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ORIGINAL STUDY

The efficacy of 1,2- intercompartmental supraretinacular artery pedicled vascularised bone graft for scaphoid proximal end non-union and avascular necrosis

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The aim is to show the efficacy of 1,2-intercompartmental supraretinacular artery pedicled vascularised bone graft in treatment of scaphoid non-union with concomitant proximal end avascular necrosis retrospectively. Twenty two cases of scaphoid nonunion with concomitant proximal end avascular necrosis were evaluated. Radiographic evaluation was made with radiographs, computed tomography, and magnetic resonance imaging. Clinical evaluation was made according to the Disabilities of the Arm, Shoulder and Hand (DASH) score, the Mayo wrist score, and the Short Form-36. Union was achieved in 18 81.8%. The mean age was 31.13 ± 5.29 years and the mean follow-up was 34.95±16.87 months. The median wrist flexion-extension range was 123.5° (100°-144°) preoperatively and 128° (82°-146°) postoperatively. The median radial-ulnar deviation was measured as 41.5° (24°-55°) preoperatively and 42° (24°-58°) postoperatively. The dominant hand was measured as 92% (p = 0.061) grip strength compared to the healthy side and the non-dominant side as 74% (p = 0.012). Improvement was observed in all patients in SF-36,DASH,Mayo score and in patients with union (p < 0.001). The radiological and clinical results of this study showed that 1,2- intercompartmental supraretinacular artery pedicled vascularised bone graft is an effective method in the treatment of scaphoid nonunion with concomitant proximal end avascular necrosis.

Keywords : Avascular necrosis ; scaphoid ; non-union ; vascularised graft ; 1, 2- ICSRA.

INTRODUCTION

Scaphoid fractures are usually seen in young adult males, aged 15-40 years *(12)*. Although the vast majority of scaphoid fractures are treated with conservative methods, it has been reported that 5%-10% of cases result in non-union *(4,14)*. These results have been reported to be generally associated with delayed diagnosis, insufficient immobilisation, poor surgical technique, the amount of displacement of the fracture and concomitant injuries *(24)*. If a non-union scaphoid fracture is not treated, it has been reported that within 10 years, osteoarthritis *(6,15)* periscaphoid arthritis and dorsal intercalated segment instability (DISI) will have developed at rates reaching 80%-90% *(26)*.

Several surgical methods have been described for the treatment of patients with non-union *(3,5,12,22,24)*. A review on this subject in literature

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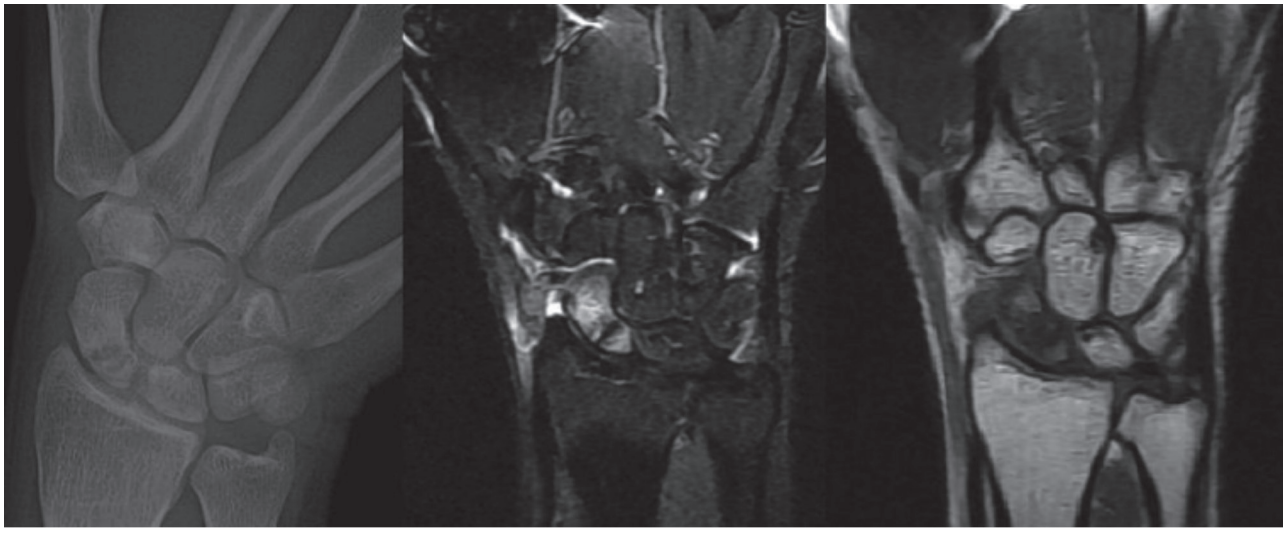

Fig. 1. — Preoperative non-union on anterior-posterior direct radiograph and scaphoid avascular necrosis on MRI.

