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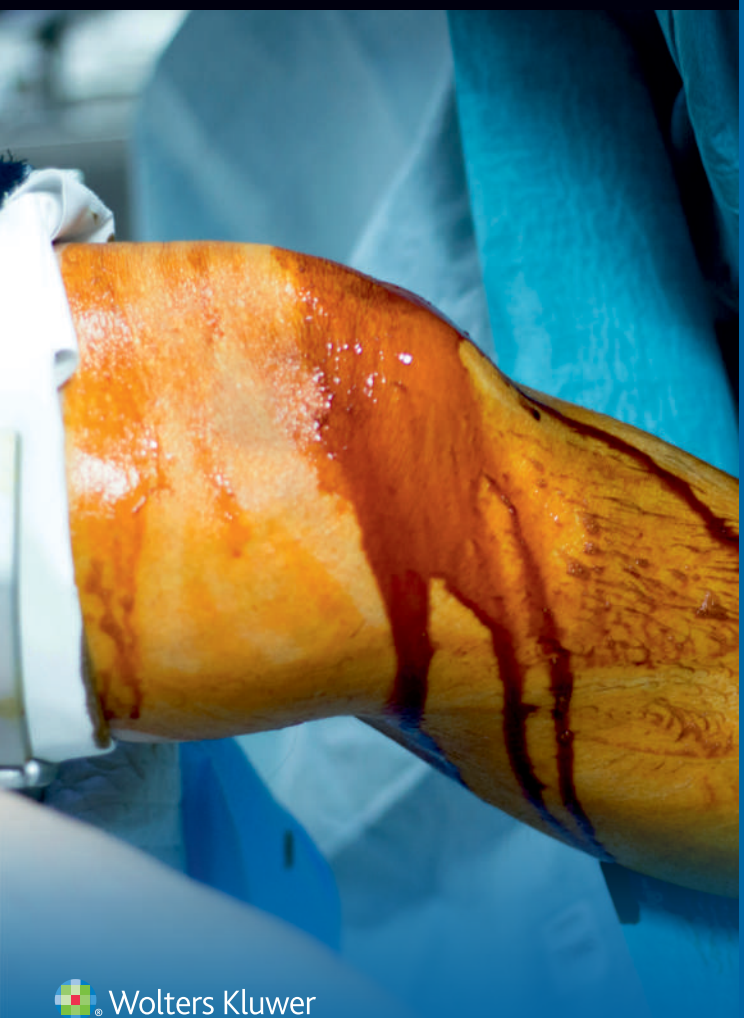

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Journal of Trauma and Orthopaedic Surgery

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Journal of Trauma and Orthopaedic Surgery (JTOS) is a continuity of the Journal of Maharashtra Orthopaedic Association.

M.O.A. Maharashtra Orthopaedic Association is a state chapter of the Indian Orthopaedic Association (IOA) founded by Dr A. K. Talwalkar in the city of Pune in 1983 with the idea of enhancing and promoting the principles and practise of Orthopaedic Surgery in the state. It has now become one of the most active State chapters in IOA and Maharashtra is proud to have produced many leaders and pioneers in Indian Orthopaedics.

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CONTENTS

The evolution of orthopaedic casting: From the legacy of plaster of paris to fibreglass and the future of breathable mesh cast technology

The history of orthopaedic casting is one of the most fascinating examples of how medicine evolves in response to both scientific progress and patient needs. Fracture immobilisation, despite appearing simple on the surface, has remained one of the cornerstones of orthopaedic care for centuries. Long before the era of joint replacements, arthroscopy, robotic surgery, and advanced trauma implants, physicians understood that broken bones required stability in order to heal properly. The methods used to achieve this stability have evolved dramatically over time, and each stage of this evolution reflects the changing priorities of medicine itself.

Today, orthopaedic casting stands at a critical turning point. The journey that began with crude wooden splints and primitive bandages evolved into the era of plaster of paris, progressed further into fibreglass technology, and is now entering a new phase driven by breathable mesh cast systems that emphasise not only fracture healing, but also patient comfort, hygiene, functionality, and quality of life.

To understand where the future of casting is heading, it is important to first understand how the field reached this point.

Early Attempts at Fracture Immobilisation

The concept of immobilising fractured limbs dates back thousands of years. Ancient Egyptian papyri describe the use of splints made from bark and linen to support broken bones. Greek physicians such as Hippocrates advocated traction and immobilisation techniques, while ancient Indian surgical texts including the Sushruta Samhita discussed fracture reduction and bamboo splinting methods. Chinese and Persian medical systems also developed regional techniques using cloth wraps, herbal pastes, leather braces, and wooden supports.

However, these early methods were inconsistent and lacked the ability to maintain stable reduction for prolonged periods. Most immobilisation techniques depended heavily on the experience of the healer and the availability of local materials. Fracture complications such as malunion, deformity, chronic pain, and disability were common.

The true transformation in fracture care began only after the emergence of plaster of paris.

The Birth of Plaster of Paris in Orthopaedics

Plaster of paris derives its name from the large gypsum deposits found near Paris, France. The material itself consists primarily of calcium sulfate hemihydrate, which hardens when mixed with water. Although gypsum had been used for centuries in art, architecture, and sculpture, its application in medicine represented a revolutionary breakthrough.

The modern orthopaedic use of plaster of paris began in the nineteenth century. During this period, Europe was witnessing rapid developments in military medicine due to frequent wars and battlefield injuries. Surgeons urgently needed methods to stabilise fractures quickly and effectively.

One of the earliest pioneers was Dutch military surgeon Mathijsen,[1] who in 1852 introduced plaster-impregnated bandages for fracture treatment. Before this innovation, surgeons often used cumbersome wooden splints or starch-based dressings that required long hardening times and provided poor immobilisation. Mathijsen's plaster bandages allowed the creation of rigid, mouldable casts directly around the injured limb.

This innovation transformed fracture care almost overnight.

For the first time, surgeons could achieve reliable external immobilisation that closely conformed to the anatomy of the patient. Fractures that previously healed with deformity could now be maintained in better alignment. Conservative orthopaedic treatment became more predictable and effective.

The use of Plaster of Paris (POP) expanded rapidly across Europe and later throughout the world. By the late nineteenth and early twentieth centuries, Plaster of Paris had become the universal standard for fracture immobilisation.[2]

The Rise of POP in India

In India, the widespread adoption of POP occurred during the British colonial period, particularly with the establishment of military hospitals and formal medical

colleges.[3] British-trained surgeons introduced plaster casting techniques into Indian healthcare systems, where the material quickly proved invaluable because of its low cost and simplicity.

After independence, POP became deeply integrated into Indian orthopaedic practice. Government hospitals, district hospitals, trauma centres, and rural clinics all relied heavily on plaster casting because it was affordable, widely available, and required minimal infrastructure.

For decades, POP remained the backbone of fracture care across India.

Its popularity was particularly important in a country with:

- High trauma burden.
- Large rural populations.
- Resource-limited healthcare settings.
- Increasing road traffic accidents.
- High patient volumes in government institutions.

Indian orthopaedic surgeons became exceptionally skilled in POP application techniques. Complex reductions, deformity corrections, clubfoot casting, and paediatric fracture management were routinely performed using plaster.

Even today, POP remains widely used across India because of its economic accessibility and familiarity.

Advantages that made POP Dominant for Over a Century

The dominance of POP for more than 100 years was not accidental. It offered several unique advantages that suited both surgeons and healthcare systems.

POP possessed excellent mouldability, allowing precise contouring around bony prominences and fracture sites. This was especially valuable in unstable fractures requiring close maintenance of reduction.

The material was inexpensive and easy to manufacture. In countries like India, where affordability remains a major determinant of healthcare delivery, this became critically important.

POP was also highly versatile. It could be used for:

- Fracture immobilisation.
- Post-operative splinting.
- Pediatric deformity correction.
- Clubfoot management.
- Serial casting.
- Spine support.
- Temporary trauma splints.

Additionally, surgeons appreciated its forgiving nature during application. The relatively slow setting time allowed adequate opportunity for fracture manipulation and correction.

The Limitations of POP Become Increasingly Apparent

Despite its enormous historical contribution, the limitations of POP gradually became impossible to ignore.

Patients frequently complained about the heavy and bulky nature of casts. Daily activities such as bathing, sleeping, climbing stairs, and dressing became challenging. The prolonged drying time often delayed mobilisation and increased inconvenience.

Perhaps the greatest issue, however, was the enclosed environment beneath the cast.

Traditional POP casts trapped sweat, moisture, and heat around the limb. This resulted in:

- Persistent itching.
- Foul odour.
- Skin maceration.
- Fungal infections.
- Pressure sores.
- Poor hygiene.
- Psychological discomfort.

In tropical countries like India, where high humidity and extreme summer temperatures are common, these problems became even more severe.

Children often inserted objects beneath casts to relieve itching, leading to skin injuries and infections. Elderly patients struggled with skin breakdown and cast-related pressure complications. Working individuals found prolonged immobilisation socially and physically exhausting.

As medicine advanced toward patient-centred care, the search for a better alternative intensified.

The Emergence of Fibreglass Casting Technology

The next major leap in casting evolution occurred during the latter half of the twentieth century with the introduction of fibreglass casting systems.[4]

Fibreglass casts were developed using woven glass fibres impregnated with polyurethane resin that hardened rapidly upon exposure to water. Initially introduced in Western countries during the 1970s, fibreglass represented a major technological advancement over traditional POP.

The material was lighter, stronger, thinner, and more durable. It allowed patients improved mobility while maintaining adequate fracture stability.

Orthopaedic surgeons rapidly embraced fibreglass because it addressed several practical limitations of plaster.

Introduction of Fibreglass in India

Fibreglass casting materials began gaining popularity in India during the 1980s and 1990s, particularly in urban tertiary care hospitals and private orthopaedic centres.[5]

Initially, adoption was limited because of higher costs compared to POP. Government hospitals continued relying predominantly on plaster because of economic considerations and high patient loads.

However, as private healthcare expanded in India, fibreglass became increasingly preferred in:

- Corporate hospitals.
- Sports medicine centres.
- Paediatric orthopaedics.
- Elective orthopaedic practices.
- Metropolitan trauma centres.

Patients appreciated the lighter weight and improved appearance of fibreglass casts. Orthopaedic surgeons valued the faster setting times and superior strength.

By the early 2000s, fibreglass had established itself as the modern alternative to POP in many urban Indian healthcare settings.

Why Fibreglass Still Failed to Fully Solve the Problem

Although fibreglass improved several mechanical aspects of casting, it did not fundamentally change the patient experience beneath the cast.

The cast environment remained enclosed.

Patients continued experiencing:

- Sweating.
- Skin irritation.
- Odour accumulation.
- Hygiene difficulties.
- Claustrophobic discomfort.
- Heat retention.

In essence, fibreglass modernised the outer shell of immobilisation, but not the physiological environment surrounding the skin.

As patient expectations evolved further, the shortcomings of both POP and fibreglass became increasingly evident.

The Emergence of Breathable Mesh Cast Technology

Modern orthopaedics is now entering a new era in which fracture treatment is no longer judged solely by radiological union or maintenance of alignment. Increasingly, patient comfort, rehabilitation experience, skin health, mobility, hygiene, and overall quality of life are becoming equally important outcome measures. This transformation reflects a broader evolution in healthcare itself, where patient-centered care is gradually replacing purely disease-centered treatment models.

This philosophical shift has paved the way for the emergence of breathable mesh cast technology.

Unlike conventional circumferential casting systems, breathable mesh casts are designed around the principles of ventilation, comfort, and functional healing. Their open and aerated structure permits continuous air circulation around the limb, reducing sweat accumulation and minimizing many of the longstanding problems traditionally associated with prolonged immobilisation. Rather than creating a sealed environment around the skin, these systems aim to create a controlled and breathable healing interface.

The concept of improving ventilation beneath casts is not entirely new. In fact, orthopaedic surgeons and biomedical engineers in Western countries have been attempting to solve the "closed cast problem" for several decades. As early as the 1980s, surgeons and inventors began recognizing that conventional plaster and synthetic casts trapped heat and moisture, creating an environment conducive to skin irritation, bacterial growth, foul odor, itching, and patient discomfort. One of the earliest documented attempts to address this issue was the development of ventilated orthopedic cast systems and cast vents that allowed airflow through the cast structure.[6] A United States patent titled "Vent for Use in an Orthopedic Cast," published in 1989, specifically described the discomfort, bacterial buildup, and skin complications associated with poorly ventilated casts and proposed integrated venting mechanisms to improve airflow beneath immobilisation devices.

During the 1990s and early 2000s, the idea of "cast aeration" gained further momentum. Researchers and inventors in the United States and Europe began experimenting with breathable padding systems, perforated casting materials, and external ventilation devices designed to circulate air through the cast.[7] The emphasis gradually shifted from simply immobilising fractures toward maintaining skin integrity and improving patient tolerance during prolonged treatment periods.

An important milestone came with the development of breathable double-knit cast padding systems. In 2008, a patented cast assembly design described multilayer breathable padding materials with integrated ventilation openings that allowed air circulation and improved drying following exposure to sweat or water.[8] The inventors specifically emphasized rapid moisture evaporation and improved hygiene as major goals of the technology. These innovations reflected a growing awareness that the

biological environment beneath the cast directly influences patient comfort and potentially even complication rates.

At the same time, another stream of innovation focused on active airflow systems. Multiple patents filed in the early 2000s described methods and devices intended to mechanically ventilate orthopedic casts.[9] These systems included airflow channels, spacers, membrane structures, and external air-moving devices capable of circulating air uniformly beneath breathable cast materials. One patent application titled "Method and Apparatus for Aerating a Cast" described a system designed specifically to improve hygiene and comfort by promoting even airflow throughout the cast environment.

Subsequent patent applications expanded upon these ideas by introducing scaffold-like spacer systems and airflow chambers integrated with breathable casts.[10] These inventions recognized that simply creating random holes in a cast was insufficient; instead, controlled airflow pathways were required to ensure effective ventilation throughout the immobilised limb. A later U.S. patent application titled "Apparatus and Method of Creating Airflow Through a Breathable Orthopedic Cast" proposed the use of breathable casting materials combined with engineered airflow systems to reduce dampness, bacterial accumulation, and odor formation beneath casts.

Interestingly, some surgeons and clinicians also began manually modifying traditional fibreglass casts by creating perforations or windows in selected regions to improve ventilation and patient comfort. Although such modifications were not universally standardized, they reflected growing dissatisfaction with completely enclosed casting systems. Over time, these ideas contributed to the broader evolution toward structurally ventilated cast designs rather than merely adding isolated holes into otherwise conventional casts.

The emergence of breathable mesh cast systems therefore did not occur suddenly. Rather, it evolved gradually through decades of experimentation involving cast ventilation devices, breathable padding technologies, perforated synthetic materials, and airflow engineering concepts. Advances in polymer science, lightweight composites, mesh structures, and ergonomic design eventually allowed these ideas to mature into clinically practical immobilisation systems.

In recent years, Western healthcare systems have increasingly explored advanced breathable immobilisation concepts including waterproof casts, thermoplastic mesh orthoses, and even 3D-printed patient-specific casts.[11] Several modern 3D-printed casts developed in Europe and North America are intentionally designed with lattice-like open structures that maximize ventilation while maintaining mechanical stability. These designs represent a major conceptual departure from traditional "solid shell" casting philosophy.

