REVIEW OF LITERATURE
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Mode of injury, age and sex distribution

In most of the cases fractures of both bones of forearm are result of some type of direct blow on the forearm.

Madden et al (1983) in his series of 105 patients reported 75% fractures caused by road accidents 1.85% accident at work, 8.33% sports injury, 7.4% due to other cause.

Shah et al (1988) reported 55.3% fractures caused by road side accidents, 14.7% industrial injuries 16.1% domestic injuries and 13.9% other cause like fall from height or hit by a stick.

By far most common cause is some kind of vehicular accident followed by hit by stick, gunshot wound, fall from height and rarely a pathological fracture.

These fractures occur more commonly in males than females and in age group of third and fourth decade.

In Burnwell and Charnley series (1964) there were 104 men and 46 women and average age was 44.8 years.

In Marek (1961) series the fractures of forearm occured in 23 males and 12 females patients and mean age was 43 years.

Andrianne et al (1984) in his series reported 64.2% males with mean age of 37.4 years.

Relevant Surgical Anatomy

The surgical anatomy of forearm creates problems in its fracture
treatment:

1. The radius and ulna function as a unit. According to study by Mallin BA, ulna is a relatively fixed strut around which radius rotates in supination and pronation.

2. In the study of 100 radius bones from cadavers, Sage (1959) gave a detailed review of complex anatomy of radius, its medullary canal and its dorsal and radial bows.

3. According to Sage (1963) and Cruess (1973), radius and ulna are joined by supinator, pronator quadratus and pronator teres which along with biceps brachii and forearm flexors exert rotatory and angulatory influence mainly on radius and slightly on ulna.

4. Hatchess and associates (1989) described detailed anatomy of interosseous membrane and stressed on the importance of maintaining this space and the triangular fibrocartilage complex at distal radioulnar joint in forearm bone fractures.

5. Schemitsch and Richards (1992) has confirmed the importance of restoration of radial bow for achieving full pronation and supination after fracture.

Biceps and supinator muscles through their insertion exert supination rotatory force on proximal third of radius. Pronator teres inserting on midshaft and pronator quadratus inserting on distal fourth of shaft, exert pronation as well as angulatory deforming force,
thus causing rotational malalignment of up to 80-100 degree in fractures at different levels through radius. Fractures of ulna are primarily affected by angulatory forces and the proximal fragment angulates towards radius. (Diagrammatic details are on next page)

**Historical review of conservative modality of treatment**

Before the advent of radiography the treatment of forearm fracture was based on correction of clinical deformity followed by application of two short wooden splints with firm pads to preserve their interosseous space with forearm in midprone position.

Plaster of paris although introduced by Majithsen in (1852) for various fractures of the body it was not applied to forearm injuries due to the fear that rigid encasement might lead to compartment syndrome and ischaemic paralysis.

Bohler in (1929) set the example of applying plaster cast after closed reduction in forearm fractures.

Knight and Purvis in (1949) analysed 100 adults with the shaft fractures of both bones of forearm treated at Campbell clinic, of which half had been treated by closed methods. Of those treated by closed methods 71% had unsatisfactory results and incidence of non union and malunion was high.

Holdsworth (1949) found that oblique and comminuted fractures of both forearm bones were also unsuitable for conservative treatment.
In a fracture of upper shaft of the radius between the insertion of the supinator & pronator teres, the proximal fragment is supinated & the lower fragment is pronated.

In a fracture of the middle or lower shaft of the radius between the insertion of the pronator teres & the pronator quadratus, the proximal fragment is in mid position (neutral rotation).
In displaced transverse fractures of both bones of forearm it is probable that the closed treatment will fail, the same applies to isolated fractures, displaced or not, in the lower half of the radius or the upper half of ulna (Smith 1956).

Sarameinto and his associates in (1975) reported the use of early functional cast brace for forearm fractures in series of 44 patients with a functional brace below elbow applied at a median time of 18 days after date of injury. Before application of the brace all fractures were manipulated under anesthesia, reduced and immobilized in an above elbow POP cast. The brace permitted flexion and extension at wrist and elbow while limiting supination and pronation. The results were rewarding with only one non union and good functions in majority patients. Sarameinto also found from this study that angular or rotatory deformity of $10^\circ$ or less resulted in minimal limitations of pronation and supination movements. The fracture healing time in this series averaged at around sixteen weeks. However the excellent results achieved by Sarmiento have not been reported by others.

