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Case Series

Management of long bone non-unions and implant failures utilizing the diamond concept: a retrospective case series

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ABSTRACT

The management of long bone non-unions and implant failures remains a significant orthopaedic challenge, imposing a substantial socio-economic burden on both the patient and the healthcare system. The "Diamond Concept" provides a comprehensive framework to address these complex scenarios by simultaneously optimizing mechanical stability and the biological healing environment. This study aims to evaluate the clinical and functional outcomes of recalcitrant non-unions treated according to this concept. A retrospective case series was conducted at a tertiary care center (SMIMER, Surat) between 2024 and 2026. Eighteen patients presenting with aseptic, infected, atrophic, or hypertrophic non-unions, as well as mechanical implant failures, were included. Treatment strategies were individualized to restore the physiological elements of fracture healing via revision osteosynthesis (single/dual plating or prosthesis) and biological augmentation (autologous bone grafting). The cohort consisted of 12 males and 6 females, with a mean duration of 7 months between the index surgery and revision. Ten cases involved the upper limb and eight involved the lower limb. Revision procedures utilized single implants (n=9), dual implants (n=7), and prosthetic replacements (n=2). Bone grafting was required in 13 cases. All followed patients achieved or are progressing toward solid clinical and radiological union, with a mean return-to-work time of 9 months from the index surgery. Precise identification of the etiology behind primary fixation failure is crucial. Adherence to the Diamond Concept through tailored mechanical stabilization and biological augmentation yields excellent union rates and functional recovery in complex non-unions.

Keywords: Non-union, Diamond concept, Implant failure, Bone grafting, Revision osteosynthesis

INTRODUCTION

Fracture healing is a complex physiological process that restores a bone to its pre-injury structural integrity. However, in approximately 1.9% of all adult fractures, this process fails, leading to delayed union or established non-union.[1] The U. S. Food and Drug Administration (FDA) traditionally defines a non-union as a fracture that is at least 9 months old with no signs of healing for 3 consecutive months.[2] However, in modern clinical practice, a more pragmatic definition is often adopted: a fracture that will not unite without further medical or surgical intervention.[3]

Non-unions and implant failures pose a profound direct and indirect socio-economic burden. The direct costs of treating non-unions-arising from extended hospital stays, multiple surgical revisions, and prolonged rehabilitation-can range from 2.6 to 4.3 times the cost of an uncomplicated fracture.[4] When complicated by infection, these costs can escalate up to 8 times that of standard fracture care.[4] Indirectly, patients suffer severe functional disability, loss of productivity, and psychological distress.[5]

The etiology of non-union is multifactorial, involving an interplay of biological, mechanical, and patient-specific risk factors. Factors such as high-energy trauma, severe soft tissue injury, inadequate reduction, and improper

implant selection frequently precipitate failure. Additionally, host comorbidities-such as diabetes mellitus, smoking, and advanced age-severely compromise the osteogenic response.[5] To address these multifaceted challenges, Giannoudis et al proposed the "diamond concept," which posits that successful bone regeneration requires the spatial and temporal coordination of four essential elements: osteogenic cells, osteoinductive mediators, an osteoconductive matrix (scaffold), and an optimal mechanical environment, all underpinned by adequate vascularity.[6,7]

This retrospective case series aims to evaluate the functional and radiological outcomes of 18 patients with complex non-unions and primary fixation failures managed using the principles of the diamond concept at a tertiary care center.

CASE SERIES

A retrospective case series was conducted at the Department of Orthopaedics, SMIMER Medical College, Surat, India, encompassing patients treated between 2024 and 2026. The study included 18 adult patients who presented with delayed union, non-union, or mechanical failure of primary long-bone fracture fixation. Both upper and lower extremity fractures were included. Patients with purely conservative management of their non-unions were excluded. Clinical and demographic data were extracted from medical records. Variables collected included patient age, sex, primary diagnosis, bone involved, interval between index and revision surgery, revision strategy (implant type and bone grafting), and functional outcome measured by the time taken to return to work. Surgical management was strictly guided by the diamond concept. Pre-operatively, the mechanical and biological deficits of each failure were analyzed.

