A Dissertation on

# EVALUATION OF RADIOLOGICAL AND FUNCTIONAL OUTCOME OF BOTH BONE FRACTURE FOREARM IN CHILDREN AGED 5 TO 16 YEARS MANAGED WITH TITANIUM ELASTIC NAILING SYSTEM

*Dissertation submitted in*

*Partial fulfilment of the regulations required for the award of*

**M.S. DEGREE in**

**ORTHOPAEDIC SURGERY**

**THE TAMILNADU DR.M.G.R.MEDICAL UNIVERSITY**

**COIMBATORE-TAMILNADU**

**APRIL 2020**

# CERTIFICATE - I

This is to certify that this dissertation titled **EVALUATION OF RADIOLOGICAL AND FUNCTIONAL OUTCOME OF BOTH BONE FRACTURE FOREARM IN CHILDREN AGED 5 TO 16 YEARS MANAGED WITH TITANIUM ELASTIC NAILING SYSTEM**is a bonafide record of work done by **Dr.R.IniyaPrasanna,** during the period of his post graduate study from **January 2018 to January 2019** under guidance and supervision in the INSTITUTE OF ORTHOPAEDICS AND TRAUMATOLOGY, Coimbatore Medical College and Hospital, Coimbtore-641018, in partial fulfillment of the requirement for **M.S.ORTHOPAEDIC SURGERY** degree examination of The Tamilnadu Dr. M.G.R. Medical University to be held in April 2020.

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# CERTIFICATE – II

This is to certify that this dissertation work titled **EVALUATION OF RADIOLOGICAL AND FUNCTIONAL OUTCOME OF BOTH BONE FRACTURE FOREARM IN CHILDREN AGED 5 TO 16 YEARS MANAGED WITH TITANIUM ELASTIC NAILING SYSTEM** of the candidate **Dr.R.IniyaPrasanna** with Registration Number 22171225 for the award of **MASTER OF SURGERY** in the branch of **ORTHOPAEDICS**. I personally verified the urkund.com website for the purpose of plagiarism Check. I found that the uploaded thesis file contains from introduction to conclusion 84 pages and result shows 7% percentage of plagiarism in the dissertation.

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**INSTITUTIONAL HUMAN ETHICS COMMITTEE**
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**CERTIFICATE OF APPROVAL**

To
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Dear **Dr.Iniya Prasanna R**

The Institutional Ethics Committee of Coimbatore Medical College, reviewed and discussed your application for approval of the proposal entitled **"Evaluation of radiological and functional outcome of both bone fracture forearm in children aged 5 to 16 years managed with titanium elastic nailing system."**No.074/2017.

The following members of Ethics Committee were present in the meeting held on 25.11.2017.conducted at MM - II Seminar Hall, Coimbatore Medical College Hospital Coimbatore-18.

| | | |
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| 15 | Mr.V.A.Shahul Hameed, +2 | Lay-Person |

We approve the Proposal to be conducted in its presented form.

Sd/Chairman & Other Members

The Institutional Ethics Committee expects to be informed about the progress of the study, and SAE occurring in the course of the study, any changes in the protocol and patients information/informed consent and asks to be provided a copy of the final report.

MEMBER SECRETARY
INSTITUTIONAL HUMAN ETHICS COMMITTE
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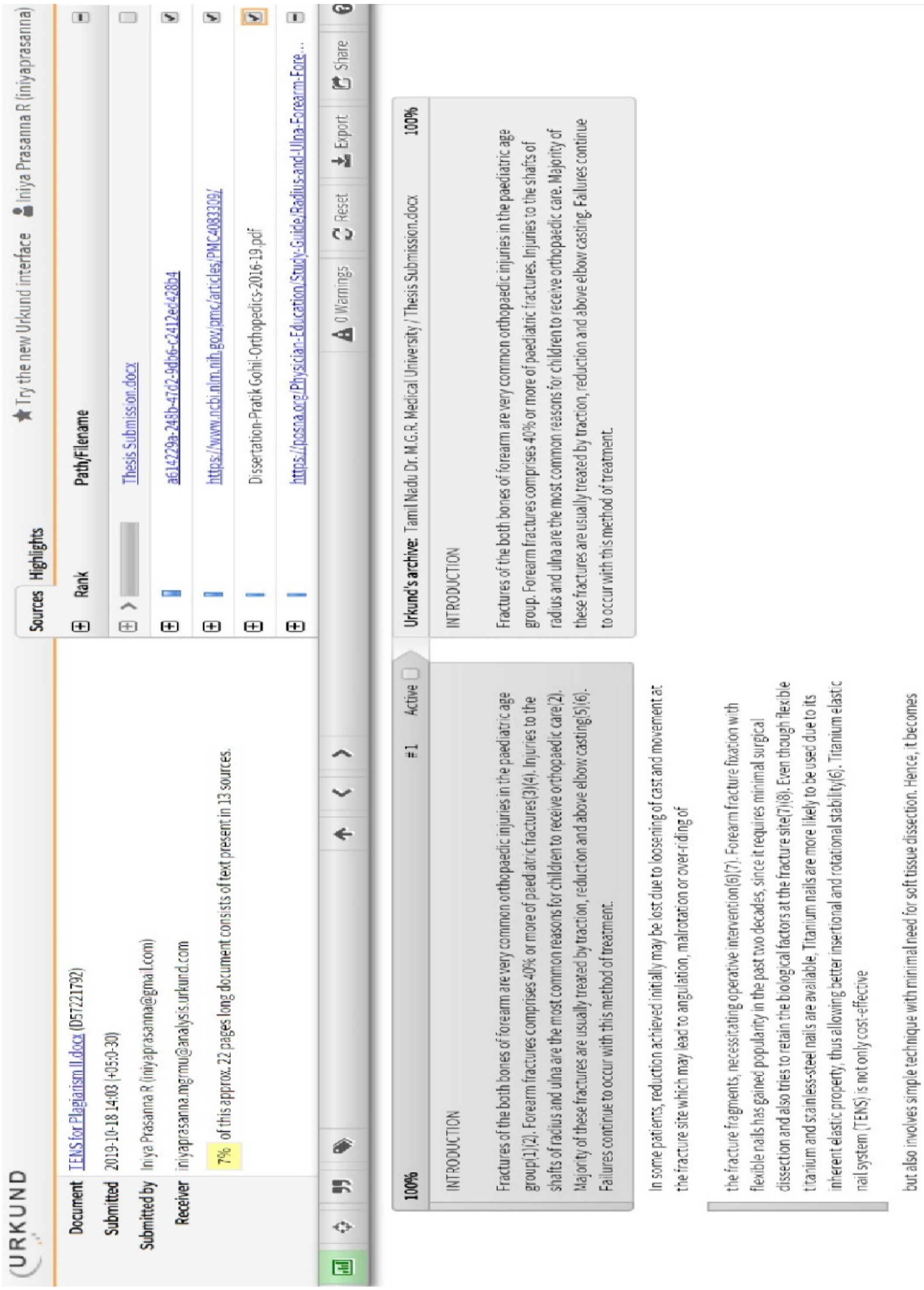
# URKUND ANALYSIS REPORT



# DECLARATION

I declare that the dissertation entitled **"EVALUATION OF RADIOLOGICAL AND FUNCTIONAL OUTCOME OF BOTH BONE FRACTURE FOREARM IN CHILDREN AGED 5 TO 16 YEARS MANAGED WITH TITANIUM ELASTIC NAILING SYSTEM"** submitted by me for the degree of M.S.Orthopaedic Surgery is the record work carried out by me during the period of**January 2018 to January 2019** under the guidance of **Prof..S.VetrivelChezian, M.S.Ortho.,D.Ortho.,FRCS., PhD.,** Director, Instituteof Orthopaedics and Traumatology, Coimbatore Medical College& Hospital, Coimbatore. This dissertation is submitted to The TamilnaduDr.M.G.R. Medical University, Coimbatore, in partial fulfillment of the University regulations for the award of degree of M.S.ORTHOPAEDICS examination to be held in April 2020.

Place: Coimbatore **Signature of the Candidate**

Date: **Dr.R.IniyaPrasanna**

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**Dr.R.IniyaPrasanna**

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# INTRODUCTION

Fractures of both bones of forearm are very common orthopaedic injuries in the paediatric age group(1,2). Forearm fractures comprises 40% or more of paediatric fractures(3,4). Injuries to the shafts of radius and ulna are the most common reasons for children to receive orthopaedic care(2). Majority of these fractures are usually treated by traction, reduction and above elbow casting(5,6). Failures continue to occur with this method of treatment.In some patients, reduction achieved initially may be lost due to loosening of cast and movement at the fracture sitewhich may lead to angulation, malrotation or over-ridingof the fracture fragments, necessitating operative intervention(6,7). Forearm fracture fixation with flexible nails has gained popularity in the past two decades, since it requires minimal surgical dissection and also tries to retainthe biological factors at the fracture site(7,8). Even thoughflexible titanium and stainless-steel nails are available, Titanium nailsare more likely to be used due toits inherent elastic property,thus allowingbetter insertional and rotational stability(6).

Titanium elastic nail system (TENS)is not onlycost-effectivebut also involves simple technique with minimal need for soft tissue dissection. Hence, it becomes the choice of stabilisation of forearm fractures in skeletally immature patients. The major advantage of this technique is not only fracture fixation without disturbing the biology at the fracture site, but also early fracture union due to this biologic fracture fixation and repeated micro-motion at the fracture site(9–11). Also, there are less chances of physeal injury, early elbow mobilisation and easy implant removal with minimal associatedcomplications. Early return of the child to school and decreased duration of post-operative hospital stay are also added advantages of this technique(12,13).

It also remains a constant challenge to the orthopaedist because of their treatment complexity and risk of complications. Though there have been vast changes in the management of forearm diaphyseal fractures in adults, developments in its paediatric counterparthas been idle as most diaphyseal forearm fractures in children, including unstable fractures, were largely managed conservatively due to the remodelling capacity of immature skeleton(14). Guided by practical experience and following the observation of outcomes of paediatric diaphyseal forearm fractures, operative interventions are being considered for the same. Inadequate understanding and overstated recommendation for conservative management of diaphyseal forearm fractures due to the inherent remodelling capacity of the immature skeleton has led the orthopaedic surgeons to accept poor outcomes and ignore the possible options to overcome such outcomes(15).

Various treatment methods such as closed reduction under sedation, plate fixation, intramedullary fixation using kirschner wire, Rush rod, Steinman pin or elastic stable intramedullary nailing are available for diaphyseal fractures of radius and ulna in the paediatric age group. As far as Intramedullary fixation is concerned, implants such as k-wires, Steinmann pin and rush rods have their own disadvantages. For example, Kirschner wires(6) and Rush nails are rigid and difficult to insert through the metaphysis of children's bones. Because of these disadvantages, flexible intramedullary nail (TENS) were devised to overcome this problem which produces a three-point fixation to maintain bony alignment and has now become a very popular method for managing forearm fractures in children.

The flexibility of titanium nail (TENS) allows for micromotion at the fracture site and seems to result in rapid fracture healing. The elastic deformation of the nail within the medullary canal creates a bending moment within the long bone that is not rigid, albeit stable enough to reduce and fix the fracture. The concept of using two pre-bent intramedullary flexible Titanium nails to recreate the interosseous space and provide dynamic internal three-point fixation was popularized by

Metaizeau, from Nancy, France. This not only allows for biological fracture healing but is also more convenient during implant removal(8).

Though this dissertation throws some light on the operative management of paediatric forearm diaphyseal fractures, it remains that there are only limited and specific indicationsfor surgery in these patients and non-operative management by closed reduction and cast application seems to be the key treatment(16). Indications for operative treatment includes compound fractures, unstable fractures, fractures in older children or adolescents and re-displacements within casts following closed reduction(13). This study focuses to assess the outcome parameters and complications associated with Titanium Elastic Nailing for diaphyseal forearm fractures in children and adolescents.

# AIM OF THE STUDY

Functional and radiological outcome analysis of diaphyseal fractures of both bones forearm in children aged 5 to 16 years managed with Titanium Elastic Nailing System.

# REVIEW OF LITERATURE

Various methods have been used for the management of forearm diaphyseal fractures. Walter Blount has declared in his publications that paediatric fractures are different from fractures occurring in adults (17,18). Robert Knight and George Purvis from Campbell Clinics in Memphisreported a whopping 71% unsatisfactory results in adult forearm fractures managed byclosed manipulation and casting(17). The failure of conservative treatment was attributed to the loss of interosseous space due to angulation and rotation at the fracture site. James Patrick identified re-angulation of forearm bones following closed reduction and casting and attributed it to cast loosening (19). Thus,open reduction was recommended when closed reduction failed. The concepts in forearm fracture management in skeletally immature patients have remained quiescent while the surgical management of adult forearm fractures keep undergoingdynamicrefinement.Blount and Hughston were strong believers of conservative management of fractures in children as they believed in the inherent capacity of paediatric bone to correct its deformities by remodelling (18,20).The ability of growing bones to spontaneously correctdeformities and to resist development of joint stiffness following prolonged immobilisation have made way for conservativemanagementof most of these fractures (21,22). However, there is no strong evidence pointing to spontaneous gradual correction of rotationalmalalignment followingdiaphyseal fractures of forearm in a growing skeleton. Thus, there is norational explanation in treating unstable paediatric diaphyseal forearm fractures by closed methodsonly to accept residual angulation or inadequate stabilization, anticipating spontaneous correction in children, especially when their limits have been defined (23). Walter Blount believedthat near normal results can be achieved with reasonably good alignment in most forearm fractures (18). Hughston stressed that alignment is the most important goal of reduction in paediatric age group(20). Both readily acceptedminimal bayonet apposition. Evans (1951), Hughston (1962),Bohler and Blount (1967) were critical of open reduction and internal fixation forpaediatric forearm fractures(24).Destot proposed the theory of intrinsic rotatory displacement in forearmfractures in 1913 (25).Blount stated that rotational deformities in childrenpersisted longer. However, they seem todisappear eventually (18). Even a small degree ofresidual angulation can result in prolonged healing and limitation of forearm rotation in diaphyseal fractures. Aitken, Evans and Hughstonstudied the remodelling capacity of immature forearm bones to correct any angulardeformity(20,24) which was proved false by Gandhi and

Wilson(26). A review of 1767 forearm fractures in children less than 12 years of age evidenced that an angular deformity of distal third forearm fracture canadequately remodel while the same could not occur in mid diaphyseal fractures in children.In addition, the remodelling capacity of angular deformity reduces dramatically after 10 years ofage (27)(28).

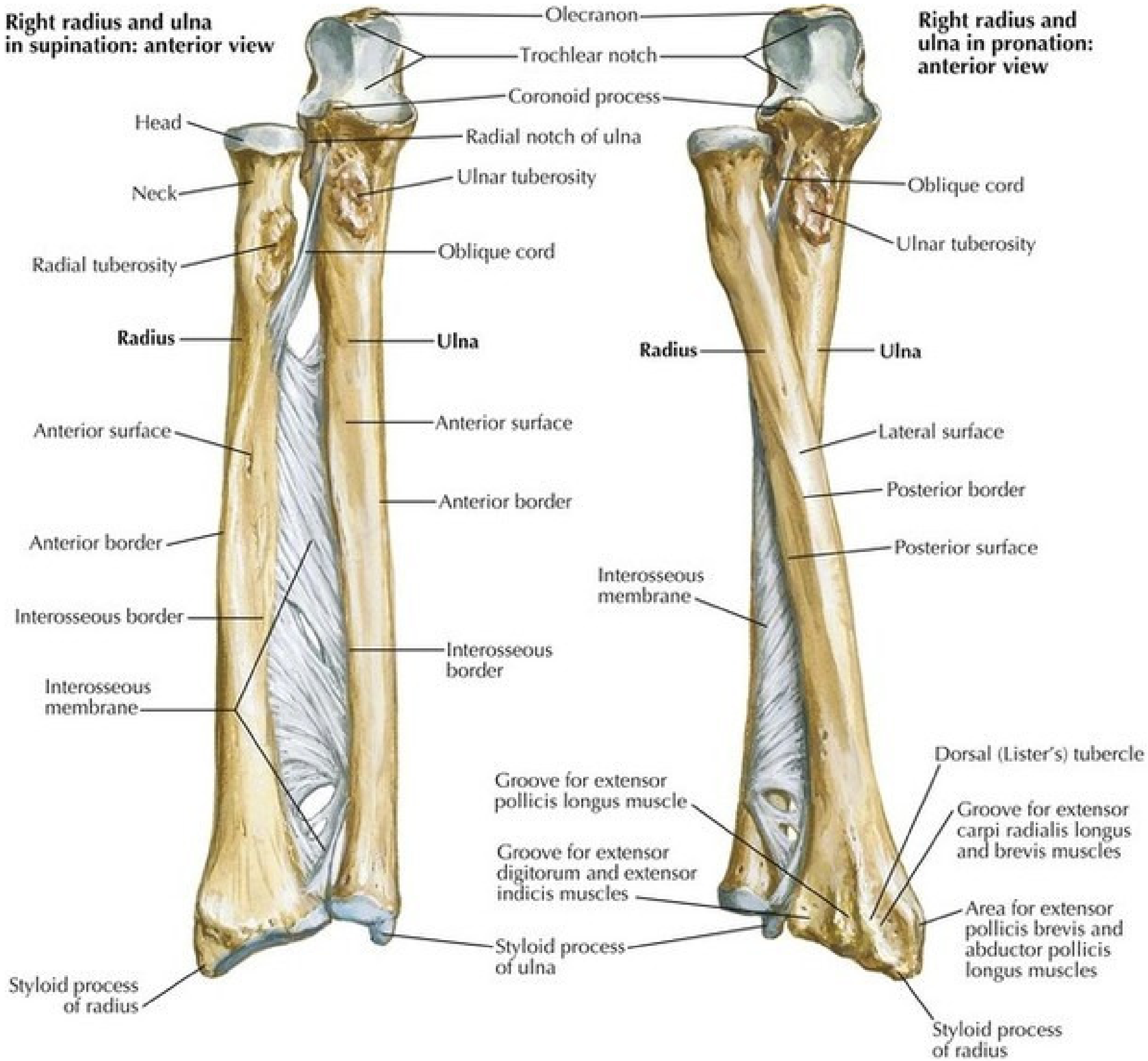
The distal radial physis ossifies around 15 to 17 years (22,26). Hencethereis not enough time left for spontaneous correction of deformities, in an older child, which takes 4 – 5years(26). The use of multiple wires for wiring the medullary canal in displaced paediatricfractures was reported by Fleischer in 1975 (2). Ligier and Amit also reported intramedullary fixation in paediatric forearm fracture (29). Intramedullary fixation is believed to be betterthanplate osteosynthesis in children. Jean Prevot and Paul Metaizeau (8) used flexibleTitanium nails for intramedullary fixation. Although non operativetreatment remains the mainstay of treating paediatric forearm diaphyseal fractures, the studies conducted by renowned orthopaedicians have attempted to point out the pitfalls and complications of this mode oftreatment.This paved the way for operative management of forearm fractures in children and adolescents.

