Outcomes of single-stage surgical treatment of diaphyseal non-union of the humerus

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Abstract

Background

Non-union of diaphyseal humerus fractures occurs in up to 30% of non-surgically managed fractures and 10% of surgically treated fractures. Failed nonoperative treatment may present with muscle atrophy, pseudoarthrosis and shoulder and elbow stiffness; and surgically treated fractures may have compromised soft tissues, broken hardware and infection. There is no accepted gold standard of treatment for this complex problem.

Methods

A retrospective cross-sectional study was performed of data collected prospectively over an eight-year period, from February 2016 to January 2024. Our single-stage surgical technique is described.

Results

We included 32 single-stage non-union surgeries. The average age was 42 years, and 59% were male. Ten patients were smokers. Twelve were open fractures, including gunshot wounds. Seventy-two per cent of patients had already had some form of surgery to their arm, and four had confirmatory signs of infection prior to non-union surgery. Three patients required a debridement post non-union surgery due to new signs of infection. Two patients required late additional unplanned revision surgery due to ongoing non-union, but also ultimately united.

Conclusion

Single-stage revision surgery may be an effective form of treatment of diaphyseal humerus fracture non-unions. In our series, this was successfully used in the setting of active infection. The authors suggest performing a biopsy in all cases of humerus non-unions.

Level of evidence: 3

Keywords: humerus, non-union, fracture-related infection, diaphyseal, plate osteosynthesis

Introduction

Diaphyseal fractures of the humerus are a common injury, accounting for between 1 and 5% of all fractures. The annual incidence is between 13 and 20 per 100 000 in the general population but this increases with age and reaches as high as 90 per 100 000 in those in their ninth decade of life.[1,2] There is a bimodal distribution, typical of trauma, with high energy injuries affecting the young, and low energy injuries affecting the elderly.[1,2]

These fractures can be successfully managed nonoperatively with a variety of splinting techniques, most commonly a cylindrical brace popularised by Sarmiento in 1977.[3] This method is preferred by many orthopaedic surgeons rather than surgical fixation and is considered the gold standard of nonoperative treatment.[1,2] The highly mobile shoulder joint allows a broad tolerance for displacement of diaphyseal fractures, and multiple studies have reported union rates of between 77 and 100% with nonoperative treatment.[4-6] Contrary literature shows conversion rates of failed bracing to surgery as high as 30%.[7]

Plate osteosynthesis is the gold standard of operative treatment of diaphyseal humerus fractures.[8] This method requires extensive soft tissue dissection for fracture site exposure and plate placement. The indications for surgical fixation of diaphyseal humerus fractures include open fractures, polytraumatised patients, neurovascular injuries, failed conservative treatment, obese patients and floating elbow.[1,2] These factors may themselves select for poorer outcomes in terms of bony union.

Non-union is traditionally defined as absent clinical or radiographic healing nine months post-injury, with a lack of evidence of progressive healing on radiographs three months apart.[7] However, Ferreira advocates that a non-union may be predicted and diagnosed before this time constraint, and proposes to define non-union as a fracture that is unlikely to heal without surgical intervention. Examples included segmental bone loss, circumferential soft tissue defects, minimal cortical contact and fractures that were plated with a fracture gap.[9]

Non-unions of the diaphysis of the humerus are common and present a challenging problem. Those treated nonoperatively are often allowed to continue with bracing for prolonged periods in the hope that the fracture may unite, resulting in muscle atrophy, pseudoarthrosis and shoulder and elbow stiffness.[10] Fractures treated with nonoperative measures may fail to unite in up to one-third of cases.[7,11] This is compared to surgically treated fractures where the very indication for surgery (i.e. an open fracture with extensive soft tissue damage), as well as the required dissection performed during the operation, may predispose to non-union. The non-union rate of humerus shaft fractures treated with plate osteosynthesis may be as high as 4–10%.[7,8,11] Non-unions following surgical treatment are often complicated by poor soft tissue, failed or broken metalware, and fracture-related infection (FRI).

In this article the authors describe the experiences, approach, surgical techniques and outcomes when treating diaphyseal humerus fracture non-unions in a limb reconstruction unit at a tertiary level orthopaedic service in South Africa.