Mechanical stability

Failed implants were removed, and the non-union site was debrided. Depending on the local biomechanical demands, mechanical stability was restored using single locking compression plates, orthogonal dual plating (to resist multidirectional torsional and bending forces), or prosthetic replacement (in cases of severe articular destruction or bone loss in the elderly).

Biological augmentation

Atrophic non-unions and significant defects were managed by introducing an osteoconductive and osteoinductive scaffold via autologous bone grafting.

The cohort consisted of 18 patients (12 males, 6 females). The age distribution showed peaks in the 20-30 years (28%) and >60 years (22%) age brackets. The anatomical distribution of the non-unions included the upper limb in 10 cases (humerus, radius, ulna) and the lower limb in 8 cases (femur and tibia).

Table 1: Baseline characteristics and surgical outcomes of the case series.

Parameters	Data/ frequency
Total cases	18
Sex	12 males, 6 females
Age distribution	Highest in 20-30 years (28%) and >60 years (22%)
Region involved	Upper limb (10), lower limb (8)
Mean time from index to revision	7 months (Range 1-18 months)
Implants used in revision	Single plate/nail (9), dual plates (7), prosthesis (2)
Bone grafting utilized	Yes (13), no (5)
Mean return to work	9 months (Range 2-21 months)
Union status	100% united/uniting at latest follow-up

The etiologies of primary failure were predominantly mechanical (implant failure due to excessive strain or poor bone stock), combined with biological host factors such as smoking, diabetes, and local infection.

Table 2: Probable confounding factors affecting non union.

Factors	N	Percentage (%)
Smoking	6	33.33
Peri-implant fracture	5	27.78
Idiopathic	4	22.22
Infection	2	11.11
Diabetes	1	5.56

The mean duration between the index surgery and the revision procedure was 7 months, ranging from 1 to 18 months. Revision surgery utilized single implant constructs in 9 cases, dual implants in 7 cases, and prosthesis in 2 cases. Autologous bone grafting was deemed necessary and performed in 13 of the 18 cases (72%) to provide the necessary biological chamber for healing.

Clinical and radiological follow-up demonstrated a 100% progression to union in the followed cohort. The functional outcome, defined by the total duration required to return to work from the index surgery, averaged 9 months (range: 3 to 21 months).

Case 1

A 65-year-old male presented with pain and deformity in the left wrist 7 months post-ORIF for a distal radius/ulna fracture. Radiographs confirmed an atrophic non-union with implant failure. The patient underwent implant removal, revision ORIF, and bone grafting, achieving solid union at 6 months post-revision.

