Non-Union in Forearm Fractures

Paklouby po zlomeninách předloktí

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ABSTRACT

Non-union in forearm fractures is an uncommon but complex problem. This is especially given the unique anatomical structure and function of the forearm, making treatment distinctly different to that of other long bone fractures. Anatomical restoration of length, alignment, rotation and the radial bow maintains the optimal stabilising effects of the forearm muscles and interosseous membrane, as well as maximising the range of movement, particularly pronation and supination.

Contemporary plate osteosynthesis using variations of the dynamic compression plate (DCP) developed by the AO group combined with established techniques of internal fixation have revolutionised the treatment of diaphyseal forearm fractures. Non-union rates have been minimised to below 5% and good to excellent functional outcomes are achieved.

Non-union of the forearm is also intimately associated with a significant pain experience, marked pre-operative functional disability and physical and psychosocial morbidity. This review examines the literature and presents a guide to management as well as the current controversies and future directions related to this challenging problem.

BACKGROUND

Forearm fracture non-unions are uncommon but complex problems that present a significant therapeutic challenge. The forearm is a unique anatomical unit with an important relationship between the radius, ulna, interosseous membrane, elbow and wrist which determines its complex biomechanics and function. Thus, treatment of both acute forearm fractures and non-unions can be distinctly different to that of other long bones. Anatomical restoration of length, alignment, rotation, radio-ulnar articulation and radial bow are essential for enabling the optimal stabilising effects of forearm muscles and interosseous membrane, range of movement, particularly pronation-supination, and overall function with positioning of the hand in space (25, 53).

Contemporary plate osteosynthesis, specifically using the dynamic compression plate (DCP) and low contact DCP (LC-DCP) developed by the AO group, combined with established techniques of internal fixation have revolutionised the treatment of diaphyseal forearm fractures. This has minimised failure to heal and rates of non-union whilst achieving good to excellent functional outcomes (8, 10, 22, 43, 46, 53). Forearm fractures treated with plate osteosynthesis demonstrate non-union rates under 5% (8, 10, 22, 46, 53) and a target rate of < 2% is stated if fracture fixation is executed with good technique in the compliant patient (8). Consequently, the published evidence for treatment of this problem is lacking (16, 26, 32, 41, 46, 57).

Non-union of the forearm is also intimately associated with significant pain experience, marked pre-operative functional disability and physical and psychosocial morbidity (3). This review discusses the current concepts and evidence base, aiming to address the controversies and provide recommendations to guide management of this challenging problem in achieving both optimal clinical and patient related functional outcomes.

CLINICAL PRESENTATION

Aetiopathogenesis of forearm non-union

A combination of injury, patient and surgical factors can contribute to the development of a non-union after forearm fracture (8, 26, 46, 53).

Injury factors

Injury factors include complex high energy trauma mechanisms leading to a combination of severe soft tissue, bony and neurovascular damage which impedes the biological healing potential to variable extents. Soft tissue trauma may involve extensive wounds, crush injury, and soft tissue loss. Fractures that are open, comminuted, segmental, intra-articular and pathological may be associated with significant disruption of the intramedullary and periosteal blood supply, displacement of fracture fragments, fracture gaps, gross instability and bone loss.

Surgical factors

Surgical factors increasing the risk of forearm non-union are related to the operative technique and the mode of osteosynthesis. The operative approach should be meticulous, involving the disengagement of any soft tissue interposition to optimise contact and direct healing, as well as minimise iatrogenic devascularisation at the fracture site. Aggressive soft tissue handling, periosteal stripping during plate fixation or destruction of the medullary canal during nailing must be avoided. Suboptimal stabilisation due to poor fixation, repeated manipulation, excessive loading and excessive early motion disrupts the mechanical environment and biological scaffold leading to delayed / non-union.

Patient factors

Forearm non-union in children is extremely uncommon compared to adults and not within the scope of this review (4). The risk of non-union increases with age following skeletal maturity and may be related to a reduced load of undifferentiated mesenchymal cells, less rapid cellular differentiation, thinner periosteum and reduced osseous vascularity (6).

Co-morbidities including anaemia secondary to blood loss and iron deficiency, as well as diabetes are shown to delay fracture healing, produce weaker callus and involve higher rates of non-union (19, 37). Diabetes is shown to alter genetic expression of collagen formation in fracture callus and affect bone healing at the cellular level (37). Non-union and delayed fracture healing is also related to malnutrition and chronic illness, including reduced levels of dietary protein and suboptimal levels of nutrition (9). A large scale study also demonstrated a high rate of metabolic and endocrine abnormalities in patients with non-union (5).

Therapeutics such as NSAIDs have been linked to delayed bone healing and non-union (20), however, large meta-analyses have shown no increased risk with treatment in high quality studies (11). Chemo-therapeutics are also implicated in limiting bone healing, particularly in segmental fractures (42). Irradiated bone is shown to have a slower rate of healing compared with normal bone and higher rates of non-union (45).

Cigarette smoking and nicotine are directly linked to delayed bone healing and non-union amongst a variety of detrimental effects on musculoskeletal tissues (34). Smoking is also associated with high failure rates in non-unions treated with bone grafting (60). The mechanism of action and direct effect on forearm fracture healing is not clearly known, but is likely to involve nicotine-induced vasoconstriction and inhibition of neovascularisation (60).

Patient noncompliance with the post-operative rehabilitation protocol is also a major risk factor in the treatment of forearm non-unions and difficult to quantify.

