Double Plating With Autogenous Bone Grafting as a Salvage Procedure for Recalcitrant Humeral Shaft Nonunion

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Research article

Keywords: humerus, recalcitrant nonunion, plate, bone graft

DOI: https://doi.org/10.21203/rs.3.rs-34226/v1

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Abstract

Background: Despite the majority humeral shaft nonunions respond well to surgical intervention, a surgeon still encounters a patient with humeral shaft nonunion who had already undergone repeated surgeries for nonunion. This study is a retrospective analysis of the efficacy of the treatment of recalcitrant humeral shaft nonunions using double locking compression plate (LCP) fixation in combination with autogenous iliac crest bone grafting.

Methods: A consecutive series of aseptic recalcitrant humeral shaft nonunion underwent surgical treatment between May 2010 and August 2017 in the authors’ institute. Standardized treatment included a thorough debridement, double LCP and screw fixation, and autogenous iliac bone graft. The injury type, the bone affected by nonunion, and the duration of nonunion were recorded for all patients. The main outcome measurements were Constant and Murley scale for shoulder function, Mayo elbow performance index (MEPI) for elbow function and the visual analog scale (VAS) for pain. In addition, all complications were documented.

Results: The study consisted of six females and nine males with a mean age of 45.3±13.1 years. Each patient had already undergone at least once failed surgical management for nonunion. The average duration that the bone remained ununited before the index intervention was 126.8±124.2 months. All patients achieved bone union without implant failure. At the final follow-up, both the mean Constant and Murley joint function score and the mean MEPI were significantly improved, and the mean VAS score significantly decreased. Each patient was highly satisfied with the treatment. Complications were only seen in four patients, including one super wound infection, one radial nerve palsy, one ulnar never palsy, and one discomfort at the iliac crest.

Conclusion: Double plate fixation combined with autogenous iliac crest bone grafting can result in successful salvage of humerus nonunions in patients who have failed prior surgical interventions.

Background

Humeral diaphyseal fractures comprise approximately 3–5% of all fractures and 30% of all humeral fractures, and 64% of humeral diaphyseal fractures involved the midshaft [1,2]. Although conservative treatment and primary open reduction and internal fixation (ORIF) of humeral shaft could result in a high union rate with a good functional outcome, posttraumatic nonunion of the humeral shaft is uncommon [2]. Reported nonunion of the humeral shaft occurred in 2–10% of nonsurgically treated fractures and in up to 13% of fractures treated by surgical treatment, with atrophic nonunion being the most common type, and commonly seen in the midshaft [3–5].

The reasons leading to humeral shaft nonunion are still unknown and maybe related to comminuted fracture, inadequate reduction and unstable fixation, poor blood supply of soft tissue envelope, fixation with distraction, the systemic state of the patient (patients with comorbid like diabetes, malnutrition),
infection, age, smoking and premature weight bearing [6, 7]. Often there is a multifactorial origin to
nonunion [8].

When a humeral shaft nonunion occurs, the involved upper extremity often presents with pain, function
loss, thus need revision. Many surgical techniques have been described for managing humeral shaft
nonunion, such as open reduction and internal fixation (ORIF) with locking compression plate (LCP) and
bone graft, dual plating, cortical strut allograft or autograft, locked intramedullary nails and Ilizarov
external fixators, and adding biologic augmentation (BMP) or assisted with low-intensity pulsed
ultrasound [9–11]. There is currently no consensus on the optimal operative treatment of humeral shaft
nonunion. As treatment for cases of recalcitrant nonunion who had already received at least once failed
surgical treatment for nonunion is more complicated and challenging, because they might existed
osteofibrosis, deformity, bone loss, soft-tissue scarring, and scalloping around screws and metallosis in the
nonunion site [12]. Although many authors have reported on the successful treatment of primary humeral
diaphysis nonunions, few papers have focused exclusively on revision procedures for salvaging
persistent nonunions following failed initial nonunion interventions. The purpose of this study was to
report authors’ experience in the use of double plates combined with autogenous bone graft in the
treatment of recalcitrant humeral shaft nonunions.

