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Comparison of clinical outcomes of autologous bone graft versus pronator quadratus pedicled vascularized bone graft in the treatment of scaphoid nonunion

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We aimed to compare the union rate and clinical outcome of autologous bone graft versus pronator quadratus vascularized pedicled muscle flap in treatment of scaphoid nonunion. Forty patients with a diagnosis of scaphoid nonunion who underwent unilateral pseudarthrosis surgery were included in this study. Notably, the scaphoid nonunion was unilateral, and the contralateral wrist was asymptomatic with normal function, per the physical and radiological examinations. Pronator quadratus vascularized pedicled muscle flap was used in 16 patients (group 1), and autologous bone graft was used in 24 patients (group 2). Patients were compared used Scapholunate angles, Natrass carpal height ratio and Mayo wrist score pre and postoperatively. Fifteen of the 16 (93.3%) patients in group 1 and 19 of the 24 (79.2%) patients in group 2 achieved bone union. Four of twelve patients in group 2 with avascular necrosis (AVN) and one of eight in group 1 with AVN were not able to achieve union. The group 2 (34%) had higher nonunion rate than group 1 (12%) in AVN patients. The scapholunat angle was significantly decreased and the Natress ratio was significantly increased postoperatively compared to the preoperative measurement in both group. There was no statistically significant difference in the postoperative measurement. The postoperative Mayo wrist score showed no statistically significant differences between both groups. The pronator quadratus vascularized pedicled muscle flap was superior to non-vascularized bone grafting in the treatment of scaphoid nonunion with AVN. However, management of the patients without avascular necrosis is not requiring the vascularized pedicled muscle flap technique.

Keywords : bone grafting; nonunion; non-vascularized; pronator quadratus pedicled vascularized bone graft; avascular necrosis.

INTRODUCTION

Scaphoid fractures constitute 60% to 70% of overall carpal bone fractures, and they are the

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second most frequent wrist fractures after distal radius fractures *(1)*. The scaphoid is connected to the surrounding bones, the radius, lunate, capitate, trapezium, and trapezoid, and 80% of its surface is covered with hyaline cartilage *(2)*. Scaphoid nonunion occurs in 10% to 15% after scaphoid fractures follow-up, and the risk of pseudoarthrosis becomes higher with treatment delay, inadequate immobilization time and inadequate fixation *(3,4)*.

Various treatment options are available for scaphoid nonunion in each disease stage, including percutaneous fixation or open reduction and internal fixation with vascularized or non-vascularized bone grafting, salvage procedures involving excision or arthrodesis of carpals for each indication *(5-7)*. The pronator quadratus pedicled vascularized bone graft was first described by Braud, who described the proximal pedicle bone grafting in the forearm and proximal carpal row *(8)*. This technique is relatively easy to perform without requiring special equipment for microsurgery that may be needed in Zaidemberg's procedure *(7)*. We hypothesized that the excellent healing potential of the pronator quadratus pedicled bone graft—as reported in previous studies—combined with a rigid fixation by using a headless compression screw might be a good treatment option for scaphoid nonunion *(7-9)*.

This retrospective follow-up study aimed to compare the union rate and clinical outcome of autologous bone graft versus pronator quadratus vascularized pedicled muscle flap in treatment scaphoid nonunion. Which technique has more successful in treatment of scaphoid pseudarthrosis with avascular necrosis (AVN) was also investigated.

MATERIAL AND METHODS

Approval was obtained from the institutional review board. We performed a retrospective study by evaluating the records of patients who were treated for scaphoid nonunion in our clinic between 2009 and 2017. All patients who agreed to participate in this study gave their informed consent before their inclusion in the study. All patients with a diagnosis of scaphoid nonunion who underwent unilateral pseudarthrosis surgery were included in this study. Patients' medical history and radiographic images were assessed using the medical registration files.

Inclusion criteria: Patients with available demographics and medical records, unilateral scaphoid nonunion, minimum 12-month follow-up after surgery, willingness to complete the questionnaires during physician office visits.

Exclusion criteria: Patients with wrist instability, wrist arthrosis, history of tendon transfer procedure, inflammatory diseases, previous wrist surgery, and distal third nonunion.

Notably, the scaphoid nonunion was unilateral, and the contralateral wrist was asymptomatic with normal function, per the physical and radiological examinations. The pronator quadratus vascularized pedicled muscle flap technique was performed by a surgeon with expertise in hand surgery (HD). The autologous bone graft was performed by an orthopedic surgeon with an equal amount of expertise in hand surgery (OA). All procedures were performed through a single palmar approach. The indication for surgery was symptomatic scaphoid waist and proximal third nonunion in all patients. All patients underwent standard radiographs and magnetic resonance imaging preoperatively to assess the location of the scaphoid nonunion and vascularity of the fragments (Figure-1).