ASSESSMENT

Pre-operative clinical assessment of forearm non-union requires a thorough history and examination. Clinical history requires definition of patient demographics, functional level and mechanism of injury, which usually involves direct, high energy trauma including impact from motor vehicle accidents, assault, sports and gunshot wounds, or indirect trauma and falls. Previous medical and operative records (ie. approach, findings and problems, implant type and post-operative course) should be analysed. Clinical examination requires a musculoskeletal examination of previous surgical incisions, soft tissue integrity, pain, swelling, signs of infection, degree of deformity, mobility at the fracture site, assessment of range of motion at the elbow, forearm and wrist, and a thorough neurovascular examination.

Investigations include simple blood tests for excluding infection (i.e. complete blood count including differential, c-reactive protein level, erythrocyte sedimentation rate) and blood cultures in sepsis. Imaging involves true posterior-anterior and lateral radiographs of the forearm, wrist and elbow. Radiological union is defined as obliteration of fracture gaps by traversing bony trabeculae or cortical bone. 2D and 3D CT scans can more clearly define the non-union site, especially when hardware obscures the area on plain radiographs. CT also defines the degree of incongruity of the proximal and distal radioulnar joint.

TREATMENT

Non-operative treatment

Closed reduction and cast immobilisation

Non-operative treatment using closed reduction and cast immobilisation is limited in its ability to control fracture fragments and maintain stability, irrespective of fracture configuration or degree of displacement. Historical studies report high non-union rates, secondary loss of reduction, and significant loss of functional range of movement (33).

Electricity and ultrasound

Since early reports on the use of electricity to treat fracture non-unions, with greater understanding of the relationship between electricity and callus formation there has been significant work on electrical modulation of this problem but little in the area of forearm fracture non-union (17). Capacitative coupling and electromagnetic field treatments have also been applied to forearm non-unions and shown to be successful adjuncts to conventional treatments (17). Low intensity pulsed ultrasound has also been utilised in the management of acute long bone fractures and non-unions (18).

Operative treatment

Rationale & general surgical tactics

Optimal function and range of motion is shown to correlate with the restoration of anatomy (53) Thus, the treatment of choice is operative and aligns with AO principles of anatomical reduction, stable compression plate fixation and preservation (or optimisation) of biology (8, 10, 22, 43, 46, 53).

Surgical tactics are defined by the diagnostic classification of hypertrophic, atrophic, oligotrophic or infected non-union.

The original surgical incision is usually utilised and potentially extended with exploration of the forearm non-union site and any associated soft tissue and neurovascular disruption. Bone loss and devascularisation is often intimately related to a loose implant. Hardware is removed and non-viable tissue debrided.

Atrophic and oligotrophic non-union requires thorough debridement of necrotic, devitalised and fibrous tissue. This is followed by techniques to stimulate bleeding at the fracture ends prior to re-osteosynthesis with additional biological augmentation, commonly using autologous bone graft. Rasps, reamers, drills (2 – 2.5 mm dia), nibblers, curettes are utilised to roughen and resect sclerotic bone on fracture fronts to bleeding surfaces and gain entry into the medullary canals of long bone segments. Osteotomes are used to decorticate the surface over a short section of the non-union site which is mobilised with the aid of laminar spreaders.

Hypertrophic non-union requires debridement and resection of callus to improve plate positioning. Fracture fronts are 'freshened' using similar techniques as above and grafting is not required.

Infected non-union requires aggressive debridement of inflamed, infected and necrotic tissue followed by delayed definitive fixation covered by targeted antibiotic therapy.

Biological augmentation with autogenous bone grafting is important in treating the majority of forearm non-unions (32). The options for bone grafting include nonvascularised structural (corticocancellous) and non-structural (cancellous) grafts, and vascularised grafts.

Non-vascularised, structural (corticocancellous), autogenous grafts have been well reported in the treatment of forearm fracture non-unions with bony defects (14, 16, 41). Good to excellent outcomes have been demonstrated despite reports of donor site morbidity related to iliac crest wounds, infection risk and slow or delayed graft incorporation (59). This mode of augmentation requires an adequate soft tissue envelope at the site of insertion enabling graft vascularisation which usually occurs within a few weeks of implantation (32).

Non-vascularised, non-structural (cancellous), autogenous grafts have less commonly been applied to the treatment of closed and originally open forearm fracture non-unions (46). This is shown to be less invasive, less painful, allowing rapid incorporation, vascularisation and improved cosmesis (46). A viable soft tissue envelope is also essential for biological support of cancellous grafts used to bridge osseous defects (46).

Vascularised bone transfer for forearm fracture non-unions utilising pedicled and free periosteal flaps, pedicled and free radial forearm osseous flaps pedicled on the posterior interosseous and anterior interosseous artery, and free fibular grafts (osseous and osteoseptocutaneous) have been reported with variable success (1, 26, 28, 41, 52, 56, 57). Despite the increased donor site morbidity and risk of infection, they represent a useful option in treating large osseous defects with scarred, devitalised soft tissues, facilitating biological viability and earlier bone healing (32). Free fibular grafts in particular are attractive options for the reconstruction of long bone defects in the upper extremity given the gross match in structure to long bones of the forearm which facilitates easier integration, fixation and wound closure around the donor site.