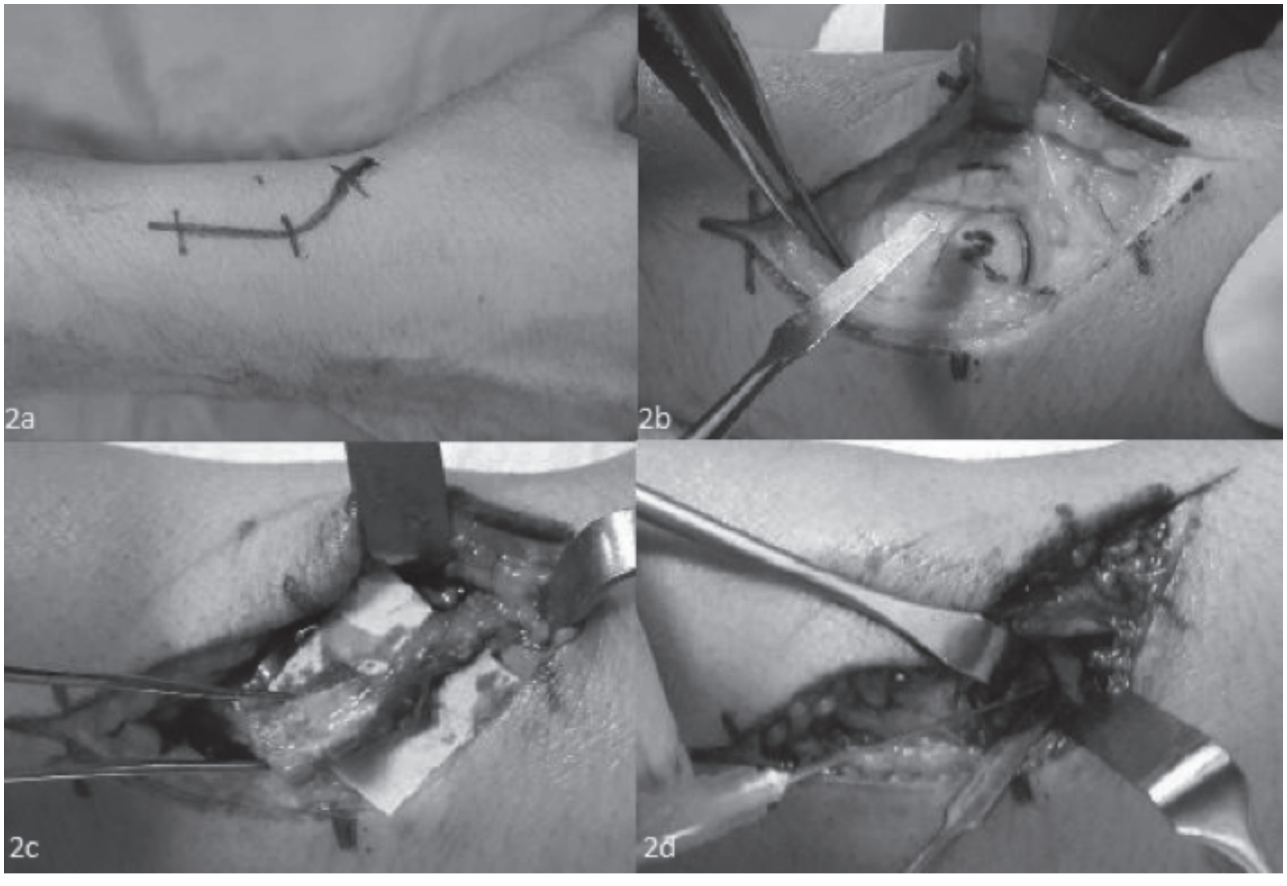

Fig. 2. — 2a) Surgical incision. 2b) İntraoperative view of 1,2-ICSRA 2c) 1,2-ICSRA pedicled bone graft 2d) View of the scaphoid non-union line.

reported that in cases of scaphoid proximal end non-union with avascular necrosis, treatment with non-vascularised bone graft achieved union at a rate of 78% *(21)*. Although the aim of the use of vascularised bone graft is to increase the rate of union, varying rates of union from 27%-100% have been seen in studies *(28,35)*.The distal radius dorsal vascularised grafting technique was first described in 1991 by Zaidemberg et al *(35)*.

