Grafting and fixation after aseptic non-union of the humeral shaft: A case series

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ABSTRACT

Purpose: Non-unions after humeral shaft fractures are seen frequently in clinical practice at about 2–10% after conservative management and 30% after surgical treatment. Non-union, displacement of structures and fixation failure can be hazardous complications. The purpose of our study was to evaluate the outcomes of an on-lay bone graft strut construction with bone chips as grafting augmentation in the management of aseptic non-unions of the humeral shaft.

Methods: From 124 eligible patients with a humeral shaft non-union, we included 48 patients. In all cases an anterolateral humeral approach was used, with an on-lay bone graft using an allograft strut construction and with bone substitute augmentation in the non-union gap. To assess the bone healing on radiographs, we used the non-union scoring system according to Whelan. Patients were followed with objective and subjective scores.

Results: In all 48 patients we achieved full bone healing without major complications. The average period of union was 124 days. In 40 cases after healing the alignment was neutral, valgus deformation occurred in 6 cases a varus deformation in 2 cases. At twelve months after surgery, all patients recovered with satisfactory range of motion of shoulder and elbow and a good quality of life, without any radial nerve palsies or other major complications.

Conclusion: Given the satisfactory results of full bone healing, recovery of the range of motion and the lack of major complications as seen in this study, we find that plating with supporting allograft as a good choice of treatment in the cases of aseptic non-union of the humeral shaft.

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1. Introduction

Non-union after humeral shaft fractures are seen frequently in clinical practice, about 2–10% in conservative management and up to 30% in surgically treated patients.¹ Factors attributing to non-unions are often related to technical errors or inappropriate treatment. Several types of treatment (conservative, intramedullary nailing, ascending pinning, plating, external fixation) can be done for humeral shaft fractures. In all cases, a precise technique and proper indication are essential for success.^{2–6} Non-union,

displacement, and fixation failure can be hazardous complications for these injuries.^{2–6} The treatment of aseptic, atrophic, non-union, with or without necrosis of the humeral head, is challenging for orthopaedic surgeons. The outcomes are often unsatisfactory for the patients, as they are associated with long-term morbidity.^{7,8} The purpose of our study is to evaluate the outcomes of plate-and-bone strut allograft with bone substitute augmentation in the management of aseptic, atrophic non-unions of the humeral shaft.

2. Materials and methods

2.1. Patient selection

From January 2006 to December 2017, patients with aseptic,

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atrophic non-unions persisting after 6 months after initial surgery of the humeral shaft were registered in two Level I Trauma Centres (Vito Fazzi Hospital, Lecce, Italy; Santa Maria della Misericordia, Perugia, Italy).

From these patients, we excluded patients with hematologic or oncologic pathology, acute or chronic infections, ASAMI non-union classification type A and C,⁹ age under 18 years, bone metabolism diseases, elbow osteoarthritis, and rheumatoid diseases.

2.2. Data collection

All non-unions were classified according ASAMI classification for long bones.⁹ All patients were informed in a clear and comprehensive way of the type of treatment and other possible surgical and conservative alternatives. Patients were treated according to the ethical standards of the Helsinki Declaration, and

were invited to read, understand, and sign the informed consent form. The institutional review board waived approval for this study.

All patients underwent the same rehabilitation protocol (see rehabilitation protocol). To assess the bone healing on radiographs, we used the Non-Union Scoring System (NUSS) in retrospective mode.¹⁰ The outcome measures during the follow-up were the shoulder function measured by Constant Shoulder Score (CSS)¹¹ and Oxford Shoulder Score (OSS),¹² elbow function using the Mayo Elbow Score (MES)¹³ and the Oxford Elbow Score (OES).¹⁴ Humeral alignment was measured using plain radiographs with standard anterior-posterior and lateral views. After one, three, six and twelve months after surgery the outcome measures were taken. The evaluation endpoint was set at 12 months after surgery. Bone union was measured using the radiographic union score as described by Whelan et al.¹⁵

Fig. 1. 40-year old male patient, treated with an intramedullary implant after a gun shot wound was referred to our institution. Because of pain and osteolysis (A) the intramedullary implant was removed and replaced by an external fixator (B). Samples were taken for cultures. When negative, after three months the non-union was exposed using the anterolateral approach (C) and the bone-and-strut graft was placed with support tot he medial side of the humerus (D). Post-operative radiographs show a neutral alignment axis (E).

