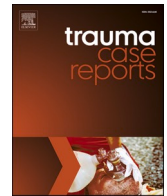




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Salvage of a recalcitrant humeral shaft septic nonunion using a linked nail-plate fixation construct with intercalary allograft

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ARTICLE INFO

Keywords:

Humerus
Nonunion
Infection
Reconstruction
Allograft

ABSTRACT

Open humeral shaft fractures comprise approximately 2% of all fractures of the humerus. Nearly 20% of open humeral shaft fractures will develop deep infection, increasing the risk of nonunion regardless of treatment method. Recalcitrant septic nonunion of the humeral shaft is a complex and challenging problem. Operative treatment should aim to eradicate infection, address bony defects, and establish a stable construct that affords early motion. We describe the case of a 38-year-old male with a recalcitrant humeral shaft septic nonunion following fixation of an open humeral shaft fracture. Management of the infection consisted of periodic surgical debridement and IV antibiotics, resulting in a 10 cm segmental defect. Definitive fixation was achieved using the combination of an antegrade intramedullary nail, intercalary femoral shaft allograft, compression plating, and autologous bone graft. In addition to achieving bony union, the patient regained his pre-injury ROM and function, which was clinically sustained at 2-year follow-up.

Introduction

Humeral shaft fractures are common, comprising approximately 10% of all long bone fractures [1]. While open humeral shaft fractures occur less frequently, one-third will exhibit delayed union or nonunion, and nearly 20% develop infection [2]. Initial management of a septic nonunion consists of hardware removal, irrigation and debridement (I&D), and often placement of a temporary antibiotic impregnated implant for 4–6 weeks with concomitant IV antibiotic administration [3]. After eradicating infection, a variety of strategies may be used to promote osteosynthesis, including definitive external fixation, intramedullary nailing, and compression plating, among others [4,5]. Supplemental techniques to address large bone defects using intramedullary allografts and vascularized fibular grafting, have been reported with some success. There is, however, limited literature addressing septic nonunion with substantial segmental bone loss [5]. Here, we report the case of a recalcitrant humeral shaft septic nonunion, following a Gustillo Anderson (GA) type II humeral shaft fracture. The patient was treated with serial debridement, resulting in a 10-cm segmental bony defect. Ultimately, a mechanically stable construct was achieved using an intramedullary nail, femoral shaft allograft, autologous cancellous bone graft, and compression plating.

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<https://doi.org/10.1016/j.tcr.2021.100427>

Accepted 7 February 2021

Available online 10 February 2021

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Fig. 1. (Left): Lateral left humerus radiograph showing a Gustilo-Anderson grade 2 open distal humerus fracture.