**Development of open reduction and internal fixation techniques**

Due to the unpredictable results, hazards and prolonged immobilization various workers studied and experimented with various techniques of internal fixation after open reduction with a variety of implants.
Intramedullary fixation devices and techniques

The use of intramedullary implant for internal fixation was initiated by Nicholason in (1857) for fracture of femoral neck. Heygroves (1918) developed technique for intramedullary nail fixation in fractures of shaft of long bones.

Lambrinudi in (1939) suggested some principles for intramedullary Kirschner wire fixation of fractures of ulna.

Rush and Rush (1937 and 1939) reported use of a Steinmann pin in the medullary canal of ulna in comminuted Monteggia fracture dislocation and later devised Rush pins for intramedullary fixation of radius and ulna.

Kuntscher (1940) presented evidence for importance of snugly fitting intramedullary fixation device.

After K-nail fixation got popularized in late 1940's various devices for medullary fixation of radius and ulna were used.

Hermann in (1943) recommended that a bone graft should routinely accompany every form of internal fixation of forearm fractures.

In 1957 Smith and Sage reported a series of 555 fractures collected from all over the country in which some form of intramedullary fixation had been used like Rush pins, Kirschner wires, Stienmann pins, Lottes nails and Kuntscher V-nails. The results were discouraging. Non union resulted in over 20% cases and malunion and poor function were common in those that did unite. Radial
bow was not maintained and use of round pin in medullary canal could not control the rotation of the fragments.

In 1959 Sage published his study of anatomy of radius and introduced Sage triangular foreram nails. The nail for ulna was straight and introduced in a retrograde manner. The nail for radius was bent to aid in maintaining the radial bow. It was introduced from radial styloid. Sage reported good results with his nails. Non union occurred in only 6.2% and delayed union in 4.9% fractures. Sage recommended the routine use of autogenous iliac bone grafts. These nails were not recommended for fractures of distal 3rd of radius and when medullary canal was less than 3mm in diameter.

Kuntscher (1959) stated that removal of marrow endosteum and some compact bone due to intramedullary reaming does not lead to any serious problem in fracture healing.

Marek (1961) used snugly fitting resilient straight square nails. The site of insertion in radius was just above the bony prominence of Lister's tubercle. The square shape of these nails prevented any rotation at fracture site. To facilitate easy negotiation of square nail for radius, the proximal one inch of radial nail was bevelled and flattened out so that it could bend easily during passage.

Caden (1961) reported a non union rate of 16.6% in forearm fractures treated with Rush pins.

Smith (1963) observed the inversely proportional relationship
between amount of callus and size of nail.

_Talwalkar (1964)_ improvised a rigid solid square nail for a fixation of forearm fractures. The square shape of the nails prevented any rotatory movement at fracture site. The square nail for radius was bevelled at distal tip, so that it could be easily introduced into the medullary canal. The ulnar nail had simple pointed tip. In 1964 he reviewed 80 cases treated by these intra medullary square nails and all fractures united with good functional results.

_Anderson (1965)_ after experiments in dogs found that union of a fracture treated by medullary nailing is almost exclusively periosteal because reaming of the medullary canal and insertion of nail destroys the blood supply of inner two third of cortex for the entire length of the nail. The damage of this blood supply and the presence of nail prevent the formation of endosteal callus. Union therefore takes place by bone formation in fracture hematoma.

If the nail is snugly fitting, union occurs promptly and minimal periosteal callus is formed. In absence of motion the capillaries abundant blood supply in organizing hematoma and new bone forms without going through cartilagenous phase whereas when the nail is loose, bone formation in fracture hematoma occurs through the process of endochondral ossification by cartilage formation.

_Cotler and associates (1971)_ used Schnieder nailing for fixa-
tion of unstable forearm fractures. More than 94% patients had excellent functional results.

*Sisk (1980)* states that satisfactory stabilization of a fracture by medullary fixation is possible under the following circumstances:

1. When the fracture occurs through the narrowest part of medullary canal, the intramedullary fixation gives stable fixation counteracting the angulatory shearing as well as rotational deforming forces. If the medullary canal in one fragment is much larger in one fragment than in other, poor control of rotational forces frequently results.

2. When the canal is curved a straight nail can still be used. Fixation is obtained at the end of nail and at the apex of curve in the bone. In these cases a resilient stainless steel nail is useful which is deflected by the cortex at one or more points of contact.