2.3. Statistical analysis

Cohen's kappa coefficient (κ) was used to calculate the concordance between the patient reported outcomes and bone healing.

2.4. Surgical technique

All patients were placed in the beach chair position with the chest elevated about 30°. The surgical approach was the antero-lateral approach to the humerus.¹⁶ After exposing the non-union focus, we removed the previous implant (when present) and surgically reduced the fracture (Fig. 1). The intramedullary shaft was reamed. The strut allograft was prepared on a separate table and was temporarily fixated during reduction with K-wires to a modelled plate 4.5 mm Locking Compression Plate® (LCP®, DepuySynthes™, Oberdorf, Switzerland). This was useful for determining length, rotation and varus-valgus axes. Allograft bone chips were then placed inside the reamed shaft, augmented with Putty® Biocollagen Crunch bone pasta (Biogen®, Bioteck™, Arcugnano, Vicenza, Italy). This augmentation consists of cancellous bone granules and allograft collagen and comes as a powder which becomes a mouldable paste when hydrated. The strut allograft then was definitively fixated in such position to primary support the anteromedial humeral cortex, with cortical screws through the allograft and locking screws through the distal and proximal humeral cortices.

The result was reviewed by fluoroscopy in three different views and with dynamic testing of the elbow. As a general guideline for rehabilitation, we prescribed a sling for three weeks with gentle use of hand and elbow as soon as the patient's comfort permits. Forceful use of the arm was discouraged, but gentle, assisted range of motion for shoulder and elbow with a physiotherapist may be added in an early stage (Appendix 1).

3. Results

A total of 124 patients with aseptic non-unions of the humeral shaft were screened to participate in the study. From this cohort, 48 patients fulfilled the inclusion criteria for this study. The demographic details are described in Table 1.

The mean follow-up period was 32 months (± 12 ; range 12–132). During the first year, no adverse events were observed. All wounds healed within three weeks and sutures could then be removed. There were no cases of deep infection or hardware failure. The average time of bone healing was 124 days using the Non-Union Scoring System in retrospective mode.¹⁵ The surgery lasted on average 107 min and the amount of red blood cell transfusion had an average of 0.8 units (Table 2).

After completed bone healing the humeral alignment type was neutral in 40 patients (83%), valgus in 6 patients (25%) and varus in 2 patients (4%). This was already present directly after surgery and was not a result of screw cut-out of hardware failure. At final follow-up at twelve months the average shoulder arcs were 142° of, 41° of extension, 58° of internal rotation, 72° of external rotation, and 118° of abduction. Average elbow arc of flexion-extension motion was 108° and the arc of pro-supination motion averaged 159°. The quality of life measured with the Constant Shoulder Score, Oxford Shoulder Score, Mayo Elbow Performance Score, and Oxford Elbow Score were all clinically significantly good after a follow-up period of one year since the surgery, almost at a pre-existent level (Table 3). The correlation between clinical and radiographic union results was high according to Cohen's kappa (κ : 0.81).

Table 1
Description of the populations.