# ANATOMY OF FOREARM

The forearm is a large non-synovial joint with nearly a 180 degrees arc of motion. It has two bones, the radius and ulna. The two bones are held together by the annular ligament at the proximal end, the triangular fibro cartilage complex in the distal end with the interosseous membrane in between the two. Due to this relationship, these bones function as a two-bone complex.Thus, an injury causing displacement of one bone usually results in displacement of the other. The radius is the lateral bone of the forearm. It has expanded proximal end, shaft and a distal end. The shaft of radius is a three-sided structure with two prominent curvatures.

The proximal end includes a head, neck and tuberosity. The head is discoid, its proximal surface a shallow cup for the humeral capitellum. Its smooth articular periphery contacts the ulnar radial notch. The neck is a constriction present just distal to the head. The shaft is triangular in cross section and widens towards its distal end. It also has a lateral convexity (approximately 10 degrees) and anterior concavity in its distal part. A second more acute curve of approximately 15 degrees with its apex medial occurs proximally near the bicipital tuberosity. The deviation along the midportion of radius is referred to as the radial bow.The interosseous border is sharp, except for two areas: proximally, near the tuberosity and distally just proximal to the ulnar notch. These two areas form the medial surface. The interosseous membrane is connected to the interosseous border. The distal end of the radius is the widest and is quadrangular in cross section. The rough lateral surface projecting distally is the radial styloid process. The posterior surface displays a palpable dorsal tubercle, the Lister's tubercle.

The ulna is medial to the radius in a supinated forearm. The proximal end has the appearance of a hook while the distal end expands into a small rounded head and styloid process. The important bony landmarks of ulna are its styloid(distally) and coronoid(proximally) processes. The three main passive restraints joining the radius and ulna include the proximal radio-ulnar joint (PRUJ), the distal radio-ulnar joint (DRUJ) and the interosseous membrane which have stabilising and load transferring functions. The above-mentioned structures also allow rotation of the radius about the ulna. The interosseous space is maximal around a near neutral position.


Right radius and ulna in supination: anterior view
Right radius and ulna in pronation: anterior view
Olecranon
Trochlear notch
Coronoid process
Head
Radial notch of ulna
Ulnar tuberosity
Neck
Oblique cord
Ulnar tuberosity
Radial tuberosity
Oblique cord
Radius
Ulna
Radius
Ulna
Anterior surface
Anterior surface
Lateral surface
Posterior border
Anterior border
Anterior border
Posterior surface
Interosseous membrane
Interosseous border
Interosseous border
Interosseous membrane
Dorsal (Lister's) tubercle
Groove for extensor pollicis longus muscle
Groove for extensor carpi radialis longus and brevis muscles
Groove for extensor digitorum and extensor indicis muscles
Area for extensor pollicis brevis and abductor pollicis longus muscles
Styloid process of ulna
Styloid process of radius
Styloid process of radius

## MUSCULES OF FOREARM

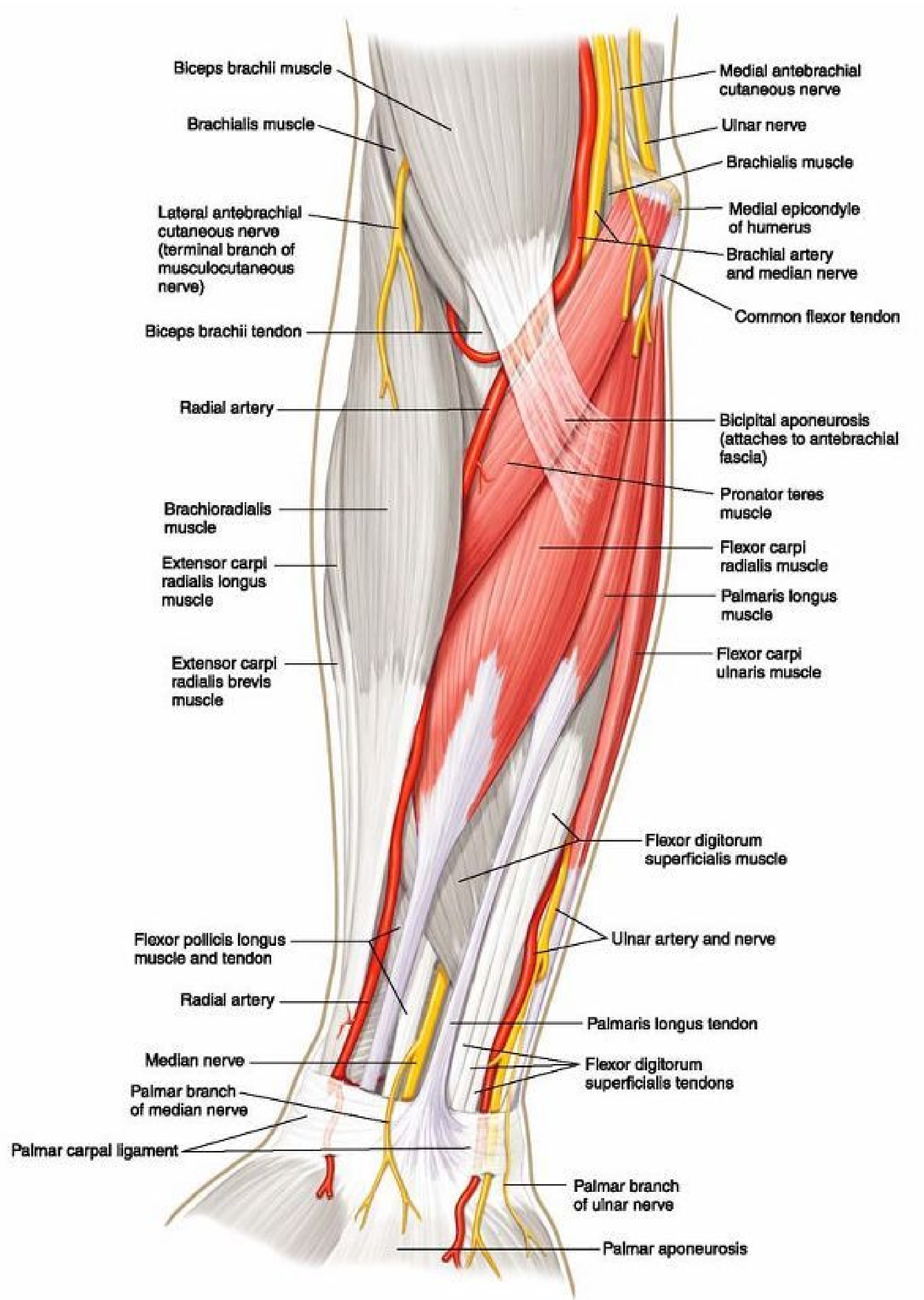
The paired bones of the forearm have an unbalanced number of muscles attached to them. Supinator attach to the proximal third of the forearm, whereas pronators attach to its middle and distal thirds.

The anterior aspect of the forearm is formed by two muscle groups which includes the mobile wad of three (brachioradialis, extensor carpi radialis longus and extensor carpi radialis brevis) supplied by the radial nerve, forming the lateral border of the supinated forearm and the flexor-pronator muscles, supplied by the median and ulnar nerves.

The flexor muscles in the anterior compartment of forearm are arranged in three groups from superficial to deep. The superficial layer comprises four muscles arising from the common flexor origin on the medial humeral epicondyle and includes the pronator teres, the flexor carpi radialis, the palmaris longus and the flexor carpi ulnaris.

The middle layer is formed by the flexor digitorum superficialis while the deep layer consists of the supinator, the flexor digitorum profundus, the flexor pollicis longus and the pronator quadratus.

Pronator teres has a humeral and an ulnar origin. The median nerve enters the forearm between the two heads of Pronator teres and supplies the same. It is inserted to the lateral surface of the middle third of the radius and is the primary pronator of the forearm.



Brachioradialis. Origin: Upper two-thirds of lateral supracondylar ridge of humerus. Insertion: Styloid process of radius.

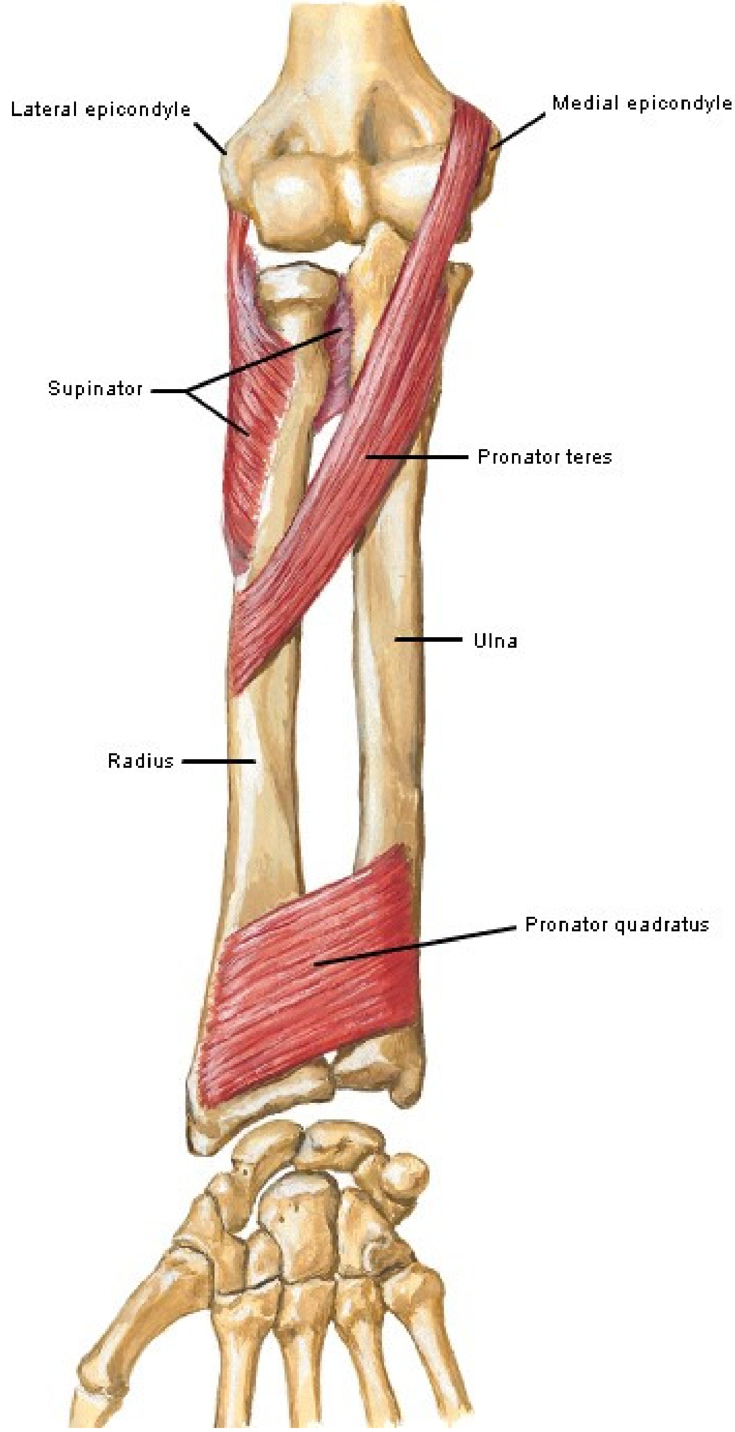
Flexor Digitorum Superficialis. Origin: Medial epicondyle of humerus, medial ligament of elbow, medial border of coronoid process of ulna, fibrous arch connecting coronoid process with anterior oblique line of radius. Insertion: Volar aspect of middle phalanges of fingers.Flexor Pollicis Longus. Origin: Middle part of anterior surface of radius. Insertion: Distal phalanx of thumb

Pronator Quadratus. Origin: Lower fourth of anterior aspect of ulna. Insertion: Lower fourth of lateral aspect of radiusPalmaris Longus. Origin: Common flexor origin on humerus. Inertion: Palmar aponeurosis.

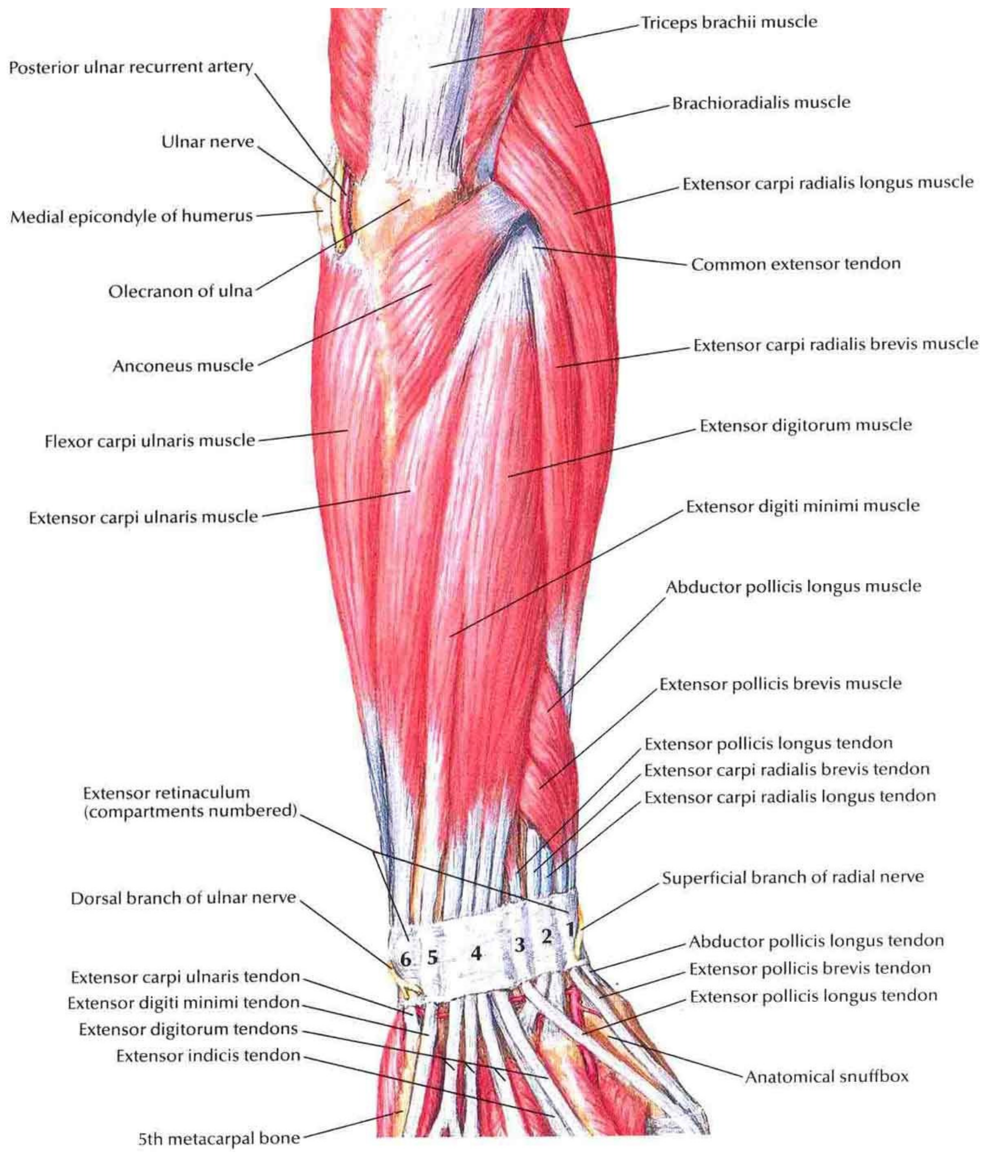
Flexor Digitorum Profundus. Origin: Proximal three fourths of anterior surface of ulna. Insertion: Distal phalanges of fingers.