Scheetz et al described extra and intra-osseous bleeding of the distal radius and the detailed use of 1,2-intercompartmental supraretinacular artery pedicled vascularised graft (1,2- ICSRA-VBG) *(27)*. In all areas of scaphoid non-union, the 1,2-ICSA-VBG provides advantages because of the proximity to the scaphoid *(23)*. Also with the aim of revascularisation, where palmar carpal arteries from the distal radius have been used, the application of various vascularised bone grafts, free vascularised medial femoral condyle corticoperiosteal flap and similar options have been preferred *(10, 11, 13, 20, 34)*.

The aim of this study was to evaluate the radiological and clinical results of patients with scaphoid proximal end non-union and concomitant avascular necrosis treated in our clinic with the 1,2-ICSRA-VBG technique and to discuss these results in the light of current literature.

MATERIALS AND METHODS

Approval for the study was granted by the Local Ethics Committee. A retrospective evaluation was made of 22 patients who presented with symptoms of proximal end scaphoid non-union and concomitant avascular necrosis and were treated with 1,2-ICSRA-VBG at our clinic between 2009 and 2014.

Patients were excluded from the study if they had previously undergone any surgical intervention to the wrist, if there was restricted wrist joint movement in the contralateral hand, an advanced degree of collapse in the scaphoid proximal end or radiographic findings of osteoarthritis in the radioscaphoid joint. The diagnosis of scaphoid proximal end non-union with concomitant proximal end avascular necrosis was made from gadolinium contrast magnetic resonance imaging (MRI) (Figure 1). In the preoperative examination of the patients, wrist flexion-extension and radial-ulnar deviation angles were measured with a goniometer and recorded. Postoperative evaluation of proximal end avascular necrosis was made with gadolinium contrast MRI.

All the patients in the study were operated on by a single surgeon using the technique described by Zaidemberg et al *(35)*.

Surgical approach

All the patients in the study underwent surgery in a supine position with a pneumatic tourniquet and regional anaesthesia (axillary block) applied. A dorsoradial incision was made on the dorsoradial side of the wrist in an 'S' shape centred between the first and second compartments. Working with a 4/0 magnification loop, a 1,2-ICSRA pedicled bone block of a sufficient size in a rectangular shape from the distal radius was retrieved with an osteotome. Taking into account the 1,2- ICSRA anatomy and variations*(1, 32, 35),* the pedicle was dissected towards the radius distal. Then the scaphoid non-union line was entered, the fracture line was visualised and the graft bed was prepared by reaming with a burr in a manner to be longitudinal to the scaphoid body whist protecting the volar cartilage (Figure 2).

The presence of avascular necrosis in the proximal end was confirmed intraoperatively by opening the tourniquet during the reaming and observing the absence of punctate bleeding. Bleeding of the retrieved vascularised bone graft was observed. The graft was placed longitudinally, perpendicular to the fracture line, within the two fragments and locking them, in a manner not to cover the dorsal bone surface and not to create a deformity and difference in the scaphoid length. Placement was made under fluoroscopy guidance. In some cases, while preparing the graft bed, gaps which could be formed were filled with spongeous grafts taken from the area from which the bone block was raised. Fixation of the screw in place was achieved with 2-3 Kirschner wires (1.2 mm) so that the bone graft was not damaged (Figure 3). The mean operating

