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Research Paper

Clinical outcomes of open-wedge corrective osteotomy using autogenous or allogenic bone grafts for malunited distal radius: A novel parameter for measuring the rate of bone union

Jae-Hoo Lee[1], Gwan-Ho Kim[2], Min-Jong Park[3]

[1]Department of Orthopedic Surgery, Seongnam Citizens Medical Center, Seongnam, Republic of Korea
[2]Department of Orthopedic Surgery, Hallym University Sacred Heart Hospital, Medical College of Hallym University, Chuncheon, Republic of Korea
[3]Department of Orthopaedic Surgery, Samsung Medical Center, Sungkyunkwan University School of Medicine, Seoul, Republic of Korea

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ORCID IDs of the authors:
J.-H.L. 0000-0003-4109-5782;
G.-H.K. 0000-0003-4530-1977;
M.J.P. 0000-0002-7206-5263.

ABSTRACT

Objective: The aims of the study were (1) to compare outcomes in terms of malunited distal radius bone union in open-wedge corrective osteotomy using autogenous or allogenic bone and (2) to introduce a new parameter that quantifies the rate of the bone union.

Methods: This retrospective study included 22 patients (14 males, 8 females) who underwent open-wedge corrective osteotomy with bone grafting for a malunited distal radius fracture between January 2006 and December 2018 were enrolled. The mean follow-up duration was 57.2 weeks (SD 46.1, range 12-206). All the patients were then divided into 1 of the 2 groups based on the graft material used: autogenous bone graft group (n = 10, 5 males and 5 females) and allogenic bone graft group (n = 12, 9 males and 3 females). We introduced the "duration of union/correction gap ratio" to represent the healing potential of each graft materials. Radiologic parameters including initial correction gap, radial inclination, radial length, palmar tilt, and ulnar variance were also measured pre- and postoperatively. Functional outcomes were assessed by grip strength, range of motion, and the disability of the Arm, Shoulder, and Hand score.

Results: Of the 22 patients, 16 (72.7%) achieved complete union within 12 weeks, 3 (13.6%) in over 12 weeks, and the other 3 (13.6%) showed nonunion. Excluding the 3 nonunion cases, the mean union duration was 10.6 weeks, and the mean correction gap was 10 mm. The mean correction gap was wider in the autogenous bone graft group, and the mean union duration was longer in the allogenic bone graft group. Autogenous bone grafts had a significantly lower duration of bone union/correction gap ratio than allogenic bone grafts (0.76 vs. 1.61, $P < 0.001$). According to the correction method (simple open-wedge corrective osteotomy vs. open-wedge corrective osteotomy OWCO), only duration of bone union/correction gap ratio reflected the actual difference between values.

Conclusion: Despite autogenous bone graft donor site morbidities, in our study, autogenous bone showed better bone healing potential than allogenic bone. In terms of bone union, autogenous bone has the benefit of better union in larger gaps than allogenic bone. Surgeons can take advantage of the newly introduced "duration of bone union/correction gap ratio" to compare the bone healing potential by graft materials or surgical options.

Level of Evidence: Level IV, Therapeutic Study

Introduction

Malunion is common after distal radius fracture (DRF), occurring in up to 24% of patients undergoing conservative treatment and in up to 10% of patients treated surgically.[1] Corrective osteotomy is often required to alleviate patients suffering from abnormal wrist joint kinematics. The goal of corrective osteotomy for a malunited distal radius is to restore normal parameters, such as volar tilt in the sagittal plane, radial inclination (RI), and radial length (RL) in the coronal plane, rotation in the horizontal plane, and distal radioulnar joint congruity.[2]

Bone grafting, which promotes bone healing and yields structural support, is the mainstay of defect filling after open-wedge osteotomy. With regard to selecting the type of bone graft, although autografts are superior in terms of bone healing potential, both autogenous and allogenic bone grafts have their own benefits and drawbacks.[3] Furthermore, the trend has been moving toward bone grafts not being necessary for an open-wedge osteotomy.[3-5] However, most surgeons cannot assure the security of corrective osteotomy without using a bone graft, particularly in cases requiring a large correction gap as a promoter of bone healing and structural support.