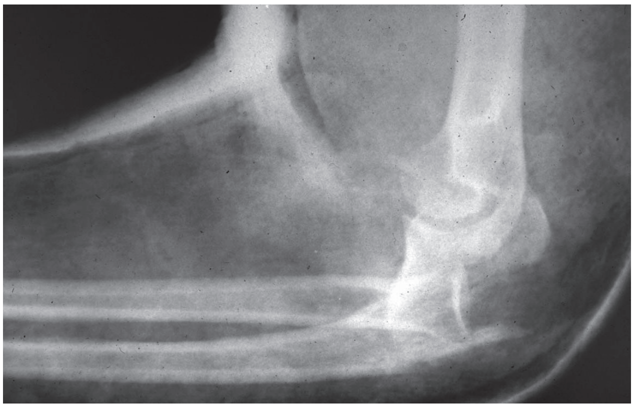
Non-union of the proximal ulna & olecranon

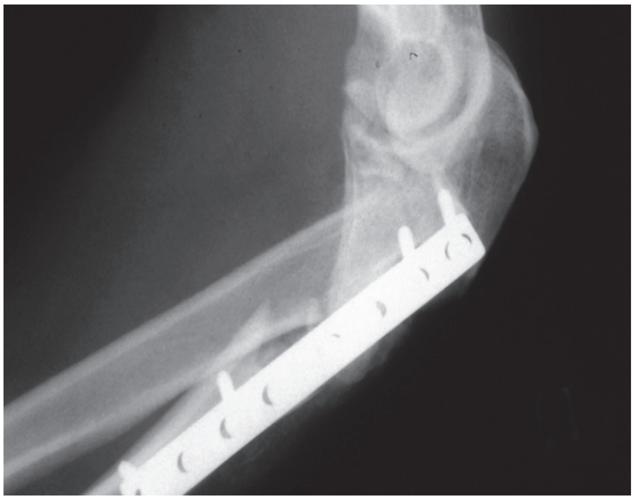
Non-union of the proximal ulna is associated with complex injuries including posterior Monteggia fractures, often occurring in elderly females with poor bone quality, anterior or posterior fracture dislocations of the olecranon and comminution (32, 47, 51) (Fig. 1). Non-union of the olecranon following operative treatment for a displaced fracture is very uncommon (32).

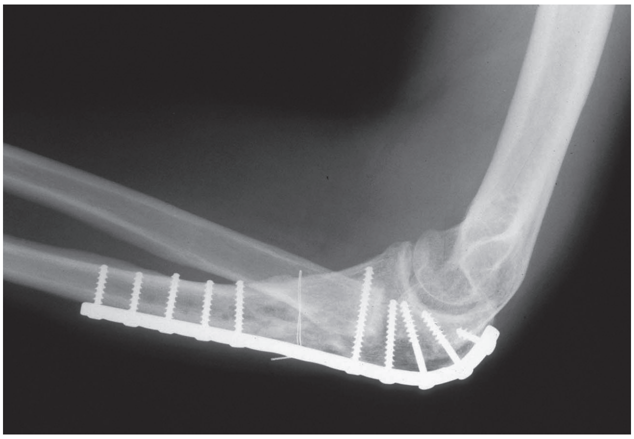
Operative risk factors for non-union in this region include plate malposition (placed medially or laterally but not posteriorly) in posterior Monteggia fractures and suboptimal screw fixation of the proximal metaphyseal region (only 2 or 3 screw fixation) (49). Hardware failure and loosening leads to deformity and recurrent radial head subluxation. Stable plate osteosynthesis and bone grafting leads to successful union, however, functional outcomes may be limited by associated bony and soft tissue injuries in this region (47). This includes severe comminution, associated radial head fractures, recurrent instability, heterotopic ossification, radioulnar synostosis and ulnohumeral arthritis (47, 54).

Surgical tactics

The non-union site is delineated through a posterior approach taking into account any proximal fragments hinged in extension by the triceps insertion. The extensor carpi ulnaris m. and flexor carpi ulnaris m. are elevated off the ulnar crista laterally and medially respecti-