The movement toward breathable casting technology also aligns closely with modern rehabilitation principles. Contemporary orthopaedics increasingly favors early mobilization, preservation of soft tissue health, and functional recovery whenever clinically feasible. Traditional rigid casts, while effective for stabilization, often contribute to muscle atrophy, skin compromise, joint stiffness, and poor patient compliance. Breathable systems attempt to reduce some of these secondary burdens associated with immobilisation.

Why Breathable Mesh Casts May Transform the Indian Orthopaedic Landscape

The introduction of breathable mesh cast systems could significantly alter fracture care practices in India over the coming decade. India presents unique environmental, demographic, and healthcare challenges that make breathable immobilisation particularly relevant.

Traditional casts often become extremely uncomfortable during Indian summers. Sweat retention, itching, foul odor, fungal infections, and hygiene difficulties are among the most common complaints from patients wearing POP or fibreglass casts. In many regions of India, temperatures routinely exceed 40°C with high humidity levels, creating ideal conditions for moisture accumulation beneath conventional casts.

Breathable mesh technology directly addresses these challenges by improving airflow and facilitating sweat evaporation. This may substantially improve patient tolerance during long immobilisation periods, especially in pediatric patients, elderly individuals, and active working populations.

The Indian healthcare system also faces an enormous trauma burden due to road traffic accidents, occupational injuries, sports trauma, and falls. High patient volumes in overcrowded outpatient departments often limit frequent follow-up visits and cast adjustments. More comfortable and hygienic immobilisation systems may therefore improve compliance and reduce cast-related complications.

Breathable mesh systems may prove especially valuable in:

- Pediatric orthopaedics.
- Sports medicine.
- Stable fractures.
- Rehabilitation protocols.
- Functional bracing.
- Post-operative immobilisation.
- Day-care trauma procedures.

Younger generations are also becoming increasingly lifestyle-conscious and expect medical treatments that interfere minimally with daily living. Lightweight, breathable, washable, and aesthetically modern

immobilisation systems align strongly with these evolving patient expectations.

Importantly, India has also begun witnessing indigenous innovation in this field. Recent Indian technologies have explored breathable, lightweight, and washable immobilisation systems specifically adapted for Indian environmental conditions. These developments suggest that India may not only adopt breathable casting technology but potentially become an important contributor to its future evolution.

The Future of Orthopaedic Immobilisation

The future of orthopaedic casting will likely move toward increasingly intelligent, personalized, and biologically integrated systems. Immobilisation technology is gradually evolving from passive structural support toward active therapeutic platforms.

Emerging technologies may include:

- Smart casts with embedded sensors.
- Moisture-monitoring systems.
- Pressure-regulating materials.
- Temperature-responsive casts.
- Antimicrobial surfaces.
- Waterproof structures.
- AI-assisted rehabilitation monitoring.
- 3D-printed patient-specific immobilisation

Some future casts may even incorporate biosensors capable of monitoring swelling, pressure changes, tissue oxygenation, or fracture healing in real time. Artificial intelligence and wearable technologies may eventually integrate with orthopaedic immobilisation to optimize rehabilitation protocols and detect complications early.

Breathable mesh casts may therefore represent the first major step toward this future.

Just as plaster of paris revolutionized fracture care in the nineteenth century and fibreglass modernized casting in the twentieth century, breathable mesh technology may define the next era of orthopaedic immobilisation—an era focused not only on stabilizing fractures, but on improving the entire healing experience for the patient.

Conclusion

The evolution of orthopaedic casting reflects the broader evolution of medicine itself.

Plaster of paris introduced reliable fracture immobilisation to the modern world and remained the foundation of orthopaedic care for over a century. Fibreglass improved efficiency, strength, and convenience, helping modernise fracture management in hospitals worldwide, including India.

Now, breathable mesh cast technology represents a new chapter—one focused not only on healing bones, but also on improving the patient's entire experience of recovery.

The future of fracture care will not simply be about keeping bones immobile. It will be about creating healing systems that are lighter, cleaner, smarter, more comfortable, and more humane.

Orthopaedic casting has travelled a remarkable journey from heavy plaster shells to breathable therapeutic support systems. And in many ways, this evolution is only beginning.

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Conflicts of interest

There are no conflicts of interest.

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Original Article

Hidden hazards: Retained shoe sole material after nail penetration injuries of the foot—A case series

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Abstract

Introduction: Nail penetration injuries to the foot are a common occupational hazard, particularly among industrial and field workers. However, its incidence has also increased in the common population in the past few years. A unique but often overlooked complication occurs when the nail penetrates the sole of the shoe and is subsequently withdrawn, leaving behind a fragment of the footwear—typically rubber or similar material—embedded in the foot. Due to its radiological properties, this retained foreign body is difficult to detect with conventional imaging and poses diagnostic as well as surgical challenges. **Materials and Methods:** We present a case series of 12 patients treated between 2018 and 2023 where retained footwear sole fragments were surgically removed following nail penetration injuries. **Results:** Twelve patients (8 males, 4 females; age range = 16–66 years) with nail puncture injuries through rubber-soled footwear were included in the study. Most injuries occurred at construction or industrial sites, with delayed presentations ranging from 1 to 6 months. Common symptoms were pain and swelling. The midfoot was the most frequently affected site. Imaging modalities such as ultrasound, magnetic resonance imaging, and computed tomography provided indirect signs, but plain radiographs were non-diagnostic. All patients underwent surgical removal of retained rubber fragments. Complete recovery was achieved in all cases. **Conclusion:** Rubber sole fragments retained in the foot post-puncture injury are radiolucent, diagnostically elusive and require removal for resolution. Clinicians must maintain vigilance and proceed to surgical exploration when suspicion persists despite negative imaging.

Keywords: *Foreign body foot*, *nail penetration injuries*, *radiolucent foreign body*, *rubber sole*

Introduction

Penetrating foot injuries caused by nails are frequently encountered, particularly among industrial, construction, and field workers who are often exposed to hazardous working conditions. These injuries are typically managed conservatively or surgically, depending on the extent of tissue involvement and presence of complications such as infection or foreign body retention. While retained metallic or wooden foreign bodies are well-documented, an under-recognized and diagnostically challenging entity is the retention of non-metallic footwear material—specifically the rubber or synthetic sole—following a nail injury.[1,2]

In many such cases, the nail penetrates the sole of the footwear and enters the foot. Patients often report successful removal of the nail; however, the soft rubber sole may be partially retained within the foot. Unlike metallic foreign bodies, rubber and synthetic materials are not easily visualized on plain radiographs due to their low radio density. This often results in missed diagnosis, especially when the initial inflammation subsides with empirical antibiotic therapy, creating a false sense of resolution. Over time, the retained material may provoke a chronic inflammatory response, sometimes resulting in

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the formation of sinus tracts or bony cavities that mimic chronic osteomyelitis.[3]

The diagnostic dilemma is compounded by the limitations of the conventional imaging. Ultrasound (USG) may show nonspecific inflammatory changes, while magnetic resonance imaging (MRI) and computed tomography (CT) scans can suggest abnormalities without definitively identifying the foreign material.[1] Consequently, unless the clinician maintains a high index of suspicion, these retained fragments may remain undiagnosed for extended periods, leading to chronic morbidity.

Materials and Methods

This study presents a retrospective case series of 12 patients treated between 2018 and 2023, all of whom had retained footwear sole fragments following nail penetration injuries. This study was conducted in a tertiary hospital in Pune. Inclusion criteria-history of nail penetration injury to the foot, surgical confirmation of retained foreign body. Exclusion criteria—foreign body other than footwear material, no surgical exploration performed, puncture injuries without footwear involvement, patients lost to follow-up. All patients had a clear history of a nail prick injury occurring through the sole of a shoe, with spontaneous or assisted withdrawal of the nail. Initial treatment taken elsewhere included wound care and antibiotic therapy, resulting in transient symptom resolution. The imaging modalities used included X-ray which often showed no radiopaque foreign body. USG revealed inflammatory tracts or fluid collection. MRI detected signal changes suggestive of inflammation or fibrosis; foreign body visualized in some but not all cases. CT scan, in 3 cases, revealed a bony cavity. All 12 patients had different location of the retained foreign body in the foot. All patients were managed surgically. Prior to surgery, patients were thoroughly counseled regarding the potential for unsuccessful removal of the foreign body and the possible need for multiple procedures in the future. We present a case of a 47 years old male construction worker who had a history of nail penetration injury at the construction site 4 months back. Patient presented to us with swelling and discharging sinus from the sole of the foot [Figure 1]. He was treated elsewhere for this draining sinus and was operated twice before he presented to us, the foreign body was not found and the sinus continued to drain. X-ray was normal. However, MRI [Figure 2] and CT scan [Figure 3] showed a hypo intense opacity and a subperiosteal cavity, respectively, with no changes of osteomyelitis at the base of medial cuneiform and first metatarsal base (midfoot region). A targeted exploration of wound, along with the help of plastic surgeon, was undertaken. Incision was taken on the plantar aspect of the foot through the draining sinus tract [Figure 4]. On dissecting through the reactive fibrotic tissue and reaching the sub periosteal plane, a black rubber foreign body consistent with protecting industrial footwear worn at the construction site was retrieved through the wound

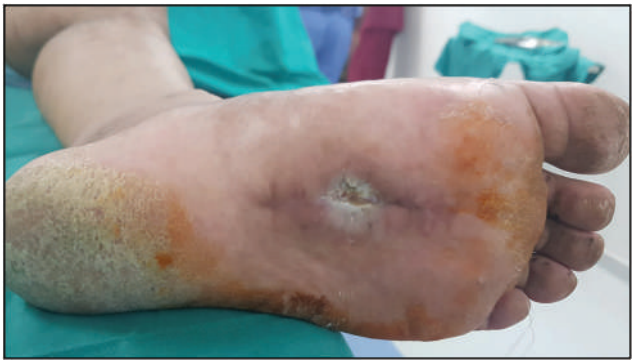

Figure 1: Clinical photograph of the draining sinus tract

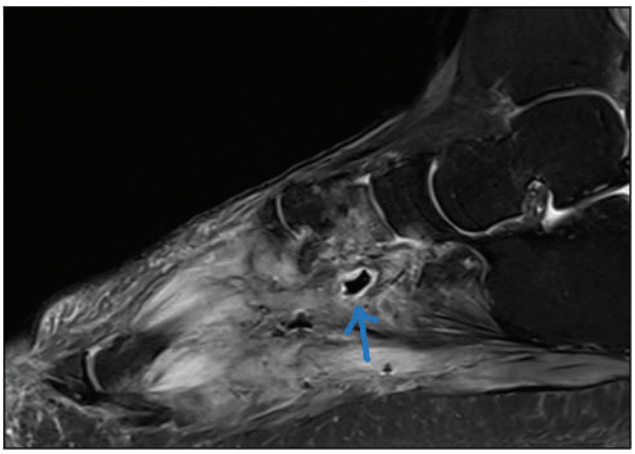

Figure 2: Magnetic resonance imaging image showing a hypointense well circumscribed structure

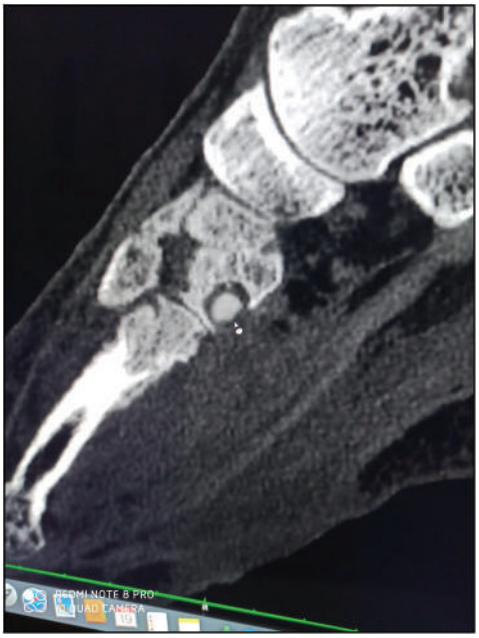

Figure 3: Computed tomography scan image showing a cavity in the bone

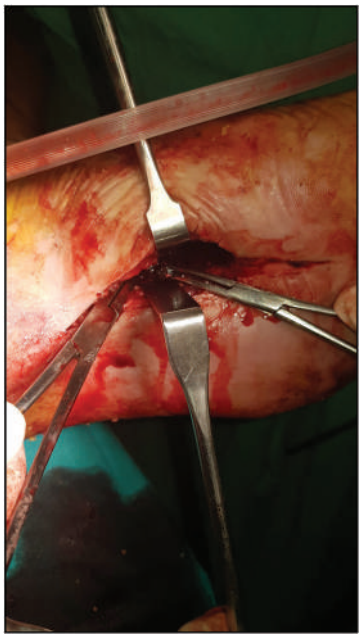

Figure 4: Intraoperative image of the surgical approach

Figure 5: The rubber foreign body

[Figure 5].Complete excision, irrigation with Povidone iodine and normal saline and layered closure was performed. There was no recurrence in the postoperative period.

Results

A total of 12 patients (8 males and 4 females), with a mean age of 37.5 years (range = 16–66 years), were included in this case series. All patients sustained nail penetration injuries while wearing rubber or synthetic-soled footwear. The modes of injury varied: Five patients were injured at construction sites, three in industrial settings, three on roadsides or open public spaces, and one at school playground. The time from injury to clinical presentation ranged from 1 to 6 months, with the majority (10 out of 12) presenting more than 3 months after the initial trauma.

The most common presenting complaint was localized pain (ten patients), followed by swelling along with a sinus (two patients), and one patient also had fever, suggesting early infection. Initial management before referral included antibiotics and analgesics in eight patients, plaster immobilization in two, and no treatment in two cases. The midfoot was the most commonly affected site (six patients).

Radiological investigations varied across patients. USG was used in five patients and demonstrated sinus tracts or nonspecific inflammatory changes. MRI, performed in four patients, showed hypointense structures indicative of fibrosis or retained material. CT scans in three patients revealed bony cavities, which in some cases mimicked osteomyelitis. Plain radiographs were unremarkable in all cases and did not contribute to diagnosis.

The interval between symptom onset and surgical intervention ranged from 1 week to 2.5 months. All patients underwent surgical exploration and removal of retained rubber or synthetic fragments. No further recurrences or long-term complications were noted during follow-up in the remaining cases.

Discussion

Nail puncture injuries to the foot are common, particularly among individuals working in construction, industrial environments, or walking barefoot or in soft footwear in public areas. While infection and osteomyelitis are well-known complications, our case series draws attention to an under-recognized yet significant issue: the retention of rubber or synthetic footwear sole fragments as a foreign body. These retained materials, due to their radiolucent nature and soft texture, are often missed during initial evaluation because of the slow inflammatory reaction to rubber and can lead to prolonged morbidity. Our series of 12 cases highlights a clinically important but under-recognized phenomenon: retention of rubber footwear sole fragments after nail penetration injuries to the foot. This complication mirrors cases reported in the literature, confirming its relevance and reinforcing several key observations.

1. Incidence and detection of retained rubber

Chang *et al.*[4] described eight cases of rubber sole fragments embedded following puncture through rubber-soled shoes; they reported that infection resolved only after removal of all rubber fragments. Similarly,

Rubin and colleagues, in a retrospective study of 96 nail puncture wounds, found 37.5% of cases needed surgical intervention—and 25% had hidden rubber foreign bodies.[5] Our findings align well, emphasizing that despite symptomatic relief with antibiotics, persistent foreign bodies can lead to recalcitrant infection or sinuses.