After experiencing several implant failures after corrective osteotomies of malunited distal radius, we found that the gaps were relatively wider, and allogenic bone grafts were used to fill the gaps in these cases. Hence, we decided to retrospectively scrutinize all cases of osteotomy in terms of bone healing and selection of bone grafts. We hypothesized that autogenous bone grafts are required for larger gaps in open-wedge corrective osteotomies (OWCOs) than allogenic bone grafts. We compared the outcomes of autogenous and allogenic bone graft use in terms of bone union after OWCO of malunited distal radius. Moreover, we introduced new parameters to quantify the bone healing potential of each bone graft material.

Corresponding author:
Min-Jong Park
hollee_who@naver.com

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Materials and Methods

This study was performed with the approval of our Institutional Review Board (SMC 2020-03-187-001). This study was conducted retrospectively in a tertiary general hospital between January 2006 and December 2018, using a chart review of 44 inpatients who underwent OWCO for a malunited distal radius.

The inclusion criteria for the study were as follows: (1) patients who underwent OWCO for a previously malunited DRF, (2) use of autogenous iliac corticocancellous iliac bone graft or allogenic structured fibular bone, and (3) internal fixation using a dorsal plate.

Patients with the following criteria were excluded: (1) history of previous surgical treatment on the affected side of the wrist, elbow, or shoulder; (2) concurrent use of volar and dorsal plates; (3) infectious, autoimmune, or systemic skeletal disease; (4) moderate–to-severe osteoarthritis or rheumatoid arthritis; (5) osteotomy site located proximal to the metaphysis-diaphyseal junction; (6) bone graft using cancellous bone; and (7) loss to follow-up before the bone union was achieved.

The initial correction gap (ICG) was assessed using the widest gap after correction on plain posteroanterior (PA) or lateral view radiographs (Figure 1). We subdivided the patients into 2 groups according to the graft material used: (1) the autogenous bone graft (autoBG) group and (2) the allogenic bone graft (alloBG) group. The outcomes focused primarily on the bone union. We invented the bone union/correction gap (D/C) ratio to compare the healing potential between autogenous and allogenic bone, to reduce any bias arising from the diverse correction gap between the groups, and to quantify the healing potential of each material. We defined a bone union as the "formation of bony trabeculae at every radiographic aspect within 12 weeks." Any union achieved after 12 weeks was referred to as "delayed union." According to the fourth annual meeting of the Danish Orthopaedic Trauma Society in 2019, we followed the definition of nonunion as "a fracture that will not heal without further intervention" or "a status that bone union at an osteotomy site may be progressing, the metal breakage occurred."[6] A musculoskeletal radiologist with 10 years of experience analyzed bony trabecular formation on a series of PA and lateral wrist radiographs. The patients routinely visited our clinic every 2 weeks until 8 weeks postoperatively and then every 4 weeks thereafter. Functional evaluation and plain wrist radiographs were obtained at each visit. We divided each group into the simple OWCO group and the distraction OWCO group to compare both groups in terms of osteotomy methods. Simple OWCO was defined as the maintenance of cortical contact. A distraction OWCO was defined as a distal fragment distracted without cortical contact, and the gap was filled with an intervening bone graft.[7]

HIGHLIGHTS

- Malunion is common after distal radius fracture (DRF), occurring in up to 24% and 10% of patients undergoing conservative and surgical treatment respectively. Corrective osteotomy is often required to restore normal wrist joint kinematics, and this method frequently needs bone grafts. This study was aimed to compare the outcomes of autogenous and allogenic bone graft use in terms of bone union after OWCO of malunited distal radius.
- There were no cases of nonunion in the autoBG. In contrast, there were 3 cases of nonunion in the alloBG. The mean correction gap was wider in the autoBG and the mean union duration was longer in the alloBG. However, this difference was not statistically significant. Autogenous bone grafts had a significantly lower D/C ratio than allogenic bone grafts.
- Autogenous bone showed better bone healing potential than allogenicbone, although there were donor site morbidities as expected. In terms of bone union, autogenous bone has the benefit of a better union in larger gaps than allogenic bone. Moreover, it may be possible to use the novel "D/C ratio" to compare the bone healing potential by graft materials or surgical options.

