3. Delayed onset isolated anterior interosseous nerve palsies may be associated with a transient episode of ischemia just before or during manipulation of the fracture. The pronated position of the forearm in some patients associated with elbow flexion could mediate the paralysis. [46]

The causes of iatrogenic ulnar nerve injury include (1) direct penetration of the nerve or its sheath by the medial pin; (2) constriction of the cubital tunnel by the pin while the elbow is in flexion; (3) medial pin injury to an unstable ulnar nerve, which subluxates or dislocates anteriorly when the elbow is in flexion; and (4) nerve contusion and edema. [47]

The predictors of ulnar nerve injury were found to be related to the operative technique. The use of crossed pins and pinning with the elbow in hyperflexion are associated with the greatest risk of iatrogenic ulnar nerve injury. [48]

The nerves can be quickly assessed by having the patient form a ‘‘thumbs up’’ sign (radial nerve), tight fist covering thumb (median nerve), the ‘‘OK sign’’ by having them approximate the thumb and index finger (anterior interosseous nerve), and to fully abduct all his/her fingers ‘starfish’ sign (ulna nerve). [9] **(Fig.14)** Special attention should be paid to ensure that the distal interphalangeal joint of the index and interphalangeal joints of the thumb are flexed when the child performs the ‘okay sign’.[48]Another good way to assess the ulnar nerve's motor portion in young children is to palpate the first dorsal web space for setting of the interosseous muscle as the child attempts to pinch you.[49] Passive assist sign is used to assess the postoperative neurological status in young children, in which the child assists in carrying out passive motor function of the involved hand using the contralateral hand. This test is useful because it shows that the child understands the command (request), and that movement of the part is not painful (without a compartment syndrome), but that the child cannot perform active extension or flexion of the hand. When this sign is observed, it should be a warning that a nerve deficit may be present. [18] The autonomous areas to be tested for sensory function assessment include volar aspect of the index finger for median nerve, the first dorsal web space for radial nerve and the ulnar border of the little finger for ulnar nerve.[9] Pinprick examination for sensation is poorly tolerated by most children and is rarely used. It is preferable to use light touch and two-point discrimination to evaluate sensation. [50]

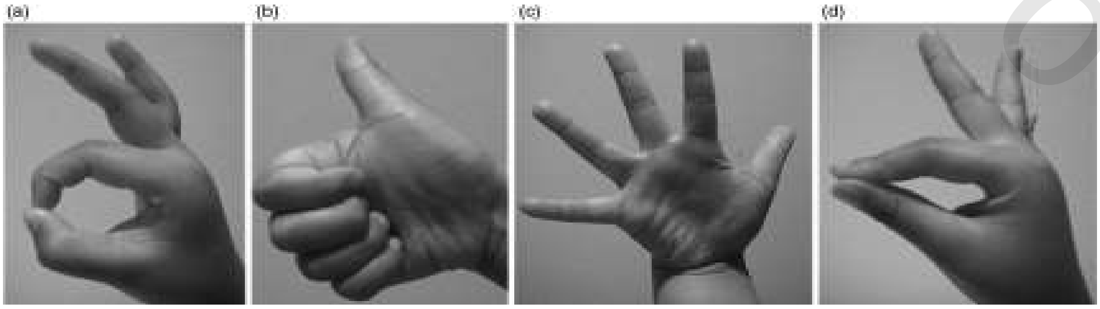

Figure (14): Motor neurological assessment: A) normal "OK" sign. B) Normal thumb up sign. C) Normal starfish sign. D) Abnormal "OK" sign.

Most deficits that occur at the time of fracture are neuropraxia (a stretch or contusion of the nerve) and spontaneously recover function in 2–3 months. If there has been no recovery of function after 4–6 months, then exploration is indicated. [51] If after 4 to 6 months, no return of function is noted, electromyelographic and nerve conduction studies to evaluate the status of recovery are recommended. Only rarely have cases been reported of permanent nerve deficits requiring later Neurolysis, grafting, or tendon transfer.[46] Neurolysis and/or repair have favourable results in children .[12] However, early exploration may be indicated if there is coexisting ischemia or a nerve injury during reduction denoting incarceration in the fracture site.[52]

A literature review demonstrated 3.6% iatrogenic nerve injury, with the ulnar nerve being involved in 81% of these cases. [52] Several attempts have been made to decrease the risk of injury to the ulnar nerve after closed reduction and percutaneous pinning of supracondylar humeral fractures. These include, medial mini incision technique, pinning only from the lateral side and ulnar nerve localization by nerve stimulator. Mini incision technique or ulnar nerve stimulation do not completely prevent ulnar nerve injuries. [53]

There is difficulty in accurately predicting the nerve location by superficial palpation, usually secondary to significant swelling. In addition, anterior ulnar nerve instability has been reported to occur in 6% to 18% of children, in which case the nerve lies anterior to the medial epicondyle and is at increased risk for damage during closed percutaneous placement.[54] It has been shown that extending the elbow while placing the medial pin is helpful in decreasing the incidence of iatrogenic ulnar nerve injury,[38]as flexion of the elbow to more than 90° in the presence of hypermobility of the ulnar nerve leads to anterior subluxation of the nerve, placing it on the medial epicondyle. However, use of small medial incision dose not reduces iatrogenic ulnar nerve injury in statistically significant manner. [48]

Three types of strategies exist in the literature for ulnar nerve injury detection in the early postoperative period. These include exploration of the nerve, removal of the medial pin, or ‘‘wait and see’’ policy. Surgical exploration has the risks of a second operation and the results with this approach are no better than the others. [54] If a three-pin technique has been utilized, immediate removal of the medial pin is recommended. With a two-cross-pin technique, removal of the medial pin should be delayed until 3 weeks after the injury to avoid loss of reduction. [50]

(2) Vascular injuries:

Most brachial artery injuries occur in association with posterolateral displacement of the distal fragment of the humerus as the artery is kinked or stretched over the metaphyseal spike of the bone. [18]

Etiology of vascular injury includes tethering of the brachial artery or its supratrochlear branch over fracture fragment leading to thrombosis or spasm, and laceration, intimal tear, or entrappment of the artery between bone fragments. The artery may be also compressed by haematoma under the tight deep fascia. Less commonly the artery may be affected during manipulation. [49]

