Allografting in Locked Nailing and Interfragmentary Wiring for Humeral Nonunions

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Abstract In this prospective study, we compared outcomes after repair of humeral nonunions when morsellized fresh-frozen allograft or autograft was used to augment repair by intramedullary nailing. Sixty-five patients with humeral shaft nonunions of greater than 6 months' duration and gross instability at the nonunion site were included and treated by locked nailing, interfragmentary wiring, and bone grafting. Graft type was determined by patient preference. Outcomes assessed included union rate and functional recovery of the arm. Secondary end points included operative blood loss, operation time, hospital stay, time to fracture healing, and complications. Twenty-eight patients with autografts and 36 with allografts were followed up more than 2 years. The baseline conditions of the two groups were similar. The autograft group had greater blood loss and longer operative time than the allograft group. The autograft group also had a longer hospital stay. The healing rate, time to healing, and functional scores did not differ between these two groups. In the autograft group,

43% reported pain and limited mobility as a result of the donor site. We concluded that when used in association with locked nailing for humeral nonunions, allografts can achieve treatment results similar to autografts but without donor site complications.

Level of Evidence: Level III, prognostic study. See Guidelines for Authors for a complete description of levels of evidence.

Introduction

The incidence of nonunion after acute humeral shaft fractures varies from 2% to 10% after nonsurgical treatment and can be as much as 30% after attempted surgical repair [36]. Humeral nonunions that result in disability of the upper extremity should be treated surgically [26]. The treatment of humeral nonunion is challenged by many problems, including difficult retrieval of failed implants, fixed angular deformity, severe osteoporosis, soft tissue scarring, radial nerve adhesion, bone defect or comminution, and adjacent joint stiffness [28, 29]. Persistent nonunion rate after attempted surgical repair is reported to occur in 4% to 44% of cases [33]. Excessive soft tissue injury, unstable fixation, and persistent fracture gap are suggested as the common causes of treatment failure [15, 35].

Locked nailing for humeral nonunions with interfragmentary wiring can provide sufficient fixation stability to allow healing [19]. Bone grafts such as vascularized bone grafts [22], strut allografts [34], or free autogenous bone grafts [19, 29] have been used in addition to internal fixation to improve healing rates of humeral nonunions. Vascularized bone grafting is technically demanding and requires microsurgical anastomosis. Strut allografting

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Each author certifies that his or her institution has approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

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necessitates substantial soft tissue stripping, which may disrupt the blood supply and actually retard the healing process [29]. Autogenous bone grafting has been associated with donor site morbidities, insufficient supply of graft, blood loss, and longer operative time and hospital stay [1, 11, 27, 30].

Autografts and allografts have been compared in spinal fusion [7, 30], but this kind of comparative study is very limited in the trauma field [5, 27]. In the current study, morsellized fresh-frozen allografts were compared with autografts in humeral nonunions treated by locked nailing and interfragmentary wiring. The hypothesis was that allografts could be as effective as autografts and prevent the complications of autografts. Our specific aims included determining whether different graft types (allograft versus autograft) when used in humeral nonunions treated by locked nailing and interfragmentary wiring resulted in different rates of healing or different functional outcomes for the treated arm. We also assessed other factors such as how either graft type was associated with operative time, blood loss, duration of hospital stay, and development of complications.

Materials and Methods

The investigation was approved by the Institutional Review Board, and all patients were fully informed and agreed to participate in the study. The inclusion criteria were humeral shaft (3 cm below the lesser tuberosity and 5 cm above the olecranon fossa) nonunion of more than 6 months' duration with gross instability at the nonunion site. Exclusion criteria were nonunions with intraarticular extension, active deep infection, or bone defect greater than 3 cm. From January 2002 to August 2006, 65 consecutive humeral shaft nonunions in 65 patients were treated by locked nailing, interfragmentary wiring, and bone grafting. The patients with full information regarding the potential advantages and risks of autografts and allografts decided the graft type according to their preference. Smokers were urged to stop smoking immediately. Infection, if any, was treated by serial débridements and removal of the loosening hardware. The nonunions were stabilized in a long arm splint before the definite procedures during infection control. Intravenous antibiotics were given for at least 6 weeks according to the sensitivity tests of the culture results. Nailing was performed only after C-reactive protein had returned to normal.

