Double plating with autogenous bone grafting as a salvage procedure for recalcitrant humeral shaft nonunion

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Abstract

Background: Despite the majority of 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 patents, 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 account for approximately 3% to 5% of all fractures and 30% of all humeral fractures, while 64% of humeral diaphyseal fractures involved the midshaft [1.2]. Although conservative treatment and primary open reduction and internal fixation (ORIF) of the humeral diaphyseal fracture can lead to a high healing rate with a good functional outcome, posttraumatic nonunion of the humeral shaft is not common [2]. It is reported in the literature that nonunion of the humeral shaft can reach to 2%–10% in non-surgical treatments and up to 13% in operative managements, with atrophic nonunion being the most common type, and commonly seen in the midshaft [3-5].

The formation of humeral shaft nonunion is related to many factors, such as comminuted fracture, inadequate reduction and unstable fixation, the 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].

As the involved upper extremity often presents with pain and function loss, patients with humeral shaft nonunion often need revisions to improve their life quality. Many surgical techniques for the treatment of humeral shaft nonunion have been described, such as open reduction and internal fixation (ORIF) with locking compression plate (LCP) and bone graft, double plates fixation, allogeneic or autologous cortical bone graft, intramedullary nails, and Ilizarov external fixators, and adding biologic augmentation (BMP) or assisted with low-intensity pulsed ultrasound [9-11]. However, there is currently no consensus on the optimal operative treatment strategy for nonunion of humeral shaft. 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 exist osteopenia, deformity, bone loss, soft-tissue scarring, and scalloping around screws and metallosis in the nonunion site [12]. Although many authors have reported on successful treatment of primary humeral diaphysis nonunion, few papers specifically address the revision procedures for salvage of persistent nonunions following failed initial nonunion interventions[2,8]. As our team's previous study had shown that double plates combined with structural auto-iliac bone graft resulted in reasonable outcomes for treatment of patients with limb nonunion, we would like to know if persistent humeral shaft nonunions response well for this treatment strategy[13]. The purpose of this study was to report the authors' experience in the use of double plates combined with autogenous iliac bone graft in the treatment of recalcitrant humeral shaft nonunions.

Methods

Study design and patients

This was a retrospective study of medical records and radiographs of 15 consecutive patients in whom an intervention of aseptic recalcitrant humeral shaft nonunion was performed between May 2010 and August 2017 in the department of orthopedic 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 followed: 1) patients had already received surgical revision at least once for nonunions of humeral shaft, and a minimum of 9 months has elapsed since last treatment and the fracture shows no visibly progressive signs of healing for 3 months [14]; 2) patients suffered pain and dysfunction 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. This study had got each patient’s informed consent to publish their individual clinical details and accompanying images.

Patients’ demographic and clinical data were retrieved from the medical records prior to revision treatments. Laboratory tests including complete blood count, C-reactive protein (CRP), and erythrocyte sedimentation rate (ESR) levels were also recorded to rule out infection. Moreover, patient comorbidities were addressed.

Surgical technique

The surgical intervention was aimed at correcting deformities, maintaining bone alignment, as well as creating an environment conducive to bone healing. After general anesthesia, all operative procedures were performed by well-trained orthopedic surgeons. The surgical approach was largely dependent upon both previous surgical treatment and the nonunion site, as well as the surgeon’s preference. Generally, an anterolateral approach was used for proximal and middle third nonunion, while a posterior approach was for distal third of humerus [15]. During exposure, care was taken to identify and protect important structures, especially for the radial nerve, 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 six 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 [16], with the entire pseudocapsule, interposed fibrous tissue and sclerotic bone clearly excised until punctate bleeding was seen at the bony ends (Paprika sign) [5]. After opening the medullary canal, 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 front of the bone graft (Fig.2).In addition, several pieces of cancellous bone were longitudinally packed 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 a 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 the 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. The 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 the 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.