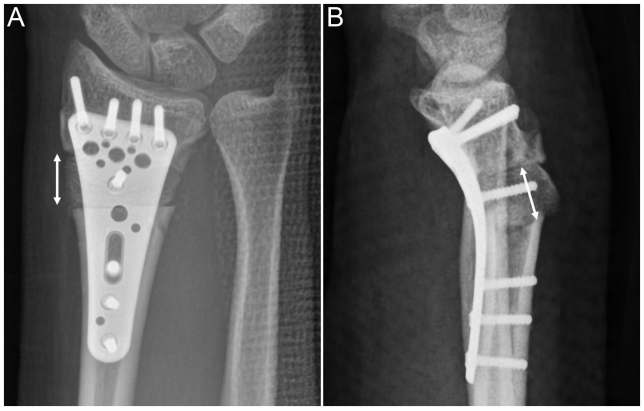

Figure 1. Measurement of the initial correction gap (ICG) on the plain posteroanterior (PA) and lateral view radiographs. We set the ICG as the widest gap among the measured lengths on the posteroanterior (PA) or lateral view. A 23-year-old male underwent an open-wedge corrective osteotomy and allogenic structured bone concurrent with dorsal and volar radio-ulnar ligament for distal radio-ulnar instability postoperatively.

Radiologic evaluation

The following radiological parameters were measured pre- and postoperatively: ICG, RI, RL, PT, and ulnar variance (UV). Radiological parameters were measured using a hand fellow.

Functional evaluation

Functional data included grip strength, range of motion (ROM), and disability of the arm, shoulder, and hand (DASH) score. Grip strength was assessed using a dynamometer (Jamar dynamometer, E. Miller, Inc., New York, NY, USA), and a manual goniometer was used to evaluate the ROM of the affected wrist flexion-extension arc. The ROM was collected in the form of a flexion-extension arc, which is the total range from full flexion of the wrist to full extension. Functional data were collected by a research assistant preoperatively and at each visit.

Statistical analyses

The initial and final follow-up data were compared statistically using a paired *t*-test and Wilcoxon signed-rank test. Student's *t*-test and Mann–Whitney *U*-test were used to perform between-group comparisons. The χ^2 test and Fisher's exact test were used to analyze categorical variables. All computations were performed using SPSS statistics software version 25 (SPSS Inc., Chicago, IL, USA), and the significance was set at $P < 0.05$.

Results

Of the 44 patients who underwent OWCO and bone grafting for a malunited DRF between January 2006 and December 2018, 22 patients who met the criteria were enrolled. The patients' demographic data are presented in Table 1. The autogenous bone graft group included 10 patients and the allogenic bone group included 12 patients. Of the 22 patients, 16 (72.7%) had complete union within 12 weeks, 3 (13.6%) in >12 weeks, and the other 3 (13.6%) showed nonunion. Excluding the 3 nonunion cases, the mean union duration was 10.6 ± 9.1 (range, 5-47) weeks, and the mean correction gap was 10 ± 3.6 (range, 3.1-19.3) mm. There were no cases of nonunion in the autoBG. In contrast, there were 3 cases of nonunion in the alloBG. The mean correction gap was wider in the autoBG and the mean union duration was longer in the alloBG. However, this difference was not statistically significant. Autogenous bone grafts had a significantly lower D/C ratio than allogenic bone grafts (0.76 vs. 1.61,

Table 1. Patient demographics

	Autogenous bone graft group (n = 10)	Allogenic bone graft group (n = 12)	*P*
Age (mean age ± SD, range)	42.1 ± 13.5 (20-60)	37.2 ± 16.44 (19-66)	0.455
Sex (male : female)	5 : 5	9 : 3	0.378
Mean follow-up duration (weeks ± SD, range)	61.3 ± 59.5 (12-206)	53.8 ± 33.6 (12-121)	0.923
Onset to surgery (month ± SD, range)	26.6 ± 32 (4-112)	34.5 ± 34.6 (4-118)	0.367
Dominant hand (right : left)	9 : 1	11 : 1	0.892
Fracture of dominant wrist (%)	50	58.3	0.391
Underlying disease (n)			
HTN	1	1	
DM	1		
Dyslipidemia		1	
None	8	10	

SD, Standard deviation; n, number; HTN, hypertension; DM, diabetes mellitus.