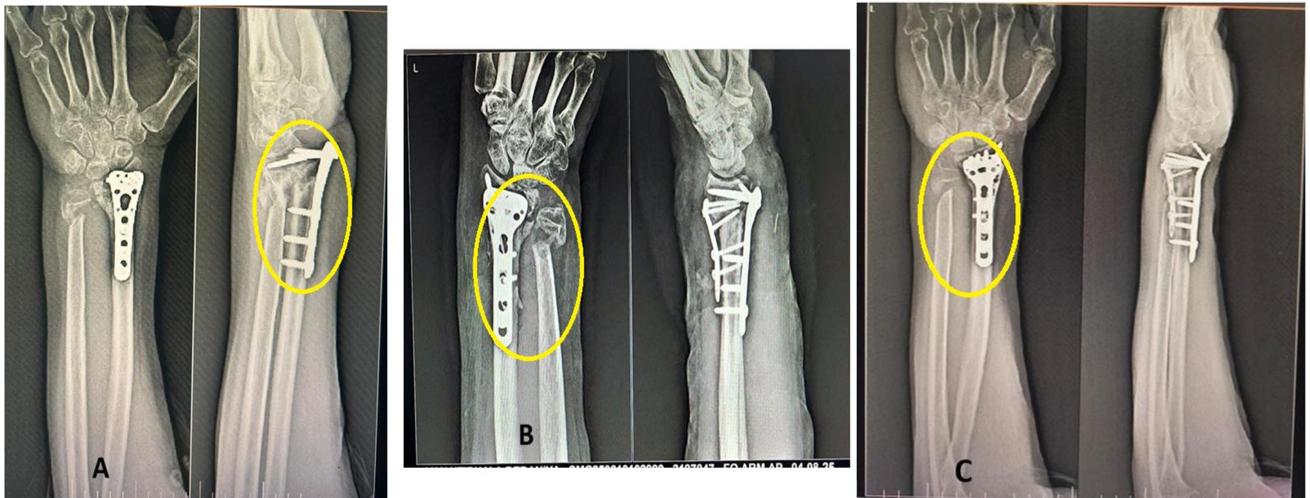

Figure 1: (A) Preoperative anteroposterior and lateral radiograph of a 65-year-old male demonstrating atrophic non-union and plate failure of the distal radius; (B): Immediate postoperative radiographs after implant removal, revision plating, and autologous bone grafting (ulna left side without DNVD after 7 months of index surgery); (C): Anteroposterior and lateral X-ray of forearm with wrist at 2 months demonstrating restoration of wrist alignment.

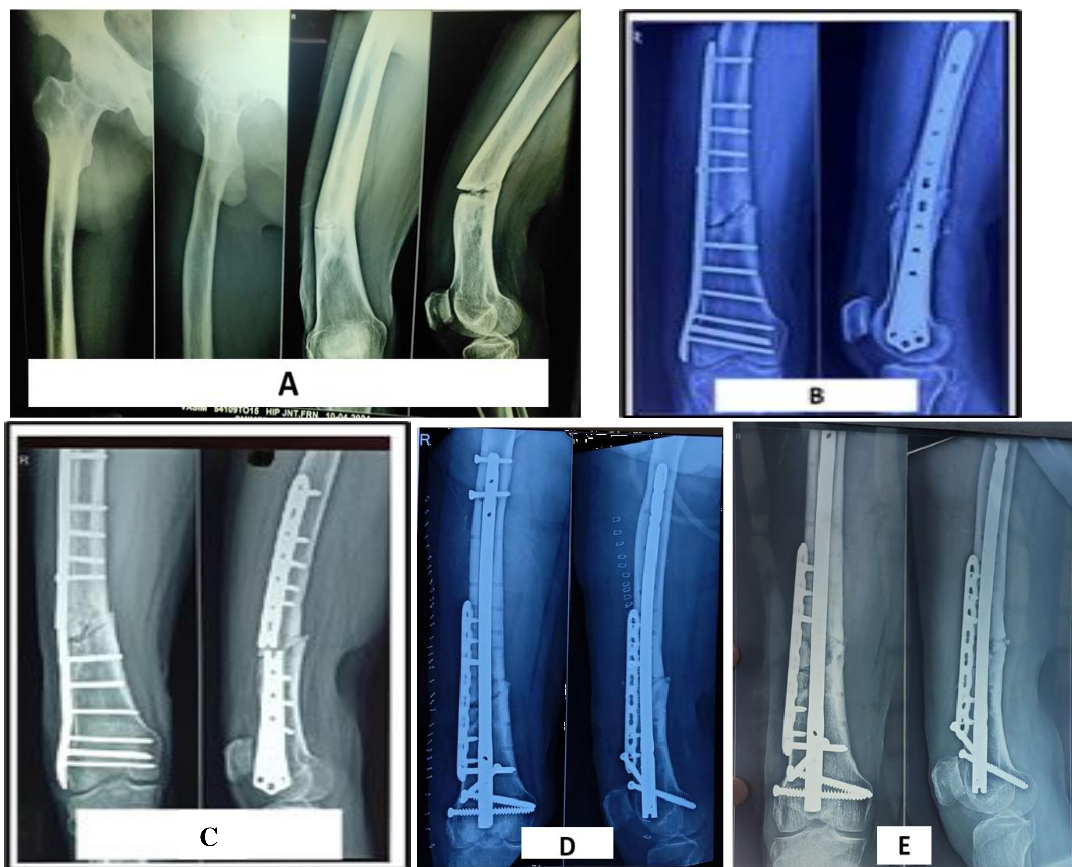

Figure 2: (A): Preoperative radiographs of a 56-year-old male showing lower third shaft femur fracture; (B): immediate Postoperative radiographs showing management of fracture via distal femur locking plate; (C): presentation of the patient 4 months post op with implant failure and non-union of fracture; (D): post op X-ray after revision surgery managed with orthogonal dual implantation; (E): Follow up X-ray after 6 months of revision surgery showing union.