Sixty-five patients with 65 nonunions were allocated to either the autograft group (28) or the allograft group (37). One patient in the allograft group died of a severe heart attack 4 months after surgery, leaving 28 and 36 patients in each group for followup longer than 2 years. There were no

statistically significant differences in patient demographics and nonunion characteristics between the two groups, except more previous operations for the allograft group. The mean age of patients in the allograft group also was slightly older (Table 1).

All the operations were done by the corresponding author, who had extensive experience in the current technique. Intravenous antibiotics with first-generation cephalosporin were given, one dose before and one dose after the operation. One patient in the autograft group and two in the allograft group had preoperative radial nerve palsy. The nerve with clear ruptured ends in the autograft group was repaired during nailing and nerve function recovered 6 months later. Tendon transfer was performed in the other two patients.

The symmetric cannulated cylindrical nails (United, Taipei, Taiwan) we used are made of stainless steel with a 5° curvature at 7 cm from the threaded end and a wall thickness of 1.5 mm. Nail diameters of 7 mm, 8 mm, or 9 mm are available and can be inserted either antegrade or retrograde. There are two parallel screw holes at the threaded end, 45° oblique to the axis of the nail and two transverse holes at the smooth end. The locking screws with both ends threaded and a smooth midshank were used. The proximal threads of the screws are 0.25 mm larger than distal threads. This specially designed screw has a higher holding power than conventional locking screws as observed in a mechanical study [20]. Open nailing was done for all patients for retrieval of the loosened implants, adequate nonunion débridement, and bone grafting. In principle, the original operative incision was used. Otherwise, a deltopectoral approach was used for proximal fractures, an anterolateral approach for middle fractures, and a posterior approach for distal fractures. The nonunion fragments were adequately exposed with protection of the radial nerve if necessary, and then the nail was inserted as described by Lin et al. [19]. The entry portal was at the sulcus just medial to the greater tuberosity for antegrade nailing and at the superior border of the olecranon fossa for retrograde nailing. The medullary canal was adequately reamed, and the nail was inserted along the guide pin. After nail insertion and before screw locking, interfragmentary wiring was applied to the cortices of the humeri (Fig. 1). A transverse drill hole was first made on each humeral fragment approximately 3 cm from the nonunion site. Two double-strand wires with a diameter of 1.2 mm were passed through the transverse holes and twisted in a figure-of-eight configuration as tightly as desired until the fracture gap and fracture motion were completely eliminated (Supplemental materials are available with the online version of CORR). The wires can be applied to the same side or opposite sides of the fragments depending on where the thickest cortices are located. Then, one locking screw at

Table 1. Patient demographics and fracture characteristics

Characteristics	Autograft (n = 28)	Allograft (n = 36)	p Value (95% confidence interval)
Men/women	16/12	17/19	0.59 (−0.15 to 0.35)
Age (years)	42.2 ± 18.4	55.3 ± 23.5	0.066 (−20.9 to 0.69)
Left/right	17/11	15/21	0.57 (−0.33 to 0.13)
Hypertrophic/atrophic	5/23	7/29	0.82 (−0.20 to 0.18)
Nonunion location			
Proximal third	7 (25%)	7 (19%)	0.78 (−0.14 to 0.26)
Middle third	16 (57%)	25 (69%)	0.47 (−0.36 to 0.12)
Distal third	5 (18%)	4 (11%)	0.67 (−0.10 to 0.24)
Previous operations	1.3 ± 0.8	1.7 ± 0.7	0.037 (−0.78 to −0.02)*
Most recent operation			
Plating	15 (53%)	21 (58%)	0.88 (−0.3 to 0.3)
Nailing	8 (29%)	9 (25%)	0.94 (−0.18 to 0.26)
External fixation	0 (0%)	1 (3%)	0.96 (−0.09 to 0.03)
None	5 (18%)	7 (19%)	0.82 (−0.20 to 0.18)
Nonunion time (months)	13.5 ± 7.3	12.2 ± 6.4	0.45 (−2.13 to 4.73)
Preoperative radial nerve palsy	1 (3.4%)	2 (5.6%)	0.85 (−0.13 to 0.08)
Preoperative brachial plexus palsy	0 (0%)	1 (3%)	0.96 (−0.09 to 0.03)
Smoking (> 1 pack/day)	14 (50%)	17 (47%)	0.99 (−0.22 to 0.28)
Preoperative Neer score	63.5 ± 9.3	60.8 ± 8.6	0.23 (−1.8 to 7.2)
Preoperative Constant and Murley score	49.6 ± 11.5	46.6 ± 10.7	0.29 (−2.6 to 3.6)
Preoperative quick DASH score	69.5 ± 7.6	72.3 ± 10.2	0.23 (−7.4 to 1.8)
Previous infection	1 (3.6%)	1 (2.8%)	0.59 (−0.08 to 0.09)
History of open fracture	2 (7.1%)	5 (14%)	0.64 (−0.22 to 0.09)
Nonunions with comminution	2 (7.1%)	3 (8.3%)	0.77 (−0.14 to 0.12)