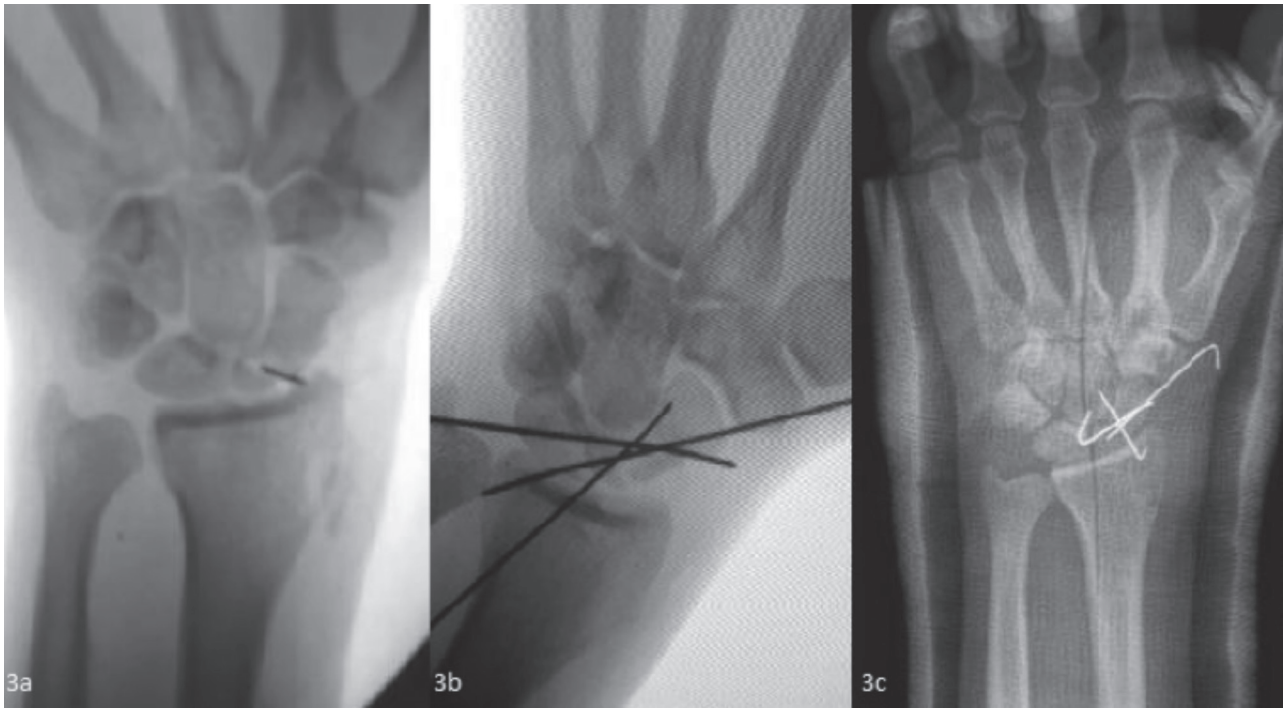

Fig. 3. — 3a) Fluoroscopic view of the scaphoid non-union line. 3b) Fluoroscopic view of fixation of the 1,2-ICSRA pedicled graft with K-wires to the non-union line 3c) Postoperative radiograph.

time was 45 mins and after opening the tourniquet, haemostasis was obtained and the layers were closed appropriately. A short-arm plaster cast was applied for 6 weeks with the wrist in a neutral position.

At 6 weeks postoperatively the plaster cast was removed and the K-wires were removed at 8 weeks. Anterior-posterior and lateral radiographs of the wrist were taken at the 6th, 12th and 24th weeks and at the final follow-up examination. The scaphoid length was measured on the radiographs and the operated and non-operated sides were compared. For evaluation of the union of the proximal end, CT was taken and for the observation of revascularization, gadolinium contrast MRI was taken of the wrists of all the patientsin the 24th month postoperatively (Figure 4).

In the postoperative clinical evaluation, all the patents were questioned in respect of age, occupation, cigarette smoking and whether the affected wrist was the dominant or non-dominant hand.

In the postoperative follow-up examinations clnical evaluation was made with the Mayo wrist score, the DASH score and the SF-36. The grip strength of both wrists was measured with a Jamar dynamometer (Sammons Preston, Bolingbrook, IL, USA). The joint range of movement (radial-ulnar angle, flexion-extension angle) of both wrists was measured with a goniometer.

Statistical analysis

The statistical analysis of the data was conducted using the SPSS 22.0 statistical software program. Descriptive analyses were stated as mean, standard deviation and median, minimum and maximum values. The compliance of the data with normal distribution was tested with the Shapiro-Wilk test. The Mann-Whitney U test was used for paired group comparisons of the data that did not fit normal distribution. The Wilcoxon sign rank test was applied for the comparison of dependent groups. The level of significance was accepted as $\alpha = 0.05$.