*James (1981)* found that delay in biomechanical maturation of callus occurs in a fracture treated by intramedullary nail as compared to that with compression plate. The delay may reflect an inhibition of formation of endosteal callus. But once union is achieved, the biomechanical quality of union similar after compression plate or intramedullary nail fixation.

**Internal fixation modality with plates and screws**

*In early 1900's Lane* in London and *Lembotte 1907* in Belgium reported the use of plates and screws for treating diaphyseal fractures.
Unfortunately, failures were frequent due to metal reaction, infection and inadequate design of fixation devices.

The effectiveness of fixation was sometime impaired by electrolytic changes around metallic plates and screws. This difficulty was overcome by the introduction of vanadium steel plates in 1913 by Sherman.

It was after the work of Venable and associates in 1937 on electrolysis and presence of metal inside body, that better and relatively inert molybdenum steel and later cobalt chromium alloy steel were developed for manufacturing the implants.

Campell and Boyd in 1941 used autogenous tibial grafts fixed to radius and ulna with bone pegs or screws for acute fractures as well as non unions but the grafts often developed fatigue fractures before they were revascularized.

Even after better metals became available many of the early plates used for fractures of radius and ulna were poorly designed. Thus, failure were very frequent and the use of plates and screws fell into disfavour.

Danis (1949) was the first to give the idea of using active compression with the help of specially improvised plates with a coapting screw at one end through which compression was applied. He observed that with this longitudinal compression system fracture was healed with very little peripheral callus, a phenomenon, which he referred to as "primary fracture healing".
Eggers and associates in (1951) introduced "slotted plate" or "contact splint". The plate was designed with slots rather than round holes. Eggers plate was much stronger than those used previously and with this plate, plate and screws slowly started gaining favour.

Venable CS (1951) also discovered an impacting bone plate to achieve close coaptation.

Bureau and Hermen (1952) introduced a plate with two parts in which a cylindrical bolt forced the fragments together.

Bagby and Janes (1958) modified a "collison plate" with oval holes allowing compression to be achieved by eccentric placement of the screws.

Jenkins and Coworkers (1960) reported a series of 165 forearm fractures in which 145 slotted plates and 20 medullary nails had been used. Overall non union rate was only 4.2%. They concluded that results were best when slotted plate was used for ulna and a slotted plate or rush pin was used for radius.

Hadden (1961) observed 212 fractures of the forearm of which 157 were treated with intramedullary rush pins, 40 with Eggers slotted plate and remaining with four hole plates. The results with Egger's plate were amazingly good where incidence of non union was 7.5%, whereas with rush pins incidence of non union was 16.6%. The cases treated with four hole plates had 40% incidence of non union.
Hicks (1961) reported a series of forearm fractures treated by open reduction and rigid internal fixation with special "Lug-plates" without use of supporting plaster and reported six percent non union.

Muller along with Algovor and Willeneger designed a compression device in 1958, but the work was published a few years later in 1961. This removable compression device was used originally with rigid 4.5mm 4 hole plates but later it was used with rigid plates of various sizes and types. It soon became very popular and was known as AISF (AO) compression plate which is used even nowdays.

De Buren (1961) treated cases of non union in radius and ulna and achieved bony union in 80% cases in 16 weeks.

Burnell and Charnley (1964) reviewed 218 fractures of the shaft of radius and ulna by standard Burn or Shermem plates from one and a half to seven inches long and number of screws varied from 2 to 8. In 197 cases there was fracture union in an average time of 20 weeks and there were 21 cases of non union. Out of 176 patients with union and intact fixation, functional results regarding supination pronation and adjoining joint movements were excellent in 69.8%, good in 15.5%, fair in 13.8% and poor in 0.8% cases.

The plates were removed in 17 cases. Two were removed for pain, six for sepsis, two for failure of fixation, one for breakage, two during scar excision, one for subcutaneous promi-
nence and two for unexplained reasons. Posterior interosseous nerve was damaged in one fracture where radius was exposed by Thompson's approach in its upper half.

Anderson (1965) noted in fractures treated with rigid fixation by plates and screws, the endosteal callus forms first and an outgrowth of callus from medullary canal fills space between cortical ends and unites them. Peripheral bone formation from periosteum and fracture hematoma is not prominent.