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. The 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) (P0.001), 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) (P0.001), 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 never 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 the great advance in orthopedic 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 coupled with soft tissue maladaptation and deformity have left the patient with a profound disability and an abandonment of optimism, especially for patients with poor financial conditions [2,3,7,10,20]. A number of methods have been designed to treat humeral shaft nonunion in order to provide adequate fixation across the fracture sites and improve the local biomechanical environment or blood supply, and each method has its drawbacks. Well recognized revisions for humeral shaft nonunion include interlocking nail, Ilizarov external fixator, and internal plate supplied with auto- iliac crest bone graft or vascularized fibular graft [9,10,12].

Interlocking intramedullary nails have been widely used in acute humeral fractures, pathologic fractures and nonunions of the tibia or femur shaft, as for humerus fixation, they have the advantages over plates of fewer tissue traumas, fewer circulatory impairments and lower risk of radial nerve injury [3]. Nailing or exchange nailing for humeral shaft nonunion had been successfully reported by some authors, the concept of this technology is improving nonunion segments biomechanical stability by using of a nail being at least one millimeter thicker than its diameter and fostering healing environment by transporting mesenchymal stem cells into the nonunion sites during 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 a 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. The reason might be a lack of cyclical loading due to weight-bearing and a higher amount of distractive and torsional loads on the humerus [23]. As 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]. All of these factors put together made the authors avoid using exchange nailing or nailing to treat 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, its disadvantages include long fixation time, risks of pin-tract infection, and patient discomfort, these make it an unreliable and rather unnecessarily complex option in non-infected nonunion [10].

Our previous studies had proved that LCP combined with autologous iliac structural bone grafting can effectively treat aseptic limb nonunions[5,13], and many researchers advocated this treatment strategy. Gessmann et al.[28] reported a 97% healing rate of anterior augmentation plating for aseptic humeral shaft nonunions after antegrade or retrograde intramedullary nailing. Also, after reviewed 36 articles, Peters et al.[29] found that plating with auto-bone grafting could achieve a union rate of up to 98% for cases with humeral shaft nonunion. In this study, we used double plate fixation combined with auto-iliac crest structural bone graft to treat patients with recalcitrant un-united humeral shaft who had failed to repeated prior surgeries and finally got a good outcome. This treatment might have the following advantages. Firstly, plate fixation is the most widely used method for long bone fixation due to economic constraints and surgeons' preference in China, and as most patients in this study showed varying degrees of misalignment or pseudarthrosis, the use of LCP fixation could achieve a high degree of cortex-to-cortex stability with compression of the bone segments while correcting deformities. Secondly, repeated prior surgeries might result in a poor biological environment for fracture repair in cases in this study, a second plate fixing vertically to the anterior of the bone graft for structural support could maintain intimate contact between the bone graft and both nonunion segments, maximizing osteoconductive, osteogenic and osteoinductive properties of autologous bone, 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. Moreover, double-plate technology could obtain absolute stability, thus postoperative functional rehabilitation could be started on 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, Martinez et al.[32] reported the use of a two-plate construct in the treatment of 22 cases of humeral shaft nonunion with a 100% healing rate.

Meanwhile, the plating technique also has complications of screw back-outs, peripheral never paralysis, and infection [31]. However, we only saw two cases with never palsy (one with ulnar nerve palsy and one radial nerve) and one super wound infection. And at the final follow-up, implant failure did not happen.

Few papers have focused exclusively on the treatment of recalcitrant humeral shaft nonunions. Borus et al.[2] performed uniform surgical repair with 4.5mm compression plating in combination with bone grafting on 7 patients with humeral diaphyseal nonunions following at least two failed prior surgical procedures, at follow-up, all nonunions healed with a good function of the affected extremity. And, 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 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 resulting in a bone healing rate of 100%, with a mean bone healing time 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 situation, 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 option for the treatment of recalcitrant un-united humeral shaft that failed prior surgical intervention for nonunion.

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 analyzed 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.

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Authors' contributions

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.

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Not applicable.

