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Original Research

Vascularized Bone Graft to the Lunate Combined with Shortening of the Capitate and Radius for Treatment of Advanced Kienböck Disease After a Follow-Up for More Than 10 Years

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Purpose: This study aimed to report the outcomes of patients with stage III Kienböck disease after treatment with a vascularized bone graft (VBG) to the lunate combined with capitate shortening osteotomy (CS) after a more than 10-year follow-up.
Methods: A VBG to the lunate was combined with CS in 10 patients with stage III Kienböck disease (6 patients with stage IIIA and 4 with stage IIIB). We performed VBG, CS, and radial shortening osteotomy (RS) on 7 patients. Among them, 4 had undergone RS previously. The passive wrist extension angle and wrist flexion angle, grip strength (GS), carpal height ratio, Stahl index, visual analog scale of wrist pain, and Mayo modified wrist score were assessed before surgery and at the final follow-up.
Results: The flexion angle decreased markedly after surgery, when GS increased in all 10 patients. Radiographic examinations revealed that the carpal height ratio decreased in 9 of 10 patients, whereas the Stahl index increased in 8 patients and remained unchanged in 2. The oldest 3 of 7 patients who underwent VBG, CS, and RS exhibited fusion of the proximal carpals except the pisiform. The mean visual analog scale decreased from 27.6 before surgery to 5.7 afterward. The Mayo modified wrist score improved in 9 patients after surgery and remained unchanged in one.
Conclusions: In stage III Kienböck disease, VBG to the lunate combined with CS relieved wrist pain and increased GS and lunate height but was followed by severely restricted wrist motion. Fusion of the proximal carpals developed in 3 of 7 patients who received VBG with CS and RS.
Type of study/level of evidence: Therapeutic IV.

Radial shortening osteotomy (RS) is a common treatment for Kienböck disease patients with ulnar-negative variance. Several cadaveric studies showed that RS reduces the load to the lunate, which suggests that it may be effective for treatment of Kienböck disease.[1–3] Capitate shortening osteotomy (CS) is indicated for patients with Kienböck disease regardless of the ulnar variance. Reduction of the lunate load after CS was also confirmed by several cadaveric studies.[1,2,4]

Vascularized bone graft (VBG) to the lunate is another common treatment of the disease.[5,6] Several authors suggested that some procedures to reduce the lunate load should be combined with VBG or vascular pedicle transplantation to the lunate to minimize postoperative lunate collapse, especially when treating advanced Kienböck disease.[7–9] They recommended combining VBG with temporal or permanent lunate unloading procedures, such as scaphotrapeziotrapezoidal or scaphocapitate fixation or arthrodesis, and shortening of the capitate or radius for patients with stage III Kienböck disease.[7–10] Indications for choosing the permanent or temporal unloading procedure of the lunate varied among these authors. Some noted that permanent unloading procedures were

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Figure 1. A 42-year-old man diagnosed with Kienböck disease with negative variance in the right hand underwent RS. Because wrist pain was not relieved, he was referred to our clinic 2 years after the RS. Radiographs show the right wrist when he first visited our clinic. The wrist was diagnosed as having stage IIIB disease.

necessary for stage IIIB patients but not for stage IIIA patients.[7,8] We recently reported that temporal scaphocapitate fixation was effective in alleviating symptoms in patients with stage IIIB disease as well as those with stage IIIA disease.[11]

More than 10 years ago, we performed VBG to the lunate combined with CS for patients with stage III Kienböck disease. For patients with ulnar-negative variance, RS was added to VBG graft to the lunate and CS. We hypothesized that this would result in no disease recurrence and little or no advancement of lunate collapse. To the authors' knowledge, no studies have reported the outcomes of VBG to the lunate combined with only CS or CS and RS after a follow-up of more than 10 years.

The purpose of this study was to report the more than 10-year follow-up outcomes of 10 patients with stage III Kienböck disease who were treated using VBG to the lunate combined with only CS or both RS and CS.