Parameters	Descriptives
Number of patients	48
Average age (range)	42.4 (18–68)
Gender (male:female)	24:20
Cause of fracture (n, (%))	
Fall from height	12 (25)
Traffic accident	12 (25)
Work-related accident	20 (42)
Gun shot wounds	4 (8)
Work Occupation (n, (%))	
Agriculture	12 (25)
Industrial sector	24 (50)
Tertiary industry	12 (25)
Injured side (of which dominant side)	
Right	12 (4)
Left	36 (6)
Primary type of fracture according to the AO classification (n, (%))	
A1	4 (8)
A2	4 (8)
A3	6 (13)
B1	8 (17)
B2	8 (17)
B3	8 (17)
C1	4 (8)
C2	4 (8)
C3	2 (4)
Surgical implant used in previous surgery (n, (%))	
Plate	12 (25)
External fixator	18 (38)
Intramedullary nail	18 (38)

Table 2
Surgical and post-operative parameters. Humeral shaft alignment was measured on the radiographs taken at 12 months after surgery.

Parameters	Descriptives
Follow-up (months, range)	32 (12–132)
Average surgical time (minutes, range)	107 (80–142)
Red blood cell transfusions (mean units, range)	0.8 (0–3)
Bone healing measured by NUSS (mean, range)	124 (84–156)
Humeral shaft alignment (n, %)	
Neutral	20 (83)
Varus	3 (13)
Valgus	1 (4)
Function outcomes after 12 months (mean degrees, range)	
Shoulder flexion	142 (84–167)
Shoulder extension	41 (30–54)
Shoulder internal rotation	58 (25–65)
External rotation	72 (25–90)
Shoulder abduction	118 (75–180)
Arc of elbow flexion-extension	108 (94–180)
Arc of elbow pronosupination	159 (102–180)

4. Discussion

Aseptic non-union of the humeral shaft poses a difficult problem for which different treatment options are available. Our series show a reproducible option to support the humeral head and maintain reduction of the distal part in the treatment of humeral shaft aseptic non-unions; in particular no complications have been found to be directly connected to the graft and no deep infections have occurred, which is similar to that found with other bone fixation techniques.^{5–8} We therefore suggest the use of our technique in aseptic non-union humeral shaft to restore the integrity of the anteromedial wall, support the humeral axis and to maintain reduction until complete healing has occurred. Autologous strut grafting with bone chip augmentation has shown to be a reliable option, with sufficient restoration of length and good functional results, yet has a higher patient morbidity from the donor

Table 3
Results of semi-quantitative questionnaires before trauma (retrospective data), pre-operative (prospective data) and twelve months post-operatively (prospective data). For all questionnaires, 0 is the worst score possible and 100 is the best score possible.

Score	Before trauma (mean, range)	With non-union (mean, range)	Twelve months after surgery (mean, range)
Constant Shoulder Score	93(86–100)	25 (12–40)	83 (62–100)
Oxford Shoulder Score	94 (86–100)	23 (range 12–38)	82 (68–100)
Mayo Elbow Performance Score	94 (90–100)	73 (56–100)	90 (82–100)
Oxford Elbow Score	94 (90–100)	70 (42–100)	93 (84–100)

site.^{5,7,8,25} The strut allograft provides more stability than one bridging plate only, and even though it is avascular, it could act as a biological scaffold for bone ingrowth on the anteromedial side which is not possible using a double-plating technique.

Other surgical options such as primary shortening, cancellous autologous bone grafts in one stage, cancellous autologous bone grafts in two stages after Masquelet techniques, pedicled bone transfers from the free border of the scapula or rib, periosteal free flap transfers or bone morphogenetic protein scaffolds have been described in literature.^{6,17–20} However, we believe in concordance to Kim et al., humeral shaft non-unions require two questions; what went wrong, and what to do?² For the first question, the technical failures in reaching adequate stability and acceptable strain for fracture healing are the foremost reason.² Since the humerus is a non-weight bearing bone, there is a lack of axial loading what promotes fracture distraction and straining which makes compression plating seem favourable.² Concerning the second question, each case should be evaluated whether union is suspected to be reached without further biological stimulation (i.e., atrophic non-union) and when necessary, how this biological stimulus can be promoted with minimal patient morbidity.² Healy et al. agree on the principles of improving the suboptimal biologic response and achieving mechanical stability by rigid fixation in treating atrophic humeral shaft non-unions.²⁴ They proposed plating and autologous iliac crest cortical bone grafts as treatment of choice in troublesome cases.²⁴