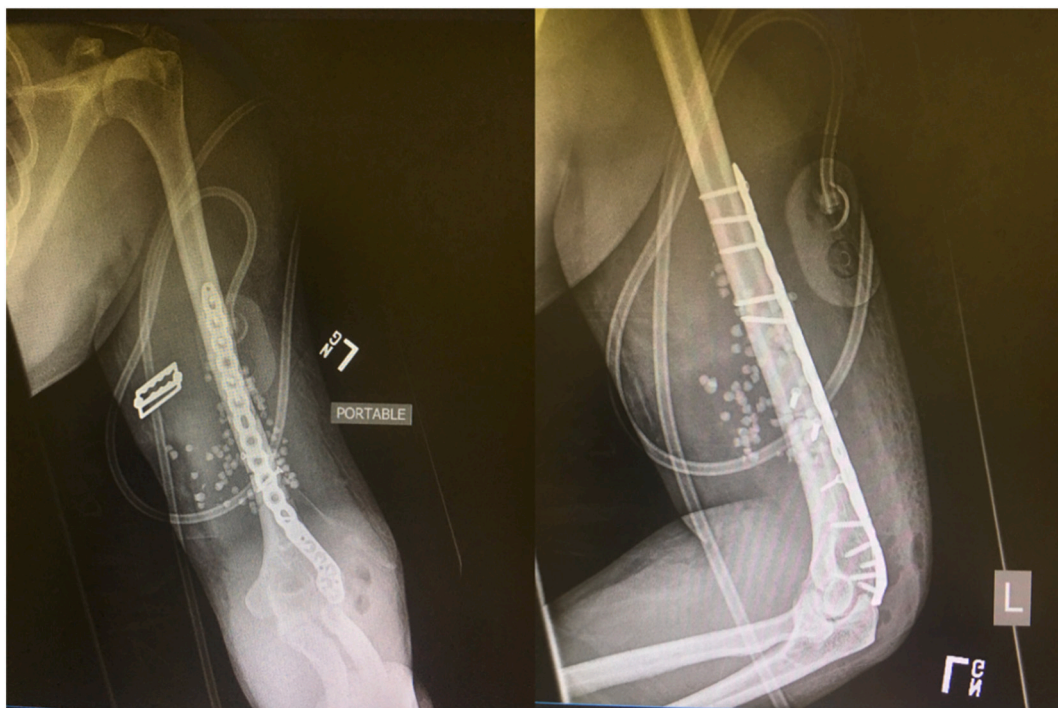


Fig. 2. (Left): AP and Lateral left humerus radiographs status post distal humeral debridement, open reduction and internal fixation, and antibiotic bead placement.



Fig. 3. A-C (Left): AP and Lateral humerus radiographs at 3 months postoperatively (a,b), and CT scan at 4 months postoperatively (c) showing delayed fracture union.

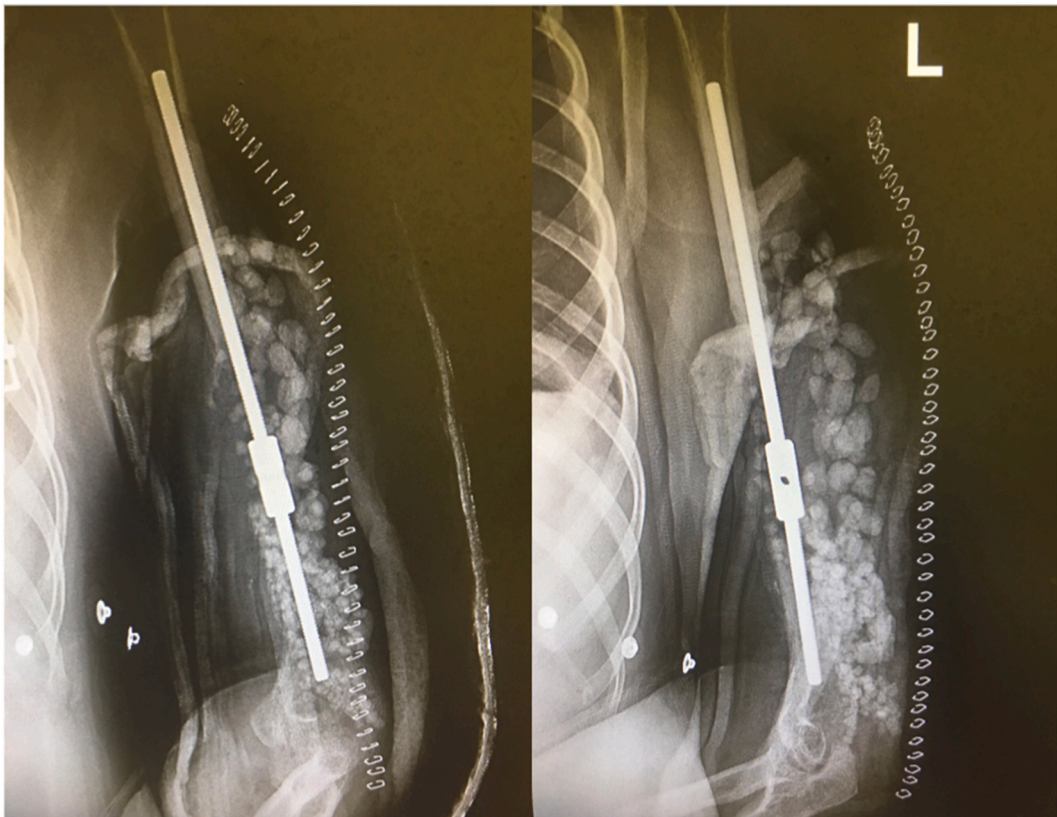


Fig. 4. (Above): AP and Lateral humerus radiographs status post debridement, hardware removal, and insertion of antibiotic beads and rod, 6 months following index procedure.