2. Imaging challenges

Multiple studies report that rubber fragments are often invisible on plain radiography. For instance, Chang *et al*.[4] and coworkers noted the difficulty of diagnosing radiolucent rubber pieces without a high index of suspicion. USG—while specific—has poor sensitivity; Arveladze *et al*.[6] noted sensitivity of just 43% preoperatively, reflected in our experience where USG sometimes showed fluid tracts but failed to confirm the foreign body. CT may reveal chronic bony changes, but these may mimic osteomyelitis, as seen in three of our cases. MRI, although capable of revealing soft tissue and signal changes, failed to consistently identify rubber fragments—similar to the limitations described by the sponge rubber case report by Roth *et al*.[7]

3. Clinical presentation: Sinus tracts and osteomyelitis mimic

Our observation of delayed sinus tract formation (4 out of 12 cases) echoes the sponge rubber case report, where a retained fragment caused granuloma formation and mimicked malignancy. In addition, rubber fragments left *in situ* may trigger osteolytic or osteoblastic lesions resembling chronic osteomyelitis or tumors—a phenomenon also noted in reports of forgotten foreign bodies mimicking osteomyelitis.

4. Management implications

Like earlier studies, ours demonstrates that despite symptomatic improvement with antibiotics and routine wound care, definitive treatment requires removal of the foreign body. Wound healing and infection resolution are dependent on full extraction of the retained rubber. This principle underscores both the findings of Chang *et al*. and broader foreign body literature.

The mid foot was the most frequently involved site in our series. The midfoot, especially the tarsometatarsal area, is a central weight-bearing region of the foot. During walking or standing, a large portion of body weight is transferred through the midfoot, increasing the likelihood of forceful contact if stepping on a sharp object like a nail. The plantar aspect of the midfoot has relatively less soft tissue and fat padding compared to the heel. This means less cushioning to absorb the force of penetration, allowing sharp objects to more easily reach deeper structures.

Surgical exploration and foreign body removal led to resolution in all cases. This outcome aligns with literature consensus that definitive management necessitates surgical intervention, particularly when conservative measures fail or chronic symptoms persist.

A key lesson from our experience is the need for a high index of clinical suspicion, especially when patients report a nail puncture through footwear and present with unresolved or recurrent symptoms. A detailed history—particularly noting the use of rubber-soled footwear—should raise early concern for retained nonmetallic fragments. Given the poor sensitivity of routine imaging, clinicians should not hesitate to pursue surgical exploration if suspicion remains high. The plantar approach requires meticulous dissection due to the complex multilayered anatomy of the sole, including critical neurovascular structures. Therefore, involvement of a plastic surgeon is advisable in cases where a deeply embedded foreign body is suspected, to ensure safe exposure and minimize soft tissue damage.

Clinical message

Few important things which we can learn from this study—(1) High index of suspicion-Strong clinical suspicion is crucial when managing foot punctures through rubber soles—even if initial symptoms abate. A detailed history (noting footwear involvement) is essential, as seen across both classic case reports and our series. (2) Imaging must be multimodal-reliance on plain radiography is not sufficient. USG may guide decision-making but lacks sensitivity. CT and MRI can identify indirect signs such as bone changes or sinus tracts. Still, definitive management may hinge on surgical exploration prompted by suspicion, not imaging alone. Communication with the radiologist is essential prior to making surgical decisions, as it facilitates accurate interpretation of imaging findings and helps guide appropriate management. (3) Early intervention improves outcomes—delays correlate with complications such as osteomyelitis or deep tissue infection. Literature demonstrates longer lead time in patients requiring surgery, and our cases echoed this; earlier in the series, delays led to more advanced pathology.

Conclusion

The consistent theme across the literature and our case series is unequivocal: rubber sole fragments retained in the foot post-puncture injury are radiolucent, diagnostically elusive, and require removal for resolution. Clinicians must maintain vigilance and proceed to surgical exploration when suspicion persists despite negative imaging. The management of rubber sole foreign bodies in the foot requires a coordinated effort involving the orthopedician, plastic surgeon, and radiologist to ensure accurate diagnosis, effective removal, and optimal soft tissue and structural repair. Future work could focus on improving imaging modalities or developing protocols for early detection.

Declaration of patient consent

Written consent for publication of patient details were obtained from the parent/guardian. Approval from institutional ethical committee was obtained beforehand.

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Author contributions

Dr. Sampat Dumbre Patil: Decision-making, reviewing, and editing the manuscript. Dr. Ameya H. Velankar: Manuscript preparation, figures, literature review, and artwork. Dr. Manoj Dinkar Pawar: Decision-making and reviewing the manuscript. Dr. Sumit Saxena: Decision-making and reviewing the manuscript. Dr. Vaishali Dumbre Patil: Radiological investigations and diagnosis and editing the manuscript.

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Conflicts of interest

There are no conflicts of interest.

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Original Article

Ability of distal medial tibial plating for the fixation of distal tibial spiral fractures: A finite element analysis

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Abstract

Purpose: Distal spiral tibial shaft fractures present fixation challenges, especially in patients unsuitable for intramedullary nailing. This study evaluated the biomechanical stability of medial minimally invasive percutaneous plating osteosynthesis (MIPO) under various physiological loads. **Materials and Methods:** A finite element model of a distal AO/OTA 42-A1.1c tibial spiral fracture was created using computed tomography data. A precontoured titanium LCP™ medial distal tibia plate was simulated with nine locking screws. Material properties were assigned to cortical and cancellous bone. Loading conditions included axial compression (600 N), varus/valgus bending (300 N at 9° offset), and internal/external torsion (6 N·m). Von Mises stress and fracture displacement were analyzed. **Results:** Axial loading produced a peak plate stress of 508.06 MPa and 2.17 mm displacement. Valgus and varus loading generated stresses of 490.17 MPa and 324.08 MPa, with displacements of 3.86 mm and 2.01 mm, respectively. External and internal torsion resulted in stresses of 354.23 MPa and 358.9 MPa, with displacements of 2.64 mm and 2.22 mm. **Conclusion:** Medial MIPO provides adequate mechanical stability under various physiological loads, with stresses remaining below the titanium fatigue threshold (600 MPa). These findings support its clinical use in patients requiring early mobilization and where nailing is contraindicated.

Keywords: *Biomechanical*, *finite element*, *fracture*, *stress*

Introduction

Tibial shaft fractures represent the most common long bone fractures. According to the AO/OTA classification system, spiral fractures (AO/OTA 42-A1) represent approximately 34% of tibial shaft fractures, followed by oblique fractures (AO/OTA 42-A2), which account for 17%.[1] Externally rotated spiral fractures are the most frequently observed and are often accompanied by a concurrent fibular fracture. These injuries can occur as a result of high-energy trauma—such as traffic accidents or falls in young males, or due to low-energy mechanisms like ground-level falls in elderly individuals.[1,2]

Especially in geriatric patients, bone quality and overall physical condition are often compromised, making early mobilization and weight-bearing essential to prevent complications related to immobilization.[3] Therefore, it is crucial to choose a fixation technique that provides sufficient stability and can support early weight-bearing.

While intramedullary nailing remains the gold standard treatment for tibial shaft fractures, it may not be suitable in certain patients due to soft tissue conditions, associated injuries, or technical limitations.[4] Recently, minimally invasive percutaneous plating osteosynthesis (MIPO) has gained traction as a viable alternative, particularly in cases with compromised anterior and medial soft tissue coverage where open reduction and internal fixation may increase the risk of wound complications. In addition, MIPO can also be used in patients with combined multiple injuries in whom intramedullary reaming is contraindicated because of

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the potential increased risk of pulmonary complications or in cases where blocking screws, locking screws, or percutaneous repositioning techniques are difficult to perform.

Katı *et al*.[5] have proposed MIPO as an effective method for managing spiral and spiral wedge tibial shaft fractures, hypothesizing that it provides improved alignment and torsional stability. Biomechanical studies further support the use of medial plating, showing superior stiffness in both axial and torsional loading and reduced fracture site displacement and rotation compared to lateral plating.[6,7] However, limited studies have specifically evaluated the biomechanical performance of the medial plates in the treatment of distal tibial spiral fractures. This study aimed to evaluate the biomechanical performance of the medial plate for the stability of distal tibial spiral fracture under different physiological loads.

Materials and Methods

A three-dimensional (3D) lower-leg finite element model that included the tibia was developed. The bony structures were generated using a computed tomography dataset segmentation from the Visible Human Project.[8] The 3D tibia model was reconstructed via the cortical shell and cancellous core. A simple spiral fracture model (AO/OTA 42-A1.1c) was made at the distal third of the tibia shaft [Figure 1A]. A common implant: periarticular distal tibial locking plate (Zimmer, Warsaw, IN) was utilized in this simulation. This medial distal tibial plate features an anatomical precontoured titanium plate and is used with 10 holes and 168 mm in length. The plate was affixed to the tibial shaft with three 3.5 mm locking screws, whereas six 3.5 mm locking screw were used for the articular fixation. The plate and screw models were simplified without threads. The placement of the medial tibial plate on the simulated spiral fracture is shown in Figure 1B.

Figure 1: The reconstructed tibial model with (A) a simulated spiral fracture and (B) implanted a medial distal locking plate

The ANSYS Workbench 19 (ANSYS Inc., Canonsburg, PA, USA) was used for computational analysis. A frictional contact behavior was defined between the fracture fragments with a coefficient of friction of 0.2 for possible contact after loading, while a coefficient of friction of 0.42 was used at the interfaces between the bone and the plate.[9] Fully constrained treatments were applied between the screws and the surrounding bone, as well as between the contact surfaces of the plate and the screw head, to simulate the mechanism of tightened locking. Both plate and screws were made of titanium and modeled according to specifications described in previous studies (Young's modulus = 110,000 MPa; Poisson ratio = 0.3), while the cortical bone was modeled with a Young's modulus of 17,500 MPa and 0.3 Poisson ratio. Material properties for the cancellous bone were assigned with a Young's modulus of 1500 MPa and Poisson ratios of 0.12. Bones and implants were modeled as linear elastic, isotropic, and homogeneous materials.

A vertical compressive load of 750 N was applied to simulate physiological weight-bearing, corresponding to loading conditions ranging from cane-assisted walking to fast walking.[10] For varus-valgus bending tests, a load of 300 N was applied at the medial side of the distal tibial articular surface in a direction deviated 9° medially from the mechanical axis of the lower limb to simulate varus stress.[11] Conversely, a 300 N load was applied to the lateral side of the distal tibial articular surface at a 9° lateral deviation to simulate valgus stress. For torsional loading, the distal articular surface of the tibia was fixed, and internal and external torques of 7.5 N m were applied to the proximal articular surface to simulate internal and external rotation forces, respectively.[10] Maximum von Mises stress in the bone plate and the maximum displacement of the fracture surface were calculated for evaluation.

Results

Under vertical loading [Figure 2], the bone plate exhibited a maximum von Mises stress of 508.06 MPa, with a corresponding fracture site displacement of 2.17 mm. Valgus loading [Figure 3] resulted in a lower peak von Mises stress of 490.17 MPa and a displacement of 3.86 mm. In contrast, varus loading [Figure 4] produced a higher von Mises stress of 324.08 MPa and increased displacement of 2.01 mm. Under external rotational

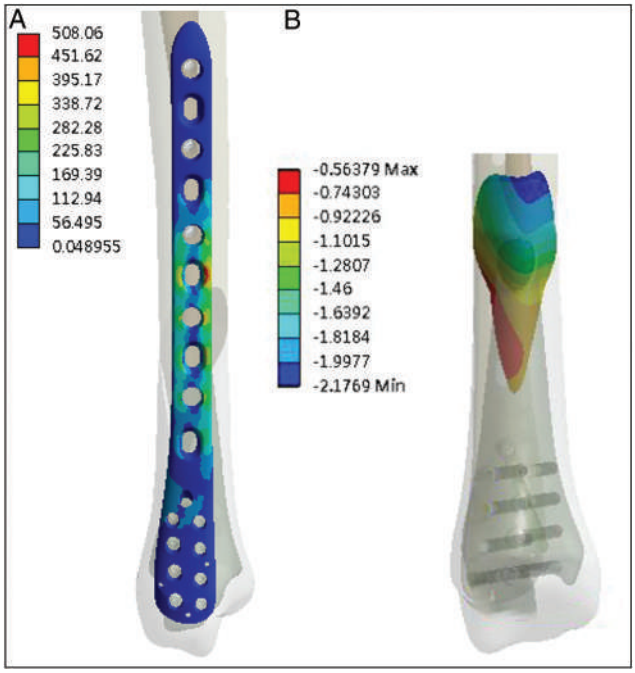

Figure 2: The results under compression load. (A) von Mises stress distribution on the plate and (B) the displacement on the fracture surface

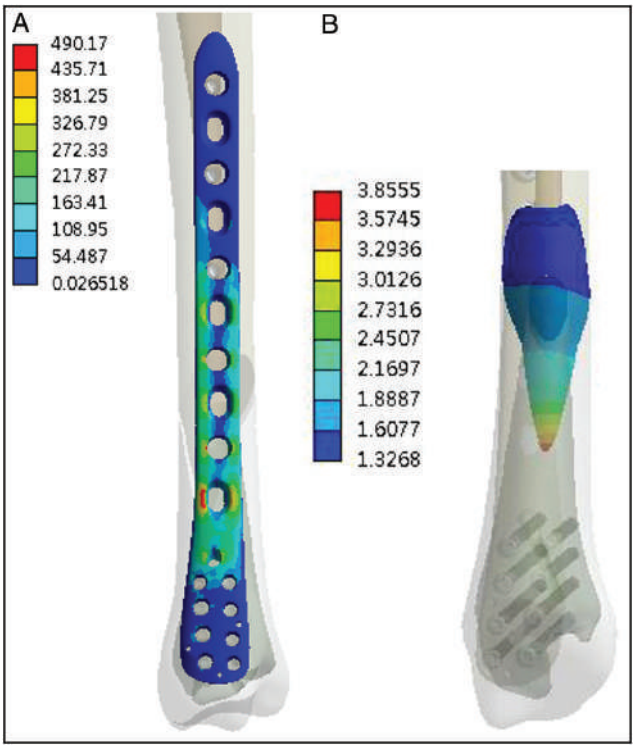

Figure 3: The results under valgus load. (A) von Mises stress distribution on the plate and (B) the displacement on the fracture surface

loading [Figure 5], the maximum stress was 354.23 MPa, with a fracture displacement of 2.64 mm. Internal rotational loading [Figure 6] resulted in a peak von Mises stress of 358.9 MPa and the greatest fracture displacement observed, at 2.22 mm.