Sargent and Teipner (1965) reported primary bone union in 100% of fresh fractures treated by double plate method without bone grafting. The functional results were excellent in 91% of cases. The remaining 9%, lacked only 10% of any motion.

Ritchie (1968) reported results of treating 33 forearm fractures with "Hick's plates". In 26 cases good functional results were achieved, rest 5 were with in 50% of normal functions.

Baker et al (1969) treated 72 patients by long 6 & 8 hole slotted plates. Satisfactory function was achieved in 68 patients. Four cases went into non union.

Naiman et al (1970) reported 100% union in a series of fractures of isolated radius or ulna treated by compression plates.

The concept of "dynamic self compressing plate" was first described by Bagby (1957, 1968) and Denham (1969) but it was developed with full technical details by Allgover et al (1970). This plate could be used as compression plate, tension band plate
and buttress plates.

The disadvantages of AISF compresion device were overcome by this "Dynamic Compression plate" or "D.C.P". The difficulties with AISF compression device were:

1. A separate compression device was required.
2. Long incision and extensive dissection was necessary.
3. Round screw hole with closed conical fit of screw heads made it difficult to position screw in any required oblique position.
4. Very rigid fixation led to stress protection and fatigue fracture related to osteopenia of the adjacent bone.

Experiments as well as clinical studies have proved distinct advantage of DCP over other compression plates.

_Dodge and Cady (1972)_ reviewed primary compression plating procedure in 78 patients with forearm fractures and reported loss of fixation in 5%, corrosion of implant in 13%, post operative sepsis in 13%, refracture in 1%, transient neuropathy of superficial radial nerve in 10% and loss of motion in 22%.

_Petxie and Tile (1972)_ reviewed 39 cases, 27 had closed and 12 had open fractures. In all cases early open reduction and AISF compression plate fixation was carried out, post operative plaster splint fixation was used only until wound healed, which resulted in good functional results.
Sisk (1975) suggested to apply autogenous iliac grafts when comminution involves more than one third of the circumference of the bone. Grafts should not be placed on the interosseous border of the bone or it may lead to cross union (synostosis) or limited rotation.

Anderson (1975) reviewed 193 fractures of radius and 137 fractures of ulna treated by compresion plate. 25.9% of cases with severely comminuted fractures had iliac bone grafts and found overall rate of union 97.9% for radius and 96.3% for ulna. The average time for union was 7.4 weeks. Functions were good in 85% and unsatisfactory in 15% of cases.

Anderson suggested that four hole compression plates may be suitable for non comminuted transverse fractures. Five and six hole plates should be used if there is significant communication or obliquity in plane of fractures. He also suggested that plates should be placed anteriorly or posteriorly selecting the surface on which it fits best. Placing plate on compression side has not produced any problem. Plate should be placed on the side of comminution as the plate stabilizes the loose fragments. He defined the union of a fracture when there was obliteration of fracture line and presence of bridging trabeculae between two fragments.

Mckibbin (1978) from animal experiments found out that less rigid plate with a Young's modulus that nearly approximates that of the bone will give better results. Titanium with Young's modulus half that of stainless steel is the most suitable metal
for manufacturing plates and other implants.

*Whiteside et al (1978)* suggested that placing the plate on the periosteum rather than on bone produces greater blood supply alteration then exposure that strips the periosteum with the muscle attached. Thus, the periosteum should be stripped sparingly with periosteal elevator, just sufficient for the application plate.

*AISF in 1979* in its manual of internal fixation recommends that at least five cortex purchase on each side of main fragment is necessary for rigid fixation in forearm bones. Also that, screws inserted too close to the fracture may split the bone. And, a plate longer than necessary is better than one that is too short.

*Grace and Eversmann (1980)* analysed 92 acute diaphyseal fractures of the forearm treated with plates and screws. The effect of early active postoperative movements was studied. Patients with open fractures and those with both bone fractures lost significant rotation of the forearm, irrespective of the treatment given. A programme of early active movement without external mobilization increased the range of movements of forearm in patients with fractures of both bones of forearm.