Methods

Study design and patients This was a consecutive retrospective review of medical records and
radiographs of 15 patients in whom an intervention of aseptic recalcitrant humeral shaft nonunion was
performed between May 2010 and August 2017 in the department of orthopaedic trauma, Honghui
Hospital, Xi’an Jiaotong University College of Medicine, Xi’an, China (Table 1). This study was approved
by the Ethics Committee of Hong Hui Hospital, Xi’an Jiaotong University. The inclusion criteria were
follow: 1) skeletally mature (18-85 years) patients satisfied diagnosis of recalcitrant nonunion, which was
a patient had already received surgical revision at least once for nonunion, and a minimum of 9 months
has elapsed since last treatment and the fracture shows no visibly progressive signs of healing for 3
months [13]; 2) patients suffered pain and weakness in the upper limb need intervention; 3) patients with
a revision procedure of double plate fixation in combination with autogenous iliac crest bone grafting.
Patients with humeral shaft nonunion received a single plate, internal nail or external fixation, or patients
with infected nonunion were excluded from this study. All patients agreed to publish individual clinical
details and accompanying images and provided written informed consent. Before undertaking revision
treatment, patients’ demographic and clinical data were retrieved from the medical records. Laboratory
tests including complete blood count, C-reactive protein (CRP) and erythrocyte sedimentation rate (ESR)
levels were also recorded to rule out infection. And, patient comorbidities were addressed. Surgical
technique The surgical intervention aimed to correct deformity, maintain bone alignment, as well as foster
environment conducive to bone healing. All patients underwent surgery under general anesthesia after
prophylactic antibiotics were given. All operative procedures were performed by well-trained orthopaedic
surgeons. Surgical approach was largely dependent upon both previous surgical treatment and nonunion
site. Generally, an anterolateral approach was used for proximal and middle nonunion, while a posterior
approach was employed when the nonunion involved the distal third of humerus [14]. During exposure, care was taken to identify and protect important structures, especially when the radial nerve was indicated, as the neurolysis would be necessary due to abundant scar tissue from multiple surgeries. The fracture nonunion site was opened and explored after original failed fixation devices were removed (except in two patients who showed no gap between nonunion sites but remained a stable plating with at least layers of cortices fixed at each side, where we left the previous plate in place and added a second plate), a thorough debridement was performed based on the Judet periosteal stripping technique [15], with the entire pseudocapsule, interposed fibrous tissue and sclerotic bone clearly excised until punctate bleeding was seen at the bony ends (Paprika sign) [5,16]. After opening the medullary canal using a drill bit, any angulation and rotation were corrected, and osteosynthesis was performed by using a 4.5-mm narrow LCP in compression mode to obtain cortex-to-cortex stability. Subsequently, a groove lying 90° perpendicular to the first plate was made at the side across the ends of the nonunion (Fig. 1a). Then, autogenous iliac crest bone graft was harvested and trimmed and loaded into the bone groove with bone graft spanning the fracture (Fig. 1b). After that, a second plate was fixed to the anterior side of the bone graft (Fig.2). Also, a few pieces of cancellous bone were packed longitudinally to bridge the nonunion site. The wound was closed in layers.