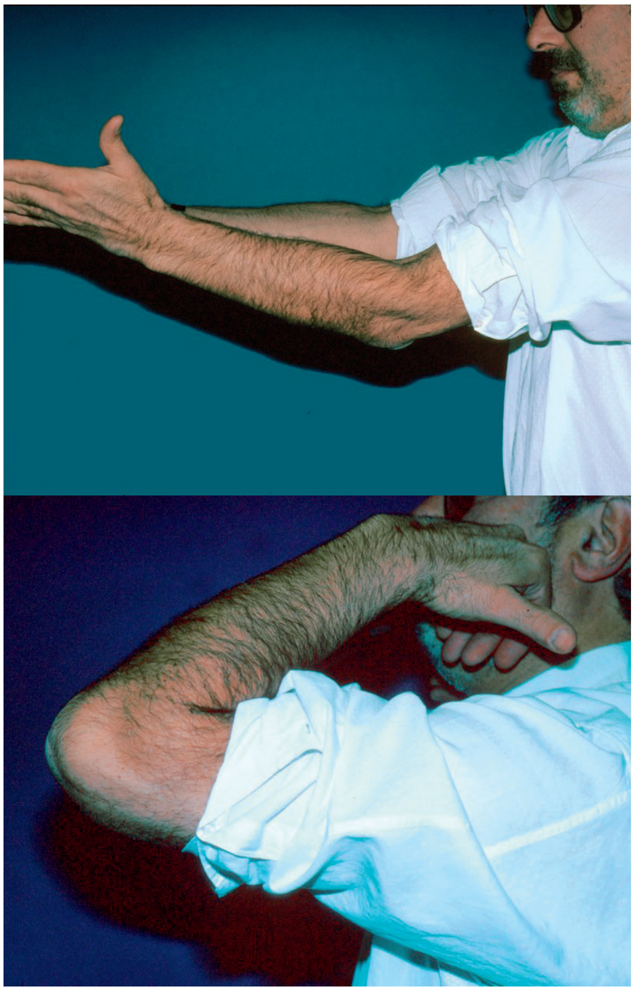


Fig. 1. A 50-year-old male with a fall from height sustaining a Type II Bado classification of a Monteggia fracture – Apex posterior proximal ulna fracture associated with posterior radial head dislocation:
1a – plain radiograph (lateral view) at injury
1b – plain radiograph (oblique view) at 3 months demonstrating failure of internal fixation
1c – plain radiograph (lateral view) at 1 year following revision internal fixation
1d –elbow flexion-extension range of motion at 1 year following revision internal fixation.

a b
c d

vely. The capsular attachments should be respected as this is an important vascular supply to the proximal ulna 58. The site is thoroughly debrided noting up to 6 mm of posteromedial olecranon may be resected without encountering complications related to valgus angulation (27) (Fig. 2).

The proximal ulna fracture is stabilised using 1.6-mm K-wires. A 3.5-mm LC-DCP or LCP is placed posteriorly, directly over the dorsal aspect of the proximal ulnar crista, the tension side of the bone. Contoured and pre-contoured, anatomical plates are placed enabling an optimal number of screws to stabilise the olecranon fragment. Orthogonal positioning of the proximal screws in relation to the distal (shaft) screws and placement with compression into good quality bone produces a stable interlocking construct 7. Intramedullary cancellous lag screws (6.5 mm) applied to contoured plates are shown to create stable constructs enabling axial compression and resistance to bending forces in the