Materials and Methods

We performed VBG to the lunate combined with CS on 12 patients from 1997 to 2005. Two of the 12 patients were excluded for inadequate follow-up. Ten patients (7 men and 3 women) who had unilateral stage III Kienböck disease were observed for a minimum of 10 years after surgery (mean, 141 months; range, 121–174 months) and were included in this study. When they first visited our clinic, 6 had stage IIIA disease and 4 had stage IIIB (Fig. 1).[12] Mean age at the time of surgery was 43 years (range, 21–66 years). Four patients had received RS in another hospital before visiting our clinic. The dominant hand was involved in 8 patients. Ulnar variance was positive in 5 patients, neutral in 2, and negative in 3 when they first visited our clinic (Table 1).

The VBG was harvested from the distal dorsal radius. Five patients with positive variance and 2 with neutral variance underwent VBG to the lunate combined with CS. Among them, 4 patients experienced recurrence or no subsidence of the wrist pain after the RS, which they had undergone in previous hospitals more than 6 months before visiting our clinic. The other 3 patients with negative variance underwent VBG to the lunate with CS and RS simultaneously. Overall, 3 patients underwent VBG and CS, and 7 had VBG combined with CS and RS (Table 1).

Assessments were composed of a physical examination, radiological examination, patient-reported outcome measures, and Mayo modified wrist score (MWS). Physical examination included wrist extension angle (EA), wrist flexion angle (FA), and grip strength (GS). The EA and FA are expressed as a percentage relative to the angle in the contralateral healthy hand. The GS of the affected hands before disease involvement was estimated from that of the healthy hands based on the result reported in a previous article.[13] According to the article, the right GS is 1.1 times greater than the left GS in right-handed people and almost equal to the left GS in left-handed people. The GS of the affected hand was expressed as a percentage of the estimated GS value before disease involvement. The radiological examination included the carpal height ratio, Stahl index (STI), and radioscaphoid angle, which were measured on

Table 1
Patient Demographics, Surgical Mode, and Clinical Results*

Patient	Age	Stage	Ulnar Variance	Operation Mode	Proximal Carpal Fusion	Mayo Modified Wrist Score	VAS of Pain
1	30	IIIB	Neutral	(RS) VBG + CS	−	Poor/satisfactory	22/0
2	66	IIIA	Positive	VBG + CS	−	Poor/satisfactory	28/3
3	21	IIIA	Negative	VBG + CS + RS	−	Good/satisfactory	10/0
4	42	IIIB	Positive	(RS) VBG + CS	+	Poo /satisfactory	51/22
5	25	IIIA	Neutral	(RS) VBG + CS	−	Poor/satisfactory	42/5
6	61	IIIA	Positive	(RS) VBG + CS	+	Poor/satisfactory	45/17
7	23	IIIB	Negative	VBG + CS + RS	−	Satisfactory/satisfactory	9/0
8	65	IIIA	Negative	VBG + CS + RS	+	Poor/satisfactory	19/10
9	63	IIIB	Positive	VBG + CS	−	Poor/good	22/0
10	37	IIIA	Positive	VBG + CS	−	Poor/satisfactory	28/0

* (RS) VBG + CS: RS was performed in previous hospitals before VBG and CS were performed in our hospital. VBG + CS + RS: VBG, CS, and RS were performed simultaneously. Ulnar variance is expressed as that measured on plain wrist x-ray image taken at the first visit to our clinic. Mayo Modified Wrist Score and VAS of pain are shown as preoperative outcome/postoperative outcome.

radiographs taken before surgery and at the final follow-up to examine whether carpal collapse would have happened after surgery. Patient-reported outcome measures included a rating of wrist pain using a visual analog scale (VAS) and patients' satisfaction with the operations using the patient satisfaction score (PSS), in which 0 = completely unsatisfied with the surgical outcomes and 100 = completely satisfied. The MWS was expressed as poor (0–24), moderate (25–49), good (50–74), and excellent (75–100). These data were collected before surgery and at the final follow-up, except for the PSS, which was recorded only at the final follow-up. This study was approved by the medical ethics committee of our hospital.

Surgical procedure

In 8 of the 10 patients, a VBG nourished by the fourth and fifth extensor compartment arteries (ECAs) was harvested from the distal dorsal radius, as described previously.[14] Briefly, a 15-cm longitudinal middorsal incision was made over the dorsal wrist and the extensor digitorum minimi tendon was exposed and removed from the fifth extensor compartment. The fifth ECA was found on the floor of the fifth extensor compartment and was exposed proximally, and the bifurcation to the fourth ECA was identified. The dorsal branch of the anterior interosseous artery was ligated just proximal to the bifurcation of the fourth and fifth ECAs. In the other 2 patients, a VBG nourished by the retrograde flow of the fourth ECAs was harvested and transplanted into the lunate because the fifth ECAs were hypoplastic.