Flexor Carpi Ulnaris. Origin: Two heads. Humeral head: from common flexor origin on medial epicondyle of humerus. Ulnar head: From medial border of olecranon and proximal three fourths of subcutaneous border of ulna. Insertion: Hamate and fifth metacarpal.

# Individual Muscles of Forearm
## Rotators of Radius - Supinated Position



The muscles in the posterior aspect of the forearm include the following:Extensor carpi radialis longus. Origin: Distal third of lateral supracondylar ridge of humerus, lateral intermuscular septum of arm. Insertion: Base of second metacarpal.



Extensor carpi radialis brevis. Origin: Common extensor origin on lateral epicondyle of humerus and radial collateral ligament of elbow.Insertion: Base of third metacarpal.

Supinator. Origin: Two heads. Superficial head: From lateral epicondyle of humerus, lateral collateral ligament of elbow and supinator crest of ulna.Deep head: From supinator crest and fossa ol ulna. Insertion: Anterior aspect of radius.

Extensor pollicis longus. Origin: Posterior surface of middle third of ulna and its adjacent interosseous membrane. Insertion: Distal phalanx of thumb.

Abductor pollicis longus. Origin: Posterior surface of ulna, adjacent interosseous membrane and middle third of posterior surface of radius. Insertion: Base of metacarpal of thumb.

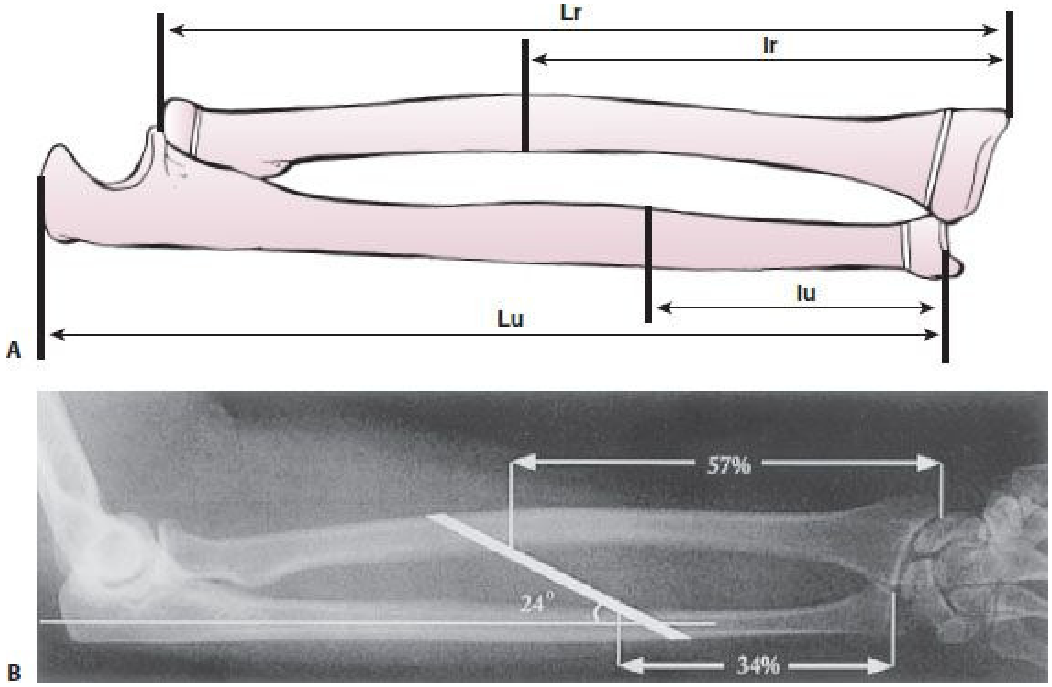
Extensor pollicis brevis. Origin: Posterior surface of radius and interosseous membrane. Insertion: Base of proximal phalanx of thumb.

Extensor indicis. Origin: Posterior surface of ulnar shaft and interosseous membrane. Insertion: Extensor apparatus of index finger via ulnar side of tendon of extensor digitorum that runs to index finger.

Extensor digiti minimi. Origin: Common extensor origin on lateral epicondyle of humerus. Insertion: Extensor apparatus of little finger.

## ANATOMY OF INTEROSSEOUS MEMBRANE AND LIGAMENT:

The interosseous membrane is a thin but strong membrane connecting the radius and ulna. It is attached to their interosseous borders. Its fibres run obliquely downward and medially. This provides attachment for the neighbouring muscles. The central oblique orientation of interosseous ligament attachment can be seen in terms of percentage of forearm length.



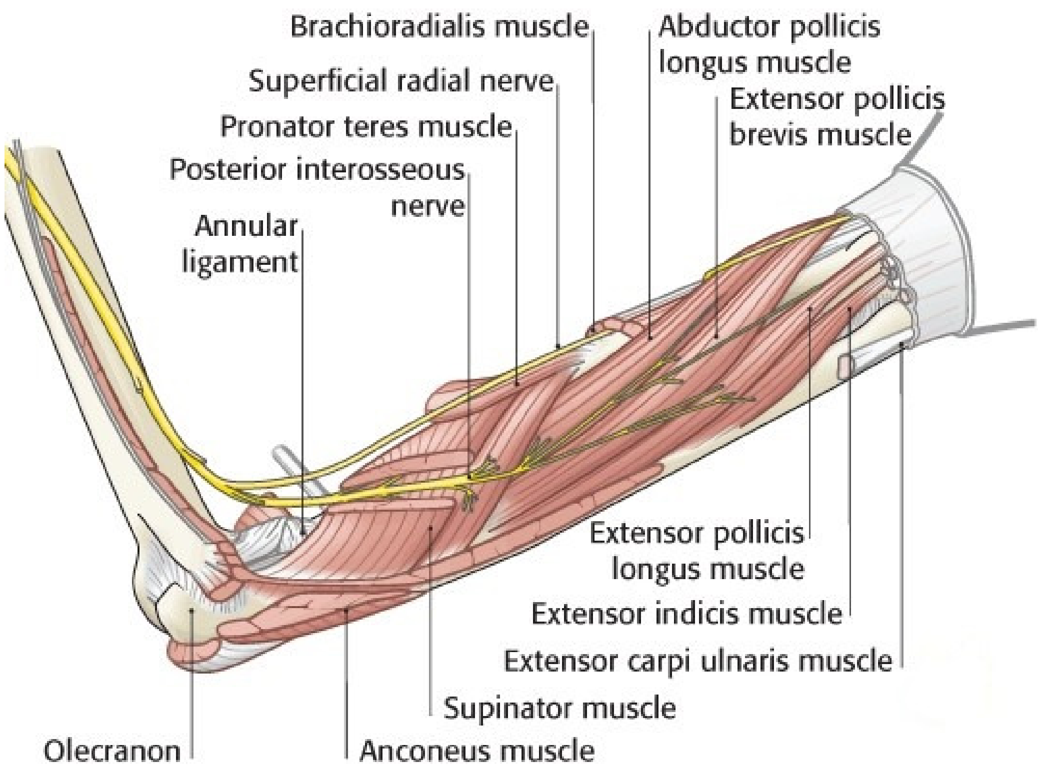

Several important biomechanical functions are carried out by the interosseous membrane, which includes:

- Transmission of load from wrist to elbow and transmission of load from radius to ulna
- It also helps maintain forearm stability as well as the stability of Distal Radio-Ulnar Joint (DRUJ)(30)

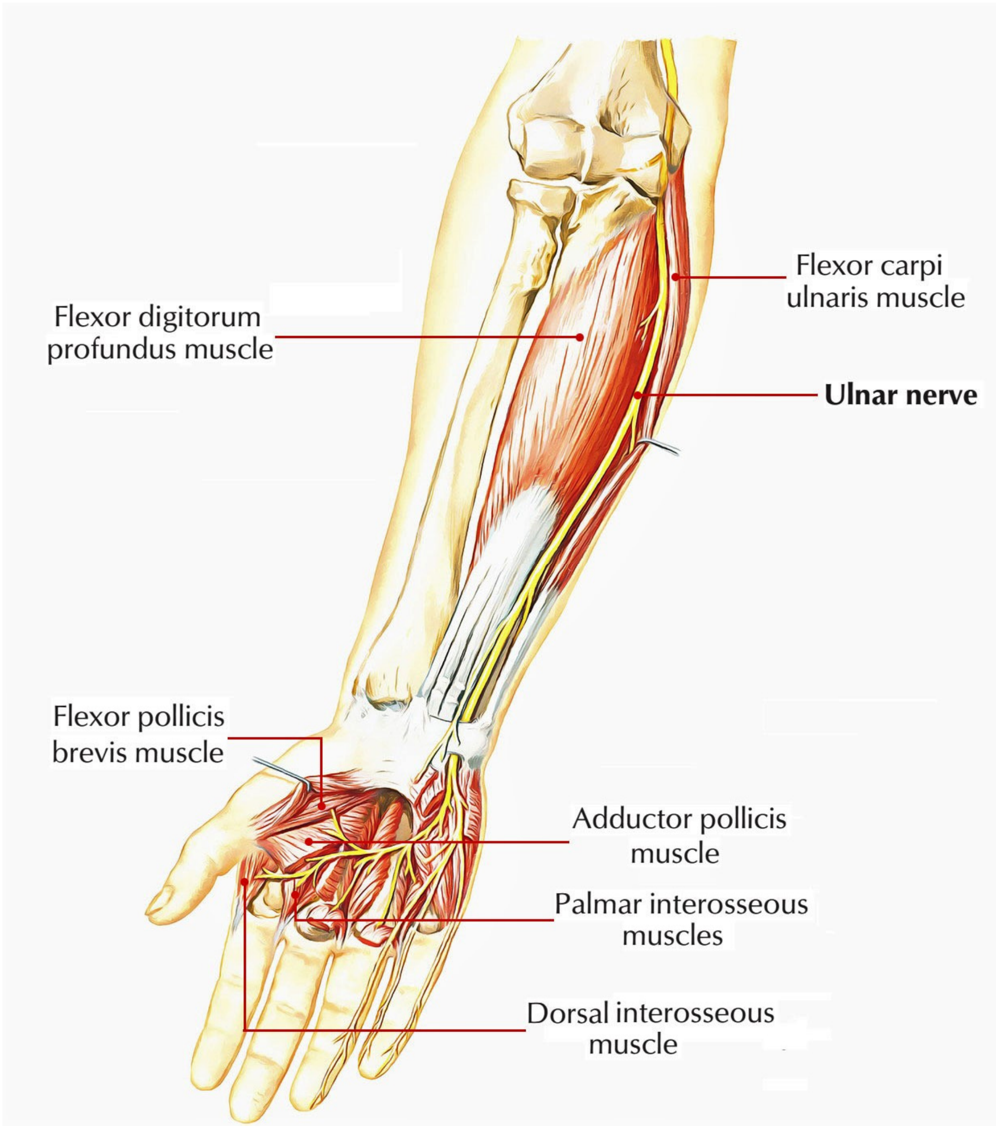
**RELEVANT NEUROVASCULAR ANATOMY:**

**1. Volar aspect:**

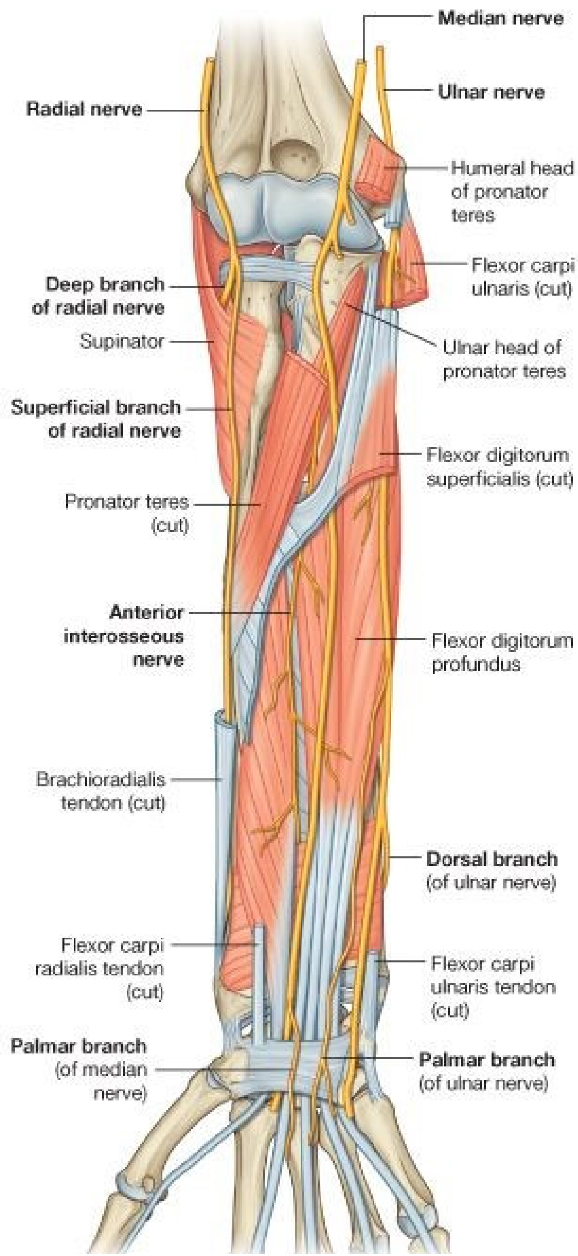
The superficial radial nerve runs distally beneath the brachioradialis and accompanying the radial artery which lies medial to it in the distal half of forearm.




The ulnar nerve along with the ulnar artery on its lateral side runs distally along the ulnar side of forearm.



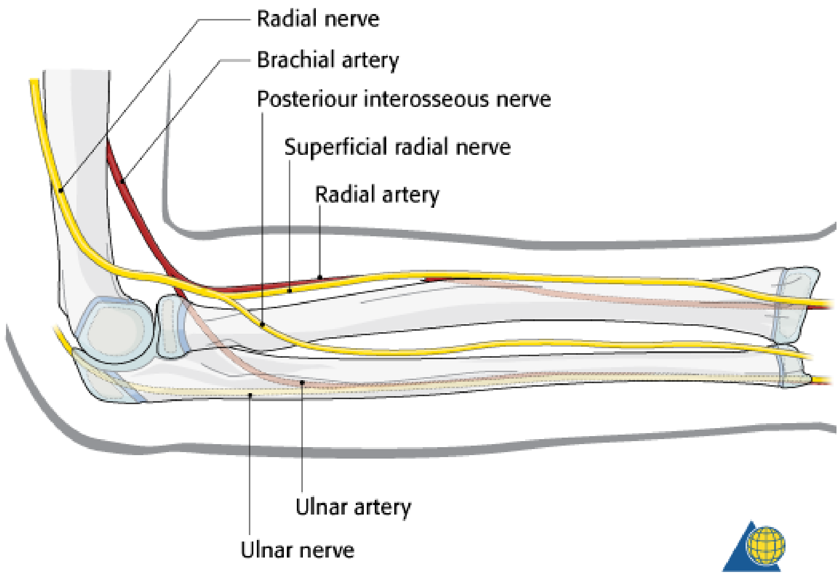

The median nerve passes between the heads of pronator teres and continues distally in the midline along the length of forearm. The anterior interosseus nerve (branch of median nerve) and the anterior interosseus artery (branch of common interosseus artery, which in turn is a branch of ulnar artery) also run down the middle of the forearm, deeper to the median nerve.



Median nerve
Radial nerve
Ulnar nerve
Humeral head of pronator teres
Flexor carpi ulnaris (cut)
Deep branch of radial nerve
Supinator
Ulnar head of pronator teres
Superficial branch of radial nerve
Flexor digitorum superficialis (cut)
Pronator teres (cut)
Anterior interosseous nerve
Flexor digitorum profundus
Brachioradialis tendon (cut)
Dorsal branch (of ulnar nerve)
Flexor carpi radialis tendon (cut)
Flexor carpi ulnaris tendon (cut)
Palmar branch (of median nerve)
Palmar branch (of ulnar nerve)

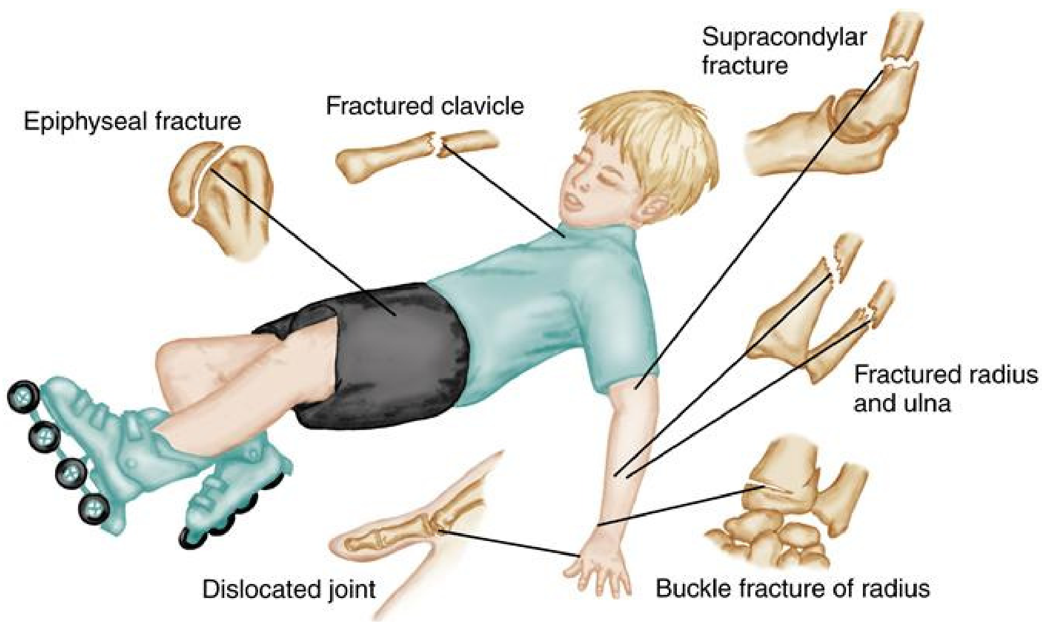
**2. Dorsal aspect:**

The posterior interosseus nerve which is a pure motor branch of the radial nerve passes between the heads of origin of supinator muscle, through the Arcade of Frohse, enter the extensor compartment of forearm and may come in direct contact with the periosteum around the neck of radius.