Vascular assessment should be based upon a combination of both clinical assessment as diminished pulse, pallor and coolness of the hand,[55] grip strength can be assessed to evaluate for the presence of a low-grade compartment syndrome,[56] and an objective assessment such as the use of Doppler ultrasound or oxygen saturation monitoring. [57]

Ipsilateral both bone forearm fracture and supracondylar humeral fractures is a severe injury and may be associated with a higher incidence of compartment syndrome. [58]

The outcome of vascular injury varies from minimal degree of deficient circulation not apparent at rest but with activity (claudication) to compartment syndrome and volkman's contracture. [4]

Closed reduction restores pulsation of the radial artery in about 80% of cases. [51] **(Fig.15)** If pulse does not return with closed reduction but the hand is viable, then observation is the treatment of choice for many authors. The rich collateral circulation around the elbow is sufficient for the viability of the arm, whereas early revascularization procedures are associated with a high rate of asymptomatic reocclusion and residual stenosis of the brachial artery. A time window ranging from 12 to 24 h is usually given in order to rule out vascular spasm. [59] Absence of the radial pulse at the initial stage of 24 h observation indicates that the brachial artery is unlikely to recover patency. [60]

However, the possibility of limb length discrepancy, claudication, cold intolerance and thrombus migration should be considered if this method of treatment is selected. Moreover, there are no series available with long follow-up and a significant number of cases to support the superiority of a treatment option that finally leads to an arm that relies only on collateral circulation. Finally, an arm without an original dominant brachial artery may probably be too inefficient to handle a future trauma complicated with an arm-threatening vascular injury or be a donor or recipient of surgical flaps. So, other authors recommend surgical exploration for the restoration of brachial artery patency to be performed after 30–35 min of close observation, even in the presence of viable pink hand after an attempt at closed reduction. A thorough exploration of the brachial artery at a mean distance of 6 to 10 cm above and below the fracture was required in order to rule out entrapment of the artery, thrombus formation or artery spasm. [60]

Angiography should not be performed before surgery in cases of a pink pulseless hand. Nevertheless, angiography requires general anesthesia of the patient and takes several minutes to perform, even in the hands of an expert radiologist, it does not cause a change in preoperative planning, besides the potential risks of angiography such as arterial injury, delay to surgery, proximity of artery to fracture site. Magnetic resonance angiography and colour-flow duplex are safe and valid techniques that may be used before surgery to assess the patency of the brachial artery. [59] However, Luria et al. concluded that exploration of the cubital foss is indicated only if intraoperative angiographic evaluation revealed a brachial artery injury. As they noted, angiography is a helpful procedure that may prevent unnecessary exploration of the brachial artery, as in the case of arterial spasm.[62] Angiography may not be sufficient to distinguish arterial spasm from an intimal tear (e.g. in the case of coexistence), which necessitates surgical intervention, moreover, a persistent arterial spasm may require removal of the adventitia.[60] However, Charles et al recommended that CT angiography may have a place in this clinical situation, if it's available, as it provides the following advantages. First, it's non-invasive. Second, CTA can provide vascular imaging of the extremity for some pediatric patients in whom conventional angiography is impossible. Third, with its superior spatial resolution, CTA allows not only vessel lumen but also vessel wall and nonvascular anatomical evaluations.

Fourth, whereas catheter angiography is a projectional technique, CT angiograms are volumetric. The data sets can be viewed three-dimensionally in multiple planes and projections. Fifth, CT scanners allow rapid image acquisitions with short exam times. Sixth, using intraoperative findings as the standard, CTA had 100% sensitivity and using clinical followup and the intraoperative findings as references, CTA had 100% specificity. However, acquiring dynamic information is not possible with CTA. This precludes direct evaluation of collateral flow and vasodilatory maneuvers to confirm vasospasm. (61)