Surgical Procedures:

Group 1: A volar Z incision was made over the scaphoid tuberosity and distal radius to expose the site of the scaphoid nonunion. The radioscaphocapitate ligament complex was divided using a zigzag incision. The scaphoid was inspected, and the nonunion was identified. The nonunion surface was exposed. The sclerotic edges of the nonunion were excised. At this point, the length, width, and depth of the resultant defect in the bone were measured. On the distal radius, the pronator quadratus was identified, and a block of bone graft measuring approximately 15 to 20 mm long was outlined at its distal insertion, close to the abductor pollicis longus tendon (Figure 2-3). Before the collection of the bone block, an L-shaped incision was performed on the pronator quadratus muscle on the radial side along the insertion margin of the muscle without detachment of abductor pollicis longus and brachioradialis tendon. Holes were made along the margin of the graft with a K-wire

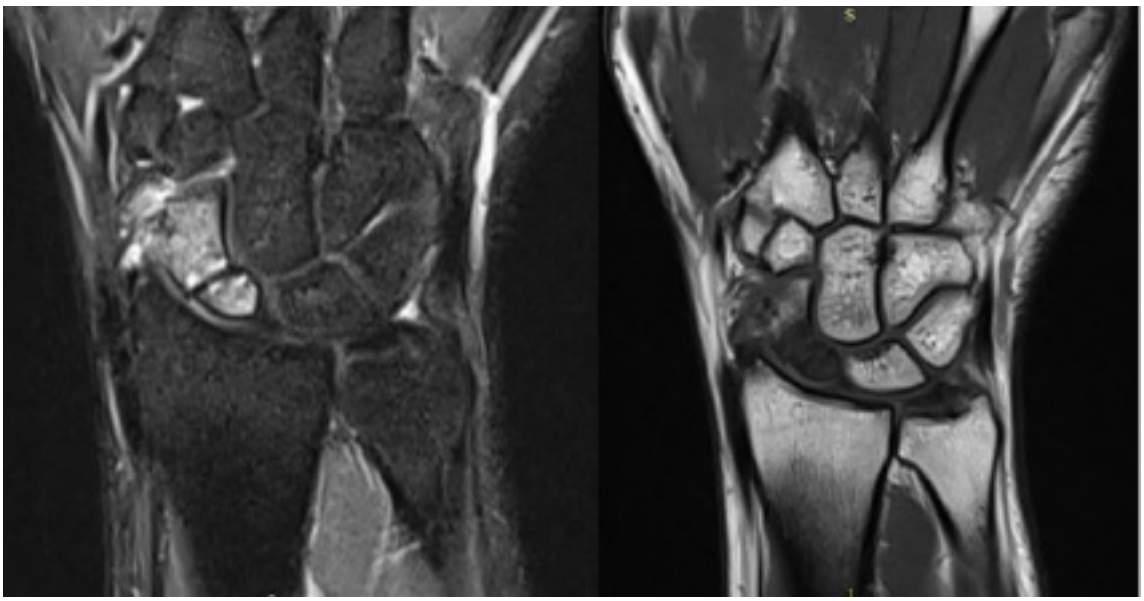

Fig. 1. – The magnetic resonance images showed the avascular necrosis of the scaphoid non-union.

to facilitate separation with a fine osteotome, and the size of the graft required was oversized by 2 mm than the measured size for tightness of the bone graft. The scaphoid fragments were distracted, and the graft was inserted into the defect. The proximal and distal scaphoid segments and the graft were then temporarily fixed with 1 or 2 K-wires introduced at the scaphoid tuberosity. We used the Acutrak headless compression screw (Acumed, Hillsboro, Ore). Fluoroscopy was performed to confirm that the wire was placed along the longitudinal axis of the scaphoid and across the bone graft into the proximal fragment. The radioscaphocapitate ligament complex was repaired, and the skin was closed. A thumb spica splint was applied for 2 weeks for strict immobilization.

Group 2: The scaphoid was approached using a standard palmar approach. After identifying