Table 2. Comparison of the duration of bone union and correction gap by graft materials

	Autogenous bone graft group (n = 10)	Allogenic bone graft group (n = 12)	*P*
Correction gap (mm, SD, range)	11.2 ± 3.9 (6.5-19.3)	8.4 ± 3.3 (3.1-13.1)	0.162
Duration of bone union (weeks)	8.1 ± 1.7 (5-12)	13.4 ± 12.9 (5-47)	0.243
Duration/correction gap ratio	0.76 ± 0.14 (0.52-0.93)	1.61 ± 1.27 (0.79-4.91)	<0.001*

Three failed cases were excluded from the statistical analysis of the allogenic bone group.
*Statistical significance. SD, standard deviation.

$P < 0.001$), which clearly indicated that autogenous bone had better healing properties than allogenic bone (Table 2).

Allogenic bone was used in all 3 nonunion cases: stable fibrous nonunion in 1 case (ICG: 9.5 mm, 52 years old) and complete nonunion leading to a metal breakage in the other 2 cases (ICG: 9.5 and 13.8 mm; 35 and 60 years old, respectively).

Significant changes were observed in the corrected angles compared to the preoperative data. However, there was no significant difference in the correction angle size between the groups (Table 3). Similar to the radiologic data, for functional outcomes, the autoBG showed significant improvements in grip strength, ROM, and DASH score from preoperative data. In contrast, the alloBG showed no significant changes compared to the preoperative assessment. Functional analysis of grip strength, ROM, and DASH scores revealed no significant differences between the groups (Table 4).

Two of the 10 patients (20%) who received an autogenous bone graft harvested from the iliac crest experienced donor site pain 1 month after surgery; however, the pain improved 2 months after surgery, and no other complications were observed.

In the autoBG, the duration of bone union was not significantly different between simple and distraction OWCOs. However, distraction OWCOs showed faster bone healing properties than simple OWCOs according to the D/C ratio. In the alloBG, even though it seemed that the correction gap was wider and the duration of the union was longer in the distraction OWCO group, the healing rate of the bone at the gap was not significantly different between groups when using the D/C ratio (Table 5).

Discussion

This study demonstrated that autogenous bone grafts are superior to allogenic bone grafts in terms of bone healing, especially when used in larger bony gaps. It is well known that autogenous bone has better healing potential than allogenic bone; however, we could not find any literature suggesting which type of material is beneficial in a particular type of gap. The importance of graft material selection has also been underestimated. In our study, all nonunions occurred when the gap was >9.4 mm, especially in cases of distraction-type correction where a simultaneous lengthening procedure was performed along

Table 3. Evaluation of the correction angles of the groups

	Autogenous bone group (n = 10)	Allogenic bone group (n = 12)	*P*
Radial inclination (°)			
Preoperative	15.3 ± 17.8 (−27.2-35.8)	16.8 ± 7.7 (0.9-26.0)	0.793
Postoperative	24.0 ± 7.0 (9.1-30.7)	23.9 ± 5.9 (8.8-31.6)	0.989
P	0.053	<0.001*	
Radial length (mm)			
Preoperative	8.1 ± 10.2 (−16.7-19.1)	8.6 ± 4.1 (0.8-13.7)	0.881
Postoperative	12.4 ± 3.3 (5.8-16.2)	12.6 ± 3.9 (3.9-16.9)	0.88
P	0.036*	<0.001*	
Palmar tilt (°)			
Preoperative	−21.0 ± 12.9 (−35.3-0)	−16.3 ± 11.6 (−36.1-9.0)	0.378
Postoperative	6.0 ± 6.2 (−3.7-14.4)	5.5 ± 6.7 (−4.7-17.8)	0.852
P	<0.001*	<0.001*	
Ulnar variance (mm)			
Preoperative	6.0 ± 5.1 (2.2-19.7)	3.0 ± 2.6 (0-7.5)	0.115
Postoperative	−0.1 ± 2.7 (−7.1-2.3)	1.1 ± 1.7 (−1.1-4.23)	0.231
P	0.005*	0.003*	

*Statistical significance; SD, standard deviation.