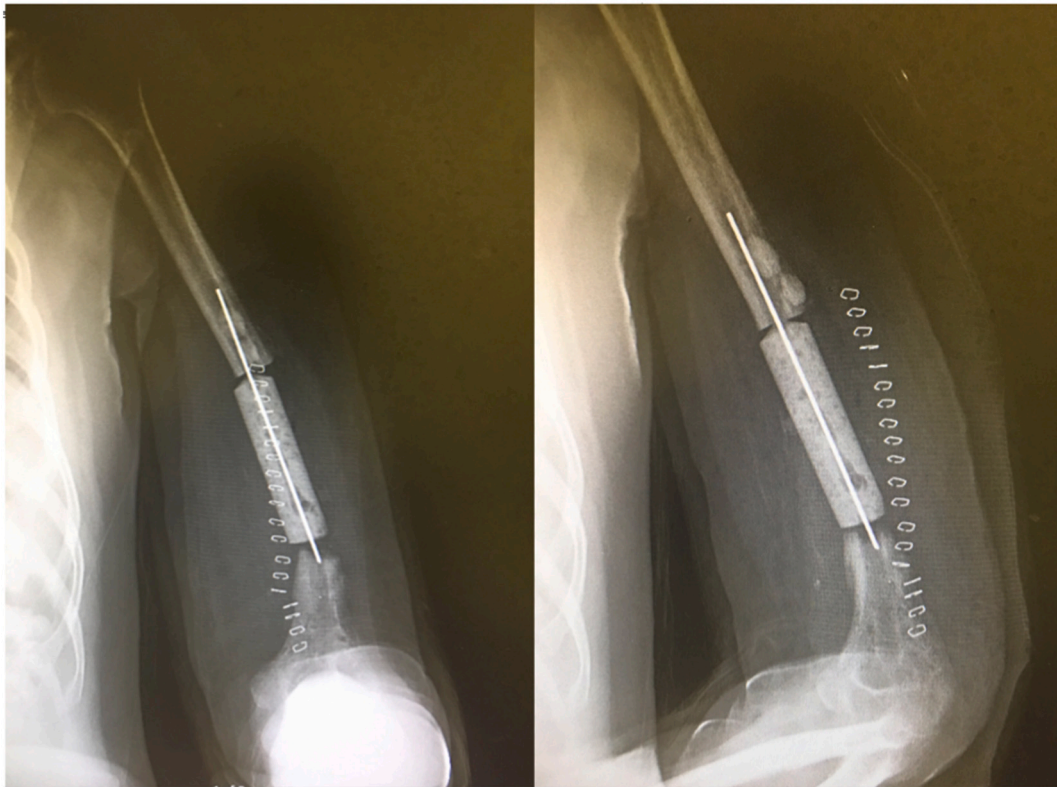


Fig. 5. (Left): AP and Lateral humerus radiographs status post repeat debridement with removal of rod and antibiotic beads, and placement of an antibiotic spacer, 9 months following index procedure.

Case report

A 38-year-old right hand dominant male laborer jumped from the second story of a burning building and suffered a GA-II left humeral shaft fracture. This was an isolated injury with a 2 cm laceration to the posterior arm without neurovascular deficit (Fig. 1). The patient underwent I&D of the wound, open reduction and plate fixation of the humerus, and placement of antibiotic impregnated beads at the fracture site (Fig. 2). His postoperative course was complicated by delayed union, initially treated with Sarmiento bracing, electrical bone stimulation, and high dose vitamin D therapy starting at three months post injury (Fig. 3-C). The patient subsequently underwent repeat I&D of a superficial wound abscess with retention of hardware at five months post injury. Operative cultures at this time grew *Enterobacter* and *Serratia* and the patient was started on IV Cefazolin for a 6-week course as per recommendations of infectious disease specialists. At six months post-injury the patient underwent a second I&D with hardware removal, and placement of antibiotic beads (Fig. 4).

Following an additional 6-week course of IV antibiotic therapy and drug holiday, approximately eight months after his index procedure, the patient was referred to us for further management. On presentation, the patient reported persistent pain at the operative site. Examination revealed a neurovascularly intact left upper extremity, and healed surgical scars without erythema or drainage. Laboratory studies, including erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP), were unremarkable. Following removal of previous hardware, an aggressive I&D was performed, and an antibiotic spacer was placed (Figs. 5). A repeat debridement, wound culture and antibiotic bead placement was performed at 12 months post injury due to persistent pain and evidence of involucrum on x-rays (Fig. 6).