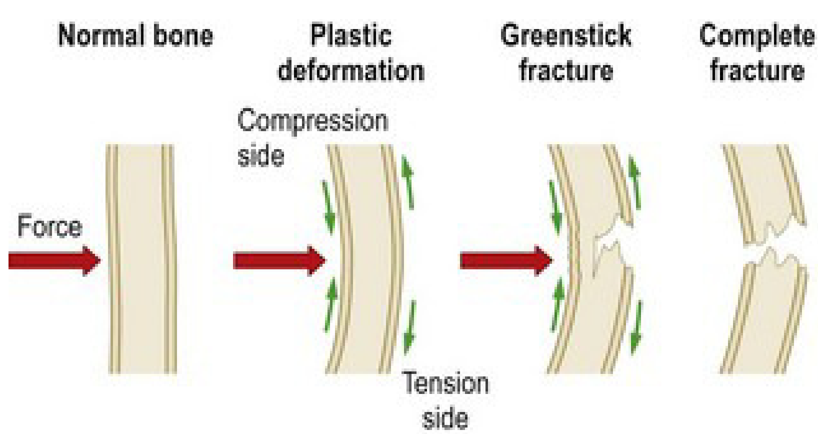
## MECHANISM OF INJURY

Fracture of forearm bones usually occur as a result of a fall on an outstretched hand and the force being transmitted to the forearm bones. Associated with a significant torsional component, these injuries can result in concomitant dislocation of either the proximal or distal radioulnar joint while a direct blow to the forearm can result in a fracture without dislocation of either PRUJ or DRUJ. Diaphyseal fractures of forearm bones can also occur from direct blows during a fall from height, in a road traffic accident or while participating in sports.(7,8)



## BIOMECHANICS OF FOREARM SHAFT FRACTURES IN CHILDREN

Paediatric bone can absorb higher energy before failure as compared to adult bones because of its porosity. Talking in relativity to time, the force when applied slowly on forearm bones initially bends the bone till its elastic limit and when this force is inadequate to fully fracture the bones, it may result in traumatic bowing i.e. plastic deformation. When the quantity of force applied is increased, it can cause a greenstick fracture which lies between plastic deformation and complete fractures and is seen on radiographs as a break in one, two or three cortices with preservation of some bony continuity(22).



In addition to problems common to all fractures of the shafts of long bones, diaphyseal fractures of the radius and ulna present specific problems. In addition to regaining length, apposition and axial alignment, achieving normal rotational alignment is necessary if a good range of pronation and supination are to be restored.

The movements of supination and pronation of the forearm involves rotatory movement around a vertical axis at the proximal and distal radioulnar joints. The axis of this rotatory movement passes through the head of radius above and the attachment of apex of the triangular articular disc below. During pronation, the entire radius moves around the ulna through the longitudinal axis of forearm.

Pronation is performed by pronator teres and pronator quadratus and supination is performed by biceps brachii and supinator. Supination is thepowerful of the two movements, because of the strength of biceps muscle.Maintenance of the interosseous space is essential for pronation and supination.

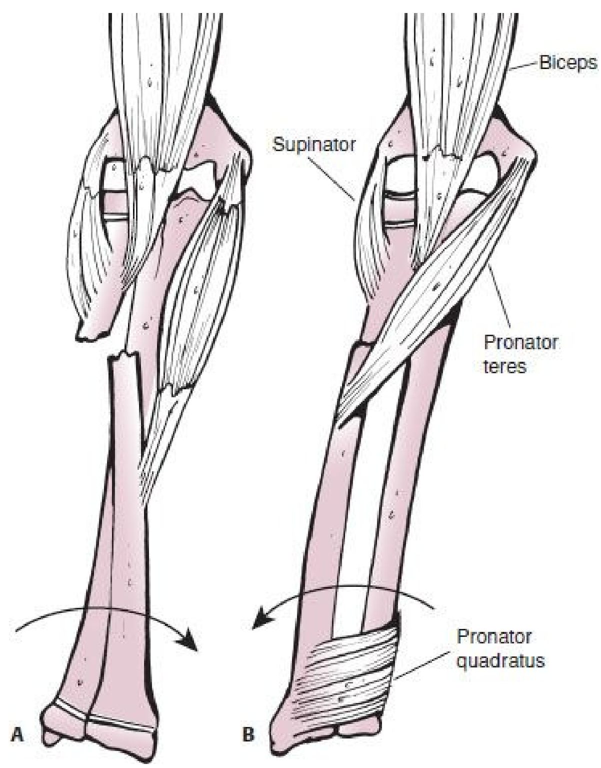
The biceps and the supinator exert rotational forces on fractures of the proximalthird of radius. Distally, the pronator teres at the level of mid shaft and thepronator quadratus on the distal fourth of shaft of radius exert both rotationaland angular forces. Fractures of distal radius tend to angulate toward theulna by the action of the pronator quadratus and the pull of long forearmmuscles.Rotational deformity will limit radioulnar movement.

The supinatormuscles are inserted proximally and the pronators distally. Consequently, in afracture of mid shaft of radius the proximal fragment supinates and the distalfragment pronates, resulting in 90° of rotational displacement. Shortening of thetwo bones following overriding may also occur. Both angular and rotationaldeformities are compounded by the presence of comminution. Hence, inaddition to regaining length, bony apposition, axial alignment and achievingnormal rotational alignment is necessary, if a good range of pronation and supination are to be restored.

## MECHANISM OF DEFORMING FORCES

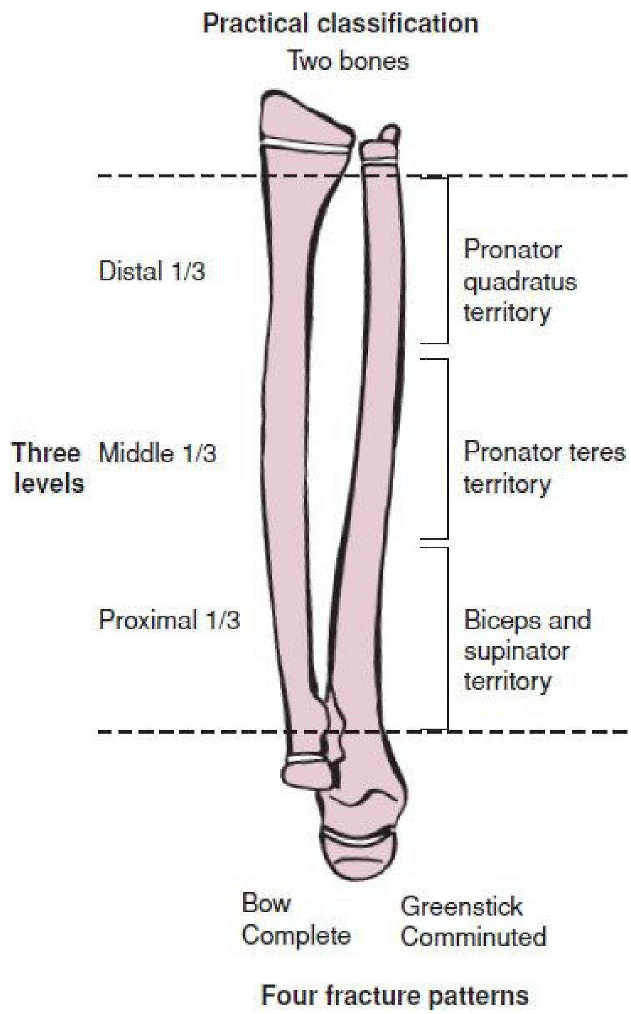
The muscle forces acting in the paediatric forearm tend to displace the fracture fragments. These include:

- the biceps and supinator inserting in the proximal third which tend to supinate the proximal forearm fragment
- the pronator teres inserting in the middle third which pronates the proximal fracture fragment and
- the pronator quadratus inserting in the distal third which also tends to pronate the distal fragment.

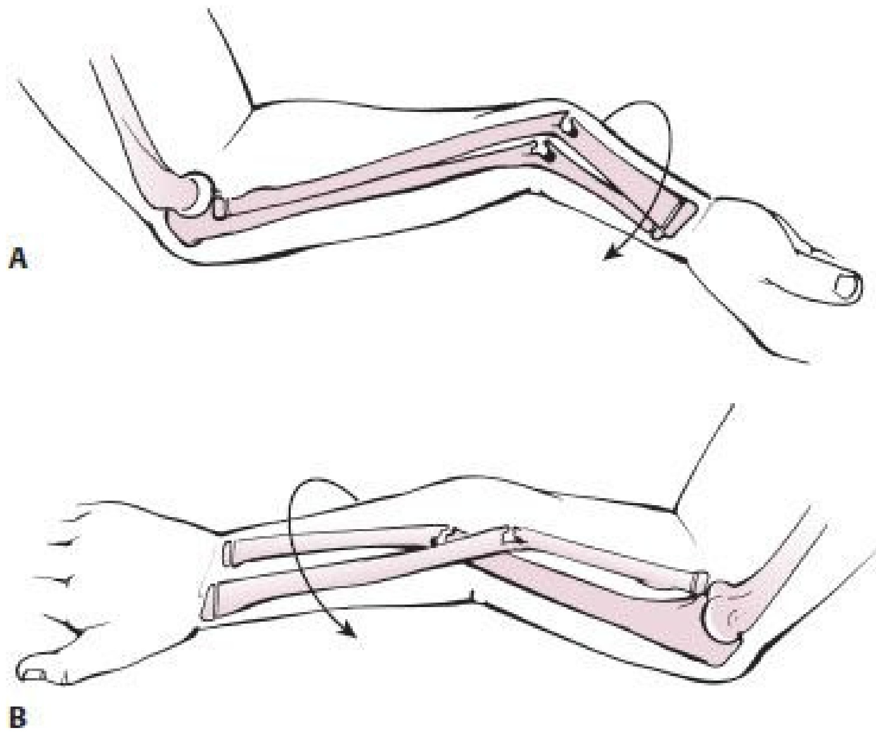


**PRACTICAL CLASSIFICATION OF DIAPHYSIS OF FOREARM BONES:**

The forearm bones can be practically divided into three segments as seen in the figure depicted below.



When the shaft fractures occur at different levels, it implies the involvement of a rotational component in the force causing injury.(31)



## PECULIARITY OF PAEDIATRIC SKELETON

The main peculiarity of paediatric bone is that it has growth potential which allows it to remodel and provides for spontaneous correction of deformities following a fracture (18,21,32). This growth potential is due to the presence of epiphyseal plates(32,33). In addition, the immature skeleton has a thicker periosteum and shorter healing time. Various studies reported high incidence of re-angulation following closed reduction of diaphyseal fractures which underwent successful remodelling (21). The cosmetic appearance of forearm depends on the quality of reduction of ulna whereas forearm rotation is determined by the alignment of radius (34). In this regard, the age, level of fracture and magnitude of angulation also determine the level to which remodelling takes place (28,35,36).

It was stated by Hughston that in a child younger than 10 years of age, a fracture adjacent to the metaphysis can remodel by upto 30-40 degrees. However, angular malunion in older children, aged 12-14 years, spontaneous correction of angular deformity can be highly unpredictable (27,36,37). It was reported by Fuller that it is difficult to anticipate spontaneous correction of deformities in children aged 11 years or more (27). Thus, it can be concluded that fracture remodelling depends to a large extent on the growth potential remaining in the epiphyseal plate. As the epiphyseal plate activity diminishes beyond 10 years of age, the ability of the growing bone to remodel also decreases (28). Distal radial fractures can remodel better than diaphyseal fractures (33). In addition, diaphyseal fractures of proximal forearm have low remodelling capacity. This can be attributed to the available growth capacity which is maximal in the distal forearm and comparatively lower in the proximal forearm. Better remodelling capacity can be seen in fractures with angulations in the plane of movements of the limb(20). The limits of angulation and malrotation have been published by Price to be between 15 and 45 degrees in children aged less than 9 years and between 10 and 30 degrees in children aged over 9 years (23). It was stated by Evans and Rang that rotational malalignment always accompanies angulation.

Due to various permutations and combinations of the pulls exerted in diaphyseal fractures of both bones forearm by supinator, pronator teres and pronator quadratus, it becomes unpredictable to determine rotational malalignment(22). In contrary to popular belief that rotational malalignment corrects with time, it has been proved that they persist (10,24,26,38). Further, malrotation of forearm limits movement and also affects the quality of life of the child(10,25,39). Limited pronation of forearm is compensated by abduction and internal rotation of the shoulder (10). However, the loss in supination cannot be compensated to the same degree by adduction and internal rotation of the shoulder. Hence it is of paramount importance to achieve not only angular reduction but also rotational alignment of forearm bones in mid-diaphyseal fractures.

## SURGICAL TREATMENT OF PAEDIATRIC FOREARM DIAPHYSEAL FRACTURES

It is well known that the gold standard treatment for most forearm fractures of the immature skeleton is conservative management (18,20,21). The trend towards operative management of forearm diaphyseal fractures can be strengthened by the fact that the need for corrective osteotomy of malunited forearm fractures following conservative management is on the rise (39–42). Further, the complication rates following surgical management of paediatric forearm fractures, cited in comparative studies of surgical versus conservative management of paediatric forearm fractures, is not only less than those in the adult group but also far outweighs the risk associated with any forearm osteotomy (39,42–44). The maximal remodelling following a fracture of the paediatric forearm bones occurs in the first two years following trauma after which it goes to a gradual decline. Thus, there is a definite risk in expecting the fracture union to remodel in a child who has around 2 years of growth left (28). It is therefore wise to appropriately intervene surgically and fix these fractures, preferably using intramedullary fixation. This is a strong argument favouring primary internal fixation in unstable both bones forearm fractures in older children.

The following indications have been laid down to prevent irrational and insensible surgeries in children:

a) Instability

b) Open fractures

c) Unacceptable alignment

d) Older children or adolescents

e) Refractures with displacement

f) Fractures associated with vascular injury

Unstable fractures can be defined as complete diaphyseal fractures of both bones of forearm around the same level with convergent displacement (45). When angulations after closed manipulative reductions have crossed the acceptable range or re-angulation occurs, then open or closed reduction an internal fixation of the fracture is indicated (41,46,47). It is considered that compound fractures are inherently unstable (35,41). In such fractures, thorough debridement should always be done prior to internal fixation (10,35). In children aged

10 years or above, the pronator quadratus or interosseus membrane may interpose between the fracture fragments preventing closed manipulative reduction and warranting the need for internal fixation (18,36,37,39,45).

The publications in the textbook “Operative Orthopaedics” by Willis Campbell remains a major factor which brought about the shift from conservative management to internal fixation of forearm fractures in paediatric population (1). The operative management of forearm fractures with appropriate indications were also cited by Daruwalla, Fuller, Schmittenbecher, Creasman and Neilson in their publications (46,12,15,30)

The various options available for internal fixation can be broadly classified into plate osteosynthesis or intramedullary fixation. Though plate osteosynthesis can provide better reduction and rigid internal fixation, the extensive periosteal stripping can result in delayed union in few cases (28,31). Also, there has been increased complications during plate exit (29,31).

The use of intramedullary devices for internal fixation can be dated back to late 1940s in the reports of Knight and Purvis (4). However, they led to poor results due to inadequate stability. Later, Charnley’s principle of three-point fixation used for maintaining reduction of fractures by cast immobilisation was modified by Rush brothers for internal fixation by the use of a straight rod in a curved bone to achieve stability.

Jean Prevot and Paul Metaizeau were the pioneers in the use of elastic stable intramedullary nailing (ESIN) of paediatric both bone forearm fractures at the Children's Hospital, Nancy; France. The landmark article was published by Metaizeau in 1986 where he reported 85 cases of paediatric forearm shaft fractures fixed with prebent flexible titanium nails (22). The interosseus membrane was recreated and fracture fragments stabilised by the inherent property of elasticity of the titanium nails and reduction maintained using dynamic three-point fixation principle. This hailed the arrival of an effective and minimally invasive technique of internal fixation. Thereafter, various publications by several authors have established positive outcomes with the use of titanium elastic nailing in paediatric forearm fractures(9,45,48–50).