Next, we performed capitohamate arthrodesis as well as capitate shortening to prevent postoperative proximal movement of the capitate and reduce the risk for capitate nonunion. After removing articular cartilage between the capitate and hamate, the capitate was osteotomized 1 cm distal to the lunocapitate joint and a 2-mm thickness of capitate was removed. Three 1.5-mm Kirschner wires (2 parallel and 1 oblique to the osteotomy line) were then inserted from the ulnar side of the hamate to the capitate, while the capitate proximal fragment was pushed distally against the capitate distal fragment (Fig. 2). The interval between the capitate and hamate was filled with cancellous bone graft harvested from the radius or iliac crest in osteoporotic patients.

Necrotic bone was removed from the dorsum of the lunate, leaving the articular cartilage and subchondral bone of the lunate. An elevator was inserted into the cavity of the lunate and was used to push the distal subchondral bone distally to retrieve the coronal length of the original lunate. A rectangular parallelepiped VBG measuring 1.0 to 1.5 cm × 1.0 to 1.2 cm × 0.8 to 1.0 cm was pressfitted to the cavity of the lunate. A cancellous bone graft was packed into the space between the VBG and the subchondral bone of the lunate. We also performed RS on patients with negative variance to make the variance 1 to 2 mm positive.[15] The osteotomy was performed 6 to 7 cm proximal to the radiocarpal joint and fixed using a volar plate so that the distal screw would not pass through the donor site of the VBG.

Results

The EA did not change markedly before and after surgery, whereas the FA decreased after surgery in 8 of 10 patients. The GS increased after surgery in all patients. Plain x-ray examinations revealed that the carpal height ratio decreased after surgery in 9 patients and did not change in the other patient. The STI increased in 8 patients and remained unchanged in 2. The mean radioscaphoid angle increased after surgery in 2 patients, decreased in 6, and remained unchanged in 2. The MWS grade increased in 9 patients and remained unchanged in one (Table 1). The VAS scores decreased in all patients (Table 1). All patients returned to their previous jobs within 4 to 11 months (mean, 6.5 months). Patients' satisfaction with the operations was good, although all patients reported greater restriction of motion of the wrist joint after surgery compared with before. Mean PSS was 90.3 at final follow-up (range, 75–100) (Table 2).

At final follow-up, 3 of 7 patients who underwent VBG with CS and RS exhibited fusion of the proximal carpals except for the pisiform bone (Table 1, Figs. 3, 4). Among these 3 patients, 2 underwent VBG and CS after unsuccessful RS that had been performed in previous hospitals. The other patient with stage IIIA disease with ulnar-negative variance underwent VBG, CS, and RS simultaneously (Table 1). No patients demonstrated nonunion of the radius or capitate, developed osteoarthritic changes around the lunate, or required additional surgery on the operated wrist because of Kienböck disease.

Discussion

In this study, in patients with stage III Kienböck disease, VBG to the lunate combined with shortening of the capitate and radius relieved wrist pain and increased GS to an average of 86% of that in the healthy wrists. As shown radiologically, the lunate height increased after the operation. Most patients were highly satisfied with the outcome. However, because these operations were followed by severe restriction of the wrist arc, especially in wrist flexion, indications for this procedure should be limited (Fig. 5). In addition, proximal carpal row fusion might occur when VBG, CS, and RS are performed in the patents aged more than 30 years.