Thirteen months post-injury, with negative cultures off antibiotics, negative inflammatory markers and no clinical or radiographic evidence of infection, a decision was made for definitive fixation. Following administration of general anesthesia and routine pre-operative antibiotic prophylaxis, the patient was positioned in the lateral decubitus position and draped in a standard sterile fashion. The previous posterior triceps splitting approach was utilized to gain access to the humeral shaft. The radial nerve was identified and protected, and the approach was extended both distally and proximally for adequate exposure. The fracture ends were debrided and prepared using an oscillating saw to accommodate an intercalary femoral shaft allograft, measured and cut to fit the 10 cm defect. Importantly, the induced membrane present was carefully preserved. The distal bone segment was cannulated and sequentially reamed under direct fluoroscopy (Fig. 7A-B). This was repeated with the proximal bone segment in retrograde fashion. Following this, a mini-open anterolateral approach to the shoulder was utilized to obtain the starting point for an antegrade humeral nail. After gaining access to the medullary canal with the opening reamer, a ball-tip guide wire was used to first cannulate the proximal bone segment, then the

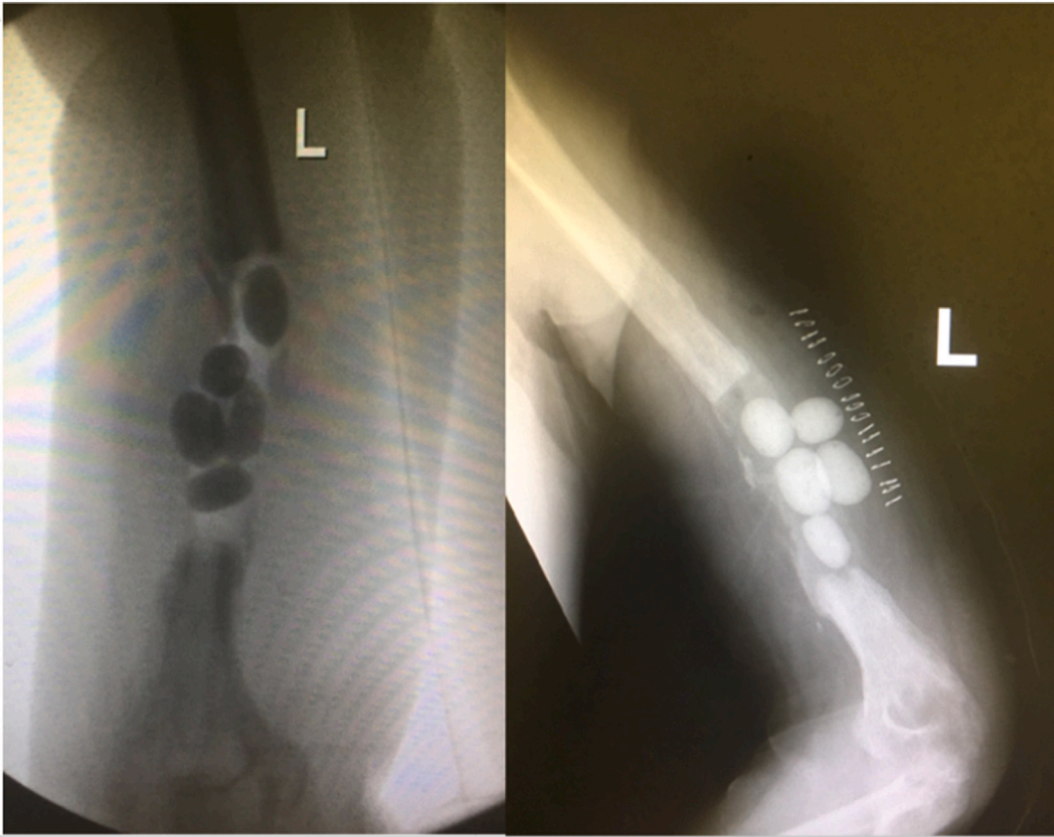


Fig. 6. (Left): AP and Lateral humerus imaging status post repeat debridement and removal of antibiotic spacer, 12 months following index procedure.