RESULTS

The demographic data of the patients are shown in Table 1. The study included a total of 22 patients,

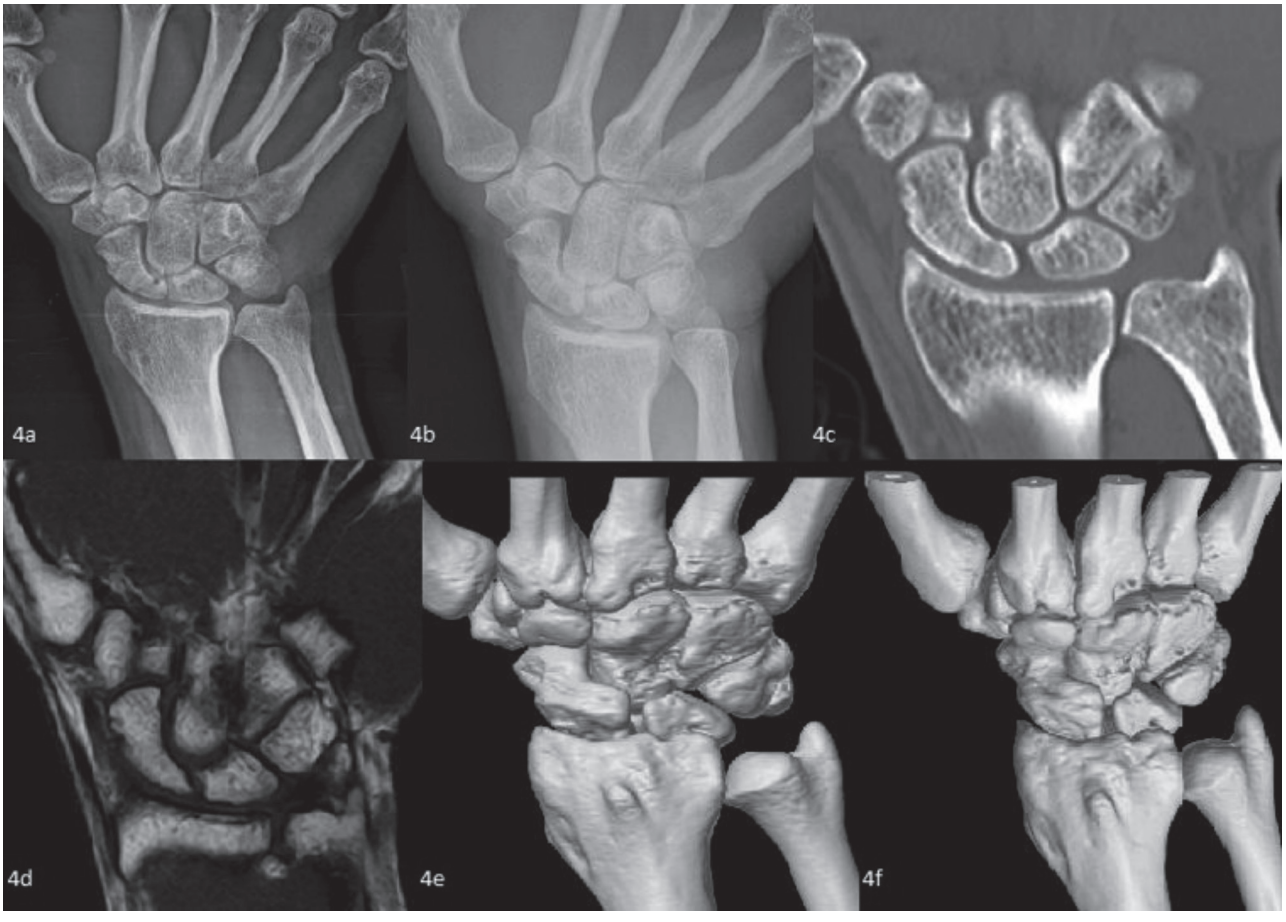

Fig. 4. — 4a) Anterior-Posterior direct radiograph of the wrist at postoperative 6 months. 4b) anterior-posterior direct radiograph of the wrist at postoperative 24 months. 4c) CT of the wrist at postoperative 24 months. 4d) MRI of the wrist at postoperative 24 months showing revascularization of the proximal part. 4e) 3-dimensional tomography showing the wrist at different angles at 24 months postoperatively.

comprising 19 males and 3 females with a mean age of 31.13 ± 5.29 years (range, 19-42 years). The mean follow-up period was 34.95 ± 16.87 months (range, 12-77 months). The time which elapsed from the initial injury to the application of the vascularised graft was 37.10 ± 47.73 months (range, 5-204 months). Union was determined in 18 patients and non-union in 4 patients. In those 4 patients with no finding of union on the direct radiographs, vascularisation of the scaphoid proximal end was not observed on MRI.