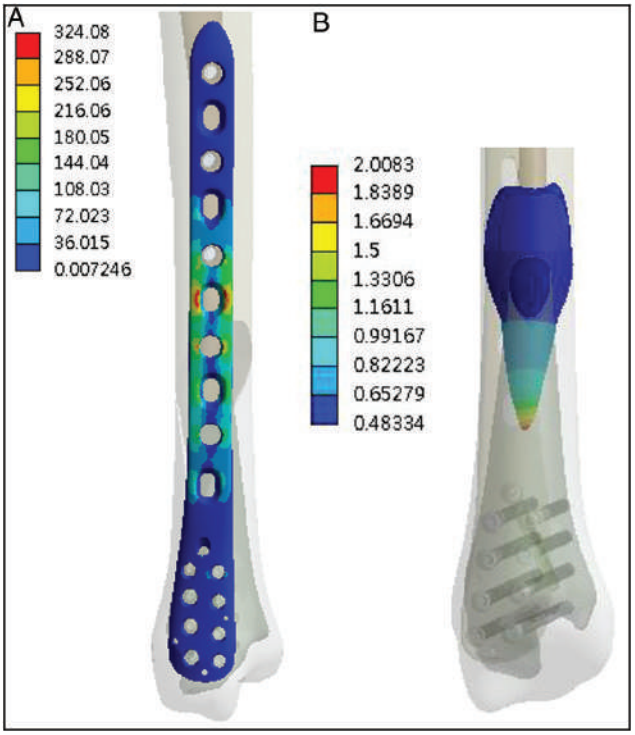

Figure 4: The results under varus load. (A) von Mises stress distribution on the plate and (B) the displacement on the fracture surface

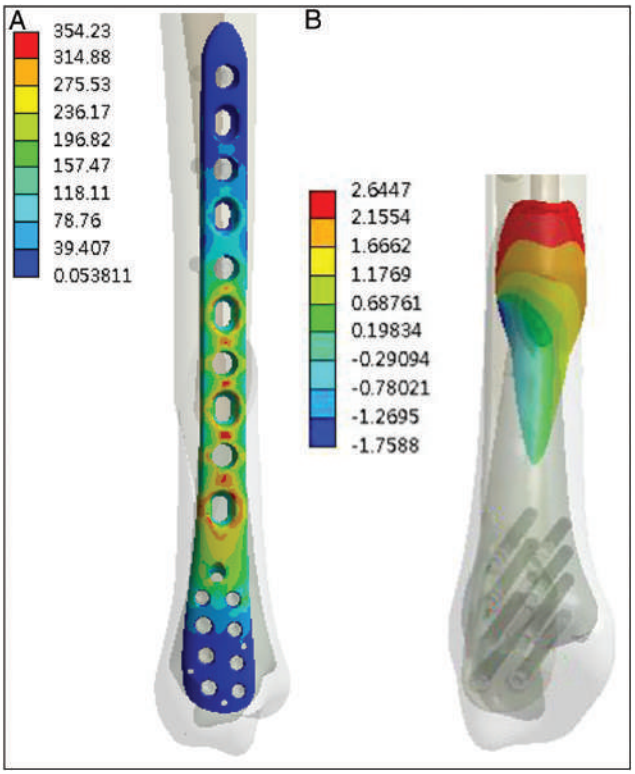

Figure 5: The results under external torque. (A) von Mises stress distribution on the plate and (B) the displacement on the fracture surface

Discussion

This study investigated the biomechanical performance of a medial distal tibial plate for the stabilization of

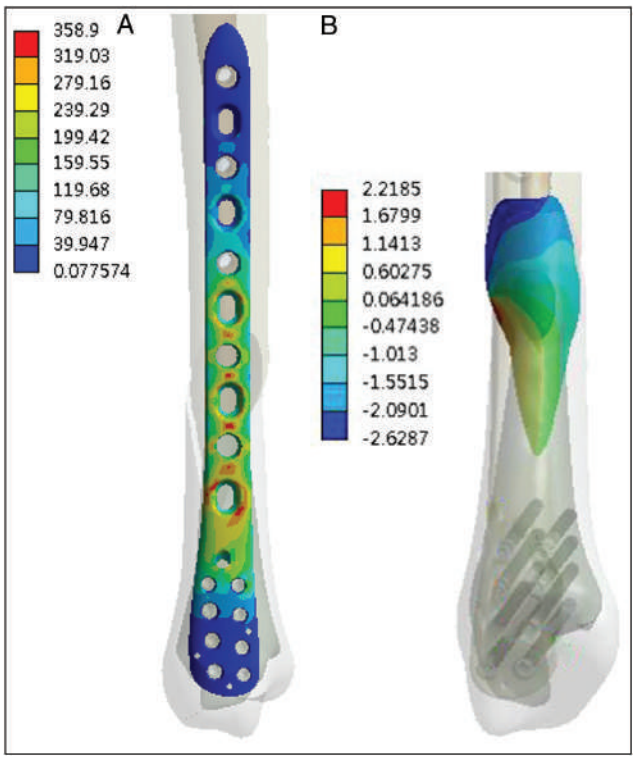

Figure 6: The results under internal torque. (A) von Mises stress distribution on the plate and (B) the displacement on the fracture surface

distal third spiral tibial shaft fractures under various physiological loading conditions. The finite element analysis demonstrated that the medial plate provided sufficient stability under vertical compressive, varus, and internal/external rotation loadings, with relatively low fracture displacement (approximately 2 mm). These findings support its use in clinical scenarios requiring early mobilization and weight-bearing—particularly among elderly or polytrauma patients who are at high risk of immobilization-related complications.

Vertical loading, which simulates normal weight-bearing, produced the highest von Mises stress (508.06 MPa) in the plate, yet the corresponding fracture displacement was limited to 2.17 mm, indicating effective load transfer and structural stiffness. Importantly, while the maximum stress remained below the commonly cited fatigue strength of titanium alloy (~600 MPa), it approached this threshold. This is clinically significant, as repeated loading cycles—especially during activities such as walking or stair climbing—can lead to fatigue failure over time if the stress approaches or exceeds the fatigue endurance limit of the implant material. Therefore, although acute performance under single-cycle loading is acceptable, the proximity to fatigue limits warrants caution in high-demand patients or those with delayed healing.

Varus loading resulted in the lowest stress (324.08 MPa) and minimal displacement (2.01 mm), likely because the loading vector aligned with the medial plate's position and construct geometry. In contrast, valgus loading, which applies a bending moment opposite to the plate's location, produced higher stress (490.17 MPa) and increased displacement (3.86 mm), reflecting the plate's biomechanical disadvantage under medially-directed bending forces. These findings are consistent with prior biomechanical studies showing superior stiffness in axial and valgus directions for medial plates, but increased vulnerability under varus loading.[6,7]

Under torsional conditions, both internal and external rotational loading resulted in moderate stress (354.23–358.9 MPa), but the highest displacement at the fracture site (2.22–2.64 mm), suggesting limited torsional control. This may be due to the geometric limitations of the plate and screw configuration in resisting rotational moments. While Katı *et al*.[5] advocated medial MIPO for spiral fractures, citing improved alignment and torsional resistance, our findings suggest that the construct alone may be insufficient to fully counteract torsional instability. In clinical practice, this may necessitate supplemental fixation techniques or altered screw configurations to optimize rotational stability, especially in active patients or complex fracture patterns.

The proximity of observed stress values to the fatigue strength of titanium emphasizes the need for careful patient selection and postoperative load management. Though none of the loading scenarios exceeded the fatigue threshold, repeated high-load activities or delayed union could potentially result in cyclic fatigue and implant failure. Therefore, long-term implant durability should be a consideration, particularly in younger or heavier patients and in those expected to return to high levels of activity.

Several limitations must be acknowledged. The finite element model utilized homogeneous, isotropic, and linear elastic assumptions for bone and implant materials, which may not fully represent *in vivo* mechanical behavior. Thread features of the screws were not modeled, and biological healing or callus formation over time was not considered. Nonetheless, the controlled and comparative nature of the simulated loading conditions provides valuable insight into the mechanical performance of the medial plating construct.

Conclusion

Medial distal tibial plating using the MIPO technique provides adequate stability for distal third spiral tibial shaft fractures under different physiological loadings, with von Mises stress remaining below the fatigue threshold of titanium alloy. However, increased stress and displacement under compression and valgus loads highlight the need for cautious application in high-demand patients.

Authors' note

We represent that this submission is original work, and is not under consideration for publication with any other journal.

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Conflicts of interest

There are no conflicts of interest.

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Original Article

Guide wire centralization for femoral nailing: A novel technique to improve alignment and reduce radiation

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Abstract

Objectives: Femoral shaft fractures are frequently managed with intramedullary nailing, where central guide wire placement is vital for optimal alignment and implant positioning. Despite various reduction techniques, literature lacks a stepwise method for consistent guide wire centralization in femoral nailing. We aim in this study to describe a maneuver in centralizing the guidewire thus reducing the radiation exposure and surgical time. **Materials and Methods:** A prospective study was conducted from January 2018 to January 2023 on 60 patients with nailable femoral shaft fractures using a novel guide wire centralization technique. The technique involved controlled manipulation of a 2.8 mm bent guide wire using a T handle to align it accurately in the distal femoral notch with reduced reliance on intraoperative fluoroscopy. **Results:** The average time for guide wire centralization among six surgeons was 5.02 min, with a mean of 8.18 C-arm shots per procedure. This demonstrated a notable reduction in operative time and fluoroscopic exposure compared to traditional methods, suggesting improved efficiency, and reproducibility.

Keywords: *Femoral shaft fracture*, *fluoroscopy*, *guide wire centralization*, *intramedullary nailing*, *surgical technique*

Introduction

Femur shaft fractures commonly occur due to high velocity trauma and have an annual incidence of 10–21 per 100,000 person-years.[1,2] These fractures are commonly treated with an intramedullary fixation device placed suitably over a guide wire. Intramedullary fixation devices are currently considered the gold standard treatment of shaft of femur fractures.[3-5] The goal of operative treatment is restoration of normal length, axial alignment, angulation, and rotation.

There are various techniques described for reduction of shaft of fracture of femur such as the use of curved hemostatic forceps and the lever principle,[6] various devices have been introduced to facilitate closed reduction, including invasive devices for direct reduction, such as bone hooks, ball spikes, the finger reduction tool[7,8], and the Schanz pin as the Joystick technique[8,9] as well as noninvasive methods for indirect reduction, such as F-tools,[10] external support devices,[11] rapid reductors[12], and reduction frames.[13] However, there is no literature on centralization of placement of guidewire in fractures of femur amenable to nailing. The distal femur has a wider medullary canal, making guidewire placement crucial for proper implant positioning. Eccentric position of the guide wires in the shaft of femur changes the direction of the reamer and in turn the nail placement, resulting in varus or valgus position in coronal plane and procurvatum or recurvatum deformity in sagittal plane. Repeated attempts to place the guidewire centrally increase the operative time and fluoroscopic exposure. Ideally, the guidewire's position in the femoral shaft should be central and at the distal end in the center of intercondylar notch.[14] However, passing the guidewire across the fracture site can be technically demanding at times, as most fractures of femur have varying degrees of deforming forces, comminution, and displacements can make it more challenging.

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In this study, we describe a stepwise approach for passing and centralization of guide wire to the "desired spot" in the notch area of distal femur, making it technically easy, with the minimal use of c-arm image intensification.

Materials and Methods

This was a prospective study conducted on nailable (subtrochanteric, mid shaft and distal third shaft femur fractures) femur fractures operated between January 2018 to January 2023.

Sixty patients were included in this study done at our center. All the surgeons participating in this study were operating in the same institution and with the assistance of same radiographer.

Inclusion criteria

1. Subtrochanteric, middle third and distal third shaft femur fracture.
2. Age more than 18 years.

Exclusion criteria

1. Compound fractures.
2. Ipsilateral fracture in tibia.
3. Polytrauma patient.
4. Femur fractures in pregnancy.

Surgical technique

After initial set up, the patient was taken on the traction table and traction given with limb in 10° of internal rotation was given [Figures 1 and 2]. The incision was taken three fingers proximal to greater trochanter and the entry was made just medial to the greater trochanter with entry awl for long proximal femoral nail or piriformis fossa for femur nail. The 2.8 mm guidewire was inserted under image intensifier control, to enter the medullary canal and was negotiated across the fracture site using suitable maneuver. The guidewire was bent about 30° around 1 cm from the tip (caudad bend) [Figure 3]. The introduction of guide wire was manual, using the universal chuck with T handle. The guide wire was tightened in the T handle in such a fashion that the caudad bend was co-planar with the horizontal limb of T handle [Figure 4]. After the entry was taken from the piriformis fossa with an entry awl, the guidewire was inserted in such a position that the concave surface of the bend done initially was facing outward laterally. Further, when resistance of guide wire making the first hit on the lateral cortex was felt [Figure 5], the guide wire was rotated quarter turn that is, 90 degs

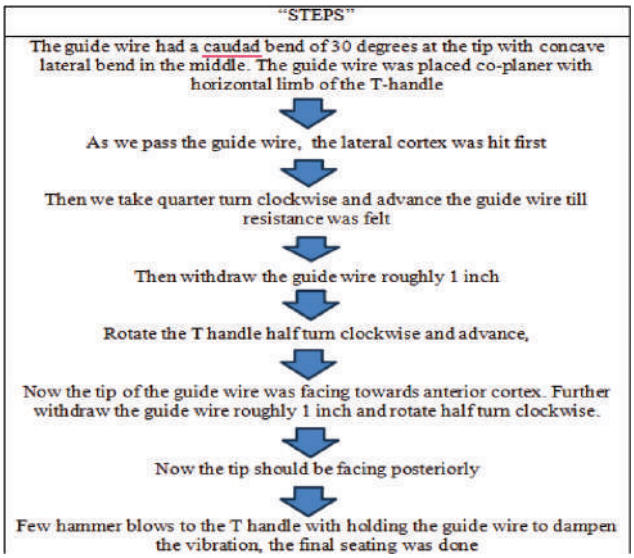

Figure 1: Steps of the surgical technique of guidewire maneuvering

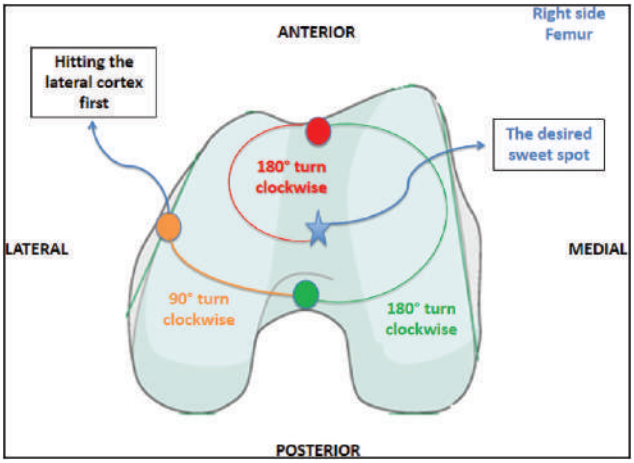

Figure 2: Diagrammatical representation of guidewire maneuvering

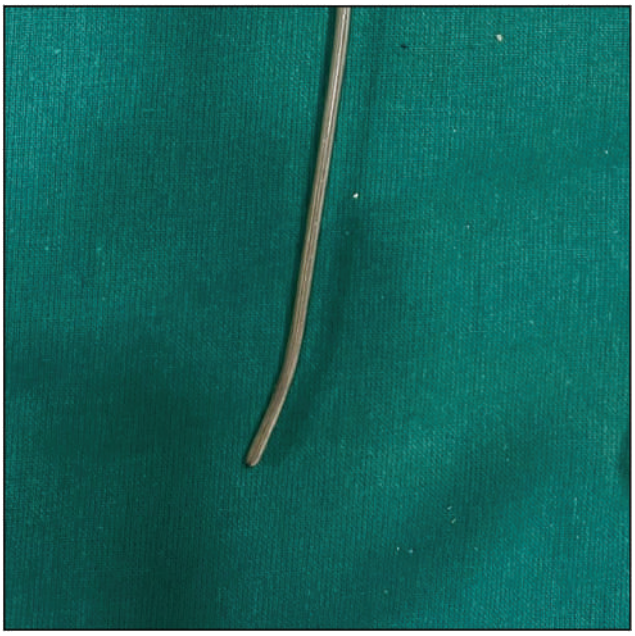

Figure 3: Caudad bend of the guidewire

outwards (clockwise for right side, anticlockwise for left side) and was moved distally till 3 inches proximal to the distal joint line. The concavity of guide wire at this point faced posteriorly [Figure 6]. The T handle was rotated half turn, that is, 180° outwards so that the concave side faced anteriorly [Figure 7] and finally the T handle with the guide wire was rotated 180° again outwards so that tip faced posteriorly and was finally seated firmly by gentle blows reaching effectively to the desired spot [Figure 8]. After this, sequential incremental reaming was done as usual and nailing procedure was completed.