95% confidence interval of difference of proportion or mean; *statistically significant.

Fig. 1A–B The schematic diagrams illustrate interfragmentary wiring applied at (A) the same side of the humeral fragments or (B) the opposite side of the humeral fragments with regard to the nail.

either end of the nail was applied. Before wound closure, morsellized cancellous autograft or thawed fresh-frozen allograft was impacted into the nonunion cleft. Blood loss

was measured by suction quantification and gauze weights and was documented by the circulating nurses blinded to the study. Postoperatively, range-of-motion exercise of the shoulders and elbows was started immediately and progressed as tolerated; however, patients were asked to avoid heavy labor using the surgically treated arm for 3 months. In our country, National Health Insurance covers a hospital stay of 7 to 14 days after fracture surgery. Generally, the patients were discharged after the postoperative pain was tolerable, and the wound was dry and clean. The range of joint motion, muscle strengthening, and arm activities were increased gradually on the basis of physical and radiographic findings. The patients were followed up regularly with clinical and radiographic examinations every 2 weeks until clinical union and then every month until eventual functional recovery.

We modified the Wolfe-Kawamoto procedure for autograft harvesting [38]. In brief, a 5-cm skin incision along the anterolateral part of the iliac crest was made, beginning 2 cm lateral to the anterior-superior iliac spine to protect the lateral femoral cutaneous nerve. Inner and outer cortical tables of the ilium were split off obliquely with retention of muscular and periosteal attachments, and the

underlying cancellous bone was obtained by curettes and osteotomes. Special care was taken not to violate the cortical tables while harvesting the cancellous bone graft. Finally, the edges of the iliac crest were reapproximated by sutures before wound closure.

Morsellized cancellous allografts were taken from the resected bone chips obtained at the time of TKA from consenting donors. The institutional bone bank undertook the collection, storage, and distribution of allografts [14]. Potential bone donors were screened by medical history and blood tests for common blood-transmitted diseases, including syphilis, hepatitis B, hepatitis C, and HIV. Bone donation was prohibited in the following conditions: a history of active hepatitis or unexplained jaundice, signs or symptoms consistent with AIDS, a recent history of acute systemic infection, steroid therapy, malignant disease, autoimmune or inflammatory disorders, metabolic bone disease, and granulomatous disease. Bacterial swab cultures were taken at the time of allograft harvesting and implantation. Harvested allograft bone was frozen and quarantined for no less than 6 months to allow for review of all test results and for the possible emergence of previously undetected disease in the donor. Each freshly harvested allograft was packed with at least three sterile layers, labeled with the blood group and Rhesus type, and then frozen at -70°C immediately while inside the operating room. These precautions follow those in the guidelines of the Centers for Disease Control and Prevention. The bacterial culture of the allografts taken at the time of implantation were all negative. All allografts were washed with copious sterile saline and bathed with gentamicin solution (80 mg in 200–300 mL saline) before implantation.

Primary end points were union rate and functional recovery. The followup was defined as the duration between the operation and the last regular followup before this article was written. Clinical union was defined as visible callus bridging the fracture in at least three cortices on radiographs and the patients could use their arms without considerable pain or weakness. Although this was an open-label study, the investigators had no special preference regarding the graft type. The end points were measured by two blinded, fellowship-trained orthopaedic trauma surgeons (SMH, XYH). The two evaluators had prestudy consensus on examination methods. Functional assessment included Neer functional score [23] and Constant and Murley score [4] for shoulders, Mayo performance score for elbows [21], and shortened Disabilities of the Arm, Shoulder, and Hand (QuickDASH) score for the upper extremity function [12]. Postoperatively, the Constant and Murley score was compared between the injured and uninjured arms. Preoperatively, the average Neer shoulder score and the Constant and Murley score for the autograft group were not considerably different from those for the

allograft group. Likewise, the QuickDASH score was not considerably different from that for the allograft group. Secondary end points included operative blood loss, operation time, hospital stay, time to fracture healing, and complications.