In the preoperative clinical evaluation, 1 patient was classified as good, 11 as fair and 10 as poor, with the median Mayo wrist score of 65 (range, 20-80). Postoperatively, the median score was 80 (range, 50-100), with 4 patients evaluated as excellent, 6 as good, 11 as fair and 1 as poor. This change in the Mayo wrist score evaluation was determined to be statistically significant ($p < 0.001$). The changes in the DASH and SF-36 scores from preoperative to postoperative were also determined to be statistically significant. These values are shown in Table 2.

When the clinical evaluation results were examined according to patients with union and those with non-union, in the Mayo score, an increase of 15 points was seen in the group where union was achieved, which was statistically significant ($p < 0.001$), and despite an increase of 32.5 points in the group where union was not achieved, this was not statistically significant ($p = 0.068$).

In the evaluation of the DASH score, a decrease of 27.95 points compared to the preoperative value

Table I. Demographic characteristics of the patients (n=22)

Age (mean±SD)	31.13±5.29	
	(19-42)	
Time since fracture	37.10±47.73	
	(5-204)	
Follow-up period	34.95±16.87	
	(12-77)	
	n	**(%)**
Gender		
Male	19	86.4
Female	3	13.6
Side		
Right	12	45.5
Left	10	54.5
Dominant		
Dominant	21	95.5
Non-dominant	1	4.5
Union		
Present	18	81.8
Absent	3	18.2

Table II. Clinical evaluation scores of the patients

	Preoperative	Postoperative	P value
MAYO	65(20-80)	80(50-100)	**<0.001**
DASH	40.40(10-69.20)	11.70(0.80-129)	**<0.001**
SF-36	99(83-124)	121.5(91-144)	**<0.001**

Table III. Analysis of the results according to the groups with union and non-union

	Preoperative	Postoperative	P value
Union (n=18)			
MAYO	65(20-80)	80(70-100)	**<0.001**
DASH	39.65(10-69.20)	11.70(0.80-129)	**0.005**
SF-36	99(83-124)	121.50(91-144)	**<0.001**
Non-union (n=4)			
MAYO	37.5(20-55)	70(50-80)	0.068
DASH	44.15(38.30-60)	32.10(5.20-47.50)	0.068
SF-36	99.50(96-101)	117(103-129)	0.068

was seen in the group with union and a decrease of 12.05 points in the group with non-union. This decrease was statistically significant in the union group and was not statistically significant in the non-union group.

In the SF-36 evaluation, an increase of 22.5 points compared to the preoperative values was seen in the patients in the group with union, which was determined to be statistically significant and an increase of 17.5 points in the non-union group was not determined to be statistically significant. These results are shown in Table 3.

Postoperatively the grip strength (kg force) of dominant and non-dominant hands was measured with a Jamar dynamometer and the values for the operated hands were compared with those of the non-operated hands. The data are shown in Table 4.

The flexion-extension angle was measured preoperatively as median 123.5˚ (100˚-144˚) and postoperatively as 128˚ (82˚-146˚). The radial-ulnar deviation angle was measured preoperatively as median 41.5˚(24-55˚) and postoperatively as 42˚ (24˚-58˚). No statistically significant difference was determined in the change from preoperative to postoperative in the flexion-extension angle ($p = 0.708$) or in the radial-ulnar deviation angle ($p = 0.073$).

When the dominant and non-dominant hands were examined separately, no statistically significant difference was determined in the changes in the flexion-extension angle or in the radial-ulnar deviation angle (Table 5).

In the measurement of the scaphoid length, the operated side was found to be mean 24.40mm (range, 20.6-28.7mm) and the non-operated side, 23.9mm (range, 21-28.6mm) and the difference was not determined to be statistically significant ($p = 0.269$).

Of the total 22 patients who underwent surgery, 11 returned to their previous occupation. In 1 patient with scaphoid non-union, despite an improvement in the joint range of motion compared to the preoperative values, the patient left work due to pain. The other 3 patients with non-union returned to their previous occupations. Apart from the 4 patients with non-union, complications were observed in 2 patients. In 1, the K-wire used for

Table IV. Comparison of grip strength(kg force)

	Patients with operated dominant side (n=13)				Patients with operated non-dominant side (n=9)			
	Operated side	Non-operated side	%	P value	Operated side	Non-operated side	%	P value
Grip strength	44 (28 –65)	48 (32 -65)	92	**0.061**	37 (22 –54)	50 (34–54)	74	**0.012**

Jamar dynamometer(Sammons Preston, Bolingbrook, IL).