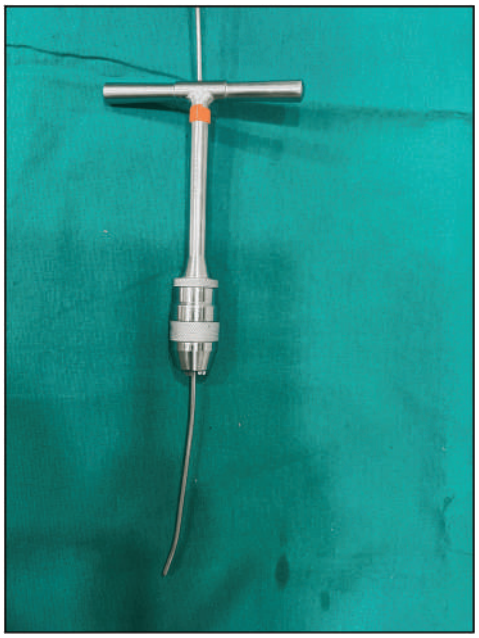

Figure 4: Co-planar guidewire and T handle

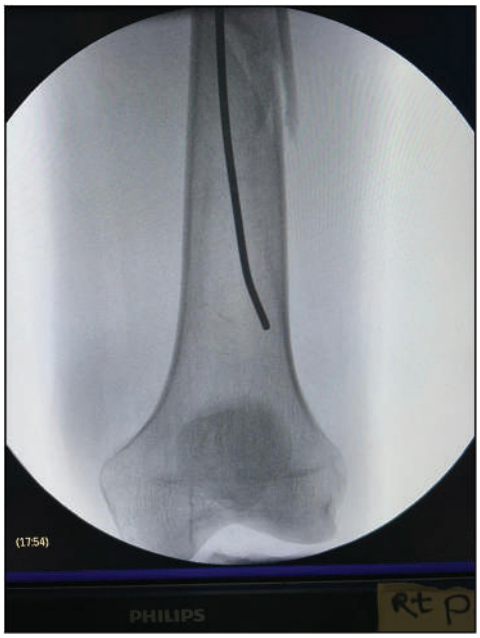

Figure 5: Hitting the lateral cortex

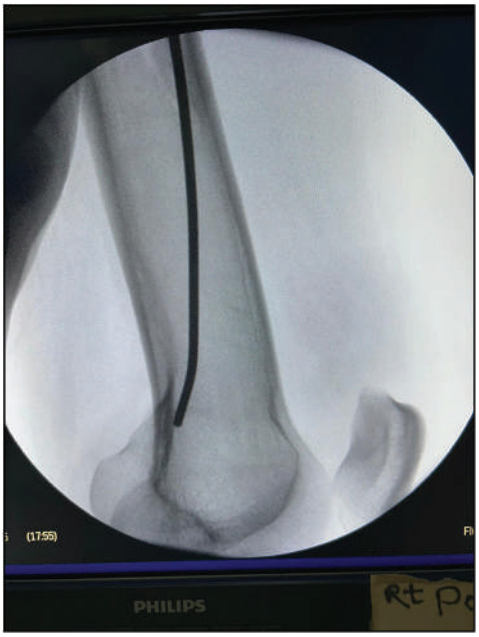

Figure 6: Posteriorly facing guidewire

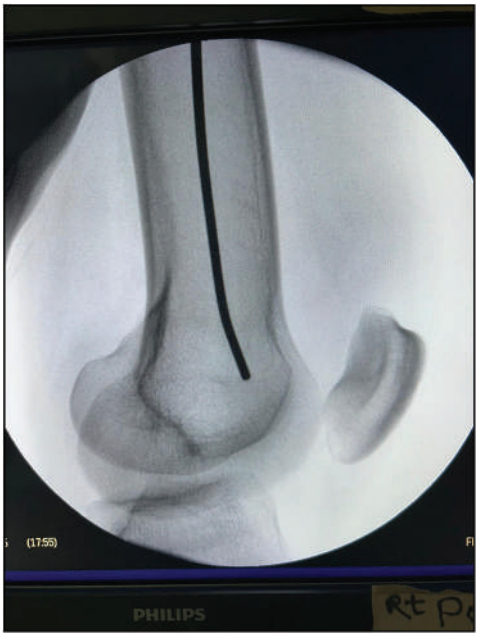

Figure 7: Anteriorly facing guidewire

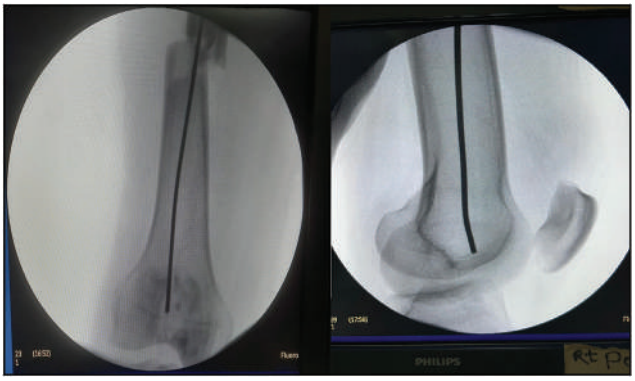

Figure 8: Guidewire reaching the desired spot

Table 1: Mean time in minutes and mean C-arm shoots

	Mean time in minutes for guide wire centralization	Mean number of C-arm shoots
Surgeon 1	3.15	7.43
Surgeon 2	4.98	7.05
Surgeon 3	5.77	9.17
Surgeon 4	5.47	8.00
Surgeon 5	5.48	9.15
Surgeon 6	5.25	8.30
Mean of all six surgeons	5.02	8.18

Result

The average time taken by all six surgeons to centralize the guidewire after crossing the fracture site was 5.02 min. This significantly improves overall surgery time compared to the traditional method, where each step of guide wire centralization is confirmed under the C-arm. In addition, the average number of C-arm shots used by all six surgeons was 8.18, substantially lower than the number required when manually guiding the guidewire into the desired position [Table 1].

Discussion

Conventionally, fracture of shaft of femur has been treated with intramedullary nailing. Intramedullary nails have proven to be safe, effective and less invasive than other fixation techniques. Use of guidewire is essential for reaming of the medullary cavity as well as placement of nail. Correct placement of guide wire is the key for final position of implant. Correct central placement of the guide wire in distal femur is difficult due to trumpet-like anatomy of distal femur.

Literature mentions different method to address rotational alignment for femur nailing such as the "cable techniques" for the determination of varus-valgus malalignment; the "hyperextension test," "radiographic recurvatum sign," "tibial plateau sign," and "meterstick technique" for length analysis; and the "hip rotation test," "lesser trochanter shape sign," "cortical step sign," and "diameter difference sign" for rotational analysis.[15] The evaluation of the profile of the lesser trochanter is one of the most widely used methods to assess femoral rotation.[16-18] However, there is no literature which mentions placement of guidewire centrally in medullary canal for addressing coronal and sagittal alignment of implant. This becomes more important for distal shaft femur fracture as any deviation from central position of guide wire will cause malalignment of the final position of nail. Knowing the trajectory of guidewire and terminal bend, its movement on rotation allows us to presumably place the nail at center of the medullary canal in antero-posterior and lateral plane. Our technique describes stepwise details of placement of guidewire for getting it centrally in canal at the desired sweet spot.

This guidewire centralization technique works well in subtrochanteric fractures, comminuted shaft femur fractures, distal one-third junctional shaft femur fractures, after preliminary reduction and guidewire negotiation in distal fragment. This surgical technique of guidewire centralization in distal fragment works well in almost more than 90% of the time depending on morphology of fracture pattern, displacement of fragments and adjuvant use of various reduction techniques. Operating surgeon takes care to bend the caudal end of the guide wire co-planar with the horizontal limb of T handle. While negotiating the fracture, if the guide wire gets directed towards the medial wall of femur, then by efforts we bring tip and caudad bend to lateral wall by appropriately half turning the T handle thus hitting the lateral wall. The use of this technique considerably reduces the exposure to radiation as the number of C-arm shoots required is reduced and surgical time is also reduced.

Conclusion

This technique is a simple method which can be used for centralization of guide wire for femur shaft fractures, subtrochanteric fractures, comminuted shaft femur fractures and distal 1/3 junctional shaft femur fractures after preliminary reduction and guide wire negotiation in distal fragment which helps central placement of final implant. This method reduces surgical time and radiation exposure and is easy and reproducible technique by most of surgeons.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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Case Report

Hybrid "Parhar Salvage" technique for infected proximal tibia nonunion in an adolescent: A complex limb salvage strategy combining Masquelet, flap coverage, and hybrid fixation

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Abstract

Infected nonunions of the proximal tibia in adolescent patients represent a complex clinical problem due to the combination of segmental bone loss, chronic osteomyelitis, and compromised soft-tissue envelope. These cases demand a carefully planned, multistaged reconstructive approach to achieve limb salvage, infection control, and functional recovery. We report the case of an 18-year-old male presenting with a chronically infected nonunion of the proximal tibia following two failed surgeries for fracture fixation. The patient exhibited persistent pain, draining sinuses, and instability, with radiographs showing extensive metaphyseal bone loss and sequestrum formation. Stage 1 involved aggressive surgical debridement, removal of all infected hardware and necrotic tissue, followed by application of a knee-spanning external fixator and placement of an antibiotic-impregnated polymethyl methacrylate cement spacer as part of the Masquelet technique. After that, Stage 2 was performed, which included insertion of a fibular strut graft and autologous iliac crest cancellous graft within the induced membrane. A long lateral locking compression plate was used for internal fixation, augmented with medial and anterior external rods to form a hybrid construct. A gastrosoleus flap was used to achieve soft-tissue coverage over the anterior tibial defect. The patient was followed-up for 2 years postoperatively. Radiographic evaluation confirmed complete osseous union, incorporation of the fibular graft, and maintenance of limb alignment. The flap healed without complication. Mild equinus deformity due to soft-tissue scarring was corrected with tendo-Achilles lengthening.

Keywords: Adolescent, complex orthopedic reconstruction, fibular strut graft, gastrosoleus flap, hybrid fixation, infected nonunion, limb salvage, Masquelet technique, proximal tibia

Introduction

Infected nonunion of the proximal tibia remains a formidable orthopedic dilemma, particularly in young patients with significant bone loss,[1] soft-tissue compromise, and chronic infection.[2] While options such as the Ilizarov method, free vascularized grafts, and bone transport exist, each has limitations, especially when prior surgeries have failed and soft tissue is compromised. The Masquelet technique has emerged as a reliable alternative, especially when combined with aggressive debridement, antibiotic control, and appropriate reconstruction.[3] This case report highlights a successful staged reconstruction using a novel hybrid internal–external fixation strategy along with soft-tissue flap coverage, ultimately salvaging the limb and restoring function.

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Case Presentation

An 18-year-old male presented to our institute with complaints of persistent pain, pus discharge, and

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instability in the left leg for over 1 month. He had undergone two previous surgeries elsewhere for a proximal tibial fracture that resulted in deep infection and nonunion, with exposure of necrotic bone. On clinical examination, the proximal tibia was swollen, tender, and had multiple draining sinuses with soft-tissue loss [Figures 1 and 2].

Prior to presentation to our unit, the patient underwent two operative procedures at outside hospitals: (1) on August 06, 2022—surgical debridement of the wound; (2) on August 09, 2022—wound debridement with application of an external fixator. Both prior procedures were followed by recurrent drainage and progressive instability, ultimately leading to referral to our center.

Radiographs revealed a grossly unstable proximal tibial segment with sequestrum and disrupted cortical integrity [Figures 3 and 4]. A decision was made to proceed with a staged limb salvage protocol.

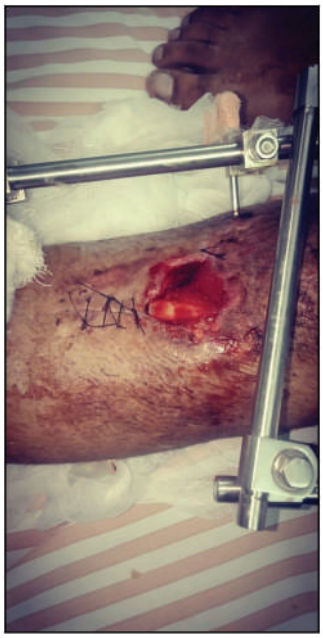

Figure 1: Preoperative clinical and pus-discharging wound on the proximal tibia

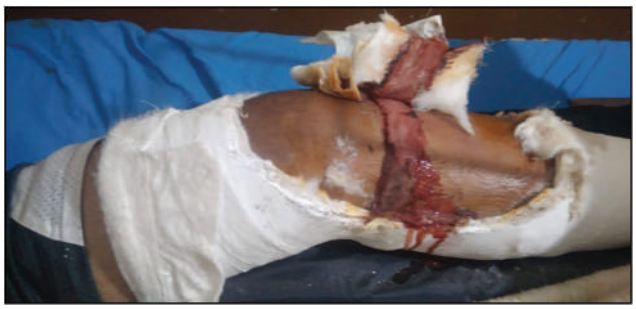

Figure 2: Preoperative clinical and pus-discharging wound on the proximal tibia

A detailed chronology of the patient's course, prior procedures, and in-house management is summarized in Table 1.