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

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Tables

Table 1: Demographic data

Patient	Gender	Side	Cause of injury	Type of primary injury	Site(thirds)	Type of nonunion	Time since injury(months)	Prior treatments	comorbidity
1	F	L	Tumbling	Closed fracture	Middle	Atrophic	120	Plate; plate+bone graft	None
2	M	L	Tumbling	Closed fracture	Middle	Synovial pseudarthrosis	368	Plate; plate+bone graft	Arrhythmia
3	M	L	Traffic accident	Closed fracture	Middle	Hypertrophic	259	Plate; 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; plate+bone graft	None
6	F	R	Crashing	Closed fracture	Middle	Hypertrophic	35	Cast; plate; bone graft	None
7	M	R	Traffic accident	Closed fracture	Middle	Hypertrophic	158	Cast; plate; plate+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
11	M	L	Crashing	Closed fracture	Middle-Distal	Atrophic	23	Cast; plate+bone graft	None
12	F	L	Tumbling	Closed fracture	Middle	Oligotrophic	20	Splint; plate	None
13	M	R	Crashing	Open fracture	Middle	Hypertrophic	319	Debridement; Plate; plate+bone graft; plate	None
14	F	R	Sports injury	Closed fracture	Middle-Distal	Atrophic	25	Cast; plate+bone graft	None
15	M	L	Traffic accident	Closed fracture	Middle	Hypertrophic	27	Plate; bone graft	None

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 (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 never palsy
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 super 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
13	14	Union	5	<10°	7	3	55	78	50	85	Radial nerve palsy
14	24	Union	6	<10°	3	0	66	92	80	100	None
15	13	Union	9	<10°	5	0	63	90	60	95	None

Figures

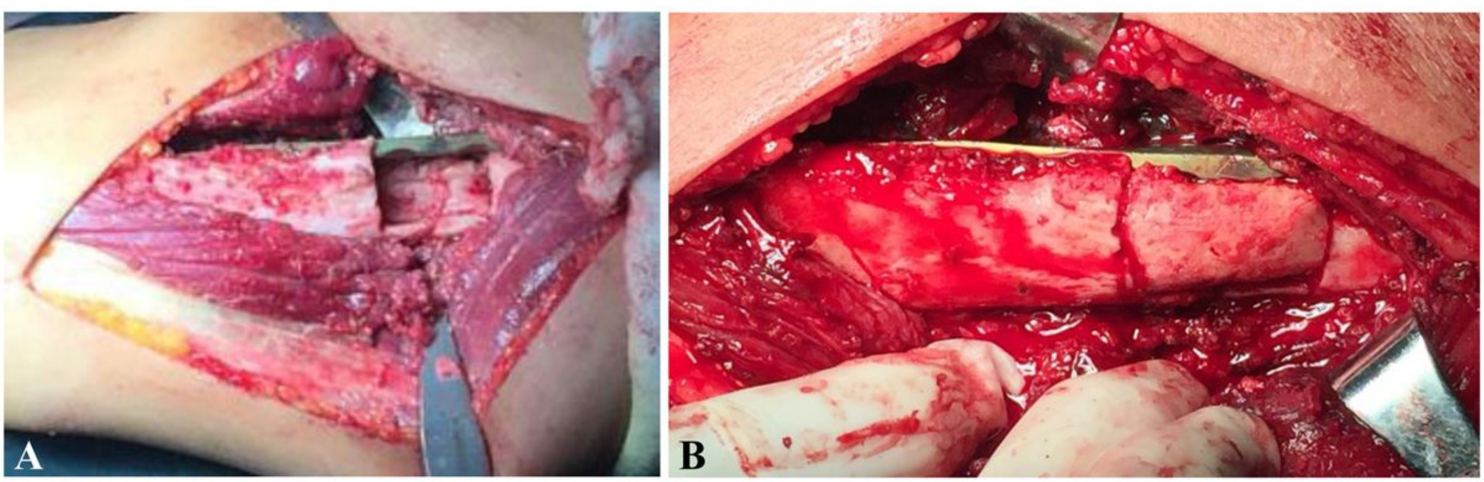

Figure 1

(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.