The titanium nail is unparalleled in its ability to stabilise the fractured bone without disturbing the fracture biology and at the same time recreating the normal anatomical bowing of forearm bones. Further, there is minimal to no complication associated with nail exit as compared to plate osteosynthesis (37). It is to be emphasized here that the fewer complications with ESIN does not allow the surgeon to bypass the techniques and principles to be followed (29).

The use of titanium nails as opposed to long pre-bent Kirschner wires (stainless steel) can be explained by their biomechanical properties. The higher elastic modulus of steel conferring its rigidity can cause stress shielding and osteolysis of surrounding bone with increased risk of refracture after implant removal. K-wires have greater anteroposterior and torsional stiffness and hence require greater force for failure. They also have a higher cut out rate and can fail at smaller displacements while the elastic titanium nails can recoil.

The decision whether or not to immobilise the forearm following surgery is in a state of dilemma. The authors of AO as well as pioneers in this field advocated against post-operative immobilisation(29). The purpose of the intramedullary fixation using titanium elastic nails is to regain near anatomical alignment of forearm as possible. Maintenance of radial bow, angular and rotational alignment with maintenance of interosseous space is necessary for normal rotational movements of forearm (51). As mid-diaphyseal forearm fractures have low potential for remodelling, re-establishing the radial bow becomes an essential part of operative management. The point of maximal radial bow varies with age, but is usually located at mid third – distal third junction of radial shaft (52). Nailing of radius alone in both bone fracture of forearm may be associated with subluxation of distal radioulnar joint (29). Restriction of forearm rotation maybe associated in an older child with residual deformity of 10 degrees or more(23).

# MATERIALS AND METHODS

This is a prospective study carried out in the Institute of Orthopaedics and Traumatology, Government Coimbatore Medical College Hospital from January 2018 to January 2019. The study was approved by the ethical committee of the college. The study included 25 children who underwent titanium elastic nailing for diaphyseal fracture both bones of forearm. All patients underwent elastic nailing of both radius and ulna in the same sitting. Thorough wound debridement was done in patients with open fractures. The patients are followed up for a mean period of 4 months. Analysis of both pre and post-operative radiographs of forearm taken in two orthogonal views were done. Loss of forearm rotation was graded clinically by the use of Price et al criteria.

**INCLUSION CREITERIA:**

1. Complete diaphyseal fractures of both bones of forearm
2. Open fractures
3. Segmental fractures
4. Highly displaced fractures (i.e.Angulation > 15 degrees, rotation > 45 degrees in children < 10 years, Angulation > 10 degrees, rotation > 30 degrees in children > 10 years)

5. Bayonet apposition in children older than 10 years

6. Both bone forearm fractures in children > 13 years

**EXCLUSION CRITERIA**

1. Pathological fractures

2. Age above 16 years

3. Age less than 5 years

4. Single bone fracture

5. Incomplete fractures

# STUDY PROTOCOL

Patients who presented to the outpatient department or the emergency department with pain and deformity in the forearm were carefully evaluated clinically for any associated injuries, skeletal or otherwise. Once patients were haemodynamically stable, radiological analysis of the forearm was carried out by obtaining two orthogonal views of forearm including the wrist and elbow joints.

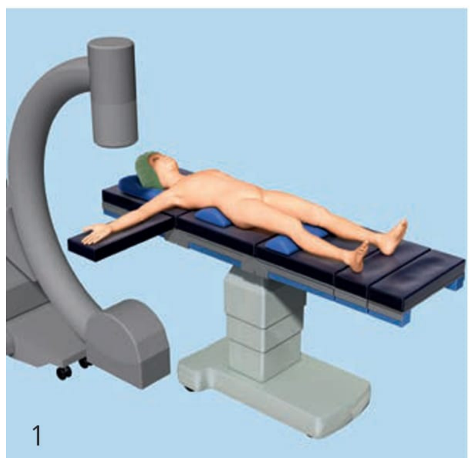
The patients were treated with closed reduction and cast application under sedation following which check radiographs in two orthogonal planes i.e. anteroposterior and lateral views were taken. If fracture reduction was found satisfactory, patients were discharged the next day and advised to attend weekly review. If fracture fragments were grossly displaced, angulated or malrotated or if the fracture was found displaced during follow up visits, such patients were planned for operative treatment.

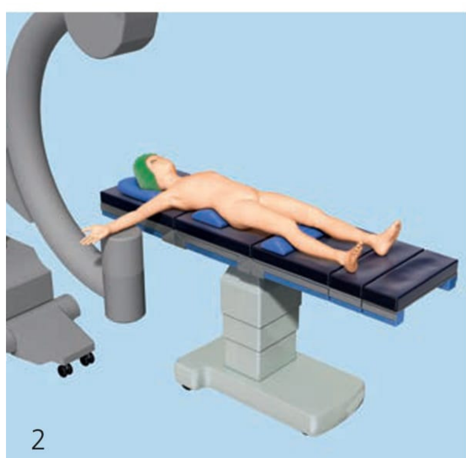
Patients who presented with compound fracture of forearm bones were taken up for emergency debridement and titanium elastic nailing.

**SURGICAL TECHNIQUE FOR INSERTION OF TITANIUM ELASTIC NAIL (AO MANUAL)**(29)

**PATIENT POSITIONING:**

The patient lying supine, should be brought to the edge of the operating table with the affected arm placed on a radiolucent arm table. The image intensifier must be strategically positioned so as not to interfere with the surgical field.



**NAILING APPROACHES:**

A. Approach to Radius:

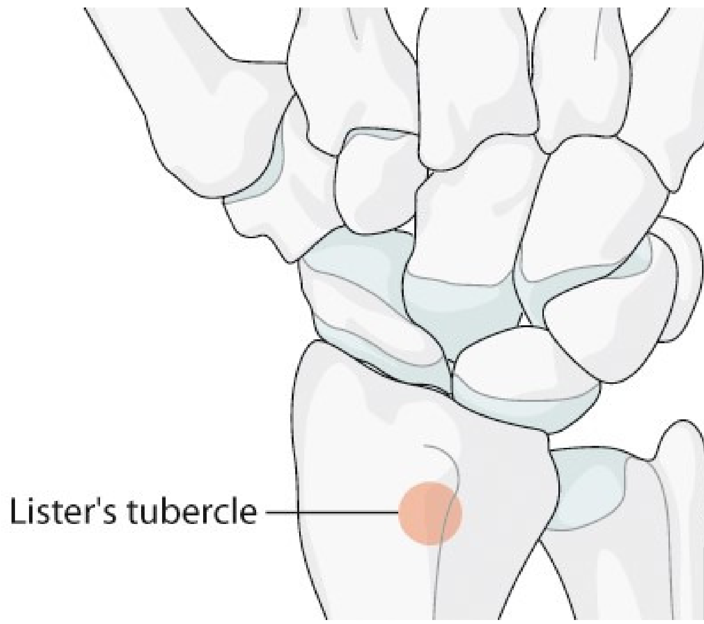
Antegrade nailing of radius is associated with high risk of injury to posterior interosseus nerve. Hence, intramedullary nailing of radius can be done by any one of the following approaches, both of which are retrograde and also tend to avoid the physeal growth plate.

I. Styloid approach:

This is done through the first dorsal compartment proximal to the distal radial physis.

II. Lister approach:

In this method the entry to the shaft of radius is gained just proximal to the Lister tubercle between the second and third extensor compartments.




In both of the above-mentioned approaches, a bone awl is used to gain entry to the intramedullary space of radius.

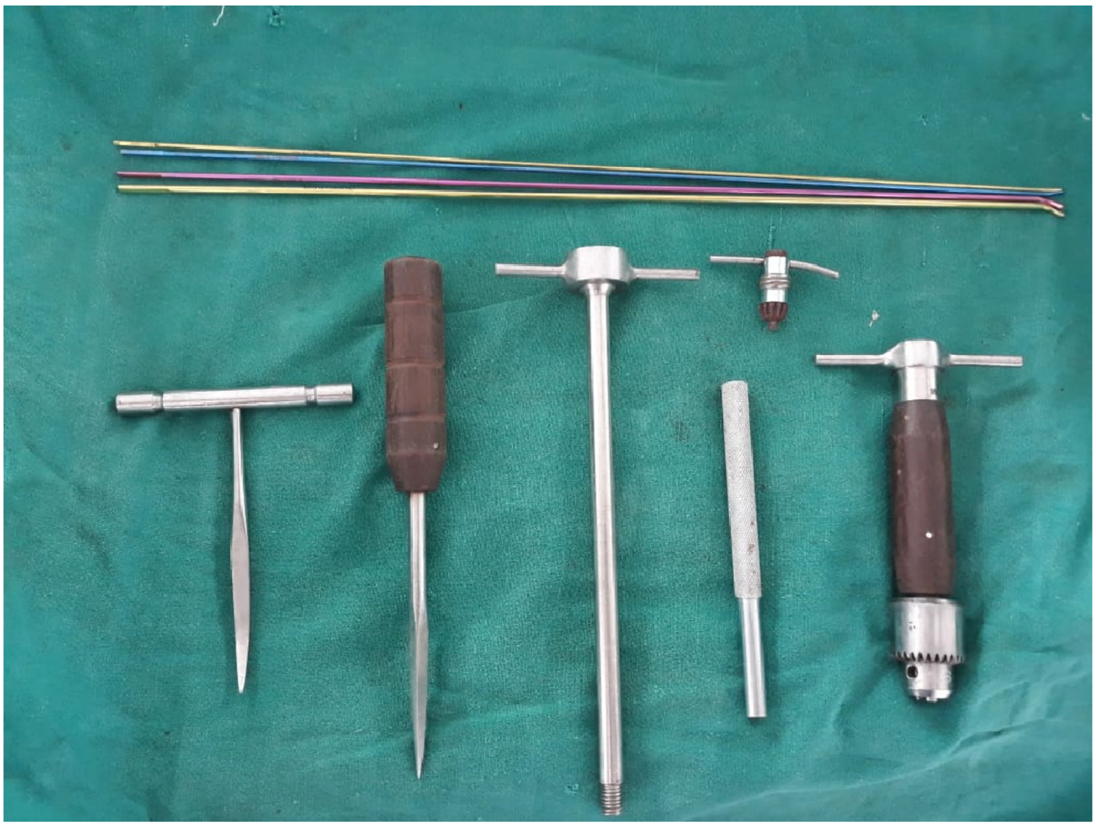
If there is any difficulty in fracture reduction, a mini open approach to radius using Volar Henry approach can be made and fracture reduction achieved and nail inserted as shown in the figure below.

B. Approach to Ulna:

A bone awl inserted at a point 3cm distal to the tip of olecranon and 4mm lateral to the posterior crest provides access to the intramedullary space of ulna. Thus,nailing approach in ulna is antegrade.

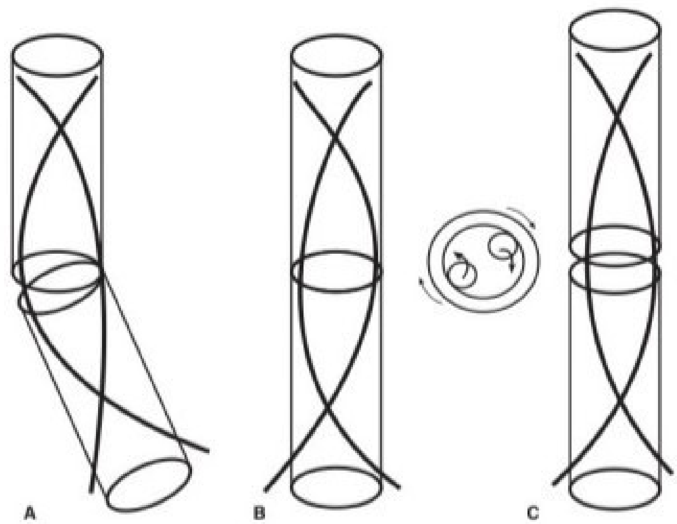
**TITANIUM NAIL INSTRUMENTATION**

The picture below shows the instrumentation necessary for elastic nail insertion along with the availability of titanium nails of varying diameters.

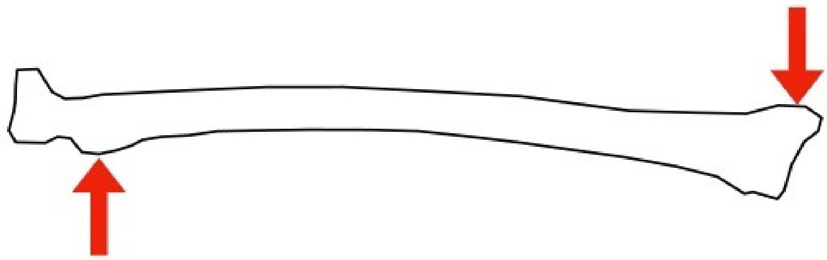


## PRINCIPLES OF FOREARM FRACTURE FIXATION USING TENS

It is mainly dependent on internal three-point fixation by firm anchorage of the nail in entry point and distal metaphyseal regions of the bone with the pre-bent part of the nail contacting the cortex opposite the entry point of nail, in the fracture zone.




The maintenance of the radial bow is a goal of forearm shaft fracture care. The most important bony landmarks of the radius are the radial styloid (rough lateral prominence) and the bicipital tuberosity (anteromedial prominence), which are oriented about 135 degrees away from each other. Maintenance of this styloid-tuberosity rotational relationship is another principle to be followed in forearm shaft fracture fixation.



- Radial bow can be evaluated in AP view
- Radial styloid (lateral)/bicipital tuberosity (medial)

As far as the ulna is concerned, two landmarks, the ulnar styloid lies in a dorsal direction and the coronoid process is in a volar direction and are oriented about 180 degrees from one another. Keeping a track of this styloid-coronoid rotational alignment of ulna is yet another important intraoperative step to keep in mind during intramedullary fixation of ulna fracture using TENS.

**SELECTION OF TITANIUM NAIL:**

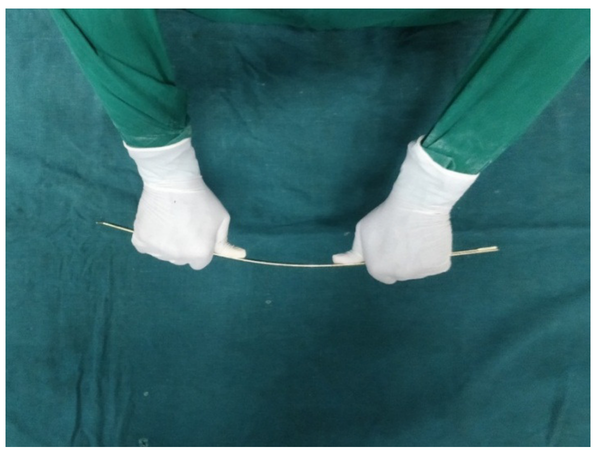
The nails used should be of appropriate size so as not to cause incarceration of the titanium elastic nails in these bones. Ideally, nails which filled around two-thirds i.e about 66% of the medullary canal diameter at the level of the isthmus should be used (29). The nail diameter commonly chosen was 2.0 mm in patients included this study.

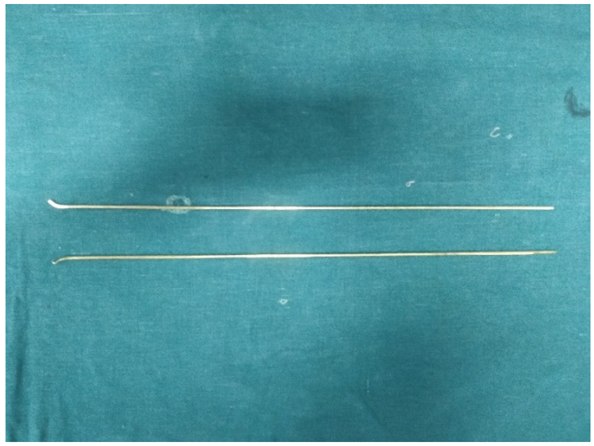
This emphasises the importance of having titanium nails of various diameters available in the implant armamentarium so as not to be in a predicament of having to settle with a nail of a smaller diameter.