Stage 1: Infection control and induced membrane formation

The patient underwent aggressive debridement with excision of all necrotic bone and devitalized tissue. A

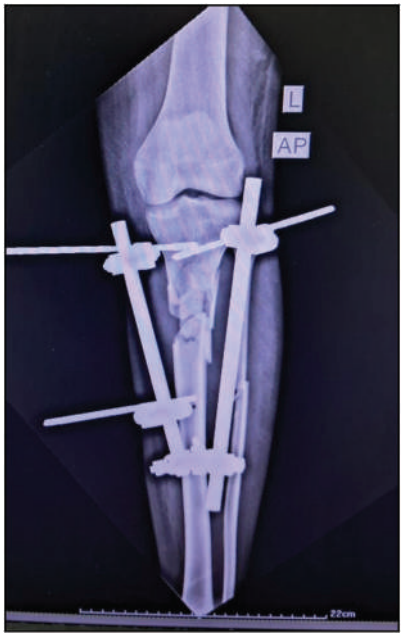

Figure 3: Preoperative anteroposterior X-ray showing infected outside operated proximal tibial fracture with segmental bone loss and failed implants

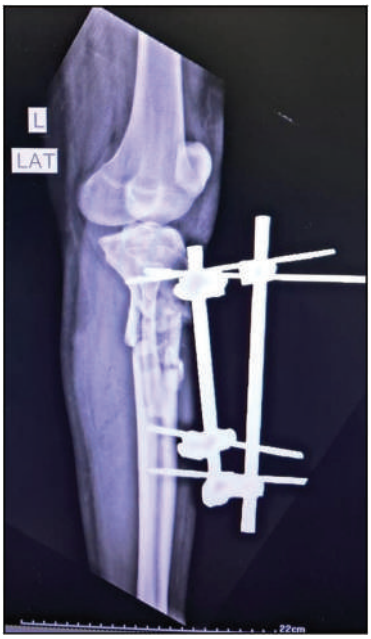

Figure 4: Preoperative lateral X-ray revealing gross instability and destruction of the proximal metaphysis

Table 1: Chronology of events

August 05, 2022	Date of injury
August 06, 2022	First surgery (debridement)
August 09, 2022	Second surgery (application of ex fix)
August 31, 2022	Presented to us with pus pouring discharge from the wound site
September 03, 2022	First-stage surgery
January 10, 2023	Second-stage surgery
June 04, 2023	Removal of ex fix (anterior rod)
July 03, 2023	Removal of the remaining fixator

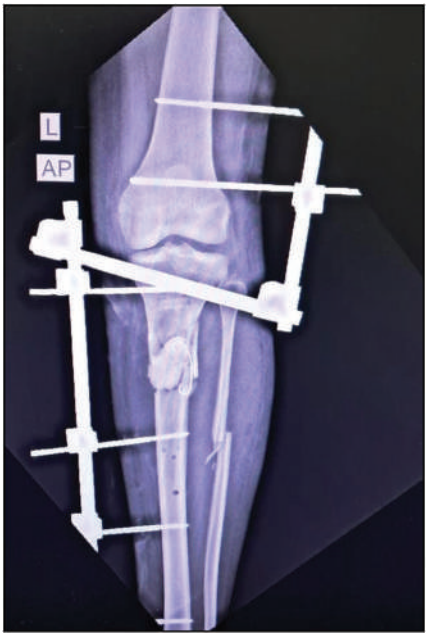

Figure 5: Post-debridement anteroposterior view after placement of an antibiotic cement spacer and a knee-spanning external fixator (Masquelet Stage 1).

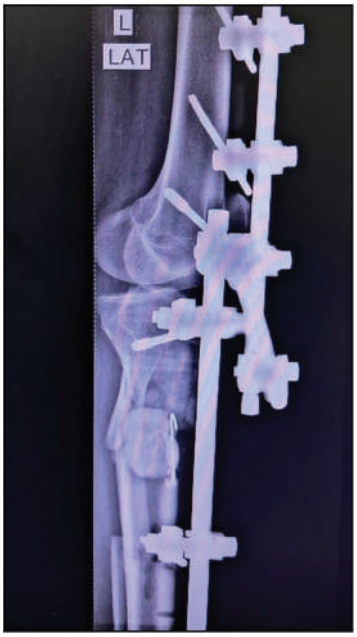

Figure 6: Lateral view after Stage 1 showing effective alignment and spacer stabilization

knee-spanning external fixator was applied to stabilize the limb and maintain alignment.[4] To promote biological reconstruction, Masquelet's induced membrane technique was initiated by placing an antibiotic-impregnated polymethyl methacrylate (PMMA) cement spacer along with vancomycin and gentamicin-laden beads within the defect [Figures 5 and 6].[5] Intraoperative deep tissue samples (three separate specimens) were sent for culture and sensitivity during Stage 1. Cultures grew *Streptococcus pyogenes* sensitive to piperacillin/tazobactam, meropenem, faropenem, and amikacin; based on sensitivity testing, the patient received intravenous piperacillin + tazobactam and amikacin for 2 weeks followed by oral faropenem for 4 weeks. Erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) values were as follows: L baseline ESR 96 mm/h, CRP 39.1 mg/L; prior to Stage 2, ESR/CRP values had decreased to 18/5.4, consistent with infection control.

Stage 2: Reconstruction with hybrid fixation and grafting

After confirming infection clearance through ESR, CRP, and sterile wound culture, the second stage of reconstruction was performed after 4 months of stage 1. A fibular strut graft was harvested and combined with autologous cancellous graft from the iliac crest, which was packed into the cavity surrounded by the induced membrane.[6] The construct was internally fixed using a long lateral locking compression plate (LCP). Given the compromised biology and history of infection, additional mechanical stability was provided by applying anterior and medial external support rods, creating a hybrid fixation

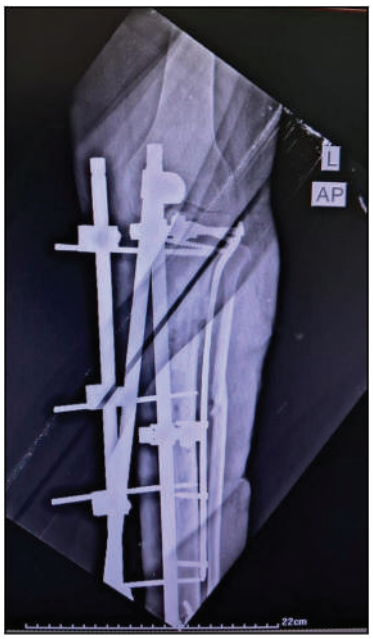

Figure 7: Anteroposterior X-ray after Stage 2 with fibular strut graft, iliac crest graft, and long lateral locking compression plate. External rods (anterior and medial) provide hybrid fixation

system combining internal and external support [Figures 7 and 8].

Due to previous soft-tissue scarring and exposed bone, a gastrosoleus flap was raised and transposed to cover the anterior tibial defect.[7]

Postoperative course and rehabilitation

The patient was mobilized non-weight-bearing for the first 2 weeks postoperatively, followed by progressive weight-bearing with walker assistance. Serial radiographs showed satisfactory callus formation and graft incorporation. The anterior external rod was removed at June 04, 2023 (9 months postoperatively) to reduce frame bulk over the gastrosoleus flap. The medial rod and the final external elements were removed July 03, 2023, after radiographic evidence of consolidation.

Pin site care is done with daily cleaning with normal saline/0.05% chlorhexidine, regular dressing changes, and patient education.

The patient was followed-up weekly in first 2 weeks, bi-weekly until 3 months, monthly until 6 months, then 3-monthly until 1 year, and 6-monthly thereafter. At the 2-year follow-up, the patient was ambulant without aids. Knee range of motion (ROM) was 0° extension

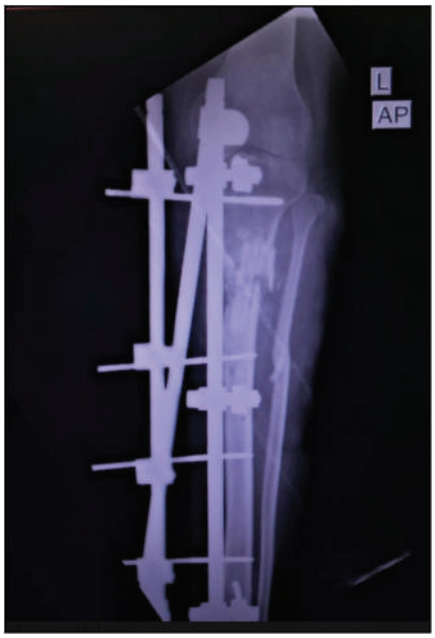

Figure 8: Lateral oblique view post-reconstruction, showing construct and anatomical alignment

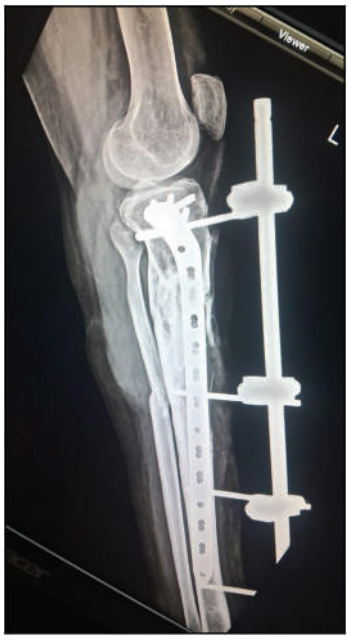

Figure 9: Nine-month follow-up lateral view showing full union, graft incorporation, and stable construct

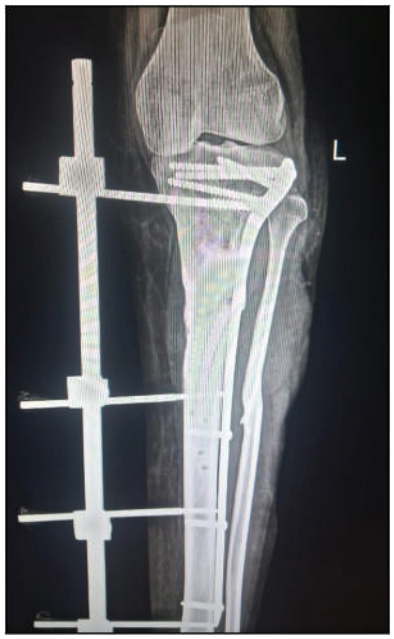

Figure 10: Nine-month follow-up anteroposterior view showing remodeling of the reconstructed proximal tibia

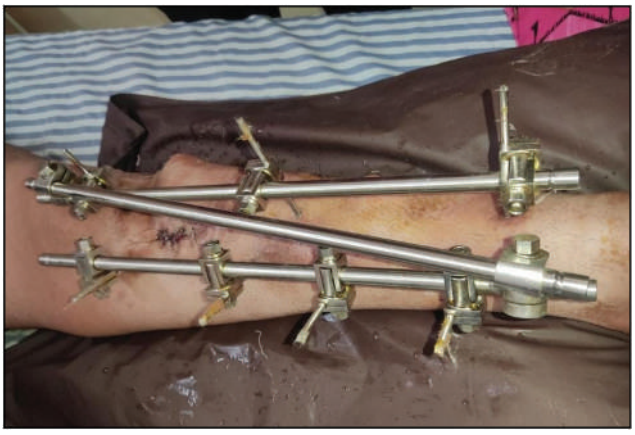

Figure 11: Clinical image showing the healed gastrosoleus flap post-second stage with no signs of wound breakdown

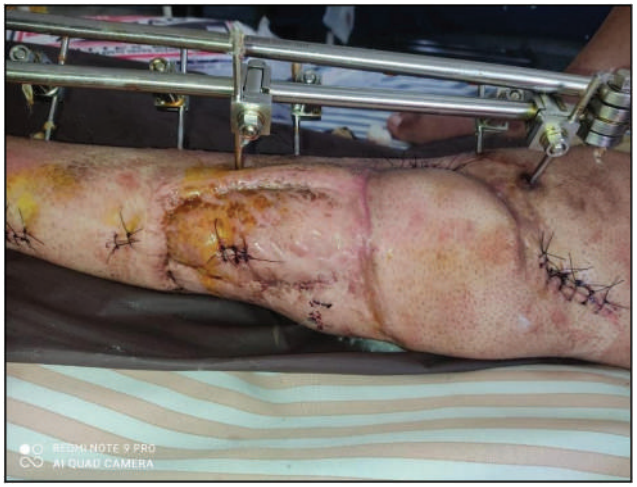

Figure 12: Lateral clinical image showing hybrid fixator construct and flap integration

to 110° flexion. Ankle ROM was dorsiflexion 10° and plantarflexion 15°

At 1 year and 3 months, the patient showed complete union of the proximal tibia, integration of the fibular strut, and remodeling of the grafted segment[8] [Figures 9 and 10]. There were no signs of infection clinically or radiographically. The flap had healed well, and the limb alignment was preserved [Figures 11 and 12]. Mild equinus was addressed with tendo achilles (TA) tendon lengthening due to calf contracture following initial necrosis.

Discussion

Infected nonunion of the proximal tibia, particularly in young individuals, is a complex orthopedic entity that demands a meticulous and multidisciplinary approach. The challenges arise from several concurrent factors: segmental bone loss, chronic osteomyelitis, poor soft-tissue envelope, compromised vascularity, and the psychological burden of limb dysfunction in active individuals.[1,8]

Traditionally, options such as bone transport with Ilizarov, free fibular grafting, or vascularized bone grafts have been employed in such scenarios.[9] However, each modality has drawbacks—prolonged external fixation time in Ilizarov, technical demand and donor site morbidity in vascularized grafts, and recurrence of infection if proper debridement is not achieved. Furthermore, in previously operated cases with failed implants and scarred tissue beds, these methods may be less effective or poorly tolerated.[10]

The Masquelet technique, pioneered by Dr. Alain-Charles Masquelet, offers a staged alternative where a biologically active induced membrane forms a well-vascularized chamber around the bone defect, conducive to bone regeneration once the infection is cleared. The technique has shown promising results in both posttraumatic and postinfective segmental bone loss, with union rates reported between 80% and 95% in recent series.[3,11,12]

In our case, we employed the Masquelet technique following thorough debridement and placement of an antibiotic-loaded PMMA cement spacer. What distinguishes this case is the subsequent construct stabilization strategy. Recognizing that plate osteosynthesis alone may not withstand the complex biomechanical forces at the proximal tibia, especially with a fibular strut, we opted for a hybrid fixation system. Anterior and medial external rods supplemented a long lateral LCP, improving torsional and axial stability and preventing micromotion at the graft–host junction.

In our patient, dual medial and lateral plateau style plating would have required extensive medial soft-tissue dissection and could have compromised the vascularity of the gastrosoleus flap. Given the history of infection and the need for flap inset over the anterior tibia, a long lateral LCP augmented with anterior and medial external rods allowed secure fixation while minimizing further soft-tissue insult. Hybrid fixation also permits staged adjustment/removal of external elements if infection recurs, a useful safety feature in the postinfective setting. Published reports support combined limited internal fixation with external/hybrid support in complex tibial reconstructions.[13,14]

The use of a nonvascularized fibular strut graft, augmented with autologous iliac crest cancellous bone, provided both mechanical strength and osteoconductive scaffold.[15] While vascularized fibula may be preferable in some cases, our approach eliminated the need for microsurgery and reduced donor morbidity. The strut acted as a biological load-sharing construct, gradually incorporating over time under a controlled mechanical environment.

Soft-tissue coverage remains pivotal in infected nonunions. The gastrosoleus flap, a robust regional flap with predictable vascularity, is particularly suitable for defects over the proximal third of the tibia. Its use here helped ensure adequate coverage, improved vascularity at the reconstruction site, and lowered the risk of reinfection.[16–18]

At the final follow-up, the patient demonstrated full radiological union, no recurrence of infection, and good limb alignment [Figures 13 and 14]. Functional recovery was substantial, although mild equinus deformity from gastrocnemius–soleus complex fibrosis required TA tendon lengthening, highlighting the importance of early soft-tissue mobilization and physiotherapy [Figure 15].