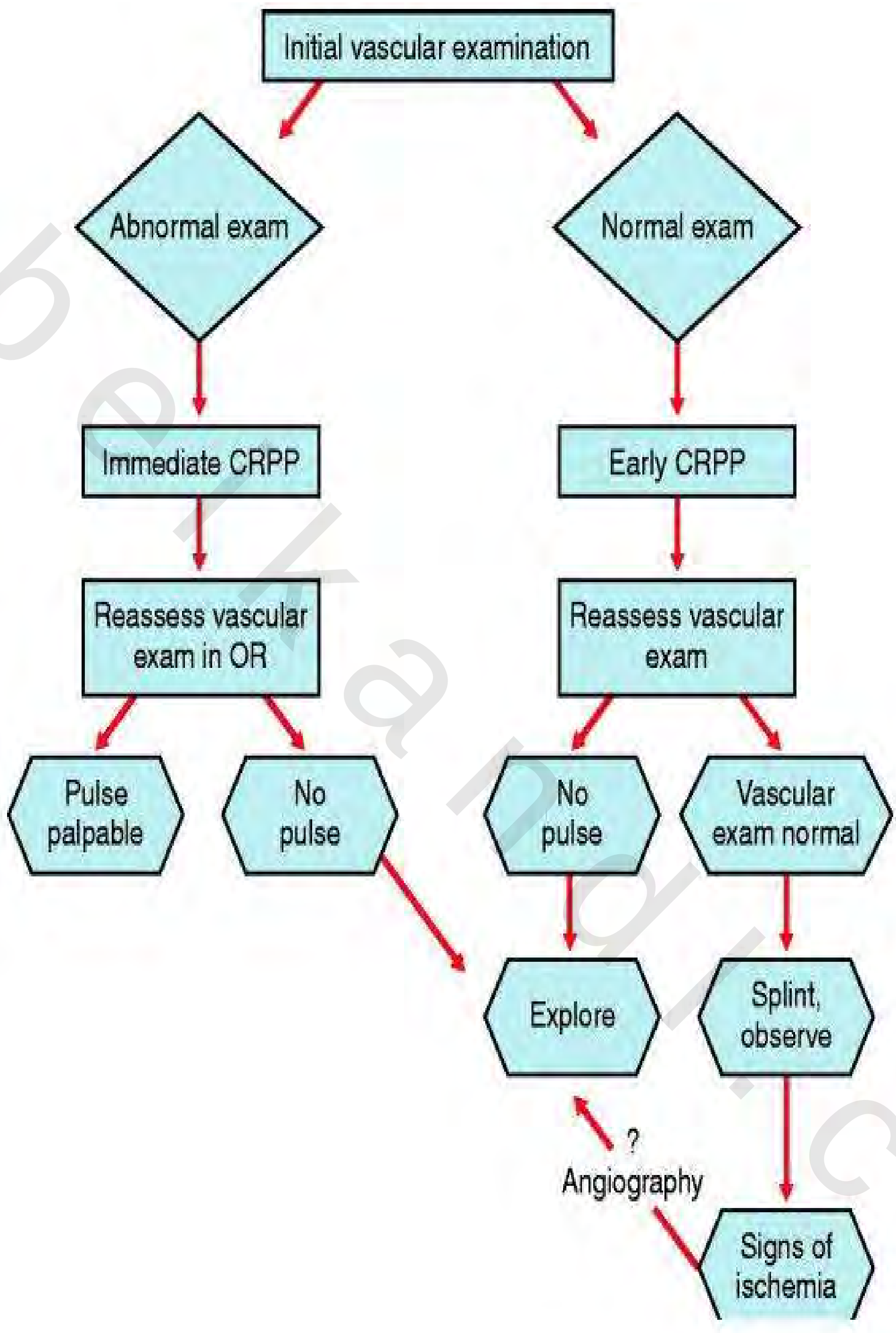

Figure (15): Flow chart to guide decision making in cases in which a possible vascular injury is associated with a displaced supracondylar humeral fracture.CRPP, closed reduction and percutaneous pinning; OR, operating room. [51]

(3) Elbow stiffnes:

All patients, even those with perfect reduction, lack full range of motion after healing but initial rapid recovery in elbow motion can be expected, followed by a progressive improvement for up to one year after the injury. This motion recovery is slower in older patients and in those with more severe injuries. Pronation and supination are usually normal. (62) Intermittent active range-of-motion exercises are started at home; they should be taught by the physical therapist to the child and the parent, explaining that the child is to carry out his or her own active range-of-motion program. (18) If elbow stiffness persists without any sign of progression after 1 month, an appropriate rehabilitation program should be considered, including active exercises against resistance. Passive mobilization may lead to increased loss of range of motion due to inappropriate nociceptive stimulation and massages are known to be responsible for the development of periarticular ossification. (62)

Impaired range of motion may be prolonged or even persistent due to underlying pathology. Malunion is the most common cause. In the sagittal plane, antecurvation leads to hyperextension and reduced flexion of the elbow. Age-dependent remodeling with growth takes more than 1 year. Rotatory malunion with a significant anterior spur restrains flexion. Complete remodeling of the spur usually takes place even in older children. (34)

(4) Cubitus varus:

The most common late comlication, but the incidence is decreasing after the use of percutaneous pin fixation. (12) Cubitus varus deformity is not the result of a growth disturbance but rather the direct result of malreduction of the fracture or loss of reduction. (48) Varus tilting of the distal fragment is the most important cause of change in the carrying angle. Internal rotation of the distal fragment does not cause cubitus varus, but is the most important factor leading to medial tilt. (18, 50) The cross-sectional anatomy of the distal humerus is the reason for the high rate of cubitus varus after displaced supracondylar fractures. Between the rounded contours of the condyles, the olecranon fossa is separated from the coronoid fossa only by a thin wall of bone. Even minor rotational deformities can lead to instability and slipping of the distal fragment into a varus deviation. (48)

Cubitus varus seldom improves by remodeling. It produces a distasteful cosmetic deformity, although sporting children (e.g. gymnasts, javelin throwers) can also feel functionally restricted. In rare cases, a cubitus varus can be associated with a troublesome catching of the triceps tendon or elbow instability. (48) It may predispose a child to subsequent lateral condylar fracture. (14, 49)

Malrotation of the distal humerus is compensated for to a large degree by the shoulder joint. As a result, the rotational component in cubitus varus deformities is of little consequence, and all that is necessary for correction of the cubitus varus deformity is a lateral closing wedge osteotomy. Occasionally, a hyperextension deformity requires the addition of a flexion component. (18)

Three basic types of osteotomies have been described: a medial opening wedge osteotomy with a bone graft, an oblique osteotomy with derotation, and a lateral closing wedge osteotomy. (18)

(5) Avascular necrosis of the trochlea

This is a rare but serious complication that may follow the extension type of fracture. [4] AVN of the capitellum as well as the trochlea has been reported, although both are extremely rare. Because the capitellar blood supply enters the distal humerus laterally and distally, a fracture that exits the lateral column very distally may lead to avascular changes in this region. Similarly, low fractures exiting medially may be at increased risk for avascularity associated with the trochlea. With elimination of the more lateral trochlear blood supply, such as may occur with a supracondylar humerus fracture with T intercondylar extension, a classic fishtail deformity of the distal humerus may occur **(Fig.16)**. The fishtail deformity is more frequently associated with an inadequately treated lateral condyle fracture. The deformity includes the loss of the normal crista dividing the capitellum from the trochlear groove and central involution of the distal articular surface. The central involution allows the proximal ulna to "settle" into the distal humerus. Clinically, the prominence of the olecranon normally seen during maximal flexion of the elbow is absent. If this complication happens the elbow should be immobilized till the elbow becomes asymptomatic. [41]

Figure (16): Fishtail deformity (loss of the olecranon prominence). Clinical findings of avascular necrosis of the distal humerus can include depression of the prominence of the olecranon secondary to a central deficiency as demonstrated in this silhouette of flexed elbows as viewed from the patient's head. [41]

(6) Myositis ossificans:

It is not common and may even be self-limiting, with resolution over a 1- to 2-year course. [50] The occurrence and severity would intuitively be expected to be increased in cases treated with open reduction, particularly if the surgery is delayed from the time of the injury. Surgical excision of the affected tissue should be performed only if the ectopic bone is clearly demonstrated to be causative of motion loss, conservative attempts to regain motion have failed, and adequate time from that of the injury has passed such that the lesion is quiescent. Bone scan has been recommended in assessing the metabolic activity level of the lesion, also plain radiographic features of clear marginal delineation and trabecularization should be well demonstrated. [51]

Treatment

Different methods of treatment of supracondylar fracture of the humerus have been used:

(1) Manipulative reduction

It entails closed reduction by manipulation under general anaethesia and immobilization by posterior plaster slab from the axilla to the wrist which is wide enough at the elbow to control side displacement. [51] **(Fig.17)**