Statistical analysis was performed using SPSS software, Version 16 (SPSS Inc, Chicago, IL). Continuous variables were compared with Student's *t* tests. Binary variables were compared with chi square tests (comparing two proportions) or Fisher's exact tests if cell counts were less than five. For power analysis, with a usual level of statistical significance ($\alpha = 0.05$ for a two-sided test) and a given power of 0.8 ($\beta = 0.2$), the present sample size could detect a minimal difference of 3.0 weeks for time to union and 4.8 points for Neer score.

Results

The overall union rate was 96.9% at followup. The fracture union rate and time to union did not differ considerably between the allograft and autograft cohorts (Table 2). An uncooperative patient in the allograft group returned to doing heavy work too early and had wire breakage and recurrent nonunion motion 5 months after the operation (Fig. 2). The patient underwent revision surgery and eventual union was achieved. One patient in each group still had a nonunion gap visible on radiographs 25 and 28 months after surgery, respectively, but their arm functions were rated as satisfactory (Fig. 3).

At final followup, the average Neer shoulder score, Constant and Murley score, QuickDASH score, and Mayo elbow performance score did not differ considerably between these two groups, therefore functional recovery was similar for patients with autografts and with allografts.

Intraoperatively, the autograft group had considerably greater blood loss and longer operation time than the allograft group, but no transfusion was necessary. The autograft group also had a considerably longer hospital stay. Iatrogenic radial nerve palsy occurred in one patient in each group, and radial nerve palsies in both patients recovered completely within 3 months. In the allograft group, one young athlete who participated in a dragon boat tournament 2 months after surgery had 25° angular malunion 1 year later, but his functional recovery was excellent with minimal cosmetic problems (Fig. 4). One patient with allografts had preoperative partial brachial plexus palsy, which was treated conservatively (Fig. 5). This patient had almost complete neurologic recovery and the atrophic nonunion achieved solid union 14 months after nailing. Although postoperative humeral shortening was common ranging from 0.5 to 3.0 cm (Fig. 6), it usually did not affect the functional recovery or cause major

Table 2. Intraoperative and postoperative variables

Variable	Autograft (n = 28)	Allograft (n = 36)	p Value (95% confidence interval)
Antegrade/retrograde nailing	18/10	21/15	0.81 (−0.18 to 0.30)
7-mm/8-mm nails	19/9	24/12	0.85 (−0.22 to 0.24)
Estimated blood loss (mL)	323.4 ± 80.2	214 ± 75.5	< 0.001 (69 to 148)*
Operation time (minutes)	111.3 ± 30.3	90.8 ± 22.2	0.003 (7.01 to 33)*
Iatrogenic radial nerve palsy	1 (3.6%)	1 (2.8%)	0.59 (−0.08 to 0.09)
Hospital stay (days)	9.3 ± 5.3	5.3 ± 2.8	< 0.001 (1.94 to 6.06)*
Followup (months)	36.5 ± 8.7	33.7 ± 7.2	0.16 (−1.77 to 6.77)
Solid union rate with one operation	27 (95%)	34 (93%)	0.85 (−0.1 to 0.14)
Time to fracture union (weeks)	18.8 ± 4.5	20.1 ± 3.8	0.22 (−3.37 to 0.77)
Screw backout	1 (9%)	0 (2%)	0.49 (−0.04 to 0.18)
Humeral shortening (cm)	1.8 ± 0.8	1.5 ± 0.7	0.12 (−0.63 to 0.63)
Postoperative Neer score	90.8 ± 6.6	88.5 ± 6.9	6.18 (−1.11 to 5.71)
Postoperative Constant and Murley score	82.6 ± 9.8	79.6 ± 9.5	0.22 (−1.85 to 7.85)
Difference of Constant and Murley score	8.2 ± 4.5	7.6 ± 5.2	0.63 (−1.87 to 3.07)
Postoperative quick DASH score	20.3 ± 5.2	17.6 ± 7.5	0.11 (−0.62 to 6.02)
Postoperative Mayo elbow performance index	92.3 ± 7.2	91.3 ± 7.5	0.59 (−2.71 to 4.71)

95% confidence interval of difference of proportion or mean; *statistically significant.