Table 4. Pre- and postoperative functional outcomes in each group

	Autogenous bone group (n = 10)	Allogenic bone group (n = 12)	*P*
Grip strength, kg			
Preoperative	44.3 ± 14.5 (30-72)	57.5 ± 17.6 (20-80)	0.217
Postoperative	53.8 ± 13.7 (40-76)	60.5 ± 18.9 (20-80)	0.281
P	0.012*	0.088	
Range of motion,°			
Preoperative	100.7 ± 17.9 (80-142)	123.5 ± 39.5 (30-146)	0.075
Postoperative	117 ± 19.9 (75-135)	112.5 ± 46.5 (20-170)	0.898
P	0.036*	0.813	
DASH score			
Preoperative	37.3 ± 19.6 (4.8-63.3)	39.8 ± 13.0 (15-55)	0.235
Postoperative	13.0 ± 16.7 (0-55)	26.6 ± 22.1 (6.8-64.3)	0.149
P	0.005*	0.51	

Three failed cases were excluded from the statistical analysis of the allogenic bone group.
*Statistical significance.
SD, standard deviation; DASH, disabilities of the arm, shoulder, and hand.

Table 5. Comparison of the correction gaps and duration of bone union by correction methods

	AutoBG group		*P*	AlloBG group		
	Simple OWCO (n=6)	Distraction OWCO (n=5)		Simple OWCO (n=5)	Distraction OWCO (n=4)	*P*
Correction gap (mm, SD)	8.8 ± 1.2	14.9 ± 3.5	0.01*	6.1 ± 2	11.3 ± 1.8	0.003*
Duration of bone union (weeks)	7.5 ± 1.2	9.0 ± 2	0.352	7.4 ± 1.9	21 ± 17.4	0.016*
D/C ratio	0.85 ± 0.06	0.61 ± 0.09	0.01*	1.28 ± 0.34	2.02 ±1.94	0.905

Three failed cases were excluded from the statistical analysis of the allogenic bone group.
*Statistical significance. SD, standard deviation; OWCO, open-wedge corrective osteotomy; D/C, duration of bone union/correction gap.

with an angular correction leading to no cortical contact either at the volar or dorsal aspect.[7] This also means that the volar cortical contacts were weak and the grafted bone material was easily absorbed; thus, the plate had to sustain the bending forces by itself, leading to plate breakage at the point of correction. Hence, we recommend autogenous bone grafting with fixation if the corrected gap is wide and radial lengthening is needed. Both volar and dorsal plate fixation can be considered if allogenic bone grafts are used rather than autogenous bone, especially in corrections with large gaps.

In the current study, we introduced the new concept of "healing power" as the "D/C ratio" as a conceptual parameter that can quantify the bone healing potential based on the type of graft material. There was no significant difference in the bone healing potential between the groups according to the results of statistical analysis (Table 2). Using the D/C ratio, we visualized the actual healing property of each material, which is defined as the complete union duration divided by the widest correction gap. Using the D/C ratio, we were able to adjust the time based on the reference gap, which made it possible to compare the healing potential of each material. We can also apply this parameter to neutralize the bias resulting from graft selection. In Table 5, when we compared the "correction gap" and "duration of bone union" alone, it showed either a significant difference or no significant difference. However, after adjusting the values according to the D/C ratio, actual values were obtained for comparison.