Longitudinal traction is applied to the fracture in the position of injury. Traction should be gentle to avoid stripping of the posterior periosteum. Do not hyperextend the fracture; because hyperextension can injure the median nerve and brachial artery by tensioning these structures over the proximal fragment. [51] Externally rotate the distal fragment; if the fragment was displaced posteromedially on initial radiographs, internally rotate if the initial displacement was posterolateral. [51] Occasionally, pronation can cause displacement when in theory it should improve the reduction and vice versa with supination. The key is remaining flexible and gently trying several methods until the best and most stable reduction is obtained. [48] If it appears that the proximal fragment has pierced the brachialis, the "milking maneuver" is performed. In this maneuver, the biceps is gently "milked" in a proximal-to-distal direction past the proximal fragment, often culminating in a palpable release of the humerus posteriorly through the brachialis. [50]

The intact soft structures, which form the ' tissue hinge' in this reduction, are the periosteum on the dorsal surface of the fracture and the tendon of the triceps which overlies it. By keeping the triceps taut, at first by longitudinal traction in the axis of the arm, and later when the elbow is flexed as longitudinal traction in the axis of the forearm, the tendon of triceps will draw the distal fragment into the reduced position. [5]

The elbow must never be flexed before lateral displacement has been corrected. By tightening the triceps tendon, flexion of the elbow will lock the fragments in whatever degree of lateral mal-alignment existed prior to flexion; no pressure applied locally can then shift it. [5]

The surgeon should verify the following points to check for a good reduction:

(a) The anterior humeral line intersects the capitellum. (b) Baumann's angle is greater than 10 degrees. (c) The medial and lateral columns are intact on oblique views. [49] While flexion may be slightly restricted as a result of the swelling, it should be possible to approximate it to within approximately 10° of normal flexion depending on correct positioning in the sagittal plane and, in particular, correction of the rotational deformity.[34]

Disadvantages of conservative treatment of displaced fractures include: frequent loss of reduction necessitating repeated manipulations which can cause elbow stiffness and physeal damage, [18] and the need for hyperflexing the elbow to maintain tension in posterior periosteal hinge but acute flexion increases the tension in an already swollen elbow, thus increasing the risk of vascular compromise by reducing arterial flow to the forearm and venous outflow from the forearm. Less than acute flexion is frequently required to maintain adequate circulation to the distal portion of the arm in patients with displaced supracondylar fractures. Unfortunately, anything less than acute flexion risks loss of fracture reduction because with even minor degrees of extension of the elbow, the posterior periosteum becomes lax and permits fracture displacement. [44] **(Fig.18)**

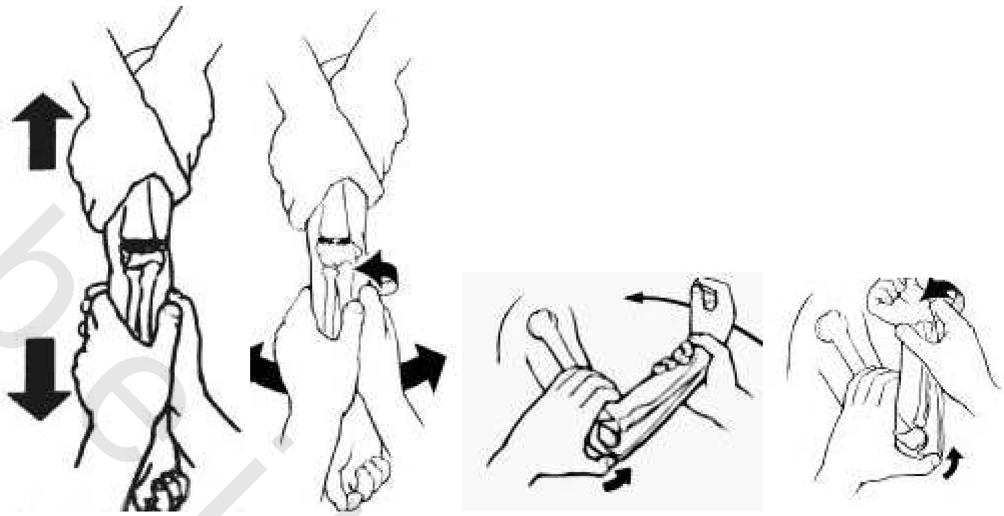

Figure (17): Manipulative reduction of supracondylar fracture of the humerus in children. [51]

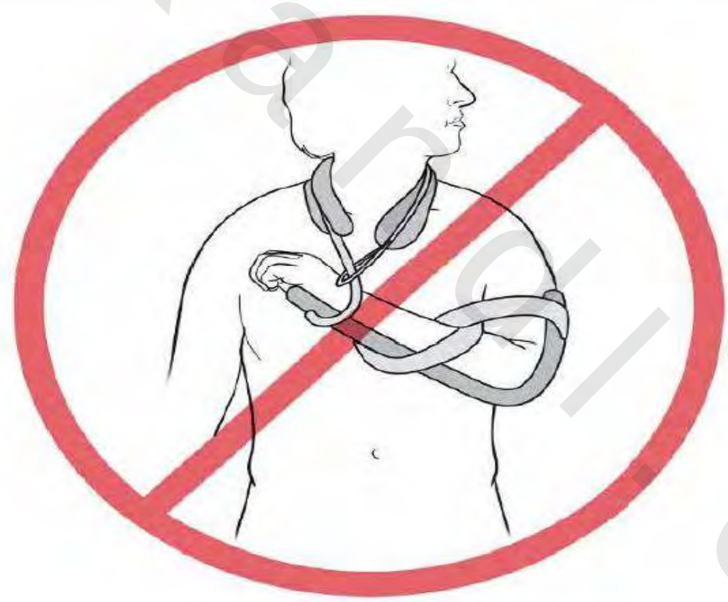

Figure (18): Avoid elbow hyperflexion. [49]

(2) Traction

Rarely traction may be an appropriate treatment for type III supracondylar fractures. The most common indication for traction would be a displaced fracture with severe swelling that precludes open or closed reduction. [47]

Two forms of traction traditionally have been used: skin or Dunlop's traction and skeletal traction. [47]