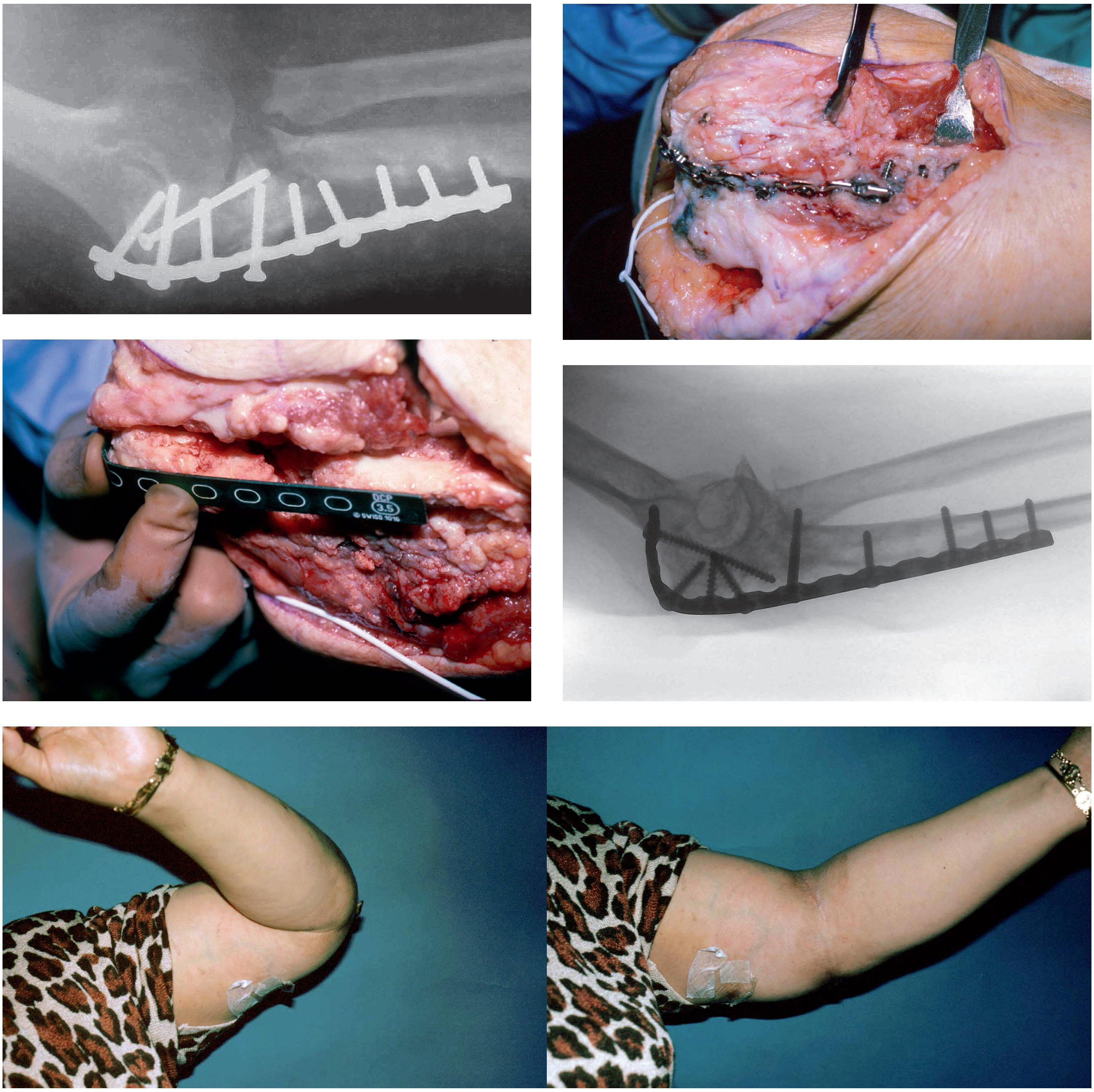


Fig. 2. A 67-year-old female with a synovial non-union of a proximal ulna fracture:
2a – plain radiograph (AP view) demonstrating failure of internal fixation and loose medial plating
2b – intra-operative image of failed internal fixation and loosening of hardware
2c – intra-operative image following thorough debridement of synovial non-union site, removal of hardware, demonstration of bone loss and DCP templating
2d – plain radiograph (lateral view) demonstrating dorsal plate fixation with autogenous cancellous bone grafting
2e – elbow flexion-extension range of motion following revision internal fixation.

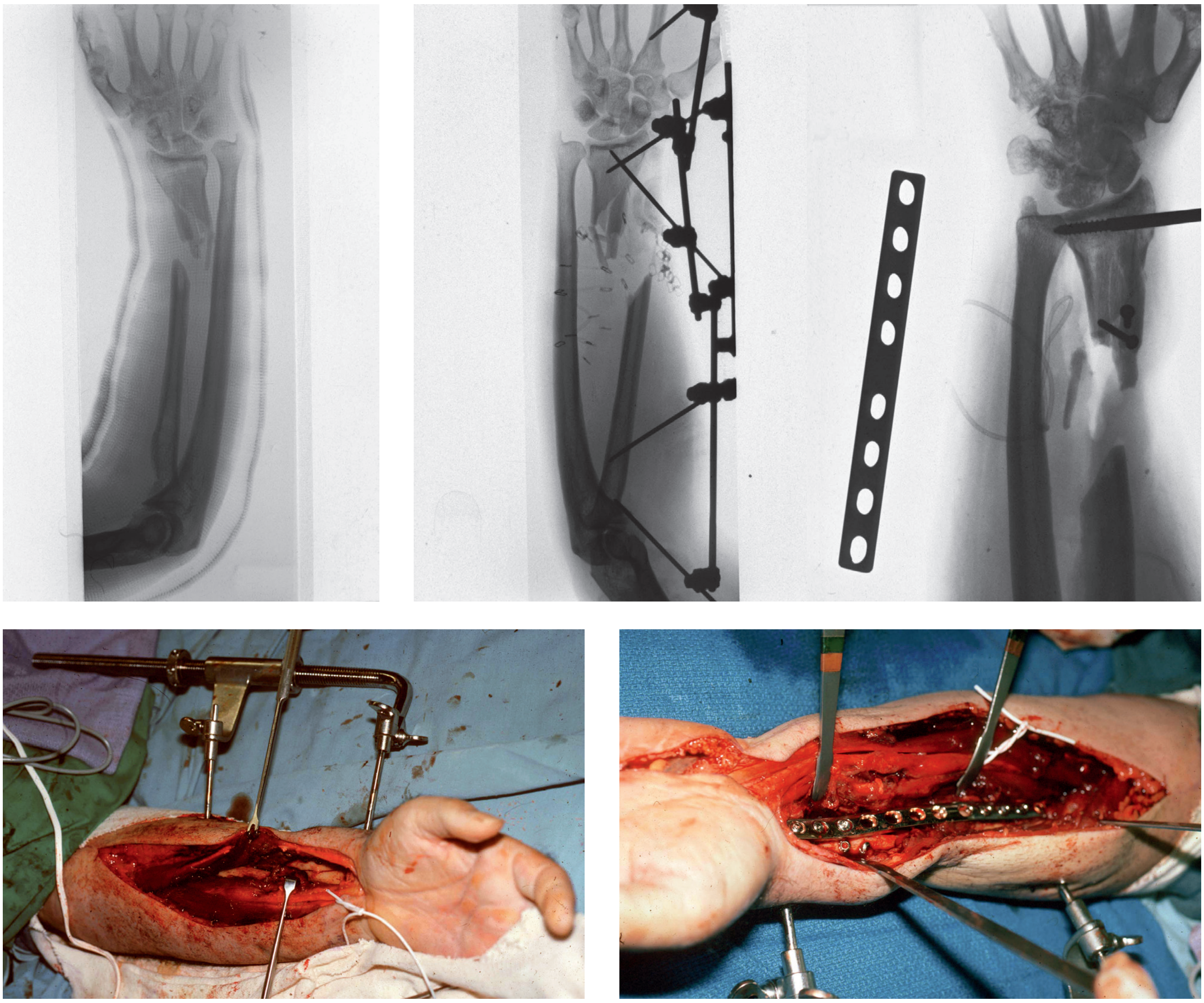
a|b
c|d
e

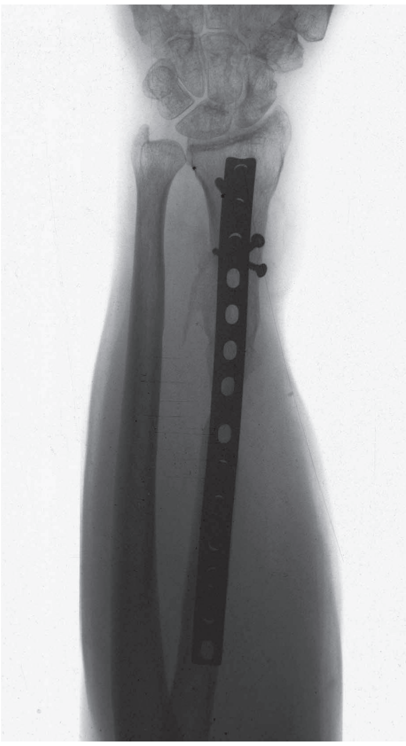
fixation of proximal ulna non-unions 31. Atrophic non-unions of the proximal ulna have been successfully treated using autogenous cancellous bone grafting with LC-DCP systems (47) as well as cortical grafts (51).