Methods

Relevant institutional and ethical committee approval was obtained. A retrospective cross-sectional study was performed of data collected prospectively over an eight-year period, from February 2016 to January 2024. Descriptive statistics were used to summarise the demographic and clinical characteristics of the study population. Continuous variables were expressed as means ± standard deviations (SD), while categorical variables were presented as frequencies and percentages. The time to union was represented as a median function with interquartile range (IQR) to account for the lack of standardisation in the patient's follow-up radiographs.

Demographic data, smoking status and comorbid medical conditions were collected. Data on the nature of the trauma, including polytrauma, multiple orthopaedic injuries or open injuries, were collected. Polytrauma was defined as injuries sustained to more than one body region or organ system. Multiple orthopaedic injuries were defined as the presence of at least two orthopaedic injuries, each requiring a different method of treatment. The laboratory test results used for the data analysis were collected during evaluation in the preoperative workup.

Patients younger than 13 years of age, patients with pathological fractures and periprosthetic fractures were excluded. Other exclusion criteria included inadequate clinical records or loss to follow-up prior to confirmation of radiographic union, and surgery performed by surgeons other than the senior author of this paper.

All patients presenting with a non-union were investigated for risk factors for non-union, with the aim of identifying those that were modifiable. Standard blood panel workup included albumin, haemoglobin, calcium, magnesium, phosphate, thyroid function and vitamin D. Where applicable, additional investigations were performed to facilitate optimisation of medical comorbidities prior to surgery (e.g. HbA1C in diabetics, and viral load and CD4 levels in HIV-infected patients).

Identified deficiencies were addressed where applicable. No surgery was performed if serum HbA1c was over 10%. Preoperative serum HbA1c target was less than 8%; however, in the setting of non-union with failed metalware, and/or confirmed FRI, surgery would be performed if the preoperative HbA1c was between 8 and 10%. Patients were counselled to stop smoking, but this would not preclude surgery. All of the HIV-infected patients were already on treatment prior to presentation and had a viral load of 'lower than detectable limits' as their baseline, prior to surgery.

All patients were seen at our outpatient clinic at ten days post operation for wound management, and again six weeks postoperatively for repeat radiographs. Thereafter patients had repeat radiographs at least every three months until union was confirmed both functionally and radiologically. This study employed the Radiographic Union Score for HUmerus fractures (RUSHU) scoring system to assess fracture union after surgical intervention.[12] All X-rays were assessed by at least two of the authors to confirm union. The primary aim of our proposed surgical technique was to achieve union. There was no intention to accurately quantify time to union, and all patients did not have radiographs at standardised time points postoperatively; therefore, comparisons of time to union became inaccurate.

Surgical approach

All patients underwent a single-stage non-union surgery. Single-dose cefazolin was given routinely as preoperative antibiotic, unless specifically 'confirmatory' criteria for FRI were identified preoperatively.[13] In FRI cases, cultures were obtained intraoperatively and then routine antibiotic prophylaxis was administered. The anterolateral approach was used as standard unless previous approaches differed, in which case that approach was used. The radial nerve was identified and protected in cases where the anterolateral approach was used. Intraoperative samples were taken for culture in all cases. Previous fracture fixation implants were removed if present. The fracture ends were delivered and debrided to healthy bone. Fibrous tissue and pseudoarthrosis tissue were excised when present. The intramedullary (IM) canal was opened at both ends of the non-union using a drill. Bone ends were refashioned to facilitate optimal apposition and maximum compression. Fractures were stabilised using large fragment plate osteosynthesis in compression mode. Whenever possible, maximal compression is achieved by creating an axilla under the plate and using both eccentric screw placement and an interfragmentary screw through the plate ('lag through plate' technique). Demineralised bone matrix (DBM) (SA Bone) was primarily used to fill large voids from previous failed fixation rather than to stimulate healing. In cases where biological stimulation was desired, autograft was used. Autograft was obtained from the fracture site and canal refashioning, and morselised from adjacent metaphysis using a small harvester or iliac crest autograft. In cases with confirmatory signs of FRI, local antibiotics were used, either in the form of antibiotic-impregnated collagen sponge (e.g. Garacol) or antibiotics mixed with manufacturer supplied calcium phosphate graft (e.g. Osteoset). After wound closure, the patient was placed in an arm sling and permitted full range of motion as tolerated. Patients were advised to avoid heavy lifting until signs of union.