Dunlop's traction is applied in a lateral direction with the patient lying supine. The arm is held in 90° of abduction with the forearm in supination. The elbow is flexed from 0 to 10°. Counter traction was applied by raising the side of the bed **(Fig.19)**. The traction can be applied using oral analgesia. The patients remained on traction for 2 weeks, after which supervised intermittent physiotherapy was started. The traction was removed completely after 3 weeks and the patients discharged with a collar and cuff sling. Repeated assessment of the carrying angle was made while the patients were in traction for the first 2 weeks and the traction adjusted accordingly. [63]

With the arm in a straight lateral position it is easier to view the carrying angle and compare it with the other side. Traction also has the advantage of being flexible, it can be readjusted and its application does not require any special expertise. It is also considered that in extension, the forces of the extensor and the flexor muscles are neutralized. Skin traction can be a temporary measure for the gradual reduction of fracture followed by fixation with K-wires. [63]

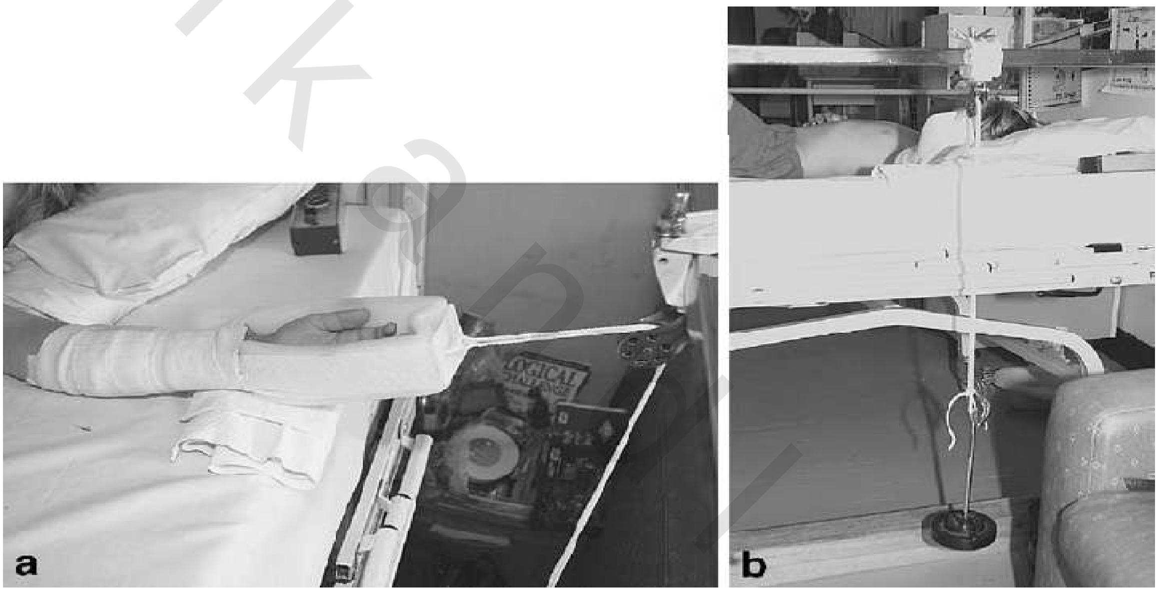

Figure (19): Skin traction. [63]

Pronation and supination of the forearm and varus or valgus tilt of the distal fragment are difficult to control and correct with this method. The forearm tends to rotate into supination, resulting in a loss of stability that ordinarily is achieved when the forearm is maintained in the pronated position in most of these fractures. This position also places the distal fracture fragment in some extension. [47]

Because of these disadvantages, if traction is necessary, it's preferable to use skeletal traction through the proximal end of the ulna with the elbow in flexion. Although some advocate side arm traction, most authors prefer overhead traction because it elevates the elbow, thereby helping to reduce swelling. Initially, traction was accomplished through the use of a Steinmann pin placed transversely through the proximal part of the ulna with the child sedated. The point of insertion is important because of the proximity of the ulnar nerve. Therefore, the pin is inserted from the medial side of the forearm at about the level of the coronoid process of the ulna, which is about 2.5 cm distal to the tip of the olecranon.

For placement of the pin, the elbow should be flexed to allow the nerve to move anteriorly and to enhance the surgeon's ability to feel the landmarks. A smooth rather than a threaded pin is used. [50]Because of the risk of injury to the ulnar nerve, a winged screw is preferred by some authors. The screw is inserted into the proximal end of the ulna at the same distance from the tip of the olecranon as used for insertion of the traction pin. It is inserted into the ulnar cortex in line with the longitudinal axis of the humerus. Another advantage of the screw is the existence of multiple holes in its wing so that the direction of pull of the traction can be altered to adjust for varus or valgus deformity.[63] **(Fig.20)** Gross displacement is corrected at this time. The arm is suspended from an overhead frame with a sling under the forearm to control its position. Three to five pounds of traction is usually sufficient to reduce and stabilize the fracture. Too much weight elevates the shoulder and twists the thorax causing the child to shift position resulting in loss of control of the fracture fragment. Suspension of the forearm in this position permits rapid reduction of edema and good control of elbow flexion. Rotational deformity can be controlled by placing the arm in either a cephalad or a caudad position. If necessary, a lateral sling around the upper arm also may provide lateral traction to correct anterior displacement of the proximal fragment. Serial radiographs must be taken, and producing adequate films may be cumbersome. Fracture stability is assessed clinically and radiographically. When the fracture is minimally tender to palpation, swelling has subsided and early callus has developed, a well-moulded above-elbow cast is applied, [47] while still in traction. The traction is removed and the arm is immobilised in this plaster cast for a further 2–3 weeks, i.e. a total immobilisation period of approximately 4 weeks. [63]

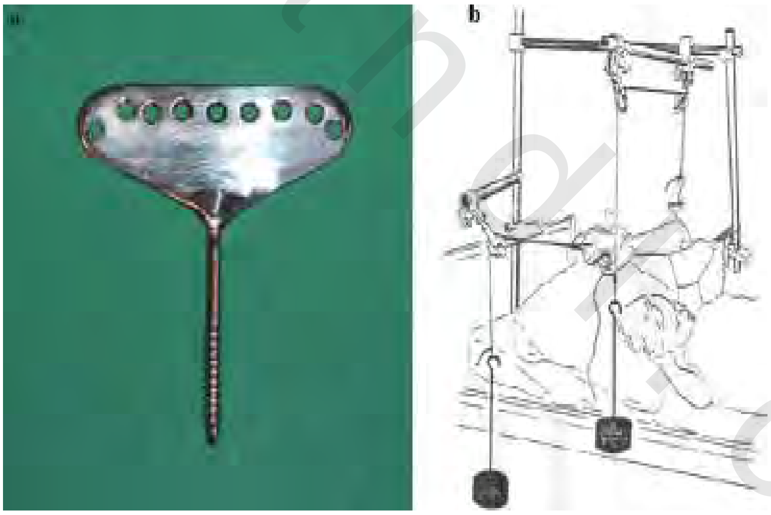

Figure (20): a) Modified Palmer olecranon screw. b) Overhead skeletal traction. [63]