A classification based on the relationship of the non--union site to the ulno-humeral articulation has been stated (51). Not surprisingly sites of injury closer to the joint demonstrate poorer prognosis (51). Severe osteoarthritis or osteoporosis of the elbow associated with proximal ulnar or olecranon non-union in elderly patients can be treated with a total elbow prosthesis (47).

Non-union of the proximal radius

Non-union of the radial neck is often an occult, undiagnosed injury due to the relatively asymptomatic presentation and well-preserved elbow function (48, 29). Studies observing the non-operative management of radial neck non-unions diagnosed following operative treatment of radial head and neck fractures de-





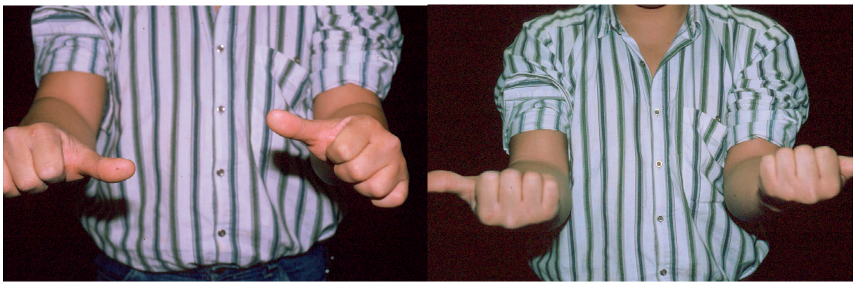
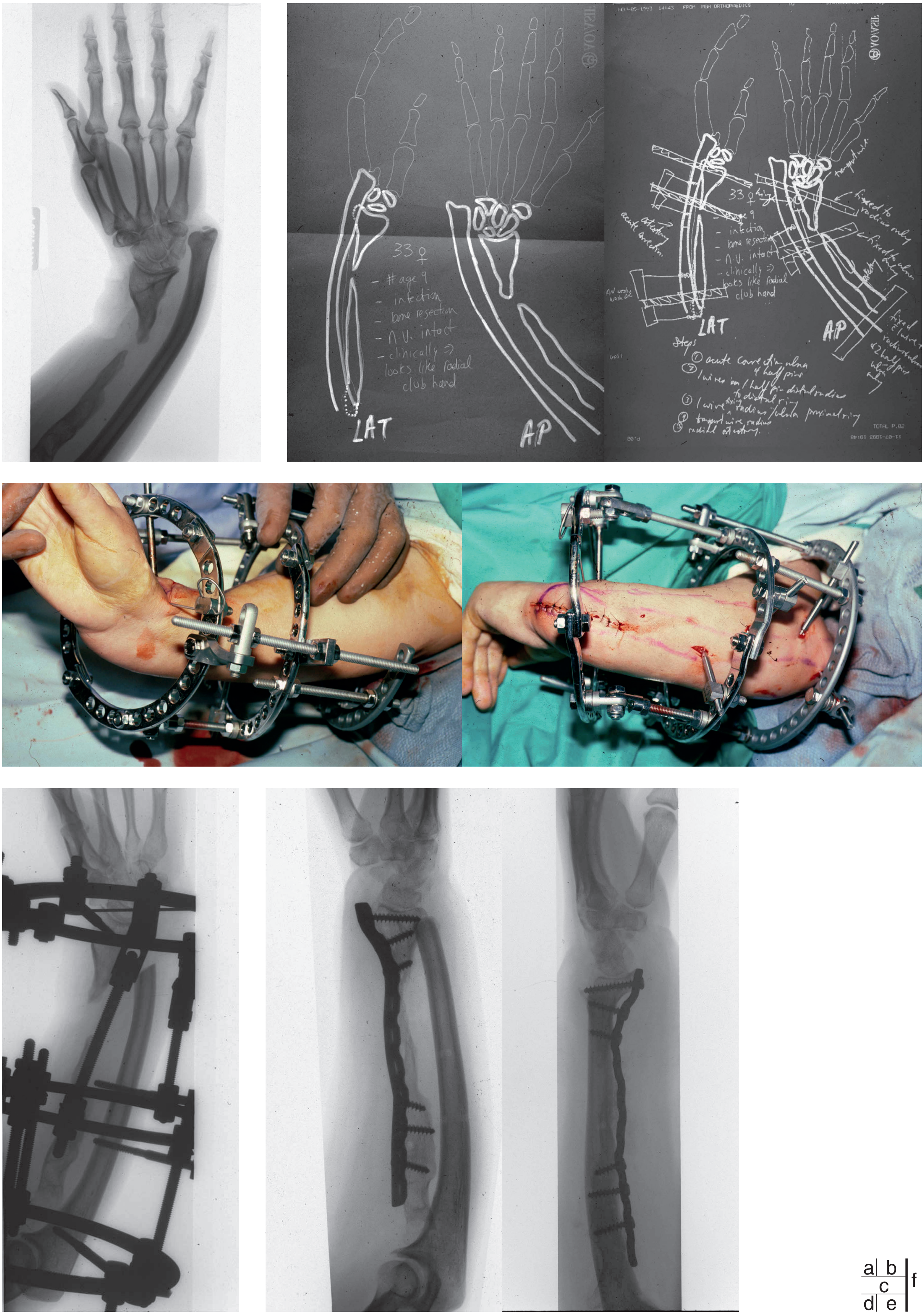