One patient who had sustained a gunshot wound (GSW) to his upper arm had a concomitant vascular injury and surgical repair with associated fasciotomies and spanning external fixation. This resulted in extensive damage to the soft tissue envelope, with skin graft and scar tissue adhering to underlying bone in some areas. Due to this, the eventual non-union that developed was deemed not amenable to plate fixation and the patient was treated with a reamed IM device. The humerus canal reamings were sent for culture but the fracture site itself was not opened.

Results

Thirty-two humerus non-union surgeries were performed on 31 patients (one patient had bilateral non-unions). The average age was 41.5 years (range 15–77). Male patients accounted for 59% (n = 19) of the cohort. Right-sided fractures (62%; n = 20) were more common than left. Mid-diaphyseal was the most common non-union location (n = 30; 94%). Proximal metaphyseal–diaphyseal junction and distal metaphyseal–diaphyseal junction accounted for one patient each.

Seven (22%) patients sustained open fractures, and five (16%) others were 'open' from a GSW. Other mechanisms of injury included motor vehicle collisions (n = 14; 44%), low velocity falls (n = 6; 19%) and pedestrian vehicle accidents (n = 3; 9%). Forty-one per cent of patients sustained other orthopaedic injuries at the time of humerus fracture, and 37% of patients were polytraumatised.

Most patients (n = 23; 72%) had already had some form of surgery on their humerus prior to the development of non-union. This included wound debridement only (n = 1), wound debridement and external fixator (n = 2), IM nail (n = 1) and, most commonly, plate osteosynthesis ± debridement of an open fracture (n = 19; 59%).

Vitamin D levels were found to be deficient (n = 19; 59%) or insufficient (n = 6; 19%) in most patients tested. Albumin levels were low in only two patients tested (n = 2; 7%). Ten (32%) of the patients were smokers. Seven patients were on treatment for hypertension, five were on treatment for diabetes mellitus, and five were on treatment for HIV infection. These results are summarised in *Table I*.

Autogenous and/or allogenous bone graft was used in 47% (n = 15) of cases. DBM in the form of bone 'dust' was used exclusively in nine cases (28%). The use of DBM was principally to fill large voids from previous failed fixation and not to stimulate healing. Autograft was used exclusively in two cases, and a mix of auto- and allograft was used in one case. Local antibiotics were used in three-quarters of FRI cases but, as the fracture site was not opened in the case of the IM nail, no local antibiotics were used. Vancomycin and gentamicin were combined with the calcium sulphate graft in two cases, and antibiotic-impregnated collagen sponge was used in one case. The authors do not recommend the use of autogenous or allogenous bone graft in the setting of confirmed FRI.

Ultimately, we achieved a 100% union rate in this series. Thirty patients (94%) with humeral non-unions progressed to union after single-stage plate osteosynthesis. Two patients (6%) required an additional unplanned revision non-union surgery at 22 and 26 months after initial non-union surgery due to ongoing non-union and plate failure. Both patients united after second single-stage revision surgery.

Table I: Demographic, clinical and injury characteristics of the cohort

Characteristic	Mean (± SD)	n (%)
Age (years)	41.5 (± 14.5)	
Male sex		19 (59)
Smoker		10 (31)
Low serum albumin (g/L)		2 (6)**
Insufficient/deficient serum vitamin D (nmol/L)		6/19 (19/59)***
HIV positive		5 (16)
Diabetes mellitus		6 (19)
Mechanism of injury:		
Road traffic injury		18 (56)
GSW		5 (16)
Fall		4 (12.5)
Other		5 (15.5)
Open fracture*		12 (37.5)
Polytraumatised		12 (37.5)
Management of initial injury:		
Nonoperative		9 (28)
Debridement only		1 (3)
ORIF plate		19 (60)
External fixator		2 (6)
IM nail		1 (3)
Confirmatory signs of FRI		4 (12.5)

SD: standard deviation; HIV: human immunodeficiency virus; GSW: gunshot wound; ORIF: open reduction and internal fixation; IM: intramedullary
*including GSW; **normal range: 35–52 g/L; ***ranges: normal > 72.5 nmol/L; insufficient 52.5–72.5 nmol/L; deficient < 50 nmol/L

Time to union was not the primary outcome metric of this study and was not able to be accurately quantified with the data available. Patient follow-up was unreliable and consequently timing of radiographs between patients varied considerably. The median time to union in this series was 133 days (IQR 150) but this number should be interpreted with its limitations in mind.