The successful outcome of this case reinforces several principles:

1. Adequate debridement remains the cornerstone in infection control.

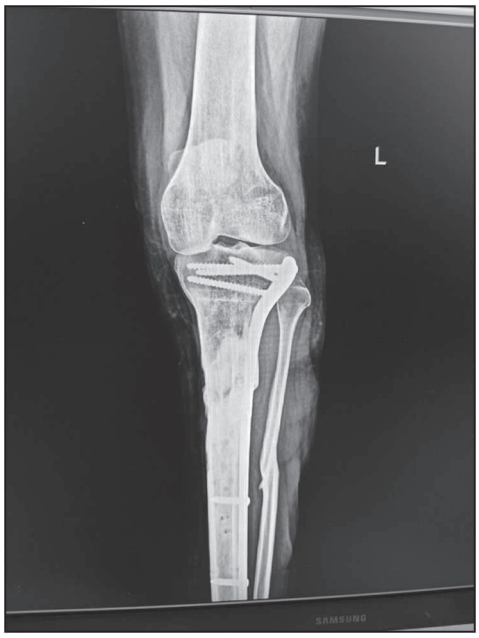

Figure 13: Shows the 2-year follow-up anteroposterior view

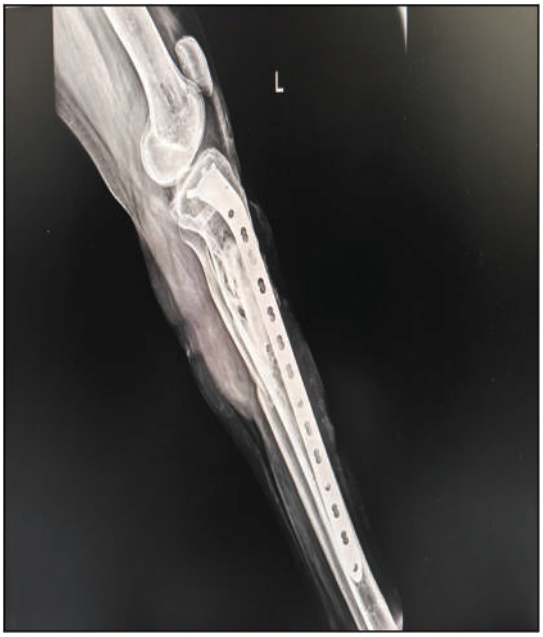

Figure 14: Shows the 2-year follow-up lateral view

2. Staged reconstruction using the Masquelet technique provides a biologically conducive environment for graft incorporation.
3. Hybrid fixation strategies may offer superior stability in biologically compromised bone beds.
4. Soft-tissue coverage is equally critical and should be addressed early in the reconstructive ladder.

We propose the term "Parhar Salvage Technique" for this integrated multimodal strategy as a reproducible protocol for similar cases. This approach is especially valuable in low-resource or nonmicrosurgical settings where vascularized grafting is not feasible.

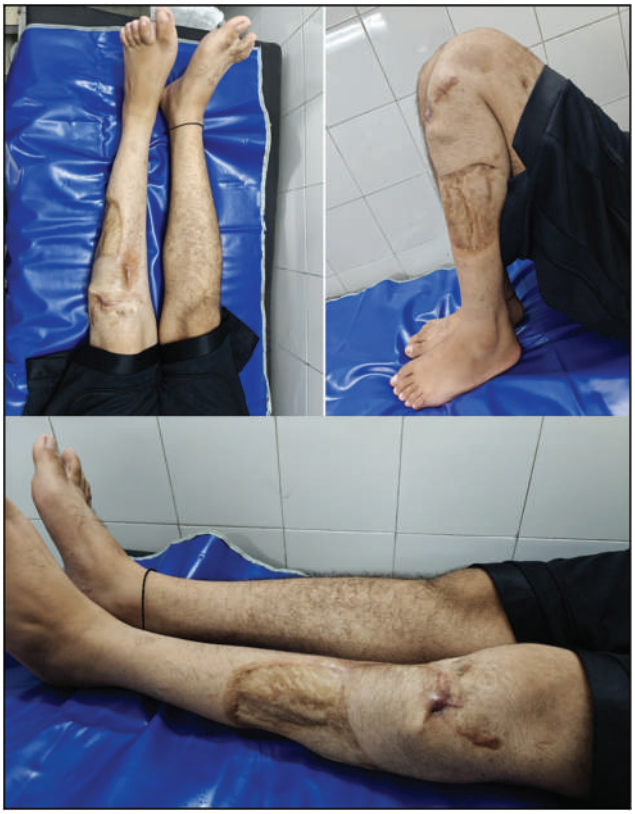

Figure 15: Shows the clinical range of motion at the 2-year follow-up

Conclusion

The management of infected proximal tibial nonunion with segmental bone and soft-tissue loss in young patients is a formidable challenge that demands a patient-specific, stage-wise approach. The "Parhar Salvage Technique," as demonstrated in this case, integrates principles of biological reconstruction with mechanical augmentation and soft-tissue management.

By combining the Masquelet-induced membrane technique, structural bone grafting (fibular strut + cancellous grafts), internal fixation with a locking plate, external rod augmentation, and gastrosoleus flap coverage, this technique offers a comprehensive strategy to achieve successful union, eradicate infection, and restore limb function. The addition of selective tendon lengthening further optimizes long-term functional outcomes in the presence of postinfective contractures.

This method is reproducible, cost-effective, and adaptable to centers with limited access to microvascular expertise. It can serve as a valuable algorithm in the armamentarium for managing complex limb salvage cases following infected tibial nonunions. Further studies with larger cohorts and longer follow-up are warranted to validate its efficacy and long-term functional outcomes.

Declaration of patient consent

The authors certify that appropriate consent was obtained from the patient for the use of clinical images and anonymized data for academic publication.

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Conflict of interest
There are no conflicts of interest.

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Case Report

External fixation with limited internal fixation for Gustilo–Anderson Grade 3B open humerus and intra-articular elbow fractures: A case report with a 10-year follow-up

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Abstract

Open fractures involving both diaphyseal and intra-articular comminuted fractures in the ipsilateral upper extremity present a complex clinical challenge. Management is dictated by the condition of the soft tissues, requiring thorough debridement, early soft tissue coverage, and appropriate bony stabilization. Diaphyseal fractures generally require functional reduction and relative stability, while intra-articular fractures demand anatomical reduction and absolute stability for optimal healing. A 21-year-old male sustained a Gustilo–Anderson Grade 3B open fracture of the humeral shaft, combined with comminuted intra-articular fractures of the distal humerus and proximal ulna due to a stone crusher injury. The wound was heavily contaminated, with bone exposure. The patient underwent thorough surgical debridement followed by fixation using a triangular external fixator combined with limited internal fixation via K-wires and cortical screws. After 3 weeks, additional screw fixation of the distal humerus was performed, and the forearm fixator assembly was removed to initiate early mobilization. Radiological union was confirmed at 12 weeks. At over 10 years follow-up, the patient demonstrated stable, painless elbow function with near-normal range of motion and was able to resume heavy manual work. In severe open fractures involving both diaphyseal and intra-articular components of the upper extremity, a hybrid fixation technique combining external fixation with limited internal fixation is effective. This approach facilitates wound management, reduces infection risk, and allows early mobilization, resulting in satisfactory long-term clinical and radiological outcomes.

Level of Clinical Evidence: Level IV.

Keywords: Compound and comminuted elbow fracture, external fixator for upper extremity, limited internal fixation, open humerus fracture, smashed elbow

Introduction

Open fractures of the upper extremity present unique challenges in orthopedic trauma management. The key principles for achieving a successful outcome include thorough debridement, early soft tissue coverage, and appropriate stabilization of the bony components. Diaphyseal fractures typically require functional reduction with relative stability, whereas intra-articular fractures necessitate anatomical reduction and absolute stability to restore joint congruity and function.[1-4]

When a patient presents with both open diaphyseal and intra-articular comminuted fractures in the same limb, especially in the presence of extensive soft tissue

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injury, implant selection and fixation strategy become particularly complex.[4-8] Here, we present the case of a 21-year-old male who sustained a Gustilo–Anderson Grade 3B compound fracture of the humeral shaft, along with comminuted intra-articular fractures of the distal humerus and proximal ulna. He was managed successfully with a combination of external fixation and limited internal fixation.

Materials and Methods

In June 2009, a 21-year-old male was brought to the emergency department following a stone crusher injury to his right upper limb. He presented immediately after the incident. There was a large open wound on the posterior aspect of the right arm and elbow, measuring approximately 15 cm × 10 cm, with exposed bone [Figure 1]. The patient was hemodynamically stable with no associated injuries or neurovascular deficits.

Radiographs revealed a diaphyseal fracture of the humerus with comminuted intra-articular fractures of both the distal humerus and the proximal ulna [Figure 2]. Following initial stabilization and blood investigations, the patient was taken up for emergency surgical intervention.

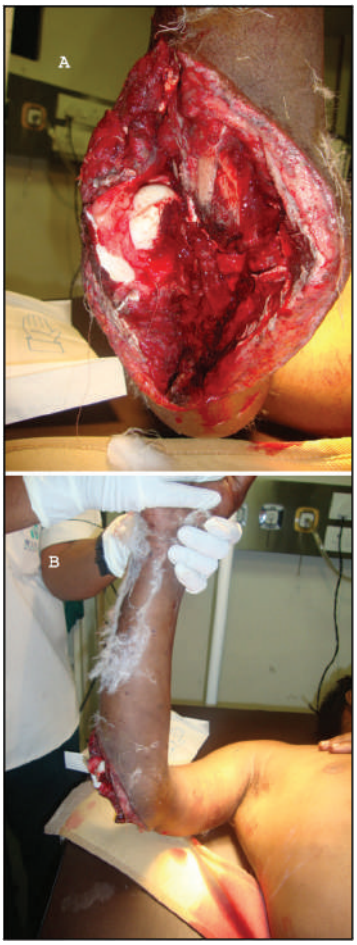

Figure 1: (A and B) Clinical photographs showing a large wound on the posterior aspect of the elbow with exposed bone fragments, along with contamination with mud particles

Surgical technique

Under general anesthesia, the wound was explored and found to be heavily contaminated with mud and debris [Figure 3A]. Thorough irrigation and debridement were performed. Anatomical reduction of distal humerus fragments was achieved and stabilized with two 2-mm K-wires. Similarly, two 2-mm K-wires were used to fix the proximal ulna fragments, taking care to protect neurovascular structures [Figure 3B and C].

A 3.5-mm Schanz pin was inserted into the proximal humeral shaft, and two 3.5-mm Schanz pins were inserted into the distal third of the radial shaft. These pins were connected using 11-mm rods to form the main external fixator frame. The K-wires were integrated using 8-mm connecting rods and clamps to construct a triangular external fixator assembly [Figures 4 and 5A–D].

Two 3.5-mm fully threaded cortical screws were inserted to stabilize the humeral shaft fracture and were supported by the external fixator [Figure 5C]. The olecranon fracture was reduced and fixed using an 18-G stainless steel wire. Wound closure was performed over a drain. The patient received intravenous antibiotics for 3 days, and the drain was removed on the second postoperative day. The wound healed without complications.

Three weeks postoperatively, the patient was taken for a second surgical procedure under general anesthesia. A 3.5-mm cortical screw was inserted into the distal humerus to further stabilize the intra-articular component. The external fixator assembly involving the forearm was then dismantled. This included the removal of two Schanz pins from the distal radius and two K-wires from the proximal ulna, along with the connecting rods [Figure 6].

Following this, the patient was encouraged to initiate active elbow range-of-motion exercises [Figure 7]. Serial radiographs were obtained at monthly intervals. At 10 weeks post-initial surgery, the complete external fixator was removed. By 12 weeks, radiological and clinical evidence of union was achieved [Figure 8].

Results

The patient has been followed for over 10 years. On final follow-up, he exhibited a fixed flexion deformity of 20° at the elbow, with further painless flexion up to 125°. Supination was near normal, while pronation had a terminal restriction of 15°. The elbow remained stable, with no signs of infection, and the patient was able to return to heavy manual labor [Figure 9].

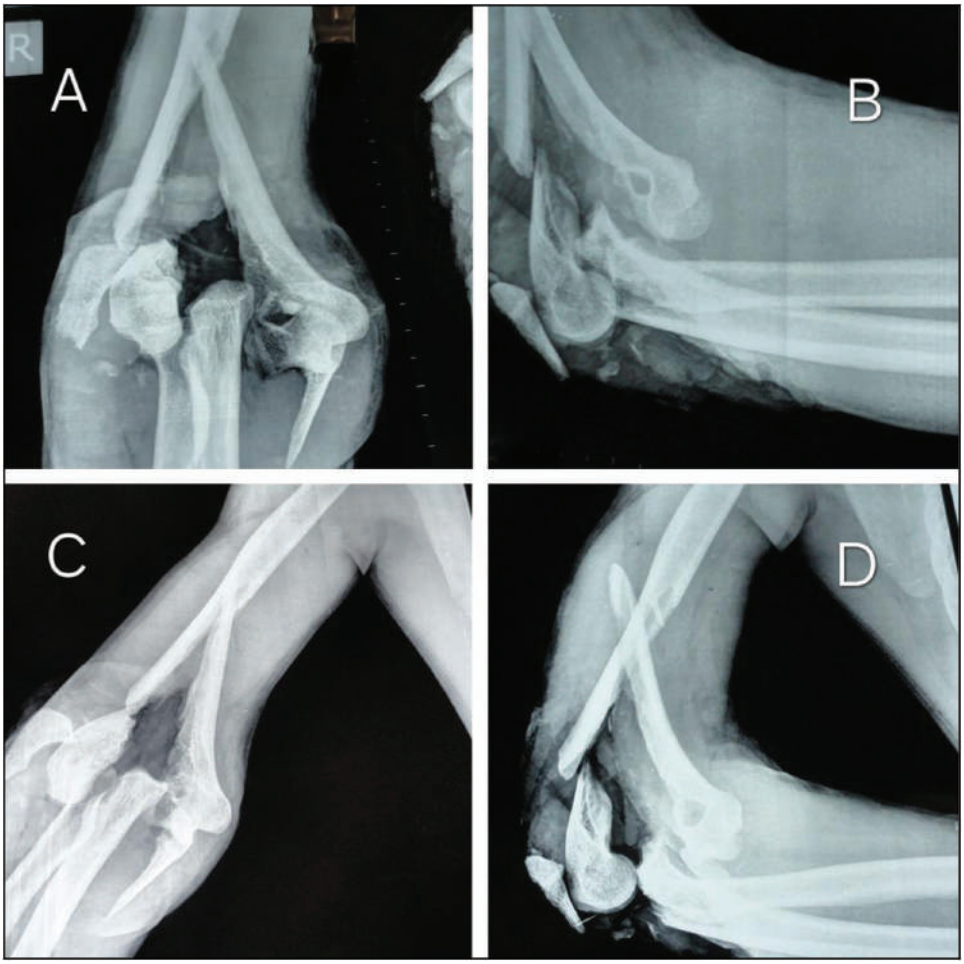

Figure 2: (A) Anteroposterior and (B) lateral radiograph of the elbow showing intra-articular comminuted fractures of the distal humerus and proximal ulna. (C) Anteroposterior and (D) lateral radiograph of the humerus showing a fracture of the humeral shaft

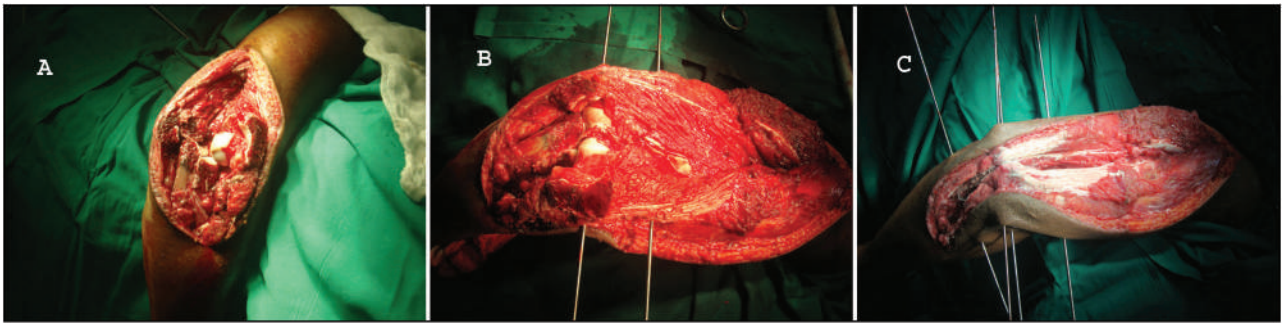

Figure 3: (A) Clinical photograph showing mud contamination of bony fragments and soft tissues. (B and C) After thorough debridement, open reduction of fracture fragments was done, and K-wires were passed, avoiding injury to neurovascular bundles