intercalary femoral shaft allograft, and finally the distal bone segment (Fig. 7C). Autologous bone graft was harvested from the iliac crest, and packed at the allograft/bone interfaces. A curved osteotome was then used to remove thin slivers of cortical bone on the native bone side (“petaling”) to expose a large surface area of bleeding bone for graft incorporation. After completion of proximal segment reaming, an antegrade intramedullary humeral nail (Stryker, Mahwah, NJ) was inserted and the guide wire removed. The humerus was axially loaded to achieve compression at the graft sites and then locked proximally via percutaneous lateral incisions. A 14-hole 3.5 mm compression plate (Synthes, Warsaw, IN) with variable locking and non-locking screw options was then positioned posterosuperiorly on the humeral shaft spanning the allograft. This plate was applied in compression mode with additional locking screw fixation (Fig. 7D-E). The nail was then statically locked distally using perfect circles technique. A distal locking screw through the plate was introduced through the anterior-posterior distal locking slot of the humeral nail, linking the constructs. The surgical wounds were irrigated and closed in the standard fashion.

The patient’s postoperative course was uncomplicated. He was kept non-weight bearing for 12 weeks, with progressive allowance of ROM exercises. Radiographs obtained at 1,6 and 12-month follow-up showed progressive fracture healing and graft incorporation (Fig. 8A-C). Clinically the patient progressed well, achieving pain free ROM from 0 to 110 degrees by 10 months, which was maintained at 2-year follow up (Figs. 9, 10).

Discussion

Nonunions of the humeral shaft are particularly devastating and can result in persistent pain, limited load bearing ability, and severely compromised function. Concomitant infection compounds these challenges by further limiting treatment options. Indeed, a number of studies have documented the difficulty of treatment of, and poorer outcomes associated with, humeral septic nonunion compared to aseptic nonunion [6,7].

Definitive external fixation and Ilizarov technique have been utilized to address a variety of complex post-traumatic problems. Ferreira et al. recently described the treatment of eight patients with humeral nonunion in the setting of Cierny and Mader stage IV chronic osteomyelitis. All eight patients underwent two-stage reconstruction consisting of initial wide resection of infected bone and soft tissue, initiation of six weeks of IV and oral antibiotics, and definitive fixation using a circular external fixator and iliac crest autograft. The authors reported successful eradication of infection and bony union in 100% of subjects [8]. In a 2019 report,