Fig. 3. A 55-year-old male with a complex high energy injury with non-union and bone loss:
3a – plain radiograph of the forearm demonstrating significant displacement, rotation, non-union, comminution and bone loss
3b – plain radiograph demonstrating stabilization of a complex forearm injury using an external fixator and intra-operative plate sizing with fixator in situ
3c – intra-operative image demonstrating use of a femoral distractor for optimising position in a complex forearm fracture
3d – intra-operative image of wave plate fixation and autogenous iliac crest graft
3e – postoperative plain radiographs (AP and lateral views) of a complex forearm fracture non-union with wave plate fixation and autologous iliac crest bone grafting
3f – postoperative images demonstrating rotational profile and performance at 1 year.

a | b
c | d
e | f


33 ♀
- # age 9
- infection
- bone resection
- N.V. intact
- clinically ⇒ looks like radial club hand
LAT
AP
Steps

a b
c
d e
f

Fig. 4. A 33-year-old school teacher with a history of childhood sepsis of the radius with severe residual deformity, disruption of the DRUJ and normal function of the hand:
4a – plain radiograph (AP view) of the forearm
4b – pre-operative planning for Ilizarov frame fixation for deformity correction
4c – intra-operative images of Ilizarov frame fixation for deformity correction and soft tissue distraction
4d – post-operative radiograph of Ilizarov frame fixation for deformity correction and soft tissue distraction
4e – plain radiographs (AP and lateral views) demonstrating wave plate fixation and autogenous cancellous bone grafting of non-union site following removal of Ilizarov frame
4f – post-operative images following wave plate fixation and autogenous cancellous bone grafting.

monstrate no ongoing symptomatic or functional deficits at long term follow-up with eventual progression to healing (32, 29). A study also demonstrates no difference in clinical outcome between operative fixation of Mason III radial head fractures to the shaft compared to non-operative treatment (44). Thus, no surgical treatment is recommended for asymptomatic radial neck non-unions despite radiographic appearances (29).

Surgical tactics

Internal fixation of both radial head and neck fractures should be considered in symptomatic cases and those involving an associated ulna fracture. Operative treatment involves anatomical plating and impaction bone grafting (32).

Non-union of the forearm diaphysis

Large series on surgical treatment of diaphyseal forearm non-unions have demonstrated non-union rates below 5% and low overall complications (8, 10, 22, 53).

Surgical tactics

General principles of operative treatment of non-unions include plate osteosynthesis and biological augmentation utilising autologous bone graft as indicated.

Long 3.5 mm DCP, LC-DCP or LCPs are applied with a high plate to screw ratio. Compression and reduction is achieved using techniques as previously described to restore anatomy and gain stable fixation. This commonly includes lag screw fixation, soft tissue release and distraction utilising an AO distractor or external fixator whilst closely observing glide of the median nerve (Fig. 3). This may be required in large defect radial diaphyseal non-unions associated with a positive ulnar variance, DRUJ disruption and soft tissue contracture. Small defect non-unions of the radius and ulna diaphysis may require minimal, symmetrical shortening of both long bones.

Recommendations for defects up to 6 cm include the use of autologous non-structural cancellous (iliac crest) bone graft (32, 46). Defects 6 to 10.5 cm in size may require vascularised osseous fibular or osteoseptocutaneous fibular grafts, especially if the viability of the soft tissue envelope is compromised (26, 52, 57).

Infected forearm non-union

Infected non-unions of the forearm are extremely resistant to healing, involving infected abnormal callus as a component of the involucrum, evidence of implant loosening and associations with poor vascularity and soft tissue integrity (Fig. 4). Clinical, biochemical and radiographic monitoring is essential for indicating resolution and guiding a plan for definitive surgical reconstruction. Recommended treatment involves aggressive surgical debridement, removal of failed metalwork, temporary stabilisation, and targeted antibiotic therapy (around 6 weeks culture-specific), prior to definitive plate fixation using structural autogenous graft (tricortical iliac crest) for segmental defects at around 7 to 14 days (Fig. 4). Devitalised soft tissues may require definitive cover and open wounds are allowed to heal by secondary intention. Vascularised bone grafts including free fibular grafts (osseous and osteocutaneous) and flexor carpi ulnaris muscle pedicled flaps have been used in these cases (40). Extensive radial defects may require conversion to one-bone forearms and ulna centralisation techniques (38).

Complications

Complications of non-union surgery additional to haematoma, infection and neurovascular injury include progressive radio-ulnar joint luxation, reduced function, range of motion (especially pronation-supination), strength and refracture following early plate removal with rates up to 25% (8, 10, 12, 23, 30). The functional outcome of healed diaphyseal forearm non-unions is improved compared to those of the proximal ulna and distal radius. This is likely due to the proximity of the PRUJ and DRUJ to the elbow and wrist respectively, more directly impacting function and motion of these joints (14, 47). The risk factors for refracture include non-union associated with poor technique, local osteoporosis secondary to reduced vascularity at the implant-bone interface, stress shielding, stress riser effect and removal within a year post-injury (23, 30). Studies demonstrate significant increase in complication rates following plate removal compared with plate retention (23).