Postoperative management

Cephalosporins antibiotics were routinely given 30 minutes preoperatively and continued for 24 hours postoperatively, and drainage was last for 48 hours. No external immobilization was need, thus, supervised functional rehabilitation including gentle active and active-assisted range-of-motion exercises of the shoulder and elbow joint were begun from the next postoperative day. Four weeks postoperatively, aggressive ranges of motion exercises were initiated, while the lifting of weights was until osseointegration or fracture healing was observed [7]. Data collection and analysis Postoperative follow-up including both clinical and radiographic evaluation was performed until bone healed, and then taken once half-yearly by an independent observer. Osseous healing was defined radiographically as the presence of at least three of four healed cortices [4]. The Mayo Elbow Performance Index (MEPI) was calculated preoperatively and at the most recent follow-up visit for each patient [17]. A score of 100 to 90 points was considered to be an excellent result, 89 to 75 points considered good, 74 to 60 points considered fair, and less than 60 points considered poor. Shoulder function was evaluated with the use of the Constant and Murley scale [18], where excellent if the score was between 80 and 100 points; good if the score was between 60 and 79 points; fair if the score was between 40 and 59 points, and poor if the score was <40 points. Pain was assessed using a visual analogue scale (VAS) on a scale of 0 to 10 [5]. Statistical analysis was performed using SPSS version 17.0 software (SPSS Inc, Chicago, IL). Differences in the findings were analyzed by paired samples T-tests, and P< 0.05 was considered statistically significant.

Results

The study consisted of six females and nine males with a mean age of 45.3 ± 13.1 years (range, 23–62 years)(Table 2). Eleven patients had involvement in the left humerus and four on the right side. Twelve patients each had fractures of mid-shaft of humerus, two had fractures at the junction of the middle and distal thirds and one had a fracture of the distal third. Thus an anterolateral approach for revision was
seen in twelve patients, while a posterior approach in three. Based on Weber-Cech classification [19], the type of nonunion was classified by radiographic standards as being atrophic, hypertrophic, oligotrophic or synovial. In this series, 7 patients were of atrophic nonunion, 2 were synovial pseudarthrosis, 5 were hypertrophic, and 1 was oligotrophic. Thirteen patients were closed fractures and 2 open fractures, in which eventually formed one atrophic nonunion and one hypertrophic nonunion upon the final intervention, and all patients were aseptic nonunion. The mechanisms of initial injury from the medical records were following: tumbling (6), traffic accident (3), crashing (5) and sports injury (1). The average duration that the bone remained ununited before the index intervention was 126.8 ± 124.2 months (range, 17–368 months). All patients had varying degrees of pain and limitation of activities of daily living, thus need surgical intervention, and each patient had undergone at least one failed attempt of operation fixation for the nonunion.
| Patient | Follow-up period, months | Outcome | Duration of bone healing, months | Angulation | VAS (pre-pos) | Constant and Murley (pre-pos) | Mayo elbow performance index (pre-pos) | Complications |
|---------|--------------------------|---------|----------------------------------|------------|--------------|-------------------------------|----------------------------------------|---------------|
| 1       | 19                       | Union   | 5                                | -10°       | 5            | 0                            | 74 96                                  | 65 100 None   |
| 2       | 45                       | Union   | 6                                | -10°       | 8            | 1                            | 36 88                                  | 50 100 None   |
| 3       | 19                       | Union   | 6                                | -10°       | 4            | 0                            | 69 84                                  | 75 100 None   |
| 4       | 16                       | Union   | 5                                | -10°       | 6            | 1                            | 46 90                                  | 55 90 None    |
| 5       | 27                       | Union   | 7                                | -10°       | 7            | 2                            | 32 91                                  | 45 85 Ulnar neuropathy |
| 6       | 14                       | Union   | 8                                | -10°       | 6            | 0                            | 56 92                                  | 60 95 None    |
| 7       | 19                       | Union   | 10                               | -10°       | 5            | 1                            | 36 78                                  | 55 85 Iliac crest discomfort |
| 8       | 21                       | Union   | 7                                | -10°       | 6            | 2                            | 34 68                                  | 45 80 None    |
| 9       | 31                       | Union   | 4                                | -10°       | 7            | 1                            | 38 90                                  | 50 95 Super superficial wound infections |
| 10      | 32                       | Union   | 6                                | -10°       | 5            | 0                            | 44 86                                  | 60 100 None   |
| 11      | 36                       | Union   | 4                                | -10°       | 4            | 0                            | 72 94                                  | 70 95 None    |
| 12      | 15                       | Union   | 8                                | -10°       | 6            | 2                            | 36 74                                  | 55 85 None    |
Patients were followed-up for an average of 23.0 ± 9.4 months (range, 13–45 months), each fracture had solid clinical and radiographic evidence of fracture union by the 6.4 ± 1.8 months (range, 4–10 months) follow-up, and none of the implants had loosening or breakage at the final follow-up. Postoperative alignment was within 10° of anatomic in 13 patients, and 2 patients had a more than 10° angulation. At the final follow-up, the mean Constant and Murley joint function score was significantly improved from preoperative 50.5 ± 15.3 points (range, 32–74 points) to 86.1 ± 8.1 points (range, 68–96 points) (P < 0.001), with 11 excellent results and 4 good results. For the elbow, the mean MEPI was 92.7 ± 7.0 points (range, 80–100 points), which was significantly improved compared with preoperative 58.3 ± 10.5 points (range, 45–80 points) (P < 0.001), with 10 excellent results and 5 good results. The mean VAS score decreased from 5.6 ± 1.4 points preoperatively (range, 3–8 points) to 0.9 ± 1.0 points (range, 0–3 points), which was statistically significant (P < 0.001). Each patient was able to resume work and was highly satisfied with the treatment (Fig. 2,3).