Four patients had confirmatory signs of FRI as per Metsemakers et al. prior to their initial non-union surgery.[13] Of those four, bacteria were cultured from intraoperative samples in two cases (*Serratia marcescens*, and methicillin-sensitive *Staphylococcus aureus*). One additional patient who did not have clinical signs of infection had positive cultures from initial intraoperative samples (*Morganella morganii* and *Escherichia coli*).

Three patients had ongoing wound drainage after their non-union surgery and were taken back to theatre for a 'DAIR' procedure (debridement, antibiotics, implant retention) at days 5, 10 and 14 after non-union surgery, respectively. One of these patients cultured *Streptococcus pyogenes* from intraoperative samples taken at this setting. These patients were treated with antibiotics, did not require further surgery, and progressed to union. It is worth noting that none of the four abovementioned patients who had confirmatory signs of FRI prior to surgery required a second debridement in theatre.

Nil radial nerve palsies were noted postoperatively. Additional complications included infection and glenohumeral joint stiffness. One patient required hardware removal and soft tissue releases with a view to increase shoulder range of motion. This was undertaken after confirmed non-union resolution.

Discussion

There is no single treatment strategy to treat all humeral shaft non-unions; however, compression plating and autogenous bone graft is widely accepted as the gold standard and has been shown to have the highest rates of union. It enables compression, correction of axial malalignment and stimulation of osteogenesis in a single procedure.[14] Other surgeons advocate substituting autogenous grafting for bone graft substitutes (e.g. DBM) and have shown high rates of union while avoiding donor-site morbidity.[15,16] Humeral shaft non-unions can be reliably augmented with either autologous iliac crest graft or DBM with comparable union rates, time to union and functional outcome. Harvesting of autologous bone graft is, however, associated with significant rates of donor-site morbidity.[16]

The majority of our cases did not require bone graft to stimulate healing. It is the authors' preference to use DBM to fill bone voids, if present, which may be combined with locally acquired autograft. If biological stimulation was required, locally harvested cancellous graft was used in most cases. Manufactured bone graft substitutes were used only in the setting of FRI to facilitate delivery of antibiotics.

Exposing bone, and indeed a fracture site, to differing mechanical environments induces a response within the bony tissue at a cellular level. At a cellular level, different tissue formation may either be suppressed or enhanced by these forces.[17] Compressive strain promotes the formation of cartilaginous tissue, and tensile strains induce the formation of fibrous connective tissue with collagenous fibres.[18] It is therefore crucial to ensure that maximum cortical contact is achieved with compression across the fracture site as described in our proposed surgical technique.

The most dominant factors that influence the amount of interfragmentary strain at the fracture site are the stiffness of the osteosynthesis construct, the size of the interfragmentary gap and the amount of loading.[19] When treating a non-union, the surgeon involved may have influence on all of these factors to a varying degree. Stiffness of construct depends on what type of implants are selected and how they are used intraoperatively. The interfragmentary gap is determined by the fastidiousness of the reduction of the fracture site, as well as the characteristics of the fracture site such as anatomical location and degree of comminution. In the setting of non-union, the surgeon has an opportunity to create a more desirable fracture configuration to best achieve bony contact and minimise interfragmentary gapping. The desired amount of loading may be prescribed by the surgeon and will be demonstrated during the patient's convalescence postoperatively. It is, however, important to note that it is not only the amount of loading that is relevant but also the type of force that is applied across the fracture site. Multiple studies have shown that axial compressive forces across a fracture site promote callus formation and maturation whereas shearing forces inhibit neovascularisation and delay fracture healing.[17]

The anterolateral approach to the humerus allows for an extensile approach to the non-union site. The radial nerve is often surrounded by fracture callus and scar tissue and requires careful dissection and identification to avoid injury when using the anterolateral approach. In some instances, it may be necessary to abandon this approach in favour of the anterior approach in cases when it is not possible to safely identify the radial nerve.[20] In the case of non-union surgery after previous attempts at plating, it may be necessary to use same approach already used.