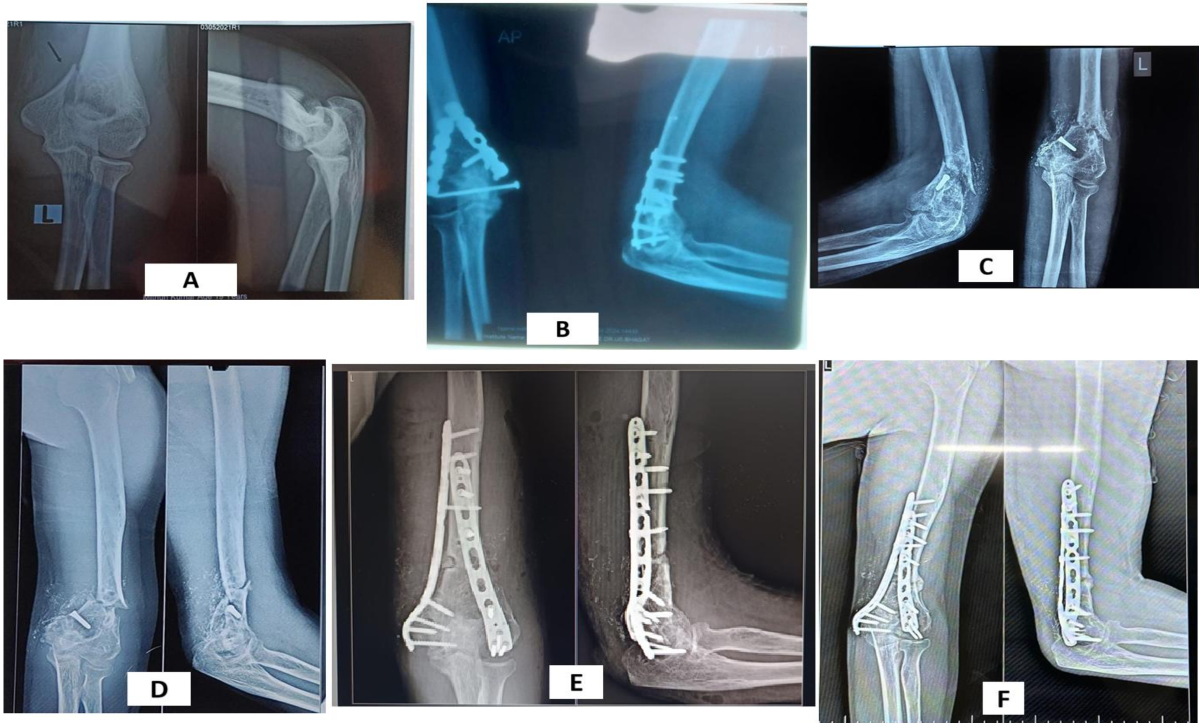

Figure 3: (A and B): Radiographs of a 23-year-old male showing a distal humerus fracture treated with dual plating; (C and D): Showing post implant removal distal humerus fracture due to trivial trauma; (E): Immediate post op x-ray treated with dual plating with bonegrafting; (F): 3 months post operative x-ray showing adequate consolidation.