Post-operative management

The post-operative management protocols of acute forearm fractures and non-unions are similar.

Non-unions involving proximal and midshaft regions should be placed in an above-elbow splint for around 10 days for wound healing. Distal non-unions can be placed in a below-elbow splint.

Active hand, shoulder and assisted elbow exercises (avoiding pronation-supination) are commenced immediately as pain allows.

In atrophic and oligotrophic non-union heavy loading, lifting, resistance activities, contact sports and pronation-supination are avoided for a minimum of 6 weeks. In hypertrophic non-union with stable fixation, controlled early movement of the wrist and elbow is permitted. The total period of immobilisation is based on the surgical experience and level of stability achieved, with resistance-strengthening exercises commenced once there is evidence of bony consolidation.

Post-operative rehabilitation directly impacts the overall outcome in this complex population, particularly given functional restoration is not only dependant on the recent operative treatment but the recovery from residual stiffness following the initial injury, previous operation(s), prolonged immobilisation and disuse atrophy.

Hardware removal is not routinely advocated in asymptomatic patients (32). Exceptions are made for dorsal ulna plates due to prominence, patients involved in contact sports and those with adverse symptoms, however, hardware removal should only be considered after around 18 to 21 months following healing (32, 50).

SUMMARY

A combination of patient, injury and surgical factors lead to non-union in forearm fractures. Anatomical reduction, stable fixation with compression plate osteosynthesis and preservation (or augmentation) of biology and vascularity are the key principles in achieving early progression to union and predictably good functional outcomes.

The principles of non-union surgery involve aggressive debridement of non-vital and infected tissue. The treatment of choice is surgical fixation with long 3.5 mm DCP and LC-DCP with a high plate-screw ratio, with or without bone grafting based on whether the non-union is atrophic / oligotrophic, or hypertrophic respectively. Bone defects under 6 cm can be reconstructed with autogenous corticocancellous grafts and over 6 cm using free tissue transfer. Adjunctive procedures include secondary lengthening or shortening procedures for malalignment, and prosthetic replacement for arthrosis, instability as well as malalignment.

DISCUSSION

Non-union following fractures of the forearm continues to provide a significant clinical and technical challenge. Whilst the evidence base on operative treatment of acute fractures is extensive, the literature on forearm non-union and clinical evaluation, operative treatment and outcomes assessment is lacking.

Assessment of progression of healing is reliant on basic clinical and radiological modalities. Future concepts include biochemical markers, imaging techniques and clinical scoring systems to more accurately assess failure of normal progression of bone healing and prediction of non-union (2). Imaging utilising radiographs and CT currently provide satisfactory definition of the site of non-union. Future directions may involve ultrasound technology and methods of assessing vascularity at the site of non-union (2).

Plate osteosynthesis has revolutionised the treatment of forearm fractures, provided excellent functional outcomes and low non-union rates. Contemporary plating systems using locking and variable angle technology and modern anatomical interlocking nailing systems are unlikely to better these outcomes significantly. However, future directions may involve the development of technical solutions to improve compression and reduction techniques (35). The trend for minimally invasive osteosynthesis allied with the ethos of 'biological surgery' has been applied to a variety of long bone fractures. The benefits of less invasive approaches, reduced iatrogenic trauma and enhanced recovery is attractive. However, this concept is unlikely to be incorporated in the management of forearm fractures and non-unions in contrast to other long bone fractures due to the requirement for anatomical reduction and the complexity of the local neurovascular and muscular anatomy.

Biological augmentation to facilitate bone healing and treat non-unions with the development of cells, growth factors, scaffold technologies within an optimal mechanical environment is rapidly advancing (13, 39). Mesenchymal stem and bone marrow cells stimulate osteogenesis, angiogenesis, self-regenerate and differentiate down cell lines to produce essential growth factors (13). Autogenous bone marrow aspirate injected at the fracture site has demonstrated healing of non-unions of long bone fractures including the forearm (21). Bone morphogenetic proteins (BMPs) from the transforming growth factor beta superfamily are essential factors in bone growth. Recombinant human BMP-7 (rh-BMP 7) is licensed for use in resistant non-unions of long bones and has been successfully applied to forearm non-unions. Further evidence for the use of BMP in treating non-union is required and studies are ongoing to define the full clinical effects, side effect profile, as well as methods of delivery and enhancement of expression via gene therapy (15). Long bone fracture healing is also enhanced by prostaglandin E2 (PGE2) (36) and platelet-derived growth factor which demonstrates healing comparable with autogenous bone graft (24). Further work is required involving statins encapsulated in nanoparticles and modulation of vascular endothelial growth factor (VEGF), parathyroid hormone (PTH), growth factor delivery and the Wnt intracellular signalling pathway.

Non-invasive adjunctive therapies including ultrasound and electrical stimulation in forearm non-union are also in demand, especially given the considerable market costs of biological bone stimulation agents (55).

Forearm non-union confers a significant clinical, functional and psychosocial impact. Although, the natural end-point of these studies is union and whilst some studies have incorporated functional outcome based on range of motion, there are no major studies describing the patient focused health related outcomes in this complex problem.

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