A 2015 meta-analysis of the treatment of humeral shaft non-unions found compression plating with autologous bone grafting to have the highest union rates (98%) when compared to other fixation methods, namely IM nailing, bone strut fixation and external fixation, when compared both with, and without autologous bone grafting. The union rate dropped to 88% with compression plating alone. Complication rates were comparatively low at 12% with compression plating and bone grafting.[21] Similarly, our cohort had a 16% complication rate, including three DAIR procedures, and two unplanned complex revision surgeries.

Naclerio et al. recommend staging surgery in the setting of frank purulence at the non-union site and advocate the use of antibiotic cement spacer and repeat theatre episodes to redebride, reculture and exchange spacers until cultures are negative. They avoid using bone graft in the setting of septic non-union.[7] Our series included a small number of infected non-unions with frank pus or a sinus confirming FRI at time of non-union surgery. These cases were also safely treated in a single stage with the addition of local antibiotics, but similarly without the use of non-synthetic bone graft.

Marti et al. reviewed 51 patients operated for humeral shaft aseptic non-unions over a 23-year period. Their surgical treatment consisted of an anterolateral approach with radial nerve identification and subsequent neurolysis, decortication, compression plating, and frequent application of autogenous bone grafts. No immobilisation with brace or cast was used after surgery. They achieved 100% union rate at one year, with 'near normal' shoulder and elbow range of motion, and had two transient radial nerve palsies.[22] The median time to union in our series was 133 days (IQR 150). Our cohort had nil radial nerve palsies, and one patient required additional surgery for glenohumeral joint stiffness.

As part of the treatment for fracture non-union, the patient should be investigated to identify and exclude certain common aetiologies that may affect fracture healing. Cessation of smoking and optimisation of nutritional status, including vitamin deficiencies and medical comorbidities, should be considered before elective non-union surgery. Metabolic or endocrine abnormalities have been identified in up to 84% of patients who fail to heal simple fractures.[7] Vitamin D deficiency and its effect on fracture healing is debated in the literature and evidence remains equivocal.[23] Eighty-nine per cent of our cohort were noted to have low levels of vitamin D. This is higher than the reported rate of vitamin D deficiency in the general population, which ranges from 36–57% in different population groups.[24] Vitamin D supplementation was initiated prior to surgery, if deficient.

Smoking is proven to be a risk factor for the development of non-union after fracture.[25,26] Patients were counselled and encouraged to stop smoking; however, surgery was not delayed if patients continued to smoke.

Adapted from the Radiographic Union Score for Tibia fractures (RUST) score, Oliver et al. have developed the 'Radiographic Union Score for HUmerus fractures' or RUSHU. This scoring system was found to have good interobserver and excellent intra-observer reliability and could be used to reliably assess humeral shaft fracture union.[12]

Giannoudis et al. have highlighted four key elements of fracture healing and proposed the 'diamond healing concept'.[27] Osteogenic cells, osteoconductive scaffolds, growth factors and the mechanical environment all contribute to bone restoration and need to be considered when addressing a non-union.[27] The authors believe that the technique described above addressed each of these four concepts and provides an acceptable treatment of humeral non-union.

This study has several limitations including its retrospective design, and that all cases were performed by a single surgeon at a single facility. This is a relatively small series of cases and results should be interpreted with caution, especially subgroup analyses. Time to union was not accurately quantified due to unreliable patient follow-up.

Conclusion

Single-stage humerus non-union surgery with fracture site refashioning and compression plate osteosynthesis is a reliable method of treatment. In our cohort, this was successfully undertaken in the setting of confirmatory FRI. We recommend that the fracture site be biopsied for cultures in all cases, even those without signs of FRI.

Ethics statement

The authors declare that this submission is in accordance with the principles laid down by the Responsible Research Publication Position Statements as developed at the 2nd World Conference on Research Integrity in Singapore, 2010.

Prior to commencement of the study, ethics approval was obtained from the University of Cape Town Human Research Ethics Committee (Ref: 604/2023). Informed written consent was not obtained from all patients for being included in this retrospective study.

Declaration

The authors declare authorship of this article and that they have followed sound scientific research practice. This research is original and does not transgress plagiarism policies.

Author contributions

DM: data capture, first draft preparation, manuscript revision
SM: data capture, first draft preparation
ML: study conceptualisation, manuscript revision

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