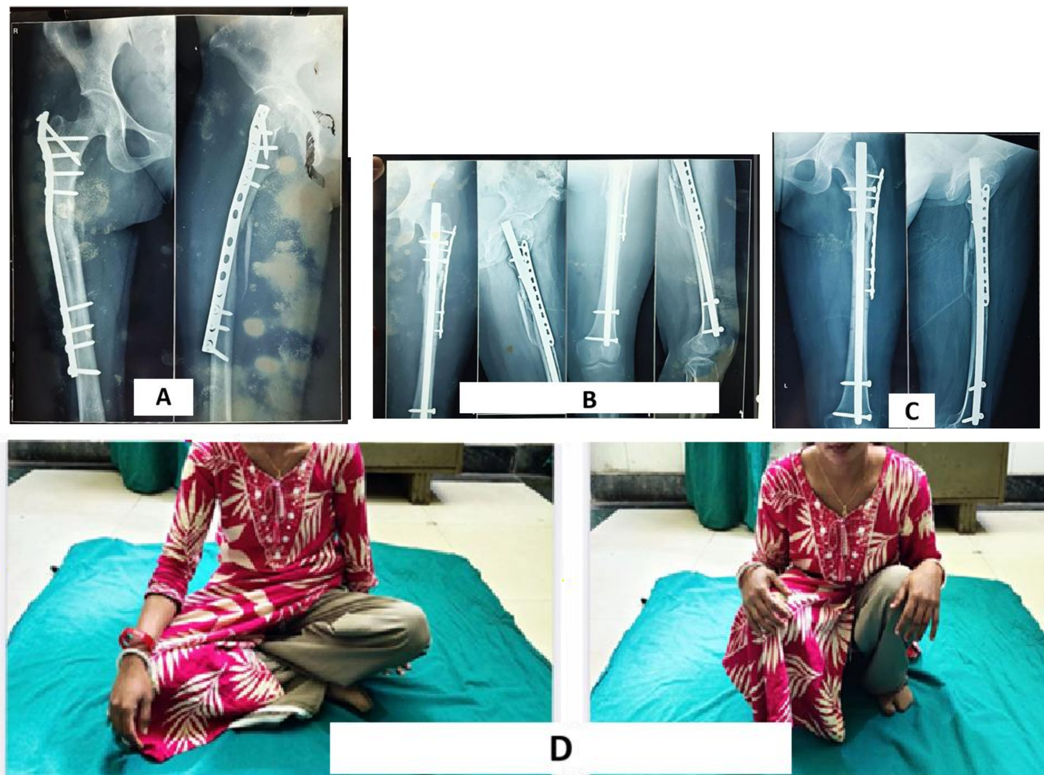

Figure 4: (A): Preoperative radiograph of a 29-year-old female presenting with a peri-implant fracture following index plating of a subtrochanteric femur fracture; (B and C): Radiographs at 1-month and 3-month follow-ups after revision surgery utilizing an intramedullary nail combined with a neutralisation plate and bone grafting; (D): clinical photographs demonstrating restored alignment, independent sitting, and hip flexion.