Complications were seen in four patients. One patient developed a super wound infection at the nonunion site, which was settled with antibiotics and dressings after 4 weeks. One patient developed radial nerve palsy and one suffered ulnar nerve palsy, and both were persistent at final follow-up. And, one complained of occasional discomfort of bone graft donate area at the iliac crest.

Discussion

Despite considerable progress in orthopaedic technology, a surgeon still encounters a patient with humeral shaft nonunion who had already undergone repeated surgery for nonunion. In some circumstances, repeated operative failures to obtain union combined with soft tissue maladaptation and deformity have left the patient with a profound disability and an abandonment of optimism, especially for patients with poor economy [2, 3, 7, 10, 20]. Numerous treatments have been devised for treatment of humeral shaft nonunion, aiming at providing adequate fixation across the fracture sites and improving
the local biomechanical environment or blood supply, each has its drawbacks. Well recognized revisions for humeral shaft nonunion include interlocking nail, Ilizarov external fixator, and internal plate supplied with auto-ilial crest bone graft or vascularized fibular graft [9, 10, 12].

Some authors had successfully reported use nailing or exchange nailing for humeral shaft nonunion, which relies on the concept of improvement of biomechanical stability by the use of a nail being at least one millimeter thicker than its diameter, as well as mesenchymal stem cells transporting into the nonunion site following reaming procedure [2, 21]. However, the heal rates varied differently. Lin et al.[22] addressed 23 humeral nonunions with revision exchange nailing, 22 patients (95.6%) showed bony union. Whereas, McKee et al.[23] achieved union after exchange nailing in only four (40%) of ten patients and Flinkkilä et al.[24] in six (46.2%) of thirteen. Interlocking intramedullary nails have been widely used in acute humeral fractures, pathologic fractures and nonunions of the tibia or femur shaft, for humerus fixation, they have the advantages over plates of fewer tissue traumas, fewer circulatory impairments and lower risk of radial nerve injury [3]. However, most of the cases in this study presented with erosion, osteopenia, and sclerotic bone, it was difficult to get adequate fixation with good rotational control by fixation with exchange nailing, also, as most cases had stiffness in the neighboring joints due to repeated prior surgeries, exchanging nailing might cause subacromial impingement and rotator cuff injury which in fact worsen the function of those joints [25]. The other reason why exchange nailing or nailing is not successful in humeral nonunion was lack of cyclical loading due to weight-bearing and a higher amount of distractive and torsional loads on the humerus [23]. All of these factors put together made exchange nailing or nailing was not the best way for cases in the current study.