*Rand et al (1981)* compared the effect of open intramedullary nailing and compresion plate fixation on the fracture union and concluded that:
i. Fractures fixed with intramedullary rods displayed higher values for whole bone and fracture site blood flow and for a longer time, reflecting a compensatory phenomenon to the blockage of endosteal blood supply for intramedullary rod. This was not found in compression plate fixation.

ii. Fractures with intramedullary rod fixation show more periosteal callus and less endosteal callus as compared to compression plate fixation.

iii. Fracture union was delayed in medullary fixation as compared with plate fixation.

iv. Osteopenia of adjacent bone due to stress protection was similar in both cases.

v. Delay in maturation of fracture union regarding its tensile strength in medullary fixation is found due to lack of endosteal callus formation.

vi. Union was delayed in presence of a loose intramedullary nail.

In 1981 Rosacker and Kopta reported 54 patients with bone fracture treated by various fixation devices like, conventional plates and intramedullary rods. They found that single most important factor associated with excellent union and functional result was the adequacy of reduction. And the best anatomical reduction were achieved in fixation with compression plates as it was difficult to apply these compression plates with suboptimal reduction. They also found that delayed surgery for about 1
to 3 weeks were favourable in attaining good primary bony union. However prolonged delay caused a reduction of quality of functional results as range of movements were gradually lost.

*Klaue and Perren in 1982* developed the "dynamic compression unit" (D.C.U.) type of fixation plate. These plates had evenly placed symmetric screw holes with oblique undercuts for improved range of inclination.

*Hadden et al (1983)* used A.O.D.C.P. fixation in 111 fractures in 108 individuals with 24% having open fractures. After 3 years they reported 97% cases with strong union and satisfactory fuctions in 80% cases. Their choice of implant was "Small fragment dynamic compression plates". Seven patients developed operative nerve injuries.

*Hidakas and Gustilo (1984)* removed 32 plates. The interval between plate application and removal ranged from 8 to 62 months. Seven refractures occurred between 2 and 4 weeks after plate removal. No refractures occurred more than 40 weeks after plate removal. They advice at least 6 weeks plaster cast immobilization after plate removal.

*Anderson and Bacastow (1984)* treated forearm fractures with compression plates and reported 98.4% union. Average time of union was 8 weeks.

*Vainiopaa et al (1987)* treated 14 children of fractures of both bones of forearm by open reduction and internal fixation. Only
four patients complained of pain or awareness of restricted movement. Limited pronation supination movements were associated with fractures of proximal third of forearm or due to shortening of ulna.

Shah et al (1988) reviewed 134 patients treated with small fragment dynamic compression plate fixation for both bone fractures. According to Anderson's criteria he achieved 86.6% excellent results, 6.7% satisfactory, 3.8% unsatisfactory and 2.9% poor results. He stated that fracture of forearm bones should be considered intra articular fractures and must be treated with open reduction and rigid internal fixation.

Sisk (1988) pointed out that plates and screws are especially useful for fractures of distal third or proximal fourth of radial shaft and proximal third of ulna.

Chapman et al (1989) reported no refractures after plate removal in 117 fractures when 3.5 mm AO. D.C.P. were used. However plate removal in three patients fixed with 4.5mm D.C.P. plates resulted in refracture in two of them.

Perren et al (1989) developed "L.C.-D.C.P." or "limited contact- Dynamic compression plate" as a further development of Dynamic compression unit or D.C.U. This L.C.-D.C.P. has some definitive advantages over D.C.P. and it complied with the concept of biological fixation. Symmetric arrangement of screw holes without solid elongation between innermost screw holes and two sloped cylinder on either side in the screw hole made the placement of plate in complex fractures easier. Lateral
cuts on the under surface caused less damage to periosteal blood supply and allowed callus and bone formation on the under surface (which is usually the tension side) of the plate as compared to flat undersurface D.C.P.

Deformation of plate holes during plate bending was kept minimal as the holes were protected by flexible cross section between holes. Due to trapezoid cross section and lateral undercuts, there was minimal defect in fracture healing on the undersurface and lateral sides of the plate and this helped in minimizing the chances of refracture after plate removal.

Bednar and Grandwiewisky (1992) suggested that plate removal must not be done before two years after application of plate, so that changes of refracture after plate removal could be minimized.

Schemitsch and Richards (1992) observed 55 patients of both bone forearm fractures treated with D.C.P. fixation. Extensive follow up was done for mean 6 years with functional and radiographic assessment. 84% patients achieved excellent or satisfactory results. Bone grafting did not affect the rate of union according to chi square test. A good functional result (>80% of normal forearm rotation) was associated with restoration of the normal amount and location of radial bow. Similarly return of grip strength was related to the restoration of normal radial bow.