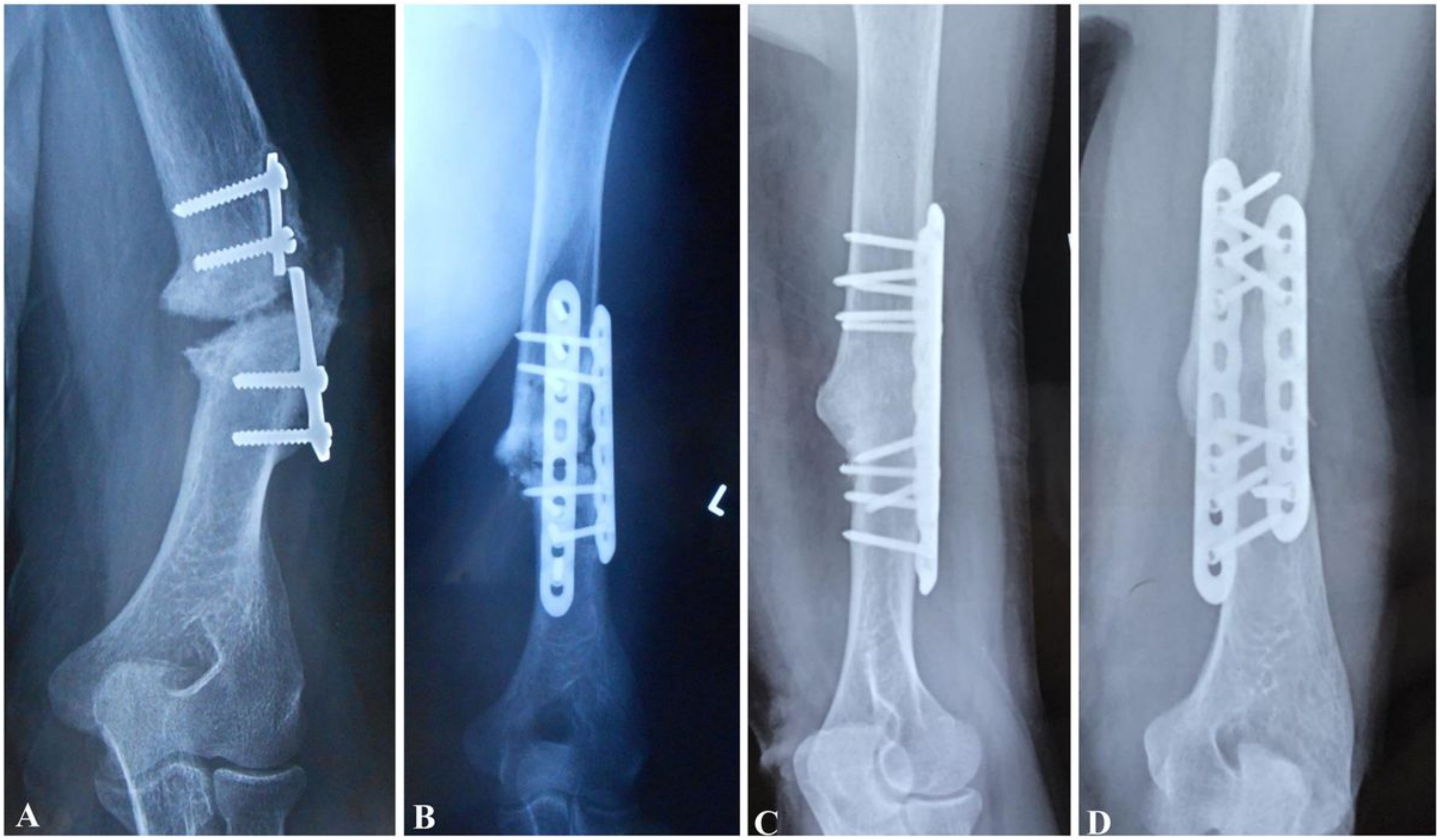

Figure 2

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.