External fixation for nonunion treatment offers high stability and compression to the nonunion sites to achieve bony consolidation. Traditionally, Ilizarov ring fixators were used for distraction osteogenesis and bone transport in cases with tibia or femur infected nonunion. This technology has been used by several authors in the management of humeral nonunion shaft and yielded a high union rate [26, 27]. However, it requires long fixation time and risks of pin-tract infection and patient discomfort because of the large size of the frame, which makes it an unreliable and rather unnecessarily complex option in non-infected nonunion [10].

Plate fixation with bone grafting for humeral shaft nonunion has been the most common practice, this technique is easy to use by all surgeons. Gessmann et al [28] reported a 97% success rate of anterior augmentation plating after antegrade or retrograde intramedullary nailing. In a systematic review of 36 articles, Peters et al.[29] found that plate fixation with autogenous bone grafting achieved a union rate of up to 98%. The cases in this study lived in northwest China, where plate fixation remains the preferred method of long bone fixation due to economic constraints and the level of medical care available. As most patients showed varying degree of misalignment, implant broken and/or loosen, or pseudarthrosis, use of LCP fixation could achieve a high degree of cortex-to-cortex stability with compression of the bone segments and correction of the deformities for those cases. Also, repeated prior surgeries might result in a poor biological environment for fracture repair in cases during this study, this is consistent with the founding of Konda et al.[30], where humeral shaft nonunions following initial operative fixation of the
index fracture were more resistant to achieving union when compared to nonunions forming after initial non-operative treatment. And they recommended plate fixation and bone graft for recalcitrant humeral shaft nonunion. Although plating technique has complications of screw back-outs, peripheral nerve paralysis and infection [31]. We only saw two cases with nerve palsy (one with ulnar nerve palsy and one radial nerve) and one deep wound infection. And at the final follow-up, implant failure did not happen.

A second plate fixing vertically to the anterior of the bone graft for structural support could maintain intimate contact between the autogenous bone graft and both nonunion fragments, maximizing osteoconductive, osteogenic and osteoinductive properties of autologous bone, resulting in bone healing rates reaching 100% in this study. More, double-plate technology could obtain absolute stability, thus postoperative functional rehabilitation could be started from the next postoperative day without any external immobilization. This had already been confirmed by other researchers. In a biomechanical study of Kosmopoulos and Nana [31], they found that 90° dual locking plate configurations were more effective in restoring the intact compressive and torsional stiffness for humeral shaft fracture, and placement of the anterior and lateral plates at 90° was found to be the best configuration for dual plating. In a clinic study, Martinez et al.[32] reported the use of two-plate construct in the treatment of 22 cases of humeral shaft nonunion with a 100% rate.

Although many authors have reported on the successful treatment of primary humeral diaphysis nonunions, few papers have focused exclusively on revision procedures for salvaging persistent nonunions following failed initial nonunion interventions. Borus et al.[2] reported a series of 7 patients with humeral diaphyseal nonunion following at least two failed surgical procedures, these patients underwent uniform surgical repair with 4.5 mm compression plating and application of autogenous bone grafting. All nonunions healed with a good function of the affected extremity. Marti et al.[8] reported a series of 51 cases of humeral shaft nonunion, ten of which had undergone at least two prior surgical procedures, all patients were applied with plating and autogenous bone grafting, all got union at one year with 96 percent excellent or good shoulder and elbow function. Also, in a report of Adani et al.[33], 13 patients with an average length of the humeral defect of 10.5 cm who had at least of 2 surgeries were treated by plate and fibular fixation, nine patients healed primarily, 3 required additional bone grafting, and 1 had a second fibular transplant. The mean period to radiographic bone union was 6 months. In this current study, before the index intervention procedure, each patient had undergone at least once failed operation for nonunion. We treated them by double plating and auto bone graft. All 15 patients achieved bone healing at an average of 6.4 ± 1.8 months. At the final follow-up, each case showed a significantly improved function of the affected limb and a significantly reduced pain. The outcomes of this study were consistent with the above reports.