Table V. Preoperative and postoperative joint range of movement angles

	Preoperative	Postoperative	P value
Flexion-extension	123.5(100-144)	128(82-146)	p=0.708
Radial-Ulnar deviation	41.5˚(24˚-55˚)	42˚ (24˚-48˚)	p=0.073

	Patients with operated dominant side (n=13)			Patients with operated nn-dominant side (n=9)		
	Preoperative	Postoperative	P value	Preoperative	Postoperative	P value
Flexion-extension	130(100-144)	130(95-146)	0.723	123(104-140)	126(82-140)	0.233
Ulnar-Radial deviation	41(24-46)	42(24-48)	0.237	42(32-55)	42(38-58)	0.174

fixation was seen to have shifted to the skin and the K-wires were removed under regional anaesthesia in the 8th week. In the other patient, 1 of the K-wires used for fixation had broken and remained within the trapezium. As the broken wire was completely within the bone, removal was not felt to be necessary.

DISCUSSION

Although approximately 25 years have passed since Zaidemberg et al *(35)* first applied the distal radius artery pedicled grafting technique to scaphoid non-unions with concomitant proximal end avascular necrosis, this technique is still in widespread current use *(1,9,17).*

When the results of treatment made with the technique are examined, union is seen at very different rates. Zaidemberg et al *(35)* reported union rates of 100%, Waters et al *(33)* also reported 100%, Waitayawinyu et al *(31)* 93%, Lim et al *(17)* 86%, Hirche et al *(9)* 75%, Boyer et al *(1)* 60% and Straw et al *(29)*, 27%.

Such a variation in reported rates of union could be associated with patient selection, whether or not the patient had previously undergone a surgical procedure, whether or not there was avascular necrosis concomitant to the non-union, differences in the implants used for fixation of the bone graft and the level of the line of non-union in the scaphoid.

In the current study, patients were not included if they had previously undergone any wrist surgery, if an advanced degree of collapse was determined in the scaphoid proximal end, if there were radiographic findings of osteoarthritis in the radioscaphoid joint, or if there was restricted wrist

joint movement in the contralateral hand, or dorsal intercalated segment instability (DISI). With union achieved in 18 of 22 patients, reaching the union rate of 82% can be considered a significant finding in the current study. In a study by Chang et al *(2)*, a union rate of 71% was reported in 34 of 48 patients, 50% of whom had concomitant avascular necrosis. As DISI deformity was present in 64% of the 14 patients where union was not achieved, it was concluded that the 1,2-ICSRA-VBG technique was not a very suitable method in non-unions with concomitant proximal end avascular necrosis. The same surgical technique was used by Waitayawinyu et al *(31)* in a study of 30 patients with non-union of a scaphoid fracture with concomitant proximal end avascular necrosis, for which no previous surgery had been applied. Of these 30 patients, 19 had a scaphoid waist fracture and in 11 the fracture was in the proximal third. Union was achieved in 28 at a rate of 93%. Özalp et al *(23)* emphasised the advantage for all non-union areas of the proximity of 1,2-ICSRA-VBG to the scaphoid bone. Due to the manner of vascularisation of the scaphoid, there is a greater incidence of non-union and avascular necrosis of fractures in the more proximal part *(7)*. In the current study, non-union after surgical treatment was observed in 4 of 22 patients, at a rate of 18%. In 2 of the patients with non-union, it was thought that as they were cigarette smokers, this could have had a negative effect on the union process.

In all the patients of the current study, fixation of the graft taken from the distal radius was provided with 2-3 K-wires. Some studies have shown that more rigid fixation is provided with the use of cannulated screws, Herbert or headless conical screws and thus the union is superior to that achieved using K-wires *(2,31)*. However, in the current study, when the dimensions and structure of the vascularised graft to be placed on the non-union line were taken into consideration, it was thought that all kinds of cannulated screws to be used for fixation would damage the graft. This view is supported by the study of Rancy et al *(25)*, in which it was reported that during the fixation of scaphoid proximal end fractures with headless screw fixation, secondary fractures may develop and damage has been observed around the implant.