Disadvantages of traction:

- Long hospital stay care is not generally acceptable as long as alternative methods are available that provide equivalent or better treatment.
- Unacceptable high incidence of cubitus varus.
- Radiographs of the distal end of the humerus are important for assessing the efficacy of the traction; however, the AP view is difficult to obtain. One must extend the elbow to obtain an adequate AP view, and this motion in itself may alter the position of the reduction of the fracture. [47]

(3) Lateral external fixator:

The main indications of this method as an alternative supplement to the existing methods are fractures that are irreducible with use of the usual closed techniques, fractures in which the original reduction that had been achieved and stabilized with percutanous pin fixation had displaced, resulting in unacceptable alignment, open fractures and fractures with a risk for compartment syndrome. (64)

The small external fixator provides major advantages over other methods. First, it facilitates the achievement of a satisfactory reduction through an indirect approach. Second, it provides rigid stability while allowing elbow motion, which eliminates the need for additional plaster immobilization, thus reducing rehabilitation time. Third, because it involves the use of a purely radial (lateral) approach, damage to the ulnar nerve is avoided. (63, 64) **(Fig.21)**

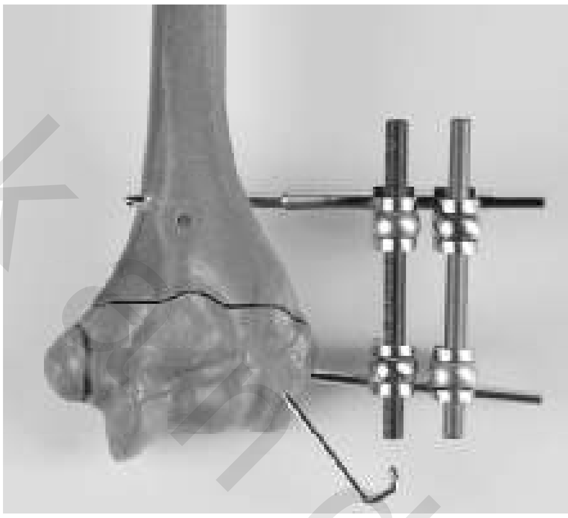

Figure (21): Schematic representation of lateral external fixation. (65)

Principles of lateral fixator application: the schanz pin should be inserted at 90° to the longitudinal axis of the proximal humeral fragment 2 cm proximal to the fracture line. In order to avoid injury to the ulnar nerve, care should be taken not to fully perforate the medial cortex. Second schanz pin should be placed perpendicular to the longitudinal axis of the distal fragment, making it parallel to the elbow joint. As with the first pin, it is important to avoid fully perforating the medial cortex of the distal part of the humerus. The schanz pins provide more rigid fixation of the fragments and can be used more effectively as joysticks to manipulate the fracture fragments. It provides good stabilization in the coronal plane, but there can still be some tendency for the fracture fragments to have rotational instability if forces are applied in the horizontal plane. To provide additional rotational stability, a 2.0 or 1.6-mm Kirschner wire is drilled retrograde from the lateral aspect (radial side) of the distal fragment into the proximal-medial cortex of the proximal fragment, crossing the fracture just proximal to the olecranon fossa. (65)

Alternatively, if the obliquity of the fracture is in the same direction the Kirschner wire is supposed to be placed, the pin can be passed antegrade from the lateral aspect of the proximal fragment to the medial aspect of the distal fragment. This single Kirschner wire is termed an anti-rotation wire, and it is fixed to the fixator rod with a combination clamp or it can be left free because it has no influence on axial stability. As with any external fixator, it is important to perform pin care on a daily basis. (64)

However, iatrogenic radial nerve injury is a risk, so it is strongly recommended that inserting the proximal pin is done in an open technique and that the pin should be placed within 2 cm above the fracture line using a drill sleeve. (65)

In case of iatrogenic radial nerve injury, early revision within days or at the time of removal of the implants is recommended. (65)

(4) Flexible intramedullary nailing (FIN)

Its advantages include high stability of the construct, which dispenses of the need for immobilization, making it a valuable option in specific cases where close monitoring of the involved region is critical (e.g., vascular bypass) and correct insertion of the nails requires that perfect reduction is achieved, which minimizes the potential for initial malunion. (66)

In case of compartment syndrome FIN facilitates monitoring since it does not need cast immobilization. Furthermore, the absence of cast avoids undesirable compression of the site. When compartment syndrome occurs, the superior stability provided by FIN as compared to other internal fixation methods greatly facilitates fasciotomy and subsequent application of dressings. (66)

The child is positioned supine on a standard operating table with the injured upper limb placed on an attached radiolucent arm table**.** The antegrade technique is best performed with the use of two image intensifiers (where possible), which allow the surgeon to obtain simultaneously an AP and a lateral view without mobilizing the elbow. The entire upper extremity is draped free to allow reduction in traction and lateral insertion of the nails. (66)

As epiphyseal fractures, sharp or tapered nails are routinely used to easily penetrate the dense cancellous bone of the distal humerus. (66)

Lateral skin incision is made over the deltoid. The hole is drilled using a drill bit that is slightly larger than the diameter of the nail; the drill is driven to the distal most portion of the incision. During the drilling procedure, the surgeon must firmly maintain the humeral shaft with the other hand to avoid misdirection of the drill. Furthermore, integrity of the far cortex must be preserved. The hole is slightly elongated to an oval shape in the line of the long axis of the humerus to facilitate oblique advancement of the nail. The second hole is drilled just above the first one. The use of the awl is not recommended due to the potential risk of slippage on the cortical bone. (66)