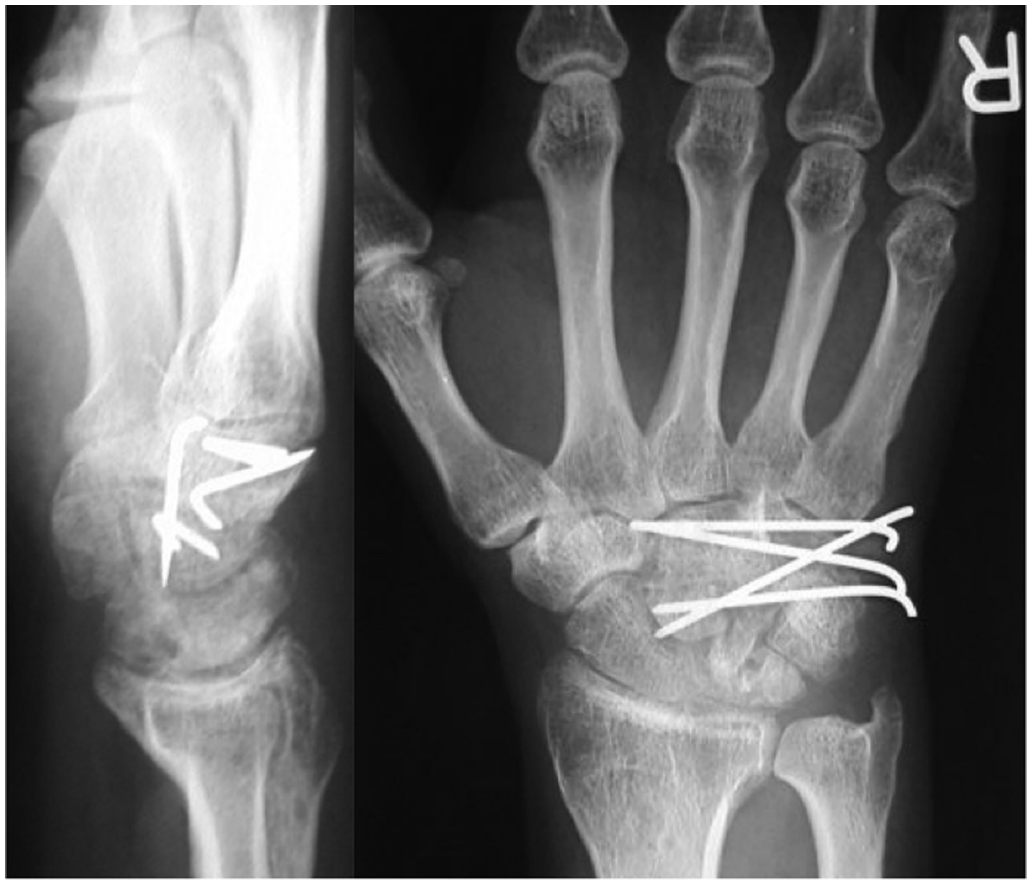

Figure 2. Plain radiographs of the patient's right wrist just after the VBG and CS performed 25 months after RS.

Table 2
Mean Values of Each Assessment Before and After Surgery*

Measurements	Before Surgery	After Surgery
Wrist extension (%)	57.4 ± 21.8 (41.8–73.0)	68.8 ± 15.7 (57.5–80.0)
Wrist flexion (%)	56.9 ± 27.2 (37.4–76.3)	35.2 ± 11.8 (26.7–43.6)
Grip strength (%)	37.8 ± 19.2 (24.0–51.5)	85.9 ± 10.7 (78.2–93.5)
Carpal height ratio	0.52 ± 0.06 (0.48–0.56)	0.48 ± 0.07 (0.43–0.54)
Stahl index	31.4 ± 9.6 (24.5–38.3)	39.8 ± 8.2 (34.0–45.6)
Radioscaphoid angle (degrees)	55.0 ± 11.4 (46.9–63.1)	55.3 ± 7.5 (49.9–60.7)
VAS of pain	27.6 ± 14.3 (17.3–37.9)	5.7 ± 8.0 (−0.05 to 11.5)
PSS (0–100)		90.3 ± 9.7 (83.4–97.2)

* Wrist extension and flexion are expressed as percentages relative to angles in contralateral healthy wrists. The grip strength of the affected hand is expressed as a percentage of that of the hand in the healthy condition, which was estimated by the grip strength of the contralateral healthy hand. The right grip strength was set to be 1.1 times greater than the left grip strength in right-handed people and almost equal to the left grip strength in left-handed people, according to previous literature.[13] Values in mean (95% confidence intervals).

(Proximal carpal fusion did not occur in patients who were aged less than 30 years in the current study.)