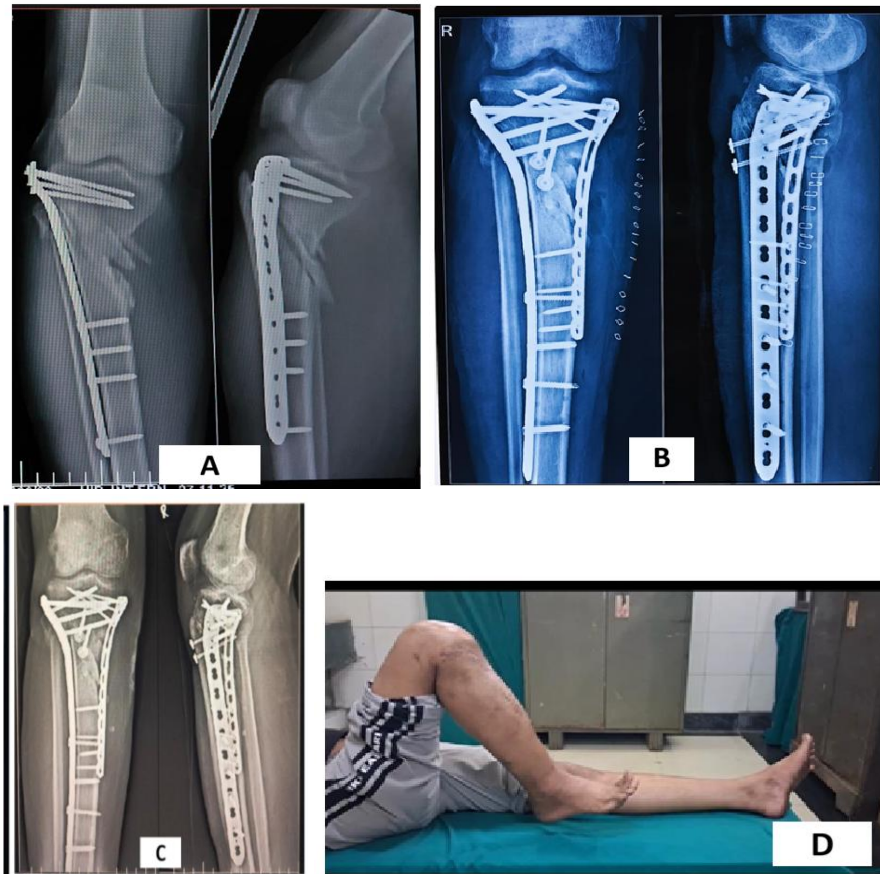

Figure 5: (A): Preoperative radiographs of a 36-year-old male showing implant failure in proximal tibia; (B): immediate postoperative radiograph showing revision osteosynthesis with dual plating to counteract varus forces; (C): radiographs at 2 months showing progressing consolidation and (D): clinical photographs demonstrating restored limb axis and excellent joint mobility.

Case 2

A 56-year-old male with a closed distal femur fracture managed by plating presented with mechanical implant failure 4 months post-operatively. Revision included hardware removal and robust stabilization with dual implantation without bone graft. He achieved independent ambulation and radiological union at 6 months.

Case 3

A 23-year-old male with a left distal humerus non-union (initially operated in 2021) underwent hardware removal and subsequent definitive revision using dual plating and bone grafting. Immediate postoperative and 3-month follow-up imaging showed excellent restoration of alignment and early consolidation.

Case 4

A 29-year-old female suffered a peri-implant fracture 1.5 months after ORIF for a subtrochanteric femur fracture. She was successfully managed using a dual implant combined with bone grafting.

Case 5

A 36-year-old male presented with an implant failure in the operated case of ORIF + PLATTING in proximal tibia fracture. He was revised with dual plating to counteract massive mechanical forces, progressing to full weight-bearing.

DISCUSSION

The successful treatment of non-union necessitates a deep understanding of fracture mechanobiology.[8] Our case series of 18 patients achieved universally positive outcomes by systematically applying the diamond concept. As established by Giannoudis et al neglecting either the mechanical stability or the biological microenvironment invariably predisposes a fracture to non-union.[7]

Mechanically, interfragmentary strain dictates the type of tissue that forms at a fracture site. Strain levels above 10% permit only the formation of fibrous tissue, resulting in hypertrophic or oligotrophic non-unions.[8] In our series, mechanical inadequacy was a primary driver of failure; therefore, we utilized dual plating in 7 of the 18 cases. Dual

plating provides superior orthogonal stability, resisting bending and torsional forces, which is specifically vital in metaphyseal regions or in the presence of comminution.

Biologically, adequate vascularity and cellular activity are non-negotiable.[7] Thirteen of our 18 cases required autologous bone grafting. Autologous bone graft remains the gold standard, as it is uniquely capable of supplying all three biological pillars of the diamond concept: osteogenic cells, osteoinductive growth factors, and an osteoconductive matrix.[8] Our findings echo the consensus that for atrophic non-unions, mechanical restabilization must be coupled with rigorous biological augmentation.[5]

Furthermore, the impact of patient-specific comorbidities on fracture healing was evident in our cohort. Factors such as diabetes mellitus and smoking are known to heavily impair osteogenesis and vascularity. Meticulous preoperative optimization of these modifiable factors is an integral, yet often overlooked, component of the holistic management of non-unions.[8]

The socio-economic implications of these injuries cannot be overstated. Recent systematic reviews have highlighted that the economic burden of non-unions outpaces that of uncomplicated fractures by up to 4.3 times, primarily due to prolonged absence from work and the high cost of revision surgeries.[9] Our data reflects this, with an average overall time to return to work of 9 months.

The limitations of our study include its retrospective design, the relatively small sample size, and the lack of a control group. However, the diverse anatomical locations and varying etiologies present a real-world snapshot of non-union management at a busy tertiary center.

CONCLUSION

Long bone non-unions and implant failures are severe complications that exact a heavy toll on patients. The meticulous application of the diamond concept-simultaneously addressing the mechanical stability of the construct while optimizing the biological healing chamber with techniques such as autologous bone grafting-yields excellent union rates. A tailored approach, considering both the fracture personality and host factors, remains the cornerstone of successful revision osteosynthesis.

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