The first nail is attached to a T-handle and inserted into the medullary canal. This first nail is advanced under fluoroscopic guidance toward the lateral column as far as the fracture site. The tip of the nail should point toward the distal fragment. The procedure is repeated for the second nail, which is inserted through the proximal hole and advanced past the isthmus. At the junction between the diaphysis and the distal metaphysis, the nail is rotated 180° to be advanced toward the medial column until it reaches the fracture site With the nails properly positioned and after the perfect reduction has been confirmed, the assistant proceeds to impaction of the nails into the distal humerus, while the surgeon ensures that correct position is maintained at all times. (66) **(Fig.22)**

At the end of the procedure, a figure-of-eight bandage is used around the elbow joint to restrain flexion and extension, and the arm is immobilized in a sling. (66)

Nails are routinely removed under general anesthesia on the third postoperative month, even earlier, if skin impingement occurs. (66)

Figure (22): Antegrade flexible intramedullary nailing. (66)

(5) Closed Reduction and Percutaneous Pinning:

The ideal treatment for type III SCHF is, according to many authors, closed reduction and percutanous pinning. However, some series report the results of open reduction and pinning as comparable to those of closed reduction and pinning. (67)

The two major complications associated with percutaneous pinning of this fracture are:

1. Iatrogenic ulnar nerve injury which often results from a pin impinging on the nerve. Management of this complication varies from pin removal and observation to. If there has been no recovery of function after 4–6 months, then exploration is indicated. (18)
2. Loss of reduction, with the development of cubitus varus deformity. (18)

The child is positioned supine on the operating room table. The fluoroscopy machine is inverted to utilize as a hand table. The patient must be brought to the edge of the operating room table to ensure that the elbow can be placed in the centre of the fluoroscopy unit. (68) **(Fig.23)**

Figure (23): Patient position for closed pinning

Closed reduction is initiated by performing the "milking manoeuvre," an attempt to remove the brachialis and biceps muscles from the distal spike of the proximal fragment by "milking" the muscle bellies in a proximal to distal direction. Next, by stabilizing the proximal arm, longitudinal traction is applied to the forearm and the elbow is gently flexed. Varus and valgus angulation is now corrected by the surgeon moving the distal humerus fragment between the thumb and index finger. After these maneuvers are performed, fluoroscopy is performed to assess the Reduction with the elbow maintained in a flexed position. While maintaining control of the arm, elbow, and forearm, a lateral view is obtained to assess flexion and extension. Once the reduction is adequate, the surgeon drives the K-wires through the skin onto the bone. The wire is then driven across the fracture with the goal of having enough space to maximally separate the pins at the fracture site while engaging both the medial and lateral columns. [68]

(6) Open reduction and internal fixation:

Open reduction is indicated mainly for failure of closed reduction which could be due to instability of the fracture or the interposition of anatomical structures such as the neurovascular bundle or the brachialis muscle (irreducible fracture) [69], also for vascular lesions requiring exploration [34], and open fractures requiring irrigation and debridement.[18] the most common reason for a failed reduction is the proximal fragment's buttonholing through the brachialis muscle. Another factor is the interposition of the joint capsule or periosteum between the fracture fragments. [63] If an anatomical reduction cannot be obtained after one or two closed attempts, an open reduction should be performed because repetitive manipulations could result in joint stiffness and transient neuropraxia. Obtaining an adequate anatomical reduction favours excellent to good functional and cosmetic outcomes as well as fewer complications. [69] Manipulation should be avoided in displaced type III posterolateral supracondylar fractures with neurovascular deficit if clinical evidence indicates that the fracture fragment has buttonholed through the brachialis muscle because the neurovascular bundle may be entrapped in the fracture site. [18] The overall rate of conversion from closed reduction to open reduction ranges from 3 to 46 %.[69]

There are four different approaches that can be used in these fractures: namely medial, lateral, posterior and anterior.

The anterior approach:

It is not a new one; it was first described by Hagenbeck in 1894.The anterior approach has the advantage of better decompression of the fracture hematoma, better visualization and control of the fracture line, easy recognition of residual malpositioning and rotation of the fracture and the advantage of recognizing the tissues that prevents proper reduction such as the brachialis muscle, joint capsule, and neurovascular structures. [10]

The skin incision was on the anterior skin crease of the elbow starting from the lateral end and extending 2.5–3 cm medially. Deep to the subcutaneous fat the brachialis muscle is revealed. The distal end of the proximal fragment generally tears the brachialis muscle. This opens a natural door to the fracture site. Both ends of the fracture as well as nerves or muscle between fracture fragments can easily be seen and documented. After clearing the material between the fractures reduction is performed. The reduction is facilitated by the surgeon pushing the proximal fragment with his thumbs while pulling on the distal part with his fingers. During this manoeuvre the arm is flexed by the assistant. Reduction is checked by palpation for a perfect fit through the wound and through the condyles. If the reduction is satisfactory two K-wires are placed crossing one other from the medial and lateral epicondyles. The ends of the K-wires are bent and left protruding the skin. In cases of neurovascular compromise the skin incision can be extended to better reveal the whole fracture line and the injured structures. After closure of the skin a long arm splint in 90° flexion was applied. [70] **(Fig.24)**

Figure (24): Skin incision of anterior approach. [70]

The medial approach:

It offers an excellent view of the medial column pathology compared with other approaches. Unlike the posterior approach, it follows an internervous plane between the musculocutaneous nerve supplying the brachialis muscle and the radial nerve supplying the triceps muscle causing no further damage to the injured elbow.(71) Ulnar nerve identification, mobilisation and retraction eliminate the risk of iatrogenic ulnar nerve palsy that may occur with blind pinning. The neurovascular structures anteriorly are well protected by the brachialis and the entire anterior aspect of the proximal and distal fragment is well visualised. Anatomic reduction of the medial supracondylar column under vision minimizes the chances of an inaccurate reduction. An added advantage of open reduction is decompression of the hematoma which reduces the risk of compartment syndrome by decreasing the resistance to venous outflow. Cross K-wire stabilization enables immobilization at less than 90° flexion further improving venous outflow. (71) **(Fig.25)**