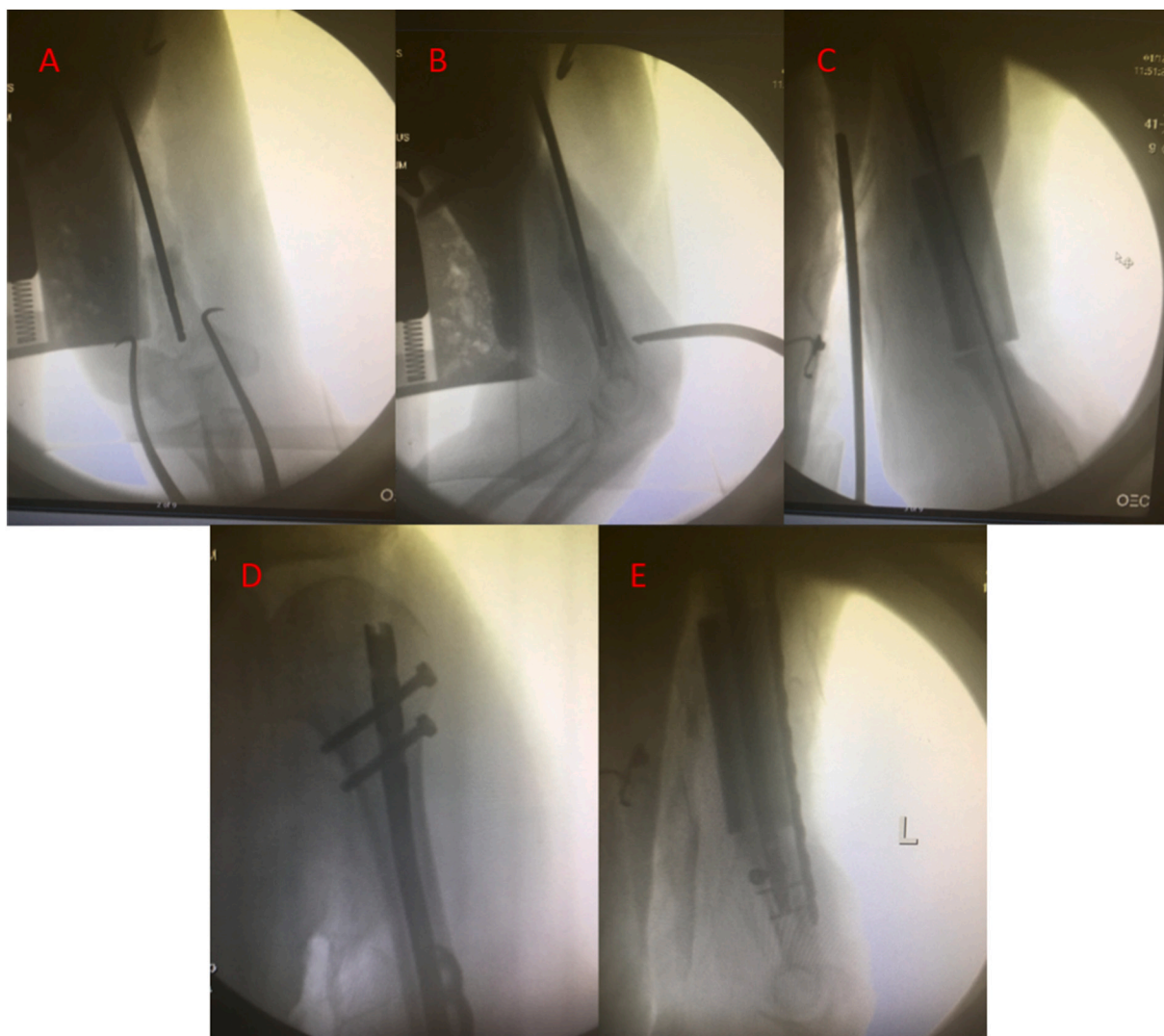


Fig. 7. (Above): Intraoperative fluoroscopic images demonstrating reaming of proximal and distal humeral segments (a,c), followed by sequential wire cannulation of proximal humerus, intercalary graft, and distal humerus (c) for passing of an intramedullary nail and subsequent plate and screw augmentation (d,e) for rigid fixation at the bone-allograft junction.

Nithyananth et al. also demonstrate similar management and outcomes in a cohort of 10 patients with infected humeral nonunion treated with definitive external fixation [5]. In both studies, the authors report pin tract infection and shoulder stiffness to be the most frequent complications.

Both vascularized and non-vascularized bone grafting has been used with some success for infected humeral nonunion. Muramatsu et al. reported successfully treating 23 patients with recalcitrant humeral shaft nonunion using vascularized bone grafts from the fibula, femur, and scapula [9]. They advocate that fibular grafts are best used for large bone defects (> 3 cm) and nonunions with poor intrinsic stability, while femoral grafts should be reserved for atrophic nonunion without significant defect. Gopisankar et al. describe the use of a compression plate and non-vascularized fibular graft strut for seven male patients with septic nonunions of the humerus [10]. They concluded that fixation using a non-vascularized fibular graft as an intramedullary strut resulted in a good outcome for septic nonunion despite prior failed surgeries.

Eradication of infection is an essential prerequisite for internal fixation. Our patient ultimately required four rounds of surgical debridement and antibiotic therapy to achieve eradication of infection. The resultant segmental bone defect was initially treated using Masquelet type technique with an antibiotic spacer and then subsequent final preparatory debridement with antibiotic bead placement and preservation of induced membrane. This final preparatory stage may be crucial to create a biologic atmosphere suitable for incorporation of a large intercalary femoral shaft allograft. The use of intercalary allograft has traditionally been associated with a high rate of postoperative complications including infection, fracture, and nonunion. We therefore sought to devise a construct to minimize these risks. In order to address the risks of postoperative fracture and nonunion, we augmented fixation. The use of intramedullary