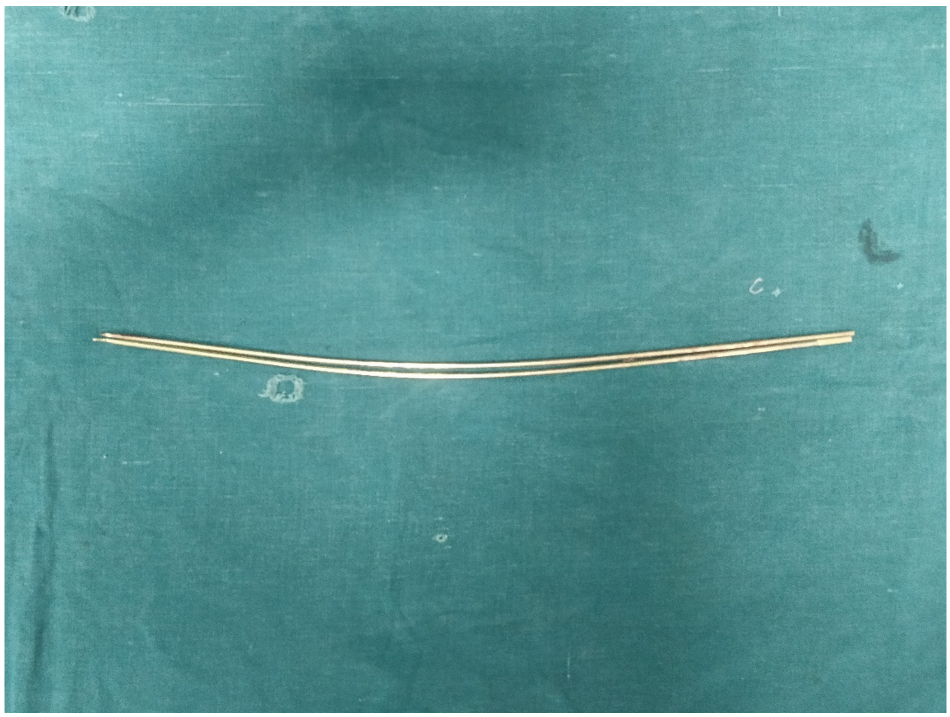
In fixing diaphyseal forearm fractures. It is better to use small diameter intramedullary nails (1.5,2 or 2.5mm) and tend to maintain some flexibility at the fracture site, thus stimulating callus formation. If larger nails are used, they can get incarcerated in the narrower part of the medullary cavity i.e. the central part for the radius and middle third-distal third junction for the ulna.

**PRE-CONTOURING OF TITANIUM NAIL:**

A pre-bent titanium elastic nail is used to produce dynamic three-point fixation, thus stabilising the fracture(37,48). Another titanium nail of similar diameter introduced into the second bone which is also pre-bent, can provide maximum cortical apposition, maintain length and provide rotational stability (44,45,48). It is of paramount importance to restore the normal anatomical bowing of forearm bones i.e. lateral bowing of the radius and posterior bowing of the ulna. This can be achieved by pre-bending the titanium elastic nails.



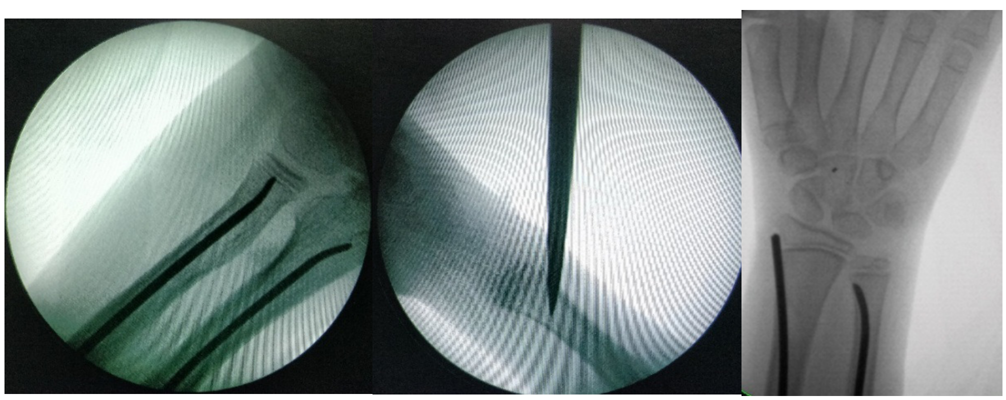




**NAIL INSERTION TECHNIQUE:**

The flattened bent tip of the titanium nail should be introduced first so that the bend comes into contact with the opposite cortex. Further insertion of the nail can be carried out by gently rotating the nail clockwise and anticlockwise alternately till it reaches the distal metaphyseal end point. These operative steps are done under fluoroscopic guidance.

Illustration showing various steps in nail insertion using fluoroscopic guidance



**RADIUS CROSSOVER SIGN:**

This simple method can be used to analyse the rotational alignment of forearm bones following green stick fractures. This method can be extrapolated to assess the rotational alignment of forearm bones following intramedullary fixation of proximal, middle or distal third diaphyseal fractures.

In this technique, anteroposterior radiographs of the forearm are obtained in with the forearm in full pronation, neutral rotation and full supination using distal humerus as reference, as shown in the figure given below.

It can be seen:

- radius crosses over the proximal third of the ulna with the forearm in full pronation
- radius crossing the distal third of the ulna with forearm in neutral rotation
- With forearm in full supination, the radius does not cross the ulna.

This method is found to be reliable and reproducible.

**COMMON ERRORS IN NAIL INSERTION TECHNIQUE:**

a) Inappropriate nail size i.e. <60% of forearm bone diameter

b) Inadequate pre-bending

c) Wrong entry point

d) Forceful nail insertion of a large size nail

e) Inadequate three-point fixation

## CLINICAL AND FUNCTIONAL OUTCOME EVALUATION

This was assessed by estimating the range of loss of rotatory movement of forearm i.e. supination and pronation. The assessment of the above range of movements was carried out using goniometer. Inspection of surgical scars was done. Assessment of functional outcome was done using Price et al criteria which depends on the degree of loss of forearm rotation.

| Outcomes | Symptoms | Loss of forearm rotation (°) |
|---|---|---|
| Excellent | No complaints with strenuous activity | <15 |
| Good | Mild complaints with strenuous activity | 15-30 |
| Fair | Mild complaints with daily activities | 31-90 |
| Poor | All other results | >90 |

## RADIOLOGICAL OUTCOME EVALUATION

Preoperative radiographs of the forearm bones in two orthogonal views were obtained to confirm the level and type of diaphyseal fractures. All fractures were classified using AO classification system. Post-operative radiographs were taken in the first post-operative day, at 4 weeks, at 8 weeks, 4 months and 9 months during the post-operative follow up period.

The evidence of bridging callus along three cortices of the diaphyseal bones along with bony trabeculae traversing the fracture was proof of radiological bony union and thus the radiological outcome. Titanium elastic nail exit was done in children who showed signs of clinical as well as radiological union.

In a true anteroposterior view of the forearm, the lateral radial styloid process points exactly opposite the medial bicipital tuberosity of radius. However, both these landmarks are inconspicuous in a true lateral projection. This diagonally opposite relationship of two bony landmarks in the same bone can also be seen in a lateral projection of the ulna where the styloid and coronary process are oriented exactly opposite one another. Radial bowing can be measured on standardised projections taken with forearm in neutral rotation. To measure the point of maximal radial bow, the maximal distance of the radial tuberosity from this point (a) is measured along with the length of radius (b).

The distal radial epiphysis maybe used as the reference point in children with incomplete ossification. A perpendicular line (r) is drawn onto (b), at the point of radial bow and the distance is measured which indicates the maximal radial bow. The site of maximal radial bow can be determined by the distance from the bicipital tuberosity to the point of maximal radial bow divided by the length of the entire bow and expressed as a percentage (a/b x 100). This method allows us to compare radial bow in patients with variable bone length. Due to this variability, the maximal radial bow (r) is reported as a percentage of the radial length (b) and is calculated as r/b x 100.

The site of maximal radial bow is at a mean distance of 60.39% of the radial length (52). The mean value of maximal radial bow is 7.21% of the total radial length. Thus, the site of maximal radial bow is at 60% of the radial length from the bicipital tuberosity and the maximal bowing should be less than 10% of the radial length.

**COMPLICATIONS:**

Complications after titanium elastic nailing may occur due to wrong indication, incorrect nail size or inefficient technique. The common post-operative complications include:

a) Soft tissue irritation at the point of nail entry due to sharp nail ends

b) wound infection

c) nail protrusion causing mechanical block

d) functional restriction of movements

e) migration of nail

f) technical failure

g) refracture with nail in situ

h) axial deviation >10 degrees

i) secondary rupture of tendons

**CLINICAL PICTURE ILLUSTRATING NAIL PROTRUSION:**

**NAIL EXIT:**

Removal of the nail too early can result in refractures. Nail removal can be done as early as the fourth post-operative month or can be delayed as long as one year after surgery. In this study, the nails were removed after clinical and radiological evidence of union, the average duration being 3-4 months. In this study, there were no refractures after nail exit till the completion of the study period.

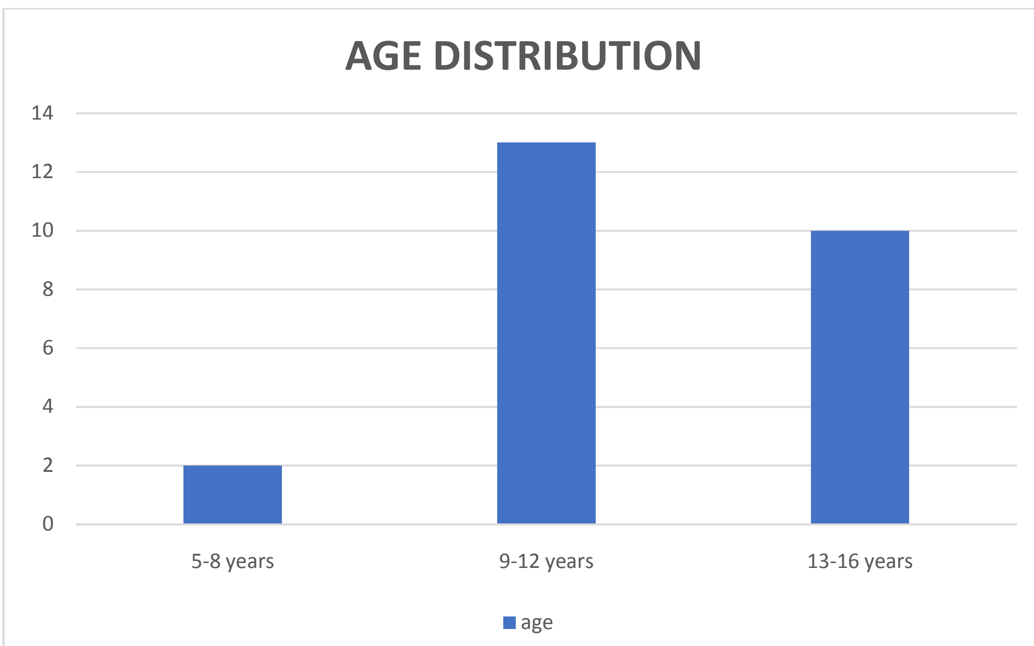
# OBSERVATIONS AND RESULTS

25 children who presented with diaphyseal forearm fractures from January 2018- January 2019 to the Institute of Orthopaedics and Traumatology, Coimbatore Medical College were included in the study and were followed till fracture union.

## 1. AGE INCIDENCE AND DISTRIBUTION:

The mean age of the patients included in this study is 11.92 years ranging from 6 to 16 years. The majority i.e. about 52% of patients belonged to the age group between 9 and 12 years of age.

| Age in years | No of patients | percentage |
|---|---|---|
| 5-8 | 2 | 8% |
| 9-12 | 13 | 52% |
| 13-16 | 10 | 40% |

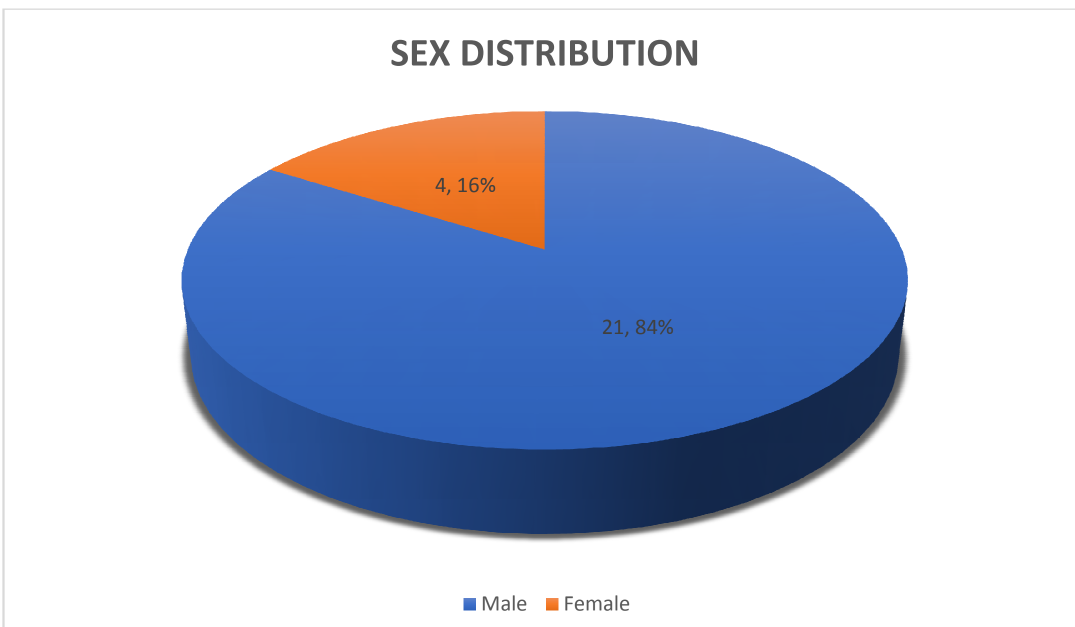


**2.SEX INCIDENCE:**

21 boys and 4 girls were included in the study. Thus, it can be seen clearly that males predominated the study with male:female ratio of 21:4

**SEX DISTRIBUTION**

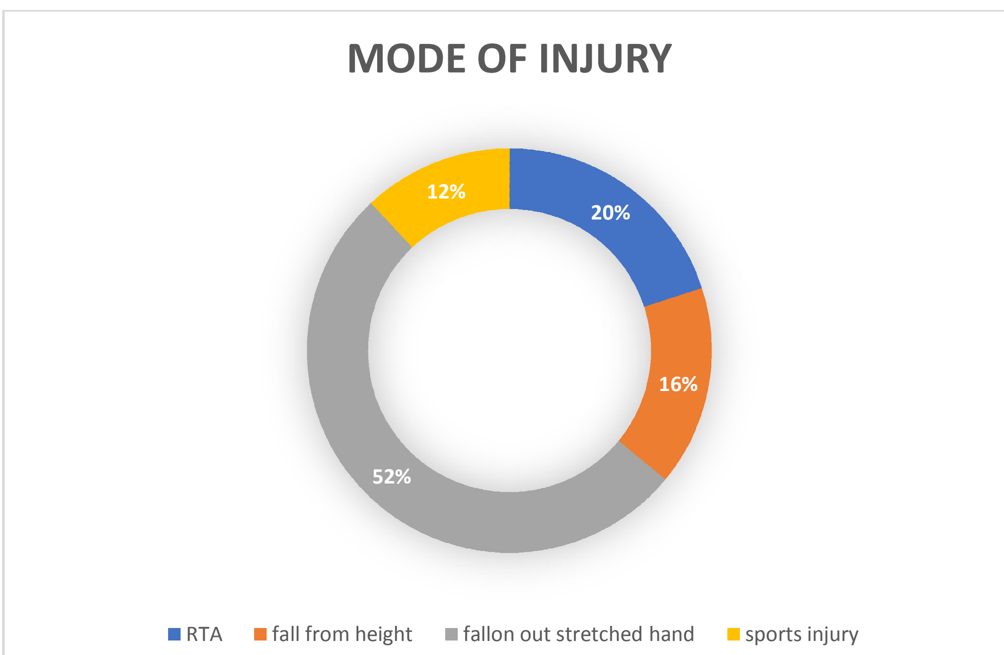
| Gender | No. of patients | Percentage (%) |
|---|---|---|
| Male | 21 | 84% |
| Female | 4 | 16% |



### 3.MODE OF INJURY:

Fall on an outstretched hand contributed to about 52% of patients presenting with diaphyseal forearm fractures and remained the number one mechanism causing diaphyseal forearm fractures in this study. Direct blows to forearm bones during road traffic accidents, fall from heights and fall sustained during sports activities also contributed to similar rates of these fractures.

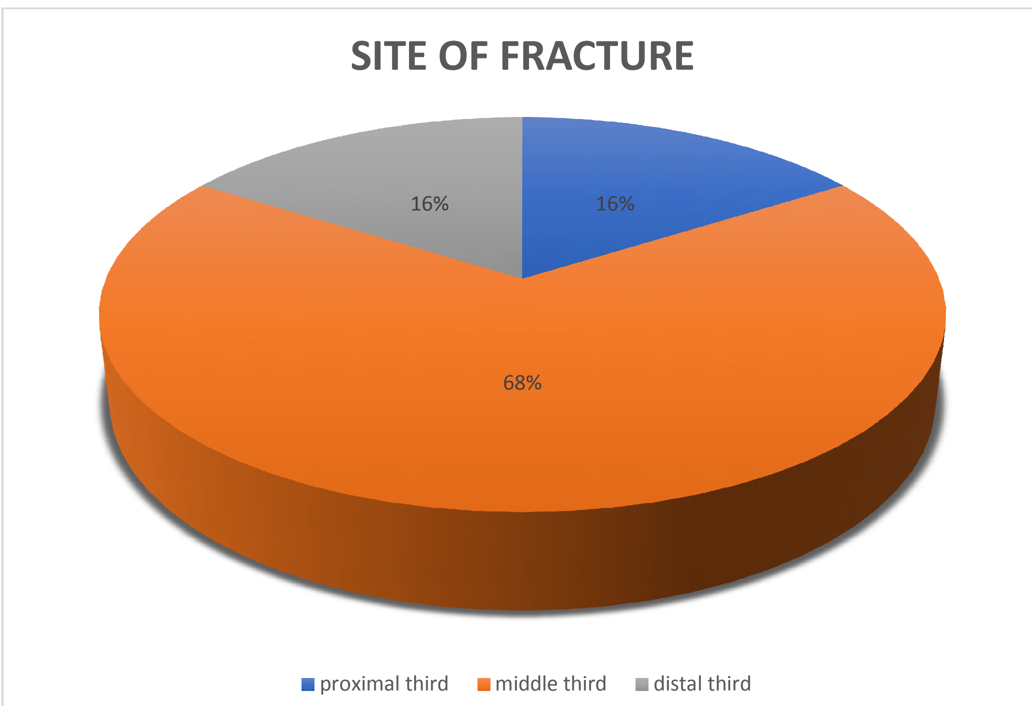
| Mode of injury | No of cases | Percentage |
|---|---|---|
| Road traffic accident | 5 | 20% |
| Fall on out stretched hand | 13 | 52% |
| Fall from height | 4 | 16% |
| Sports injury | 3 | 12% |



## 4. FRACTURE DISTRIBUTION:

In this study, based on the level of fracture in the forearm, it is observed that around 68% of diaphyseal fractures occurred in the middle third of forearm.