We attempted to revascularize the lunate to unite fractures of the lunate and restore the lunate height almost equal to the healthy lunate using VBG revascularization. We performed CS to reduce the mechanical force transmitted from the distal carpal row to the lunate. We carried out RS on patients with negative variance to decrease the proximal stress load to the lunate. Just after VBG to the lunate, the structural strength of the lunate is decreased by avascular necrosis caused by disease advancement and the surgical procedures of VBG, including creating a bone hole in the lunate for VBG interposition. It was anticipated that a long time would be necessary for the VBG to integrate into the lunate to make it strong enough to resist mechanical loading of the wrist,[11] which is why we performed permanent decompression procedures in addition to VBG.

In a collapsed lunate with advanced Kienböck disease, the lunate coronal height is decreased and the sagittal height (length between the most palmar and most dorsal portions of the lunate on the sagittal plane) is increased. Vascularized bone graft to the collapsed lunate (with increased sagittal and decreased coronal heights) increased the coronal height so that the lunate bone had greater sagittal and coronal heights than the original lunate (Fig. 5). This large lunate had poor mobility, which might be the reason for the restricted arc of the wrist (Figs. 3, 4).[11]

Waitayawinyu et al[10] performed CS and VBG on patients with stage II or IIIA disease. They reported that the mean arc of

Figure 3. Plain radiographs of the wrist 1 year after VBG and CS.

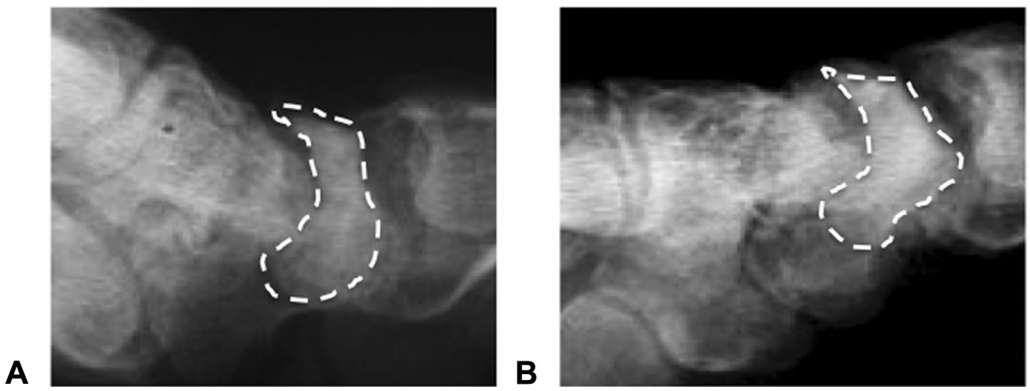

Figure 4. Plain lateral radiographs of the wrist with **A** the maximum extension and **B** flexion 1 year after VBG and CS. The motion of the lunate (dashed line) was severely restricted.

the operated wrists was 78% of that of the contralateral wrist at an average of 41 months' follow-up. The arc of the operated wrists was much greater in the study by Waitayawinyu et al than in the current study, possibly because the previous authors performed the operations only on patients with stage II or IIIA disease, who had minimal lunate collapse. A VBG into a minimally collapsed lunate would not change the size of the lunate, likely leading to better range of motion in the operated wrists.

Three of 7 patients who received the VBG, CS, and RS developed fusion of the proximal carpals except for the pisiform bones. These 3 were the oldest of the patients who were having the 3 operative procedures. The other 4 patients who had not developed proximal carpal row fusion despite having undergone these 3 modes of surgery were aged 30 years or younger (Table 1). These observations suggest that age might be related to proximal carpal bone fusion.

Surgical interventions to intramedullary bone are followed by an increase in the vascularity of the bone around the surgical site. Some authors attributed the efficacy of RS in the treatment of Kienböck disease to both an increase in lunate vascularity and a decrease in mechanical stress to the lunate.[16] Illarramendi et al[17] treated Kienböck disease using the core depression procedure of the radius and lunate and reported good outcomes. They speculated that the core depression may have increased the vascularity around the wrist, including the lunate. Both RS and CS as well as VBG may have increased the vascularity of the lunate. Angiogenesis is a key factor in new bone formation at the