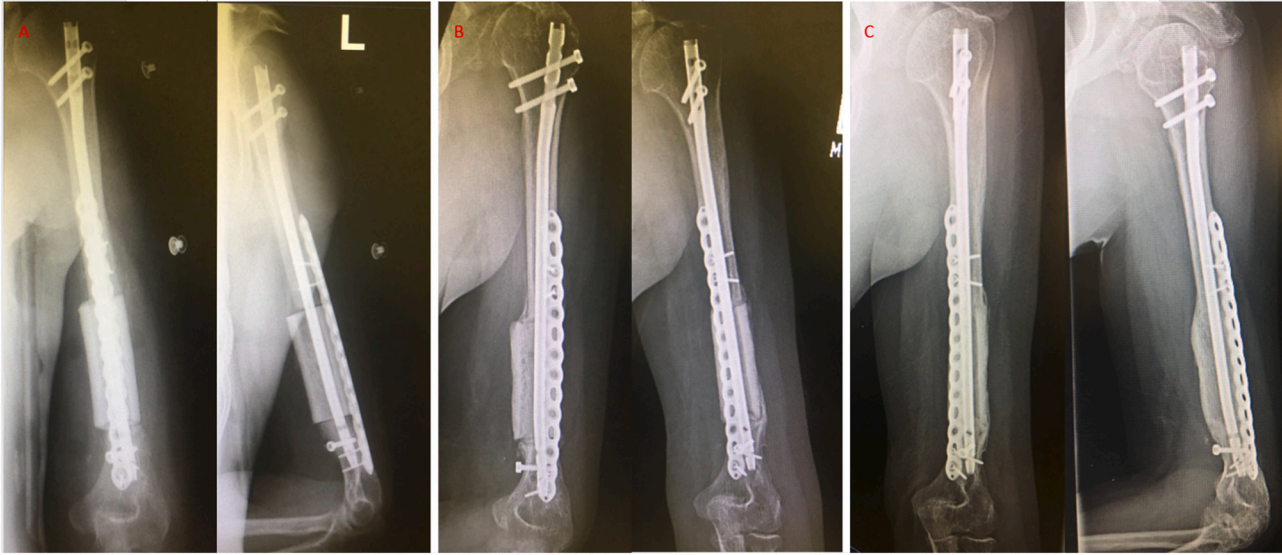


Fig. 8. (Above): AP and Lateral left humerus radiographs at 1-month (A), 6-month (B), and 12-month (C) postoperative visits demonstrating progressive healing and allograft incorporation.



Fig. 9. (Above): Clinical pictures at one year postoperative visit demonstrating elbow range of motion of 0–110 degrees.

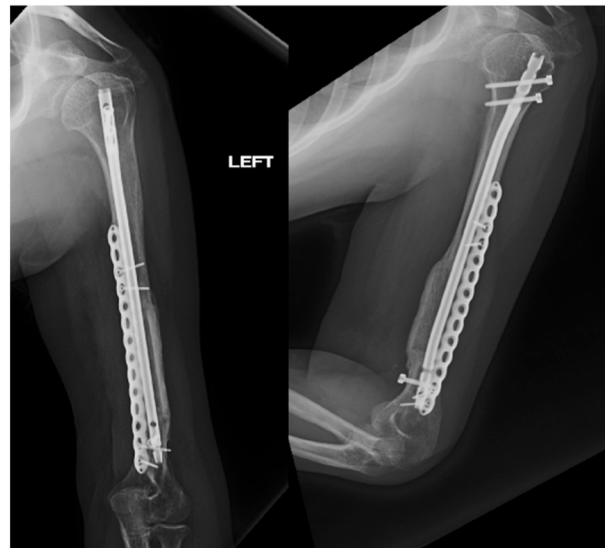


Fig. 10. (Left): AP and Lateral left humerus radiographs at 24-month follow up demonstrating complete healing and allograft incorporation.

fixation with compression plating creates a rigid construct that affords substantial stability, particularly at the location of the intercalary allograft. Enhanced stability at graft/host interfaces along with an enhanced biologic milieu from an induced membrane and careful preparation of the graft/host sites also appears to be crucial for successful incorporation.

In conclusion, we describe the case of a 38-year-old male with a recalcitrant septic nonunion and segmental bony defect following fixation of a GA II left humeral shaft fracture. Definitive fixation was successfully achieved using a combination of an antegrade intramedullary nail, intercalary femoral shaft allograft, compression plating, and autologous bone graft. In addition to achieving bony union, the patient regained his pre-injury ROM and function, which was clinically sustained at 2-year follow-up. The methodology and fixation construct shown here is a powerful combination of modern techniques to address a challenging orthopedic pathology.

Funding

None.

CRediT authorship contribution statement

SPT, AMG, JL prepared the manuscript and figures. MKS managed the patient and supervised the manuscript preparation. All authors approved the submitted manuscript.

Declaration of competing interest

The authors have no conflicts of interest to disclose.

Acknowledgements

None.

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