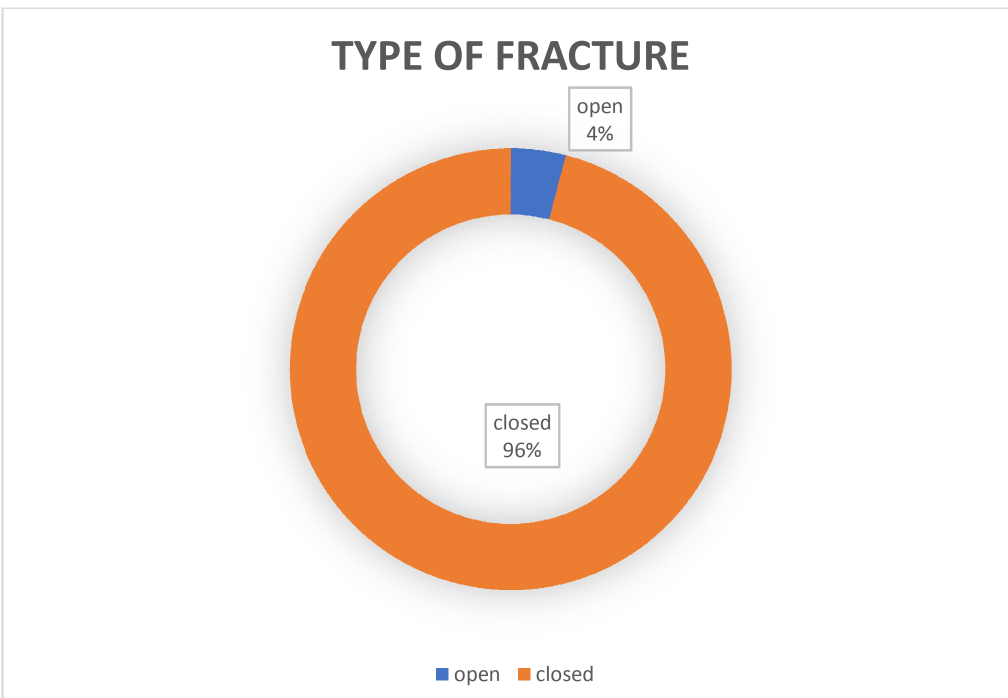
| Site of fracture | No of cases | Percentage |
|---|---|---|
| Proximal third | 4 | 16% |
| Middle third | 17 | 68% |
| Distal third | 4 | 16% |



### 5. TYPE OF FRACTURE:

Based on the presence or absence of external injuries, the majority of cases that presented to us was closed fracture.

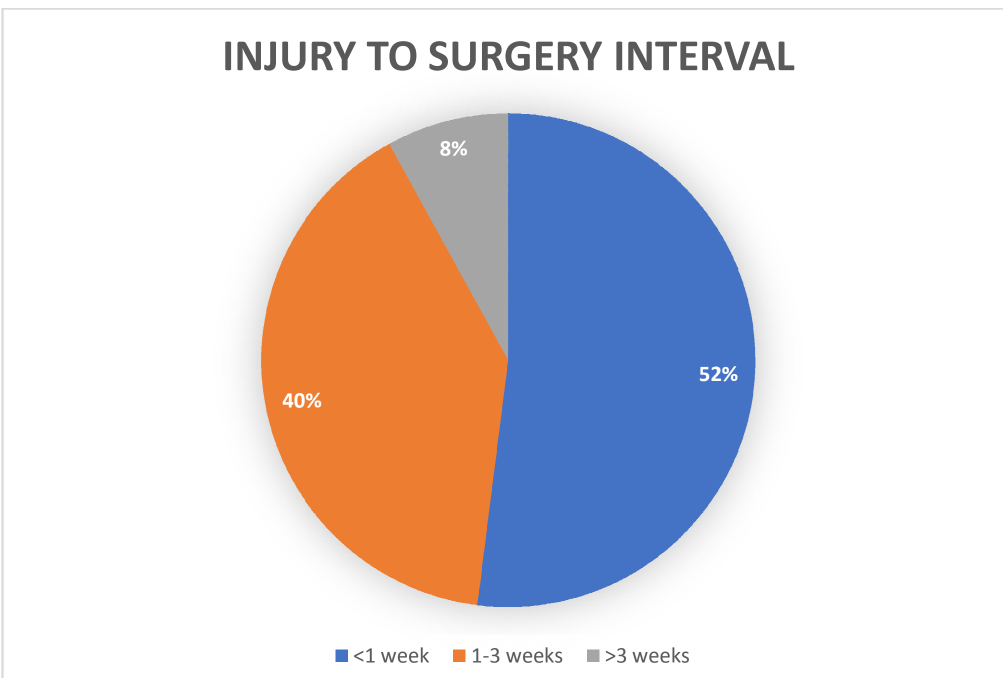
| Type of fracture | No of cases | Percentage |
|---|---|---|
| Open/ Compound | 1 | 4% |
| Closed | 24 | 96% |



**6.INJURY TO SURGERY INTERVAL:**

Majority of the patients included in this study were operated in the first week following trauma.

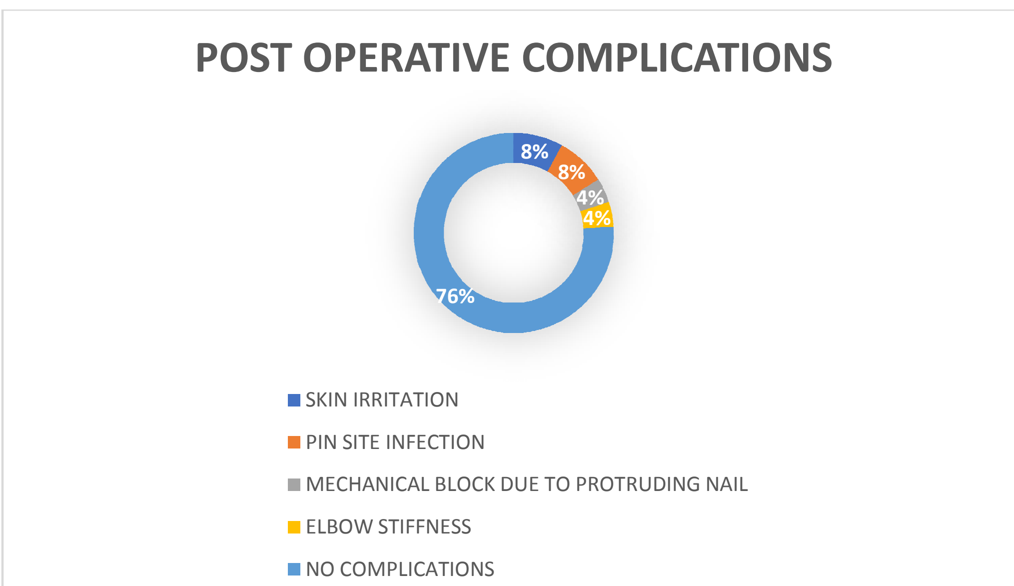
| Injury to surgery interval | No of patients | Percentage |
|---|---|---|
| <1 week | 13 | 52% |
| 1-3 weeks | 10 | 40% |
| >3 weeks | 2 | 8% |



## 7.POST OPERATIVE COMPLICATIONS:

The most common complications with elastic nailing in this study included skin irritation and pin site infection which contributed to about 8% each. Mechanical block due to protruding nail and elbow stiffness were observed in this study.

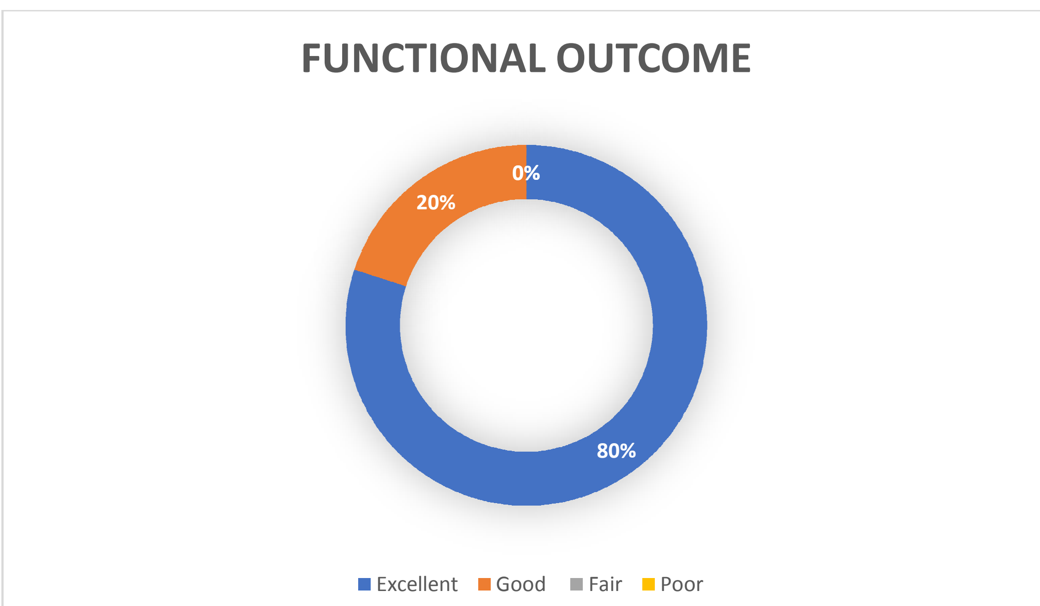
| Post-operative complications | No of patients | Percentage |
|---|---|---|
| Skin irritation | 2 | 8% |
| Pin site infection | 2 | 8% |
| Mechanical block due to protruding nail | 1 | 4% |
| Elbow stiffness | 1 | 4% |
| Wound infection | 0 | 0 |
| Refracture | 0 | 0 |
| Nail migration | 0 | 0 |



## 8.FUNCTIONAL OUTCOME:

The functional outcome was graded according to Price et al criteria which is based on the amount of restriction of forearm rotational movements. According to this criteria, excellent results were achieved after elastic nailing of forearm fractures in children with less than 15° of loss of forearm rotation.

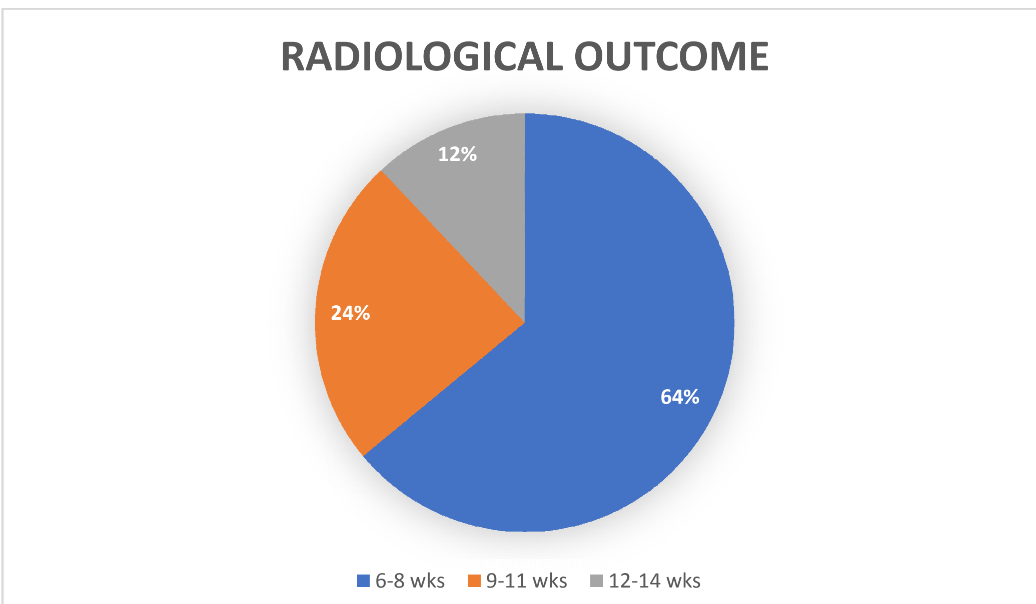
| Functional outcome (Price et al criteria) | No of patients | Percentage |
|---|---|---|
| Excellent | 20 | 80% |
| Good | 5 | 20% |
| Fair | 0 | 0 |
| Poor | 0 | 0 |



## 9. RADIOLOGICAL OUTCOME:

In this study, bony union was achieved in a mean time of 8.36 weeks, range being 6 weeks to 14 weeks. Radiological union of fracture was observed in about 87% of patients before 13 weeks and more than half of the patients achieved radiological union before 8 weeks.

| No. of patients | Time taken for radiological union in weeks | Percentage |
|---|---|---|
| 16 | 6-8 | 64% |
| 6 | 9-11 | 24% |
| 3 | 12-14 | 12% |



# DISCUSSION

Diaphyseal forearm fractures in children is a common injury. The trend in the management of unstable forearm diaphyseal fractures in children is moving towards operative management and fixation using titanium elastic nails rather than closed reduction and casting as was done earlier. Results were analysed both clinically and radiologically. The results of closed reduction caused unacceptable functional and cosmetic outcomes in children who sustained unstable diaphyseal fractures of the forearm (26,40).

The most common indication for internal fixation of diaphyseal forearm fractures include angulation and malrotation greater than 45 degrees in a child below 9 years of age and more than 30 degrees in a child over 9 years of age.

As radius and ulna function as a single unit, it is imperative that two nails of same diameter with one nail in each of these bones are used as recommended by many authors (29,39). In this study, all 25 patients were operated and fractures fixed with a titanium elastic nail in each of radius and ulna. The diameter of the titanium nails used were 1.5mm in 10 patients, 2.0mm in 12 patients and 2.5mm in 3 patients.

It has been shown in the literature that nearly 15% of all paediatric diaphyseal forearm fractures are unstable and require internal fixation (27,45). Internal fixation was done as a primary procedure in five of these 25 children which included an emergency debridement and flexible nailing for a Gustilo Anderson type II fracture of diaphyseal forearm fracture. This implies that 4 patients i.e. 16% of the study population had unacceptable alignment and the average angulation was greater than 30 degrees, which was also unacceptable(23) and hence were treated with internal fixation using titanium elastic nails. Comparable results have been produced with closed and open reduction(53). Open reduction was performed using mini open incision in patients with difficult reduction.

The use of rigid Kirschner wires that are more resistant to axial compression forces and torsion forces as compared to the elastic titanium nails, does not imply better results with the use of these wires for intramedullary fixation due to stress shielding and risk of cut out and refracture both with the implant insitu as well as after implant exit (54). This can be attributed to the lower bending threshold of these wires.

Although there is no definite consensus in immobilising the limb post operatively using an above elbow plaster, all the patients in our study were immobilised with elbow in 90 degrees of flexion and forearm in neutral rotation for 4 to 6 weeks. The type of fixation achieved using titanium nails is relative stability and so the use of a splint post-operatively can be justified to some extent. Also, there is but a negligible risk of elbow stiffness in children following immobilisation as compared to adults (9). Therefore, it is preferable to immobilise the limb which also helps to decrease post-operative edema, decrease pain and provides protection to the active child. In this study, all patients were protected with an above elbow plaster for a mean period of 4 weeks post-operatively.

All patients have to be monitored carefully for the development of compartment syndrome which has to be picked up by the treating orthopaedician at the earliest. If not done, this can lead to the dreaded complication of Volkmann's ischemic contracture. None of the patients in our study developed compartment syndrome.

The mean age of the patients included in this study is 11.92 years, the range being 6 to 16 years. The youngest patient was 6 years old who underwent titanium elastic nailing for an unstable closed diaphyseal fracture of forearm that had re-displaced after closed reduction and cast application. He had mechanical block to terminal range of elbow extension due to protruding nail and superficial pin site infection. Pin site infection subsided after mild soap and oral antibiotics for one week. In this patient, bony union was achieved around 6 weeks and nail exit was done at four months. Full range of elbow extension was achieved about 2 weeks following nail exit.