Fig. 2A–F The (A) radiograph of a 43-year-old man showed a humeral nonunion and loosened plate 18 months after the first operation. The (B) anteroposterior and (C) lateral radiographs 2 months after revision retrograde nailing, wiring, and allografting showed good condition of fixation and bone grafts. However, the (D) radiograph obtained 5 months after surgery showed nonunion displacement with wire breakage. Ten months after revision surgery with allografts again, the (E) anteroposterior and (F) lateral radiographs showed solid union and the patient had excellent functional recovery.

cosmetic problems. No patients had deep infection, intraoperative or postoperative fracture, implant failure, or heterotopic ossification. The nails were removed exclusively on request of the patients; 11 patients in the autograft group and 16 in the allograft group underwent nail removal after fracture union without further major damage of joint function.

The autograft group sustained increased morbidity caused by the additional surgery for harvesting the iliac crest autograft. Immediately after surgery, intense pain with limited mobility and antalgic gait occurred in 12

patients (43%), moderate pain in nine (32%), and mild pain in seven (25%). These symptoms gradually subsided in 2 weeks. Two elderly patients (7%) with intense pain had pelvic wing fractures during harvesting bone grafts on the thin pelvic wall. One (3.5%) superficial infection was well treated by intravenous antibiotics. One year postoperatively, four (14%) patients still had discomforting paresthesia or pain at the donor site, especially when wearing belts. Two (7%) of these four patients had impaired sensation and numbness over the lateral upper thigh. However, these symptoms subsided and gradually

Fig. 3A–D The (A) anteroposterior and (B) lateral radiographs of a 58-year-old woman showed an atrophic humeral nonunion and severe osteopenia 14 months after antegrade Rush pinning. The nonunion line (arrows) was still visible on (C) anteroposterior and (D) lateral radiographs 28 months after nailing, wiring, and autografting. However, the patient was satisfied with this condition with a Neer score of 89 and Constant and Murley score of 80.

were tolerated by the patients. Only two patients (7%) still had occasional pain at followup, but their normal activities were not compromised.

Discussion

Cancellous autograft harvested from the iliac crest has been used for more than 100 years with great success, and

Fig. 4A–F The (A) anteroposterior and (B) lateral radiographs of a 25-year-old man showed a disabling humeral nonunion with two loose and failed plates. Good alignment and bone healing 2 months after nailing, wiring, and allografting can be seen on these (C) anteroposterior and (D) lateral radiographs. However, the fracture angulated progressively. One year later, the (E) anteroposterior and (F) lateral radiographs showed 25° malunion, but the functional recovery was excellent with only a slight cosmetic complaint.

Fig. 5A–E A 38-year-old woman experienced a severe traffic injury. (A) A radiograph obtained 6 months after her injury shows an atrophic humeral nonunion with brachial plexus palsy and Rush pin infection. The pin was first removed to control infection. (B) A significant nonunion gap and osteoporosis are evident. Six weeks after pin removal, the nonunion was treated with nailing, wiring, and allografting and the (C) effective gap elimination can be seen. The (D) anteroposterior and (E) lateral radiographs obtained 16 months later showed solid union and the patient had a satisfactory functional recovery.

has become the gold standard for augmentation of bone healing and remains the standard with which new bone substitutes are compared. Allograft bone is an attractive alternative to autograft because it avoids donor site morbidity, is relatively abundant, and can be used off the shelf. Today, the use of allografts has become widespread

Fig. 6A–D The (A) anteroposterior and (B) lateral radiographs of a 68-year-old woman showed a painful humeral nonunion with severe bone comminution and a loosened nail 12 months after antegrade nailing. The (C) anteroposterior and (D) lateral radiographs showed solid union 10 months after nailing and allografting. With an excellent functional recovery, the patient willingly accepted a humeral shortening of 3.0 cm.

and approximately one-third of the bone grafts used in North America are allografts [14, 30]. Some authors have emphasized bone grafting for treatment of humeral nonunions [13, 29, 35], but published studies with direct comparison of the effectiveness of autografts with that of allografts are still lacking. This study was conducted to compare rates of healing and functional outcomes between allograft and autograft augmentation in the humeral nonunions treated by locked nailing and interfragmentary wiring.