Although autogenous bone has osteoinductive, osteogenic, osteoconductive, and histocompatible properties,[8] autogenous bone grafts require an additional surgical site, leading to postoperative pain and complications.[9,10] Hollawell et al[11] reported a 19.73% complication rate after iliac bone grafting. Moreover, other complications, such as infection, hematoma, fracture, pain, hypertrophic scarring, sensory nerve damage, and chronic pain, were noted 2 years postoperatively. Hence, surgeons tend to prefer allogenic bone grafts to autogenous bone grafts to reduce surgical time and complications. In terms of bone healing properties, several reports have argued that allogenic bone grafts have comparable bone union capacity to autogenous bone grafts.[12-14] Lareau et al[14] showed comparable outcomes of autogenous and allogenic bone grafts in a systematic review of 159 foot and ankle studies (5327 patients). Allogenic bone grafts have an advantage over autogenous bone grafts owing to their lower comorbidities and the ability to achieve synostosis. Grier et al[12] also suggested that allogenous grafts have equivalent bone healing properties and fewer complications. However, as in our study, from a rough glance at the results, it is easy to miss the substantial difference in healing potentials according to the materials (Table 2). We found that the autoBG had significantly lower D/C ratios than the alloBG, implying that autogenous bone grafts showed superior healing potential in terms of bone union compared to allogenic bone grafts in wider correction gaps. This implies that using the D/C ratio clarifies that autogenous bone achieves faster bone union in the same bony gap.

Nonunion occurred in 3 cases in which allogenic structured bone was used with a dorsal approach and radial lengthening. The ICG measurements of the 3 nonunion cases were 9.46, 9.5, and 13.8 mm, respectively. In 2 cases, implant failure occurred at 14 and 16 weeks after surgery (Figure 2). In the remaining patient, the total absorption of the grafted allogenic bone and subsequent subsidence at the gap occurred without implant breakage. Bone union was not

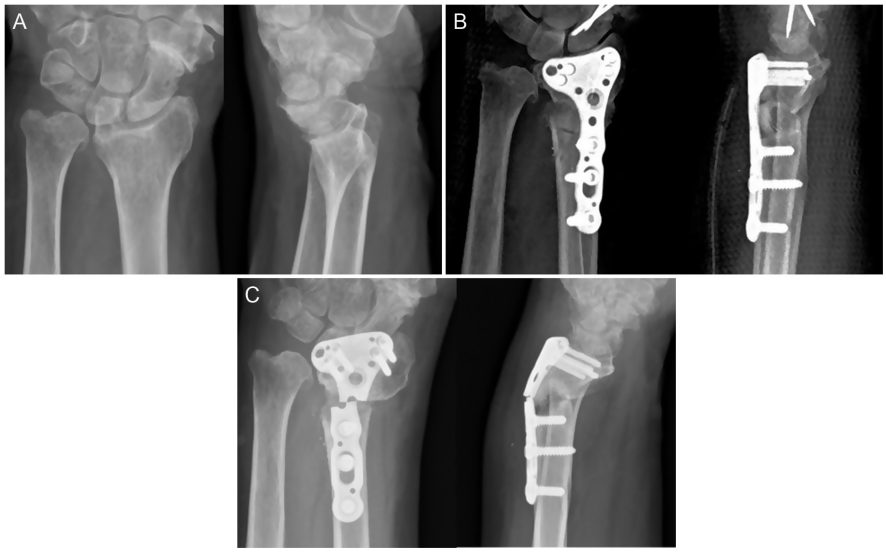

Figure 2. A-C. A 60-year-old woman with malunion at the distal radius underwent an open-wedge corrective osteotomy and allogenic structured bone graft using the dorsal approach (A) pre-operative plain posteroanterior (PA) and lateral view radiographs. The correction values were as follows: ICG, 13.8 mm; RI, −1.5 degrees; RL, −0.2 mm; UV, −5.6 mm; PT, 45.8 degrees (B) postoperative plain PA and lateral view radiographs. Metal breakage occurred 14 weeks postoperatively during daily activity (C). ICG, initial correction gap; RI, radial inclination; RL, radial length; UV, ulnar variance; PT, palmar tilt.