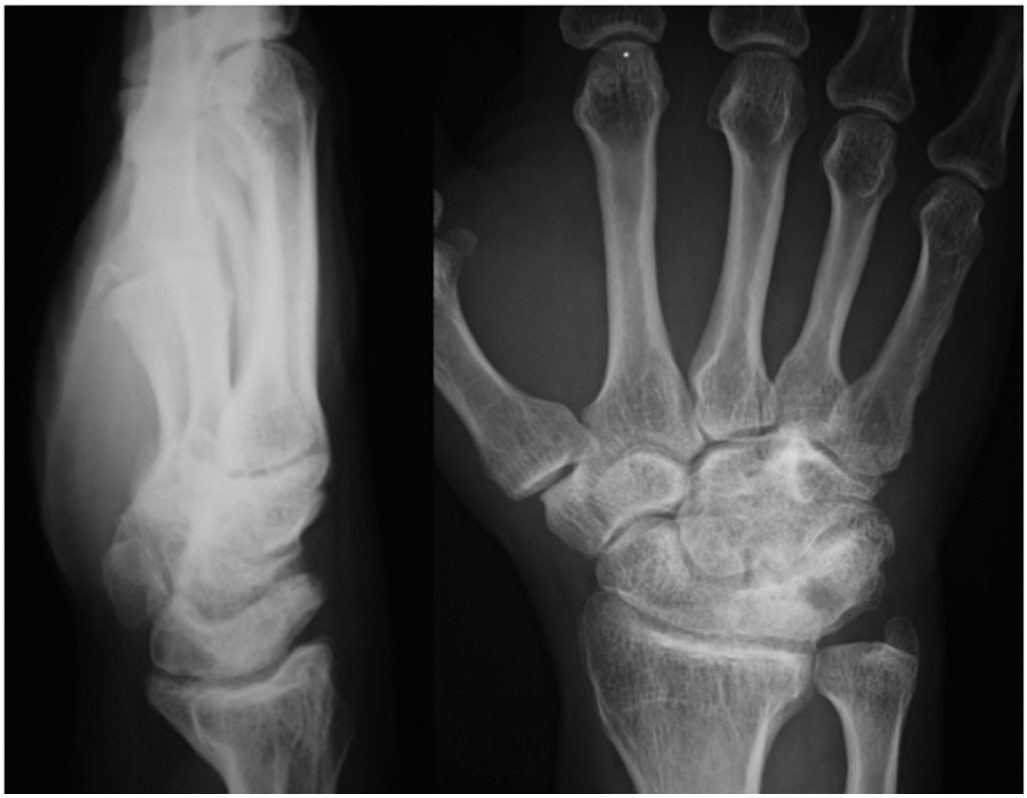

Figure 5. Plain radiographs of the patient's wrist 10.5 years after the VBG and CS. Bone fusion between the scaphoid, lunate, and triquetrum can be seen. The STI increased from 28 to 33 after CS and VBG. The MWS and VAS improved from 25 to 70 and from 51 to 22, respectively, after the operation. The PSS was 75 at the final follow-up.

osteochondral junction in osteoarthritic joints.[18,19] In advanced Kienböck disease, the articular cartilage of the lunate may be injured by age-dependent osteoarthritic changes and collapse of the lunate caused by disease progression. New bone might have formed in the injured articular cartilaginous surfaces of the lunate when the angiogenesis of the lunate was activated by VBG transplantation and osteotomy of the capitate and radius.

Another option for treating advanced Kienböck disease is proximal row carpectomy (PRC) of the wrist. Croog and Stern[20] reported average 10-year outcomes of PRC in patients with stage III and IV Kienböck disease. They reported that the average wrist flexion-extension arc and GS were 78% and 87%, respectively, of those in the contralateral wrist at the final follow-up. Compared with their outcomes, the range of wrist motion was inferior in our study although the recovery of GS was similar. However, they noted that 3 of 21 patients (14%) needed additional surgery. Another long follow-up study of PRC for Kienböck disease reported that 17 of 144 patients (12%) required revision surgery.[21] In our study, all patients were relieved from wrist pain and had no additional surgery, although the cohort did not include stage IV patients and had a smaller number of patients compared with the study of Croog and Stern.[20,21]

Vascularized bone graft followed by CS with or without RS increased GS, reduced wrist pain, and enabled all patients to return to their jobs within 11 months after surgery. This procedure can be indicated for patients with stage III Kienböck disease with a severely collapsed lunate. However, this procedure was followed by severe restriction of wrist motion and the potential for proximal carpal fusion. Proximal intercarpal fusion might have occurred from the degenerated and injured articular cartilage of the lunate, the vascularity of which was promoted by the double joint-leveling osteotomy (CS and RS) and the VBG.

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