Our study has limitations. First, the study results potentially might be biased because of the nonrandom and open-label design. However, evaluation by blinded evaluators and using hard end points could decrease the biases. Second, our power analysis found the current sample size could detect a difference of 3.0 weeks for time to union and 4.8 points for Neer score. It is possible this cohort may not be large enough to detect a statistically significant difference smaller than that.

Equally high healing rates of humeral nonunion treated by locked nailing with interfragmentary wiring were found in both groups of patients, although the patients with allografts tended to be older and have more previous operations. This result is consistent with previous reports that stable fixation and fracture compression are the main factors contributing to successful results [13, 16] regardless of different kinds of bone grafts. High failure

rates of locked nailing in the treatment of humeral nonunions have been reported [8, 15, 16, 25, 26]. Possible explanations for those high failure rates are that the size discrepancy between the locking screws and the nail holes may cause initial instability and lack of compression may cause residual fracture gap [19]. These problems may be worsened further by the physiologic distraction and torsional forces in the upper extremities and may lead to persistent nonunion [25, 35]. To overcome these problems, we used interfragmentary wiring technique to eliminate the initial instability and residual fracture gap and to resist the physiologic distraction and torsional forces [19]. Interfragmentary wiring also could provide more efficient compression than ordinary compressive locked nails [35]. The tight interdigitation between the nonunion fragments could further enhance the fixation stability and facilitate eventual nonunion healing and functional recovery. This technique could be done with limited soft tissue dissection. A soft tissue dissection of only 3 cm in length at both fragment ends, which was also the necessary length for nonunion débridement, was required for application of the interfragmentary wires. Morsellized allografts have been used successfully to restore the lost bone stock in hip arthroplasty [9, 31, 32]. Allografts, principally osteoconductive, may retain a variable number of osteoinductive activities [2]. In the current study, impaction of the morsellized bone chips into the cleft of nonunions might contribute to release of bone morphogenetic factors, leading to eventual nonunion healing. Unfortunately, widespread use of allografts creates shortages [7]. Currently the most convenient source of allografts is femoral heads from patients undergoing hip arthroplasty [24]. Our study showed patients undergoing TKAs also could be an ideal source of cancellous allografts as compared with cadaveric donors, which might carry a higher risk of infection than living donors [24].

The average Neer shoulder score, Constant and Murley score, QuickDASH score, and Mayo elbow performance score did not differ between these two groups at the final followup. Both groups had an equally significant improvement in functional outcomes. Although antegrade nailing has been condemned because of the threat of shoulder injury, we agree minimal tissue damage, deep insertion of the nail, and meticulous rotator cuff repair can minimize shoulder impairment [8, 19]. It was likely strong interfragmentary compression led to postoperative humeral shortening as much as 3 cm in the current patients; however, the shortening usually did not affect functional recovery and the cosmetic complaints usually were negligible as long as solid union was achieved.

Our patients with allografts did effectively avoid the complications of autografts. The average operation time for

the allograft group was approximately 20 minutes shorter than that of the autograft group, which required an extra procedure for bone graft harvesting. Hospital stay was, on average, 4 days shorter for the allograft group, which might imply a quicker recovery from postoperative pain. Severe donor site pain is the most disabling symptom after harvest of iliac bone grafts, and this discomfort may persist for years [1, 6, 11, 17, 18, 37, 39]. In the allograft group, shorter operation and anesthesia times and less blood loss were beneficial for high-risk patients, and the shorter hospital stay could restore the patients' daily activities earlier and decrease the hospitalization costs. This could be important for surgeons and patients in choosing the graft type before surgery. Infection has been reported as a major risk and disadvantage when using allografts [3, 5, 10, 14]. However, it is postulated that the infection does not seem to be caused by the graft but is more related to the operation as long as the bone banking guidelines are appropriately followed [14]. The morsellized allografts used in our patients had a low infection risk and usually were resorbed and replaced by new host bone.

Our study revealed allografts can produce treatment results as good as those with autografts in humeral nonunions treated with locked nails and interfragmentary wires. Union rates, time to union, and functional outcomes are similar between both graft types. Allografts effectively prevent the donor site complications of autografts. Prospective comparative studies with other types of fixators such as plate osteosynthesis along with bone grafting are warranted.

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