Limitations of this study are related to its retrospective nature and small patient numbers. In addition, we are unable to make a direct comparison between plate fixation and other fixation strategies. Because of the rarity and complexity of this specific problem, it was not possible to include a control group. Despite its limitations, this series demonstrates that double plating in combination with auto-bone graft achieves successful outcomes in recalcitrant humeral shaft nonunion. And, to the knowledge of the authors, this is
the largest series of patients who had undergone multi-surgeries for nonunion treated by double plating the technology.

**Conclusion**

Double locking compression plate vertical fixation in combination with autologous iliac cancellous bone grafting can provide an absolute stable fixation of nonunion segments for early functional exercise, and allow structural autologous bone grafts for optimal bone healing. The technique is a valuable adjunct for the treatment of recalcitrant un-united humeral shaft that failed prior surgical intervention for nonunion.

**Abbreviations**

LCP, locking compression plate

MEPI, Mayo elbow performance index

VAS, visual analog scale

ORIF, open reduction and internal fixation

BMP, biologic augmentation

CRP, C-reactive protein

ESR, erythrocyte sedimentation rate

**Declarations**

**Ethics approval and consent to participate**

This study was approved by the Ethics Committee of Hong Hui Hospital, Xi’an Jiaotong University and written informed consent was obtained from each patient.

**Consent for publication**

Not applicable.

**Availability of data and materials**

The datasets used/or analysed during the current study are available from the corresponding author on a reasonable request.

**Competing interests**

The authors declare that they have no competing interests.
This study was supported by Natural Science Basic Research Program of Shaanxi (Program No. 2020JM-689).

ZW and YZ participated in the design of this study. DF, XW, LS, XC, KZ carried out the studies and performed the statistical analysis. DF drafted the manuscript. All authors read and approved the final manuscript.

Acknowledgements

Not applicable.

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Tables
| Patient | Gender | Side | Cause of injury | Type of primary injury | Site(thirds) | Type of nonunion | Time since injury (months) | Prior treatments | Comorbidities |
|---------|--------|------|----------------|-----------------------|-------------|----------------|---------------------------|----------------|--------------|
| 1       | F      | L    | Tumbling       | Closed fracture       | Middle      | Atrophic       | 120                       | Plate; bone graft | None         |
| 2       | M      | L    | Tumbling       | Closed fracture       | Middle      | Synovial pseudarthrosis | 368                       | Plate; bone graft | Arrhythmia    |
| 3       | M      | L    | Traffic accident| Closed fracture       | Middle      | Hypertrophic    | 259                       | Plate; bone graft | Diabetes mellitus |
| 4       | F      | L    | Tumbling       | Closed fracture       | Middle      | Atrophic       | 24                        | Splint; plate   | None         |
| 5       | M      | L    | Crashing       | Closed fracture       | Middle      | Synovial pseudarthrosis | 226                       | Splint; bone graft | None         |
| 6       | F      | R    | Crashing       | Closed fracture       | Middle      | Hypertrophic    | 35                        | Cast; bone graft | None         |
| 7       | M      | R    | Traffic accident| Closed fracture       | Middle      | Hypertrophic    | 158                       | Cast; bone graft | None         |
| 8       | M      | L    | Crashing       | Closed fracture       | Middle      | Atrophic       | 21                        | Plate; bone graft | None         |
| 9       | F      | L    | Tumbling       | Open fracture         | Distal      | Atrophic       | 17                        | Debridement; plate; bone graft | None         |
| 10      | M      | L    | Tumbling       | Closed fracture       | Middle      | Atrophic       | 19                        | Plate; bone graft | None         |
|   | Gender | Side | Injury   | Fracture Type | Localization | Classification | Age | Treatment                      |
|---|--------|------|----------|---------------|--------------|----------------|-----|--------------------------------|
|11 | M      | L    | Crashing | Closed Fracture | Middle-Distal | Atrophic       | 23  | Cast; plate+ bone graft        |
|12 | F      | L    | Tumbling | Closed Fracture | Middle       | Oligotrophic   | 20  | Splint; plate                  |
|13 | M      | R    | Crashing | Open Fracture  | Middle       | Hypertrophic   | 319 | Debridement; Plate; plate+ bone graft; plate |
|14 | F      | R    | Sports injury | Closed Fracture | Middle-Distal | Atrophic       | 25  | Cast; plate+ bone graft        |
|15 | M      | L    | Traffic accident | Closed Fracture | Middle       | Hypertrophic   | 27  | Plate; bone graft              |