In all 25 children diaphyseal fracture of radius and ulna occurred around the same level i.e. either proximal third, middle third or distal third. 4 patients had sustained fracture of the proximal third while 4 others sustained fracture in the distal third and the rest all had sustained fracture in the middle third of forearm.

The fracture pattern of radial diaphysis was oblique in 18, transverse in 7 and segmental in none. The pattern of ulnar diaphyseal fracture was oblique in 18, transverse in 6 and segmental in one. All fractures were classified using the AO classification system and broadly categorized as either simple (oblique and transverse) or complex (segmental, wedge and fracture comminution) fractures.

Correction of malunited fractures in a child with a functionally compromised forearm has higher risk of complications (37,42,45). In this study, only one patient presented late with mal-uniting diaphyseal fracture of both bones of forearm. The patient was initially managed with closed reduction and above elbow slab and was last at follow-up. The patient attended the outpatient department 40 days later and presented with mal-uniting diaphyseal forearm fracture. He was planned for mini open reduction and internal fixation using titanium elastic nail. The fracture went on to unite after 13 weeks with restriction of terminal 20 degrees of pronation. No other post-operative complication was seen and the functional outcome was good, according to Price et al criteria.

In this study the average time taken for bony union after fracture fixation was 8.36 weeks. Relatively younger children of the group with simple closed fractures had quicker time to union and achieved better functional results.

The incidence of open fractures in this study is 4%. The only patient in this study who was operated on an emergency basis had sustained a Gustilo-Anderson type II compound midshaft fracture of forearm who was treated with thorough wound debridement and elastic nailing. All other patients were operated in the elective theatre including the boy who presented with a maluniting fracture.

The average post-operative stay in the hospital was 3 days in patients who underwent closed reduction and titanium nailing while the same was around 5 days for patients who underwent open reduction and those who sustained compound fractures.

In all the 25 patients with closed fracture of the forearm, the ulna was reduced and fixed by closed methods under fluoroscopic guidance while the radius required mini open reduction in 2 patients in this study The patients who were treated with open reduction and those who presented with an open fracture had a longer hospital stay as opposed to those who underwent fixation by closed methods.

The immature paediatric skeleton with growth potential and having a thicker periosteum promotes healing by external callus formation, augments the stability of the fracture and has remodelling capabilities. In children who have sustained compound fractures, fractures in the proximal third of forearm, fractures with comminution and mal-uniting fractures the stability and remodelling capabilities is not as expected as in simple, closed fractures, fractures in middle or distal thirds in which the time to surgery is less than a week from the time of injury.

A teenage boy included in the study had an associated fracture of the distal humerus i.e. floating elbow. Open reduction and K-wire fixation was done for the distal humerus while titanium nailing was carried out for the diaphyseal forearm fracture. Post-operatively, the limb was protected and immobilised in an above elbow splint for around 2 months. Initially he developed elbow stiffness and skin irritation, which improved after regular visits to the physical therapist with supervised passive range of movements exercise for stiffness. Skin irritation was due to the protruding K wires and it improved after exit of the wires.

Yet another girl child sustained ipsilateral isolated fracture of the tibial shaft which was treated by open reduction and internal fixation using plate osteosynthesis. No post-operative complications were seen.

Till the end of the follow-up period, there were no patients who sustained refracture.

Another patient required a mini open approach for reduction and fixation of radius while the ulna was reduced under fluoroscopic guidance and titanium nail inserted. Bony union was achieved in 8 weeks and he had good functional outcome.

The functional outcome in all patients was graded according to Price et al criteria. 80% of patients in this study had excellent results, 20% had good outcome while there were no patients with fair or poor results.

Fracture union was achieved after an average period of 8.44 weeks. In this study, the longest time taken for bony union was 16 weeks and the shortest time for union was 6 weeks.

The titanium nails were removed in all patients at an average interval of 24 weeks after fixation. It is essential to confirm clinical as well as radiological union before implant exit. Although implants were taken out as early as 24 weeks rather than the recommendation to wait for around a year after surgery, the patients in this study group did not sustain refracture or any other complication even after the second procedure.

None of the patients in this study had any neurological complications like paraesthesia in the region supplied by superficial radial nerve. Also, there were no cases of refracture, nail migration or wound infection.

# CONCLUSIUON

Titanium Elastic Nail is utilized as an orthopaedic implant since 1980s. The elastic nails initially used were Nancy nails. It was named so, as it was used at the paediatric hospital in Nancy, France by Jean-Paul Metaizeau. The advantages of titanium elastic nail over rigid intramedullary devices like Kirschner wires for limited internal fixation include the following:

1. It provides dynamic three-point cortical contact, thereby providing accurate and safe stabilisation of long bone diaphyseal fractures.
2. Less chances of physeal injury.
3. The inherent elastic property of pre-bent titanium nail helps re-establish the radial bow, thereby maintain interosseous space and preserve forearm function.
4. Minimal soft tissue dissection even if open reduction is used.
5. Shorter operating time thereby decreasing radiation time.
6. Less duration of hospital stay and early return to school.
7. Early elbow mobilisation.

8. No loss of fixation after initial fracture stabilisation.

9. Early fracture union due to repeated micro-motion at the fracture site.

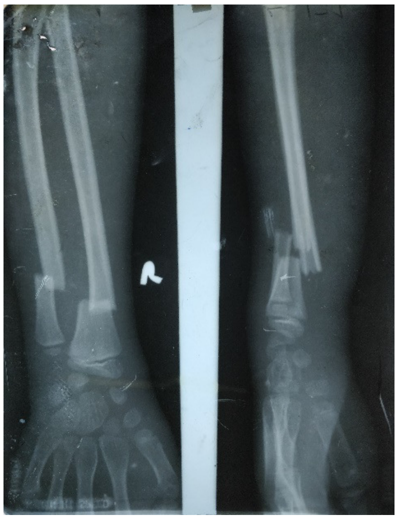
10. Easy and safe implant removal and no occurrence of refracture.

In conclusion, all potentially unstable and grossly displaced fractures of forearm shaft in children should be approached surgically and treated with elastic nail, as the functional results are found to be good.

# ILLUSTRATIVE CASES

## PATIENT 1:

**Pre-op:**



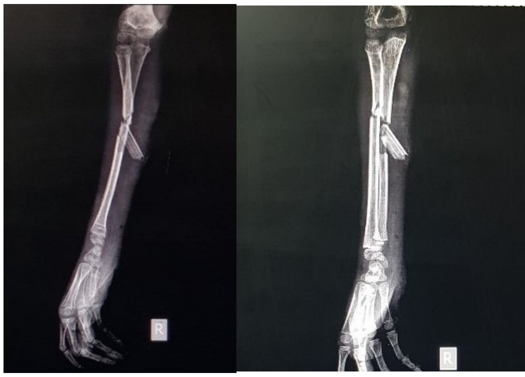
**Post-op:**

**After nail exit:**

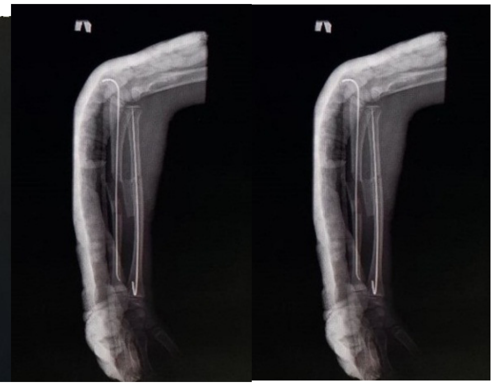
**Functional outcome:**

**PATIENT 2:**

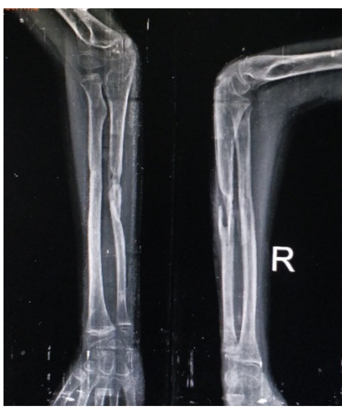
**Pre-op:**



**Post op:**



**After nail exit:**




**Functional outcome:**

**PATIENT 3:**

**Pre-op:**

**Displacement after reduction:**

**Post-op:**

**Functional outcome:**

**Patient 4:**

**Pre-op:**

**After reduction:**

**Post-op:**


**Functional outcome:**

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# ANNEXURES

## PATIENT EVALUATION PORFORMA-
## FOREARM ESIN STUDY

| | | |
|---|---|---|
| Name | : | |
| Age | : | |
| Sex | : | |
| Hospital Number | : | |
| Father's Name | : | |
| Address | : | |
| Phone number | : | |
| Date of Injury | : | |
| Mode of Injury | : | |
| Side of Injury | : | Right / Left |
| Site of Fracture | : | Proximal $3^{rd}$ / Middle $3^{rd}$ / Distal $3^{rd}$ |
| Type of Injury | : | Open / Closed |
| Associated injuries | : | |
| Initial treatment | : | |
| Date of Surgery | : | |
| Indication | : | |

- Instability

- Open Fracture

- Unacceptable Reduction

Time Interval from injury to surgery:

Fixation method : Closed reduction/ Mini-open reduction

Diameter of nail used : 1.5/2/2.5mm

Post-operative complication:

Compartment Syndrome - Yes / No

Delayed Wound Healing - Yes / No

Hardware Complication - Yes / No

Secondary Procedure - Yes / No

Duration of Post-operative Immobilization -

Wrist ROM

- Dorsiflexion

- Palmar flexion

Forearm ROM

- Supination

- Pronation

Elbow ROM –

-Flexion

-Extension

Duration to Bony Union -

Duration to Implant Exit –

# CONSENT FORM

I Mr/Mrs.hereby volunteer to let my son / daughter participate in the study **"EVALUATION OF RADIOLOGICAL AND FUNCTIONAL OUTCOME OF BOTH BONE FRACTURE FOREARM IN CHILDREN AGED 5 TO 16 YEARS MANAGED WITH TITANIUM ELASTIC NAILING SYSTEM".** I was explained about the nature of the study by the Doctor, knowing which I fully give my consent to participate in this study. I also give consent to take clinical photographs for the purpose of the study.

**Date:**

**Place:**

**Signature of the Parent**

## ஒப்புதல் படிவம்

பெயர் :

வயது , பாலினம் :

முகவரி :

அரசு கோவை மருத்துவக் கல்லூரியில் எலும்பு முறிவு மருத்துவத்துறையில் பட்ட மேற்படிப்பு பயிலும் மாணவன் மரு. இனிய பிரசன்னா அவர்கள் மேற்கொள்ளும் **"EVALUATION OF RADIOLOGICAL AND FUNCTIONAL OUTCOME OF BOTH BONE FRACTURE FOREARM IN CHILDREN AGED 5 TO 16 YEARS MANAGED WITH TITANIUM ELASTIC NAILING SYSTEM"**குறித்த ஆய்வில் செய்முறை மற்றும் அனைத்து விபரங்களையும் கேட்டுக் கொண்டு எனது சந்தேகங்களை தெளிவுப்படுத்திக் கொண்டேன் என்பதை தெரிவித்துக் கொள்கிறேன்.

எனது மகன்,மகள் இந்த ஆய்வில் கலந்து கொள்ள முழு சம்மமத்துடனும், சுய சிந்தனையுடனும் சம்மதிக்கிறேன்.

இந்து ஆய்வில் என்னுடைய மகன்,மகளின் விபரங்கள் பாதுகாக்கப்படுவதுடன் இதன் முடிவுகள் ஆய்விதழில் வெளியிடப்படுவதில் ஆட்சேபனை இல்லை என்பதை தெரிவித்துக் கொள்கிறேன். எந்த நேரத்திலும் இந்த ஆய்விலிருந்து நான் விலிகிக் கொள்ள எனக்கு உரிமை உண்டு என்பதையும் அறிவேன்.

இடம் பெற்றோரின் கையொப்பம்

நாள்

# MASTER CHART

| SNO | NAME | AGE/SEX | MODE OF INJURY | SITE OF FRACTURE | CLOSED/ OPEN | ASSOCIATED INJURIES | TIME INTERVAL FROM TRAUMA TO SURGERY IN DAYS | POST OP COMPLICATIONS | LIMITATION OF FOREARM ROTATION | PRICE et al CRITERIA | TIME TO BONY UNION IN WEEKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | KABILAN | 11/M | RTA | MIDDLE THIRD | OPEN - TYPE II | SEGMENTAL ULNA | 0 | NAIL PROTRUSION | 20˚ OF PRONATION | GOOD | 12 |
| 2 | VIGNESH | 12/M | FALL ON OUTSTRETCHED HAND | MIDDLE THIRD | CLOSED | NIL | 2 | NIL | 0˚ | EXCELLENT | 7 |
| 3 | JANANI | 13/M | RTA | MIDDLE THIRD | CLOSED | IPSILATERAL TIBIA FRACTURE | 2 | NIL | 0˚ | EXCELLENT | 7 |
| 4 | PREETHI | 14/F | FALL ON OUTSTRETCHED HAND | PROXIMAL THIRD | CLOSEED | NIL | 2 | SKIN IRRITATION | 10 ˚ | EXCELLENT | 8 |
| 5 | ASHWIN | 12/M | FALL ON OUTSTRETCHED HAND | MIDDLE THIRD | CLOSED | NIL | 2 | NIL | 0˚ | EXCELLENT | 9 |
| 6 | SURESH | 15/M | FALL ON OUTSTRETCHED HAND | PROXIMAL THIRD | CLOSED | NIL | 2 | NIL | 20˚ | GOOD | 10 |
| 7 | PRATHISHA | 9/F | SPORTS INJURY | DISTAL THIRD | CLOSED | NIL | 3 | NIL | 0˚ | EXCELLENT | 6 |
| 8 | PRIYA | 8/F | FALL FROM HEIGHT | MIDDLE THIRD | CLOSED | NIL | 5 | NIL | 0˚ | EXCELLENT | 6 |
| 9 | RENUKA DEVI | 11/F | FALL ON OUTSTRETCHED HAND | MIDDLE THIRD | CLOSED | NIL | 5 | NIL | 0˚ | EXCELLENT | 7 |
| 10 | GIRISH | 13/M | FALL ON OUTSTRETCHED HAND | MIDDLE THIRD | CLOSED | NIL | 5 | NIL | 0˚ | EXCELLENT | 8 |
| 11 | BHARATH | 12/M | SPORTS INJURY | MIDDLE THIRD | CLOSED | NIL | 5 | NIL | 10˚ | EXCELLENT | 9 |
| 12 | SACHIN | 10/M | FALL ON OUTSTRETCHED HAND | MIDDLE THIRD | CLOSED | NIL | 6 | NIL | 0˚ | EXCELLENT | 7 |
| 13 | ARUN | 15/M | FALL ON OUTSTRETCHED HAND | PROXIMAL THIRD | CLOSED | NIL | 6 | NIL | 20 ˚ | GOOD | 9 |
| 14 | IBRAHIM | 11/M | FALL ON OUTSTRETCHED HAND | MIDDLE THIRD | CLOSED | NIL | 7 | NIL | 0˚ | EXCELLENT | 7 |
| 15 | MADHAVAN | 9/M | FALL FROM HEIGHT | MIDDLE THIRD | CLOSED | NIL | 9 | NIL | 0˚ | EXCELLENT | 6 |

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| 16 | DEVAKI | 11/F | FALL ON OUTSTRETCHED HAND | DISTAL THIRD | CLOSED | NIL | 9 | NIL | 0˚ | EXCELLENT | 7 |
| 17 | ROHIT | 12/M | SPORTS INJURY | MIDDLE THIRD | CLOSED | NIL | 10 | NIL | 0˚ | EXCELLENT | 9 |
| 18 | MOHAMED AARISH | 11/M | FALL ON OUTSTRETCHED HAND | DISTAL THIRD | CLOSED | NIL | 11 | NIL | 0˚ | EXCELLENT | 8 |
| 19 | DHEENADAYALAN | 16/M | RTA | MIDDLE THIRD | CLOSED | FLOATING ELBOW | 12 | SKIN IRRITATION, ELBOW STIFFNESS | 25˚ | GOOD | 14 |
| 20 | PRANESH KUMAR | 6/M | FALL ON OUTSTRETCHED HAND | MIDDLE THIRD | CLOSED | NIL | 15 | MECHANICAL BLOCK, SUPERFICIAL PIN SITE INFECTION | 10˚ | EXCELLENT | 6 |
| 21 | BARATHI RAJ | 13/M | FALL FROM HEIGHT | MIDDLE THIRD | CLOSED | NIL | 16 | NIL | 0˚ | EXCELLENT | 8 |
| 22 | SURENDHAR | 14/M | FALL ON OUTSTRETCHED HAND | MIDDLE THIRD | CLOSED | NIL | 18 | NIL | 10˚ | EXCELLENT | 7 |
| 23 | MANIGANDAN | 14/M | RTA | DISTAL THIRD | CLOSED | NIL | 18 | NIL | 0˚ | EXCELLENT | 11 |
| 24 | RAGHU | 14/M | RTA | PROXIMAL THIRD | CLOSED | NIL | 25 | NIL | 10˚ | EXCELLENT | 8 |
| 25 | KARTHICK | 12/M | FALL FROM HEIGHT | MIDDLE THIRD | CLOSED | MALUNITED FRACTURE | 43 | NIL | 20˚ | GOOD | 13 |