Discussion

Open fractures involving both diaphyseal and intra-articular segments of the upper extremity pose a significant management challenge due to the differing biomechanical requirements for fracture healing and the complexity of soft tissue injury. Diaphyseal fractures typically require functional reduction and relative stability, which can be achieved with intramedullary nailing or plating.[2,3] In contrast, intra-articular fractures demand anatomical reduction and absolute stability to restore joint congruity and permit early mobilization.[3,4]

In high-grade open fractures, such as Gustilo–Anderson Grade 3B injuries, contamination and soft tissue damage increase the risk of infection, complicating implant choice. Extensive internal fixation alone in contaminated wounds may lead to deep infections, while external fixation facilitates wound care but risks joint stiffness if used exclusively.[1,5,6]

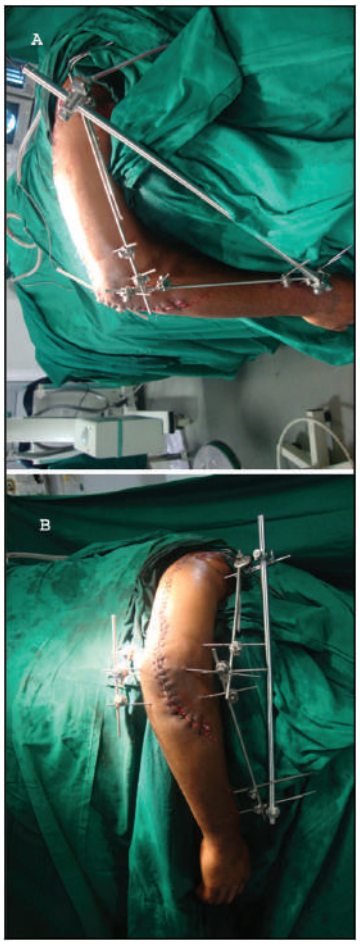

Figure 4: (A and B) Clinical photographs illustrating a joint-spanning external fixator with 8- and 11-mm connecting rods

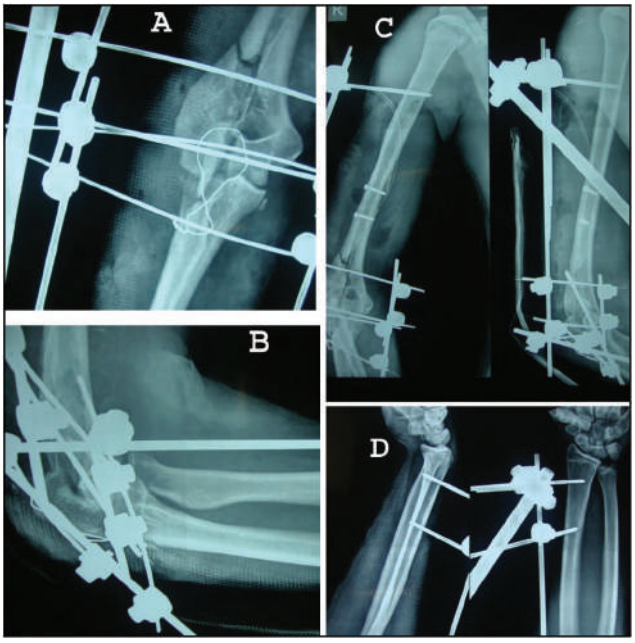

Figure 5: (A–D) Postoperative radiographs showing two K-wires in the distal humerus and two K-wires in the proximal ulna. Two Schanz pins in the distal one-third of the radius and one in the proximal third of the humerus shaft were used and connected with rods. Two 3.5-mm screws were used for the fixation of diaphyseal fragments

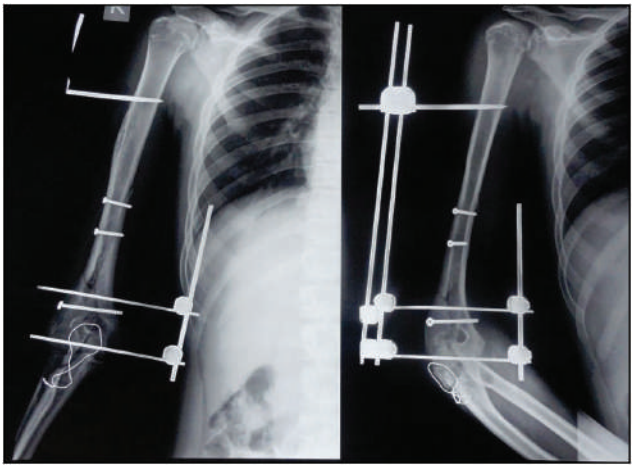

Figure 6: At 3 weeks, the forearm external fixator assembly was removed, and one 3.5-mm screw was inserted in the distal humerus metaphyseal region

Hybrid fixation techniques that combine limited internal fixation with external fixation have been described to balance these concerns. Skaggs *et al.*[6] reported successful use of hybrid external fixators in managing severely comminuted juxta-articular fractures, providing stability while preserving joint function. Similarly, Ring *et al.*[7] highlighted the efficacy of thin-wire external fixation in salvaging contaminated distal humerus fractures. Stavlas *et al.*[5] demonstrated that unilateral hinged external fixators provide adequate stability and allow early motion in complex elbow injuries.

In this case report, the combination of a triangular external fixator with limited internal fixation using K-wires and screws allowed for anatomical reduction of intra-articular fractures and relative stability of the diaphyseal fracture. This method facilitated wound care and soft tissue healing while minimizing infection risk. Early removal of the external fixator components and initiation of active motion prevented elbow stiffness and promoted functional recovery.

Long-term follow-up confirmed satisfactory outcomes, with a stable and painless elbow and near-normal range of motion, enabling the patient to return to heavy manual work. These findings aligned with Lerner *et al.*'s[8] observations on the benefits of modular hybrid external fixation systems for high-energy elbow fractures and supported the principles of early debridement and fixation advocated by Rajasekaran[9] for open fractures.

Thus, hybrid fixation offers a practical and effective solution for managing complex open fractures with combined diaphyseal and intra-articular involvement. Successful outcomes depend on meticulous

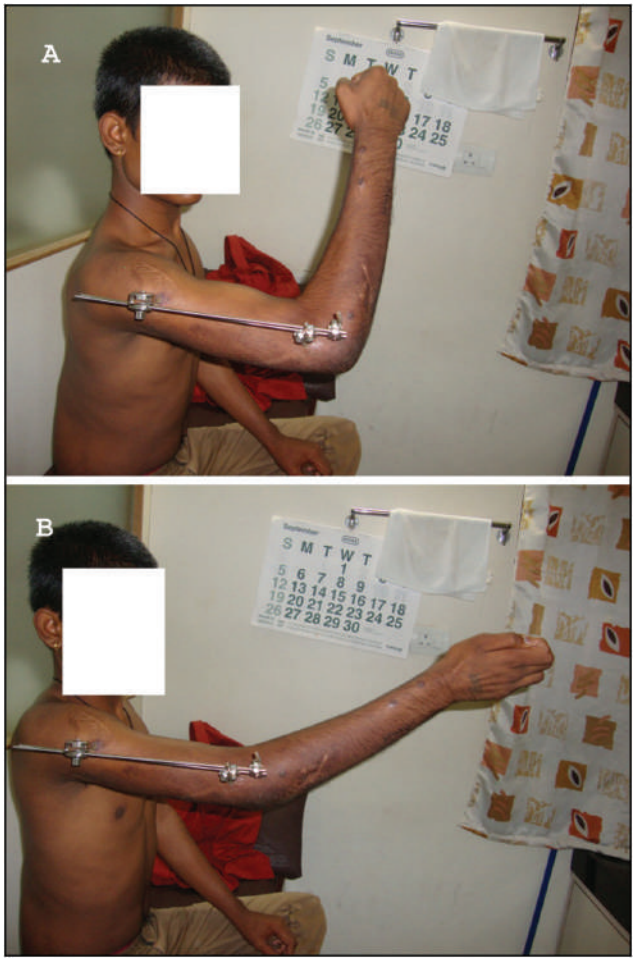

Figure 7: At 3 weeks after removal of the forearm assembly, active elbow movements were started. (A) flexion at elbow. (B) extension at elbow

debridement, appropriate implant selection, and staged rehabilitation.

Conclusion

Management of complex open fractures involving both diaphyseal and intra-articular segments of the upper extremity requires careful balancing of fracture stability and soft tissue care. The combined use of external fixation with limited internal fixation offers an effective solution by minimizing infection risk, allowing thorough wound management, and providing sufficient stability for fracture healing. This hybrid approach enables early mobilization, reduces joint stiffness, and results in favorable functional outcomes, even in severely contaminated injuries.

Clinical message

In complex open fractures involving both diaphyseal and intra-articular components of the upper extremity with significant soft tissue injury, a hybrid fixation approach

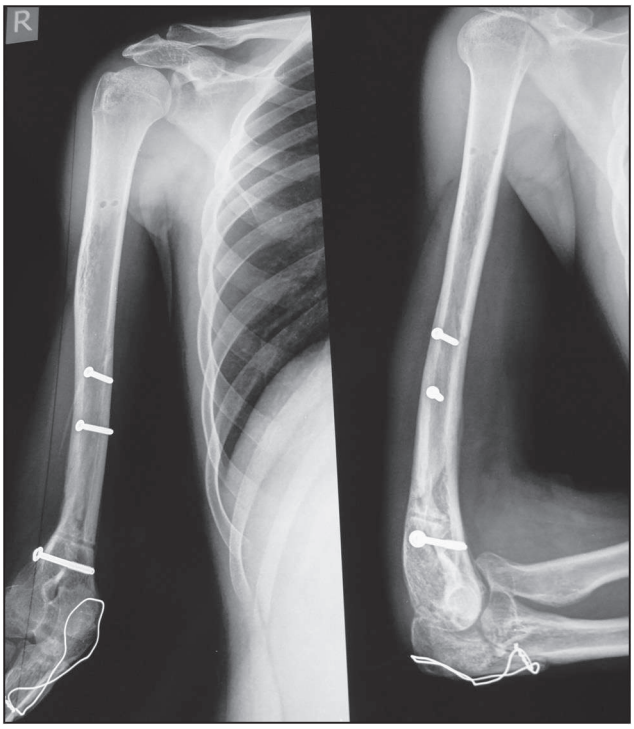

Figure 8: Radiographs showing complete union of intra-articular and diaphyseal fractures

combining limited internal fixation and external fixation provides a balanced strategy. This method facilitates infection control, ensures fracture stability, allows early joint mobilization, and leads to satisfactory long-term functional outcomes.

Declaration of patient consent

Written consent for publication of patient details was obtained from the parent/guardian.

Author contribution

SDP: Decision-making, preparation, reviewing, and editing the manuscript. AHV: Manuscript preparation, figures, literature review, and artwork. GSW: Reviewing and editing the manuscript. VDP: Radiological investigations, diagnosis, and editing the manuscript

Ethical approval and Institutional Review Board statement

Ethical approval from the Institutional Ethics Committee was obtained beforehand.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

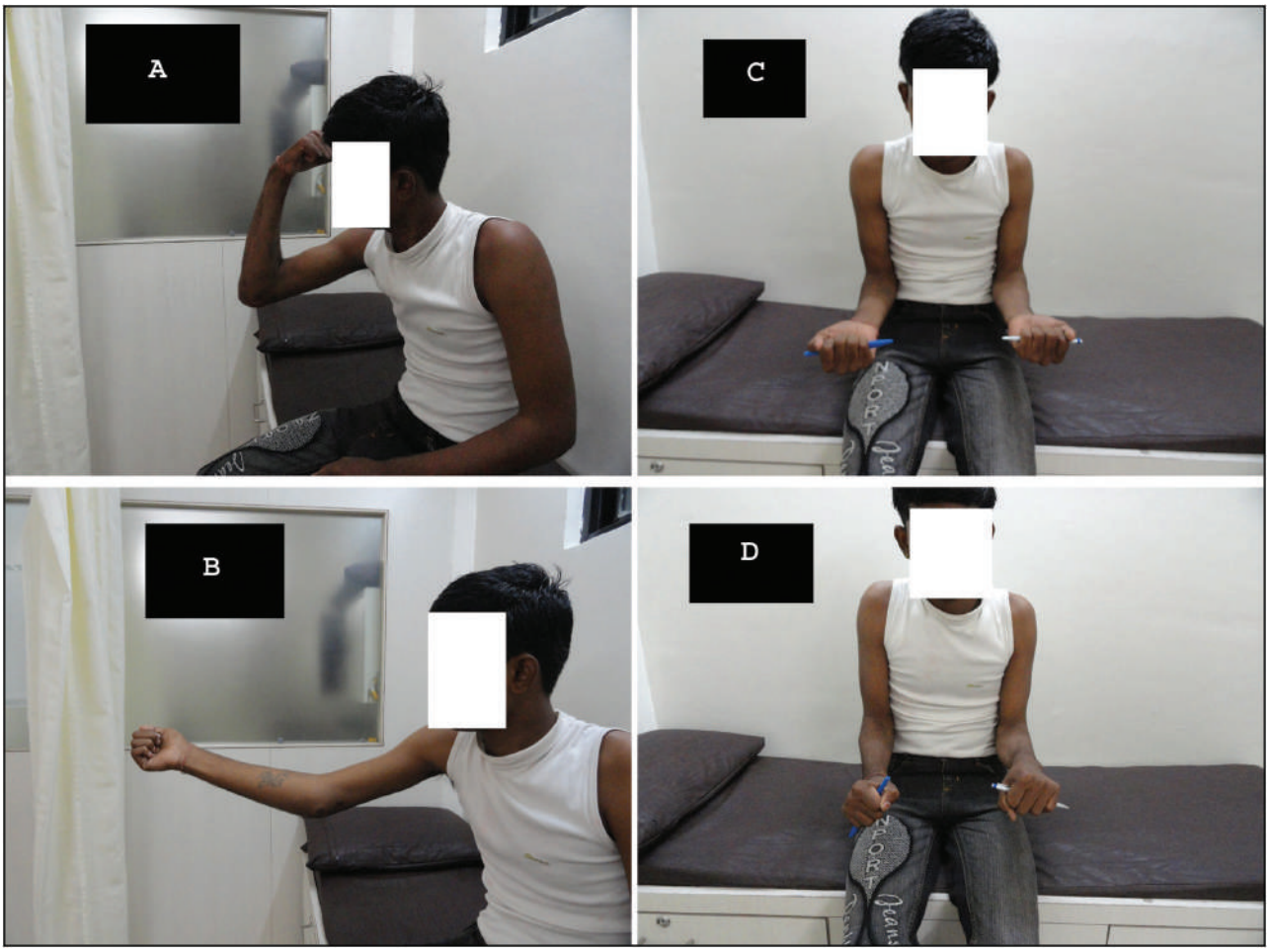

Figure 9: Clinical photographs showing active range of movements at the right elbow at a 10-year follow-up. (A) flexion at elbow. (B) extension at elbow. (C) supination. (D) pronation

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