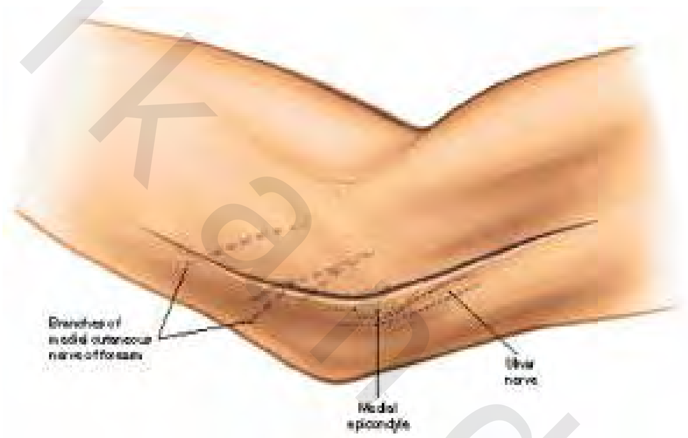

Figure (25): Skin incision of medial approach (73)

The patient is supine and a strict medial incision is made starting 3–5 cm proximal to the elbow crease and extending 2 cm beyond it. The ulnar nerve is identified and mobilized to the length of the skin incision. The brachialis is subperiostealy elevated from the proximal fragment and the fracture hematoma drained. The entire anterior breadth of the proximal humerus is visualised. The elbow is flexed to 20° and gentle traction given to visualize the distal fragment. Occasionally a sharp periosteal elevator is necessary to reflect the entrapped common flexor origin distally 2–3 mm. After the entire breadth of the distal fragment is visualised anteriorly 2–3 mm distal to the fracture line, the fracture is reduced by gentle traction and flexion with the thumb pressing the olecranon anteriorly. The quality of reduction is assessed by inspecting the medial column anteriorly, medially and posteriorly and the fracture line anteriorly. A pair of artery forceps may be used to feel for a step in the lateral column. Generally the fracture spikes interdigitate to lock the reduction. Cross K-wires are passed medially and laterally, distal to proximal. Elbow movements are checked. If extension is not full the lateral wire has impaled the lateral collateral ligament or the common extensor origin and its insertion site is changed. The wires are cut long and left protruding for 3 cm to facilitate subsequent removal .The tourniquet is deflated and the wound washed with saline. After checking for the capillary refill the subcutaneous fascia and skin are closed. The elbow is immobilised at less than 90° flexion. [71]

The lateral approach:

Lateral exposure provides alignment by using the anterior cortex of the fracture allows the surgeon to visualize and extract the interposed soft tissues. Although lateral exposure has the advantage of protecting the posterior vascular structures nourishing the distal humeral epiphysis, the lateral scar is often found unacceptable. And raise the incidence of iatrogenic ulnar nerve injury. There is no true internervous plane, because both the triceps and the brachioradialis muscles are supplied by the radial nerve. [72]

A lateral curved incision that extended from the lateral condyle 5-6 cm proximally to the interval between the biceps and the brachialis muscles was used for the lateral approach as the patient was supine with the operated arm in slight adduction over the body. After incision of the fascia, the fracture line was accessed with blunt dissection between the aforementioned muscles. After the reduction, fixation with crossed K wires was done. [73] **(Figu.26)**

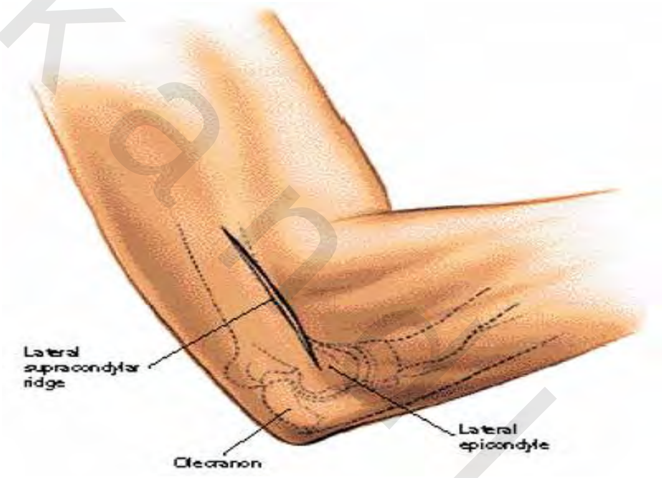

Figure (26): Skin incision of lateral approach. [72]

The Posterior approach:

The posterior approach allows excellent visualization obtained by providing good visualization of the distal humerus both medial and lateral fracture surface especially one with posterior comminution that allows exact anatomic reduction with no resultant angular or rotational deformities. No other approach provides an assured anatomic reduction at all times. [7]

Furthermore, this approach gives the surgeon a good view and sense of positioning during placement of the k-wires. Likewise, there is no risk of neurovascular injury. [73]

A longitudinal incision on the posterior aspect of the elbow beginning 5 cm above the olecranon in the midline of the posterior aspect of the arm. Just above the tip of the olecranon, the incision is curved laterally so that it runs down the lateral side of the process. To complete the incision, curve it medially again so that it overlies the middle of the subcutaneous surface of the ulna. [73] (**Fig.27)**

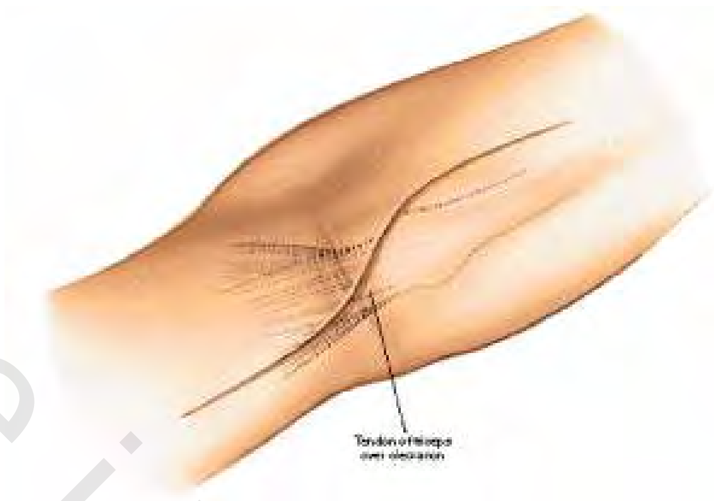

Figure (27): Skin incision of posterior approach. [73]

The Ulnar nerve found and protected, then triceps muscle cut in a reverse V shape , and two K-wires sent from epicondyles in crosswise way . After process is finished, triceps muscle is sutured and layers closed. [73]