The importance of blood supply is emphasized in multiple studies, showing that blood supply is essential to increase bone healing and to avoid infection of the foreign body material.^{7,8,17–21} Kerfant et al. reported on five cases of aseptic and multi-operated non-unions of the humerus with free fibular transfer.²¹ They concluded that this technique was a reliable option to allow satisfactory bone union. Although non-vascularised bone grafting is effective in small bone defects, covered with well-perfused soft tissues, they are less reliable when the gap defect is greater than 6 cm and when soft tissue vascularisation is poor.²¹ However, vascularised bone grafts imply greater patient morbidity, yet might provide higher biomechanical strength than non-vascularised techniques.^{7,8,17} Nevertheless, in our series we have seen no complications of material failure or osteolysis around the fixation screws. Also the additional stripping of soft tissues and periosteum to place the strut allograft seemed comprehensible pre-operatively, after debridement of the non-union gap.

The functional results of our study are in line with other literature concerning humeral non-unions.²² The union rate when treated with open reduction and internal or wire fixation ranges in literature between 80 and 100% with a total range of flexion-extension motion arc between 71° and 102° (average 91°).²² Dembélé et al. reported on 22 cases of non-union of the humeral shaft in 22 patients using compressive plate fixation combined with a corticosponeous autograft after open reduction.²³ Even though compression was not possible in our cases and one patient needed 10 months to reach consolidation, our overall consolidation rate was 100%, showing that plate-and-bone strut allograft with bone chip augmentation technique had comparable bone union

outcomes. Our series had 40 out of 48 patients with a neutral humeral axis, most likely because of the large exposure reached by the surgical approach. Nevertheless, it must be taken into consideration that a humerus can heal with deformities without compromising functionality (<20° anterior angulation, < 30° varus/valgus angulation, < 3 cm shortening).⁵

A limitation of the current study are the limited number of patients, which are selected in two level 1 trauma centres, and therefore might not be a completely representative sample of patients since the chances of concurrent trauma are higher than in peripheral hospitals. However, our centre acts as a referral centre for difficult cases and a similar caseload in peripheral hospitals probably could not be reached in this study period. Another limitation is the retrospective nature of this study and potential recall bias for the questionnaires regarding the pre-trauma quality of life.

5. Conclusion

The plate-and-bone strut allograft with bone substitute augmentation for patients with a humeral shaft non-union has shown promising results regarding an union rate of 100% and recovery of functional result measured with semi-qualitative patient questionnaires. We therefore recommend treatment of invalidating non-union of the humerus shaft using our technique which has less comorbidity than autologous bone transplants.

Conflicts of interest

All authors disclose any financial and personal relationships with other people or organizations that could inappropriately influence (bias) their work. Examples of potential conflicts of interest include employment, consultancies, stock ownership, honoraria, paid expert testimony, patent applications/registrations, and grants or other funding.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jcot.2019.08.020>.

Appendix

Rehabilitation Protocol

Phase 1 (first 4 weeks)

- Immobilization support for 4 weeks
- Pendulum exercises
- Avoid external rotation for first 6 weeks

Phase 2 (approximately weeks 5–9)

If there is clinical evidence of healing and fragments move as a unit, and no displacement is visible on the x-ray, then:

- Gently assisted motion
- Active-assisted forward flexion and abduction
- Gentle functional use week 3–6 (no abduction against resistance)
- Gradually reduce assistance during motion from week 6 on

Phase 3 (after week 9)

- Add isotonic, concentric, and eccentric strengthening exercises
- If there is bone healing but joint stiffness, then add passive stretching by physiotherapist.

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