M, male; F, female; Classification of nonunion based on Weber-Cech classification.
### Table 2: Postoperative outcomes

| Patient | Follow-up period, months | Outcome | Duration of bone healing, months | Angulation | VAS (pre-pos) | Constant and Murley (pre-pos) | Mayo elbow performance index | Complications |
|---------|--------------------------|---------|----------------------------------|------------|--------------|-----------------------------|-------------------------------|---------------|
| 1       | 19                       | Union   | 5                                | ≤10°       | 5            | 74                          | 96                          | 65            | 100          | None         |
| 2       | 45                       | Union   | 6                                | ≤10°       | 8            | 36                          | 88                          | 50            | 100          | None         |
| 3       | 19                       | Union   | 6                                | ≤10°       | 4            | 69                          | 84                          | 75            | 100          | None         |
| 4       | 16                       | Union   | 5                                | ≤10°       | 6            | 46                          | 90                          | 55            | 90           | None         |
| 5       | 27                       | Union   | 7                                | ≤10°       | 7            | 32                          | 91                          | 45            | 85           | Ulnar nerve palsy |
| 6       | 14                       | Union   | 8                                | ≤10°       | 6            | 56                          | 92                          | 60            | 95           | None         |
| 7       | 19                       | Union   | 10                               | ≤10°       | 5            | 36                          | 78                          | 55            | 85           | Iliac crest discomfort |
| 8       | 21                       | Union   | 7                                | ≤10°       | 6            | 34                          | 68                          | 45            | 80           | None         |
| 9       | 31                       | Union   | 4                                | ≤10°       | 7            | 38                          | 90                          | 50            | 95           | Supersupper wound infections |
| 10      | 32                       | Union   | 6                                | ≤10°       | 5            | 44                          | 86                          | 60            | 100          | None         |
| 11      | 36                       | Union   | 4                                | ≤10°       | 4            | 72                          | 94                          | 70            | 95           | None         |
| 12      | 15                       | Union   | 8                                | ≤10°       | 6            | 36                          | 74                          | 55            | 85           | None         |
| 13      | 14                       | Union   | 5                                | ≤10°       | 7            | 55                          | 78                          | 50            | 85           | Radial      |
Figures

Figure 1

(a) A groove lying 90° perpendicular to the first plate was made at the side across the ends of the nonunion. (b) Showing structural auto-bone graft was loaded into the bone groove.
Figure 2

A 58-year-old man sustained a left humerus shaft fracture and underwent plate fixation 30 years ago, and because of nonunion one year postoperatively, he was treated with intervention of plate fixation combined with autogenous iliac crest bone. However, the humerus fracture still did not unite until he visited our institution. (a) Preoperative plain X-ray showing classic synovial pseudarthrosis nonunion of the left humerus with a broken plate. (b) X-ray immediate after revision surgery showing double plating by LCP with autogenous iliac crest bone graft. (c, d) X-ray 45 months after index surgery showing consolidate bone union.
Figure 3

A 42-year-old man sustained a right humeral shaft nonunion with a duration of more than 26 years, he had undergone 4 times surgeries before asked the authors for help. (a) X-ray showing nonunion with implant failure 4 years after the last revision. (b) Fixation using double LCP and bone graft. (c, d) X-ray 8 months postoperatively demonstrating osseous union.