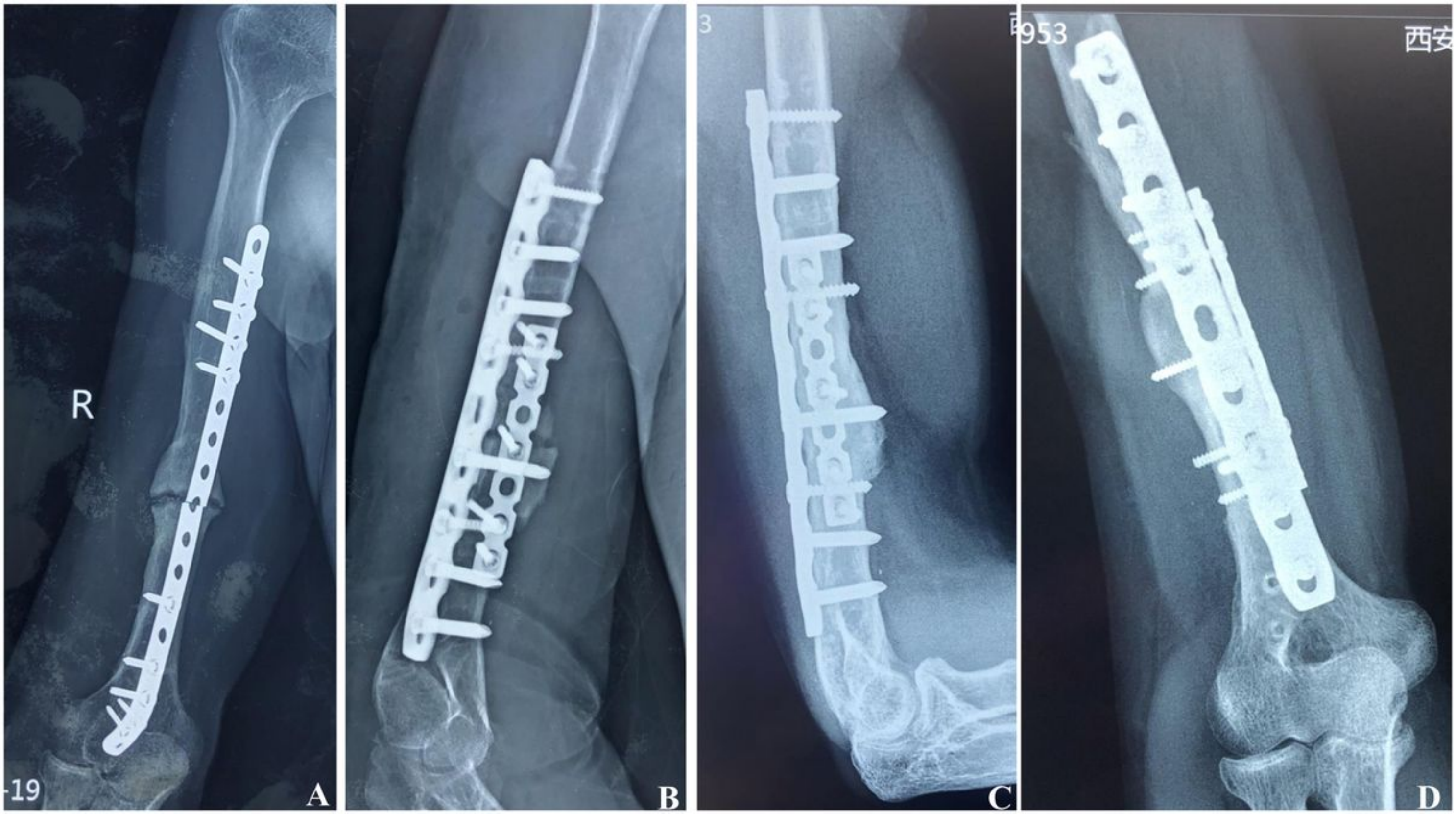

Figure 3

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.