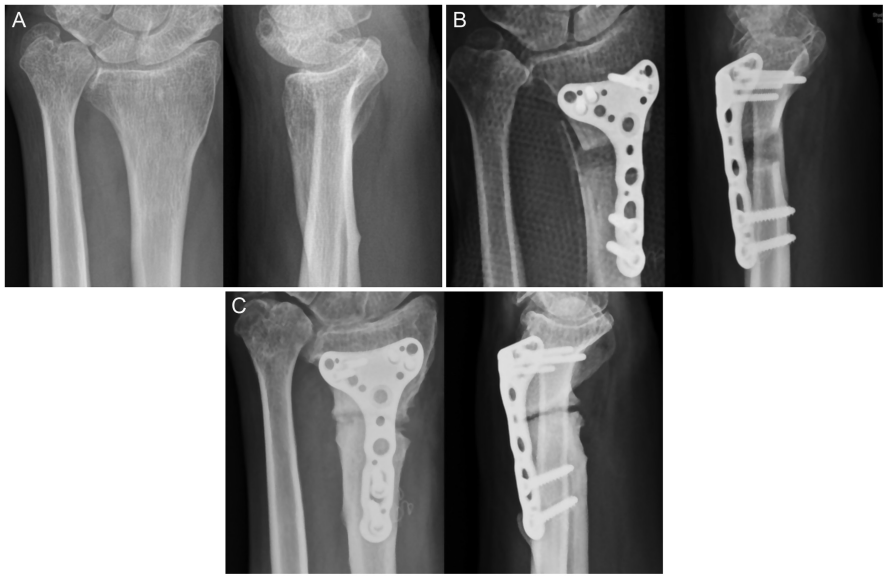

Figure 3. A-C. A 52-year-old man who underwent an open-wedge osteotomy with radial lengthening showed stable fibrous nonunion of the surgical site 2 years and 5 months after surgery. The preoperative plain radiographic view (A). The initial correction gap was 9.5 mm (B). He had no discomfort in daily activity and bone absorption around screws on the plain radiographic views (C).

achieved, but stable fibrous nonunion was achieved 126 weeks after surgery (Figure 3). Seven of the 12 corrections using allogenic bone grafts were of the distraction type. In 4 of the 7 patients who underwent distraction OWCO, 1 achieved a prolonged delayed union at 47 weeks, another had a stable fibrous nonunion, and the other 2 showed implant breakage. We used allogenic bone grafts and dorsal plating on these 4 patients. Otherwise, 4 of the 10 cases in which autogenous bone grafts were used in distraction-type correction, as introduced by Haghverdian et al. did not show any nonunion. Haghverdian et al[7] stated that all nonunion and implant failure cases occurred in patients in whom distraction-type correction was performed. They indicated that the distraction type has characteristics of bone healing at 2 separate interfaces and that more extensive soft tissue dissection is required for adequate distraction, leading to diminished vascularity. However, the authors did not evaluate bone union using a graft material. In the current study, we supported the work of Haghverdian et al by drawing a significant difference according to the type of correction in each group (autogenous vs. allogenic).