All the patients in the current sstudy were applied with a short-arm plaster cast for 6 weeks postoperatively. Liang et al *(16)* considered that immobilisation in the postoperative period with a plaster cast could cause stiffness in the joint and therefore applied a mobile wrist fixator and started movement in the early period after graft fixation with Herbert screws or K-wires. All of the 11 patients treated in this way achieved union and it was emphasised that the external fixator contributed to the increased range of joint movement in the postoperative period, fibrous tissue did not form in the joint because of the distraction effect and rehabilitation of the joint was better.

When literature is examined, it can be seen that there are varying results related to preoperative and postoperative joint range of movement following union of scaphoid fractures treated with 1,2-ICSRA-VBG. While some studies have reported an increase in joint range of movement compared to preoperative values *(18,35)*, others have reported no significant difference *(28,31)* and in contrast, some have reported reduced range of movement compared to preoperative values *(1,33)*. Hankins CL and Budoff JE *(8)* stated that such different results could not be associated with a single reason and could be due to factors such as technical reasons for the stiffness in the wrist, biological causes and the period of postoperative immobilisation. It has also even been reported that radial deviation and extension could be reduced from the mass effect of the vascularised pedicled graft and ulnar deviation and flexion could be reduced because of the tightening effect of the vascular pedicle and thus the effect is from the graft itself. However, in a cadaver study, such an effect was not observed and it was therefore concluded that stiffness could develop more associated with technical and biological reasons and the period of immobilisation. In the current study, no statistically significant difference was determined in the median values of the preoperative and postoperative flexion-extension angles ($p=0.708$) and the radial-ulnar deviation angles ($p=0.073$). In accordance with these findings obtained in the current study it can be considered that fixation with K-wire and the immobilisation period did not affect the results of this surgical technique.

There are previous studies in literature in which grip strength has been measured with a Jamar dynamometer. Hirche et al *(9)* achieved 80% grip strength in the dominant hand and 84% in the non-dominant hand in comparison with the healthy side and Malizos et al *(19)* reported this rate at 82%. There are also studies which have reported grip strength rates of 99% *(17)*. In the current study, in the comparison of the grip strength of the operated hands with the healthy hands at the final follow-up examination, the grip strength was measured as 92% in the operated dominant hands and as 74% in the operated non-dominant hands. While the change in the dominant hands was not statistically significant ($p = 0.061$), the change in the non-dominant hands compared to the healthy side was determined to be statistically significant ($p = 0.012$).

In the evaluations of the Mayo wrist score, the DASH score and the SF-36 of the patients in the current study, a statistically significant increase was determined compared to the preoperative scores in the 18 patients where union was achieved ($p < 0.001$). In the 4 patients where union was not obtained, despite the increase compared to the preoperative scores, the increase in this group was not determined to be statistically significant ($p = 0.068$). Although the increase in these 4 patients with non-union was not statistically significant, 3 of these patients returned to their previous occupations and the other 1 changed occupation. In 2 of these patients with non-union, the result could have been negatively affected as they were the first cases to be applied with this surgical technique. Good knowledge of the 1,2-intercompartmental supraretinacular artery with variations is necessary and this is dependent on the experience of the surgeon.

A limitation of this study could be said to be that grip strength was not measured preoperatively with the Jamr dynamometer. Therefore, the evaluation was made by comparison of the grip strength with the healthy side postoperatively. Many different methods are used in the treatment of non-union and avascular necrosis associated with a scaphoid fracture. Free vascularised medial femoral condyle corticoperiosteal flap is one of the preferred options, particularly in cases with scaphoid deformity *(10)*. However, donor site morbidity and the need for microsurgery experience in the application are disadvantages. The most significant advantage of the 1,2- ICSRA-VBG technique is the proximity to the scaphoid, thus there is no donor site morbidity and it is an effective method which can be easily learned and applied.

In addition, according to our surgical experience, as the periosteal extensor retinaculum is held more tightly to the bone, this is a protective anatomic property against stripping from the bone in dissection of the vascular pedicle. Therefore, in comparison to the volar vascular bone graft technique, which we intially occasionally applied, we consider the dorsal vascular bone graft to be more reliable.

In conclusion, surgical treatment of proximal end scaphoid fractues with concomitant avascular necrosis with 1,2- ICSRA-VBG can be considered to be an easily applicable, effective method to obtain union and revascularisation of the proximal end. However, the experience of the surgeon is also important in obtaining good results.

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