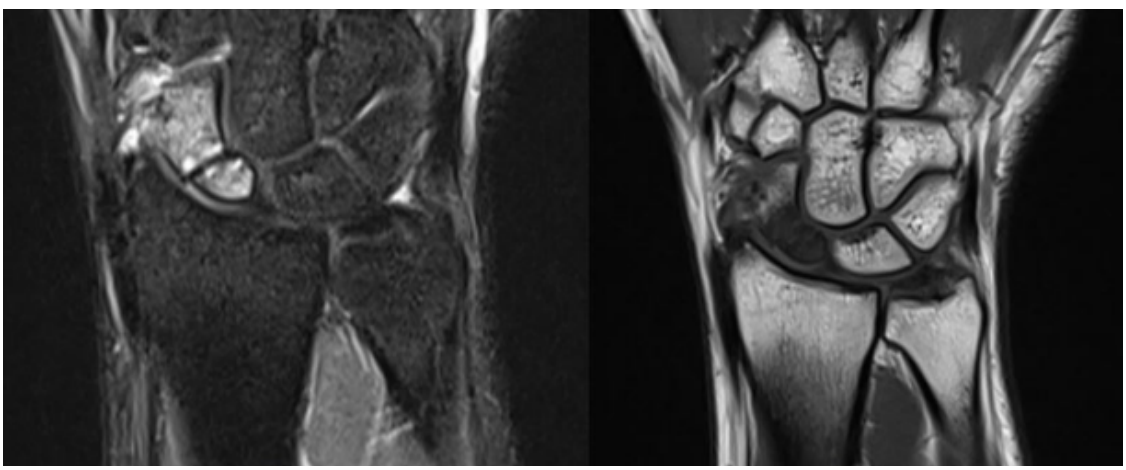

Fig. 2. – The pronator quadratus was identified, and a block of bone graft was harvested close to the abductor pollicis longus tendon. Before the collection of the bone block, an L-shaped incision (Figure 2-A) was performed on the pronator quadratus muscle on the radial side along the insertion margin of the muscle without detachment of abductor pollicis longus and brachioradialis tendon (Figure 2-B).

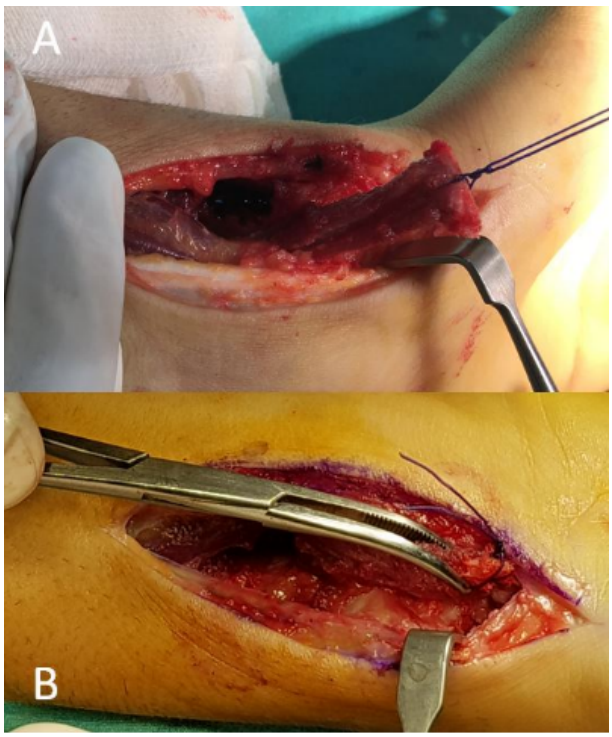

Fig. 3. – The pedicled vascularized bone graft transported carefully (A) and placed the non-union area.

the site of nonunion, the interposed fibrous tissue was excised until viable bleeding was noticed. Dimensions of the wedge graft were determined by measuring the gap in the scaphoid (width, length, and depth). The anterior surface of the trapezium was notched with a rongeur to facilitate screw placement. An autologous bone graft was then harvested from the iliac crest and tamped into place. A screw the measured guidewire length was then inserted over the guidewire, and prominences of the graft on its volar and radial aspects were excised.

Two weeks after surgery, the splint was changed to a removable thumb splint. Patients were encouraged to perform active wrist and thumb motions as tolerated without the splint. The wrist was kept immobilized for the rest of the day. Six weeks after surgery, splinting was discarded, and patients were encouraged to perform enhanced wrist mobilization without a load on the operated hand. About 3 months after surgery, patients were allowed to use the wrist for daily activities based on the surgeon's assessment of the overall stability of the fixation, the progress of the bony union, and the patient's pain level. Depending on the recovery of grip strength and range of wrist motion, patients returned to heavy work approximately 6 months after surgery.

The wrist range of motion was measured using a goniometer, in degrees, from the neutral position to flexion, extension, radial deviation, and ulnar deviation by a senior surgeon (MAO). Pre- and postoperative VAS scores were used to evaluate the functional results. The grip strength was measured using a JAMAR hand dynamometer (Therapeutic Equipment Corporation, Clayton, NJ). Per the guidelines for the use of the JAMAR dynamometer, issued by the American Society for Surgery of the Hand, the second grip handle was used for all patients. The mean of three successive trials was used for both the injured and uninjured hands, and recorded as a percentage of the unaffected side, as recommended by the American Society of Hand Therapists. Grip strengths were adjusted by 10% for analysis of the non-dominant hand *(10)*. The key and tip pinch strengths were assessed using a specific dynamometer (FEI, Irvington, New York, USA). Measurements were made on both the