According to the 2 cases of implant failure, 1 patient whose plate broke at 14 weeks postoperatively underwent revision surgery using an autogenous iliac structured bone graft with dorsal plating. Bone union was achieved 12 weeks after the revision surgery, while the duration of postoperative immobilization was 5 weeks. The other patient whose metal failure occurred at 16 weeks after the initial surgery underwent revision surgery using an autogenous iliac structured bone graft with dorsal plating and with 5 weeks of immobilization; however, implant breakage recurred 7 weeks after revision surgery. The patient had no choice but to undergo a second revision surgery using an allogeneic structured bone graft with dual plating both volarly and dorsally. Bone union was achieved within 11 weeks. This patient received an allogenic bone graft instead of autogenous bone because the patient refused to use his own bone because of donor site pain after the previous autogenous bone graft. Including the patient who achieved stable fibrous nonunion, these 3 patients had no distinctive factors in common attributing to the failure, other than the following 4 factors: first, allogenic bone grafts were used in those 4 cases; second, the correction gap was >9 mm; third, all-metal breakage occurred at the osteotomized point and screw-plate junction; and fourth, all corrections were distraction type with the dorsal approach. Huang et al reported that both mechanical and biological factors contribute to implant failure in a retrospective study of 6 patients with fracture nonunion and plate breakage. In the literature, 2 metal breakages occurred at a screw-plate junction owing to the bending stress of the bone.[15] In the current study, implant breakage occurred at screw-plate junctions in the same manner. We could assume that the structural instability conferred by the delayed union of the osteotomy site was preceded by implant breakage. One patient had fibrous nonunion at 126 weeks after surgery. A short-arm splint was applied for 6 months. The initial correction gap was 9.5 mm, and dorsal plating was performed. In the patient, we observed that the grafted allogenic bone was completely absorbed starting from the regular visit at 12 weeks postoperatively, and new bone was formed from each end of the osteotomy site. Gap subsidence was also observed; however, at 126 weeks postoperatively, the patients achieved stable fibrous nonunion and were satisfied with their final status without pain in their daily activities. Miramini et al[16] reported that the initial strain tolerance is up to 100%, but as the initial callus becomes calcified, a strain of only 2-10% is tolerated. Hence, only fibrous tissue can tolerate strain and remains intact. The flexibility of fixation leads to excessive strain and fluid flow within the fracture site, resulting in excessive fibrous tissue differentiation and delayed healing. According to the experience, corrective osteotomy using an allogenic bone graft and dorsal plating requires a longer immobilization duration. Dual plating on both sides of the wrist is a possible option for corrective osteotomy using an allogeneic bone graft with a larger gap.

Many authors have stated that allogeneic bone grafts are comparable to autogenous bone grafts in terms of graft incorporation. In a cross-sectional review of 51 adult patients who underwent lateral column lengthening for flatfoot correction, Grier et al indicated that there were no differences between autogenous and allogenic bone grafts in terms of bone healing.[12] In a randomized study of lateral column lengthening surgeries for flatfoot correction, Dolan et al compared cortical autoiliac bone grafts to freeze-dried tricortical allografts. They also found

no significant differences between the 2 groups in terms of the duration of bone healing.[13] Despite both studies stating that there were no prominent differences in graft materials, it is obvious that there must be differences between the 2 materials in terms of their biological properties, including differences in osteogenesis, osteoinduction, and osteoconduction. In the current study, the duration of bone union was 2-fold longer in patients using autogenous bone grafts, which supports the superiority of autogenous bone that intervenes in autogenous bone, yielding faster graft incorporation and absorption.

Our study has several limitations. First, a small amount of data (smoking, bone mineral density in the elderly, and postoperative satisfaction) was missing due to the retrospective nature of the study. Second, we measured the correction gap using plain PA and lateral radiographs. Further studies using computed tomography scanning to obtain exact measurements are necessary. Third, this study included a small number of patients. We attempted to elicit a cutoff correction gap to determine a specific norm to determine whether to use allogenic or autogenous bone but failed due to the small sample size. Thus, a larger sample size is needed in future studies. Fourth, due to the retrospective nature of the study, we lacked intraoperative measurements of the size of the graft materials. It would have been better to measure 3-dimensionally and its volume. Finally, there could be a selection bias when choosing graft materials in wider and harder cases. However, it also revealed the superior healing potency of autogenous bone, even in wider gaps. Despite these limitations, this study elicited meaningful results and provided concepts for quantifying bone healing potential.

Despite autogenous bone graft donor site morbidities, in our study, autogenous bone showed better bone healing potential than allogenic bone. In terms of bone union, autogenous bone has the benefit of a better union in larger gaps than allogenic bone. Surgeons can take advantage of the newly introduced "D/C ratio" to compare the bone healing potential by graft materials or surgical options.

Ethics Committee Approval: This study was approved by authors' Institutional Review Board (SMC 2020-03-187-001).

Informed Consent: Written informed consent was obtained from all participants who participated in this study.

Author Contributions: Concept – M-J.P.; Design – J-H.L.; Supervision – M-J.P.; Materials – M-J.P.; Data Collection and/or Processing – J-H.L., G-H.K.; Analysis and/or Interpretation – G-H.K.; Literature Review – J-H.L., G-H.K.; Writing – J-H.L.; Critical Review – M-J.P., G-H.K.

Declaration of Interests: The authors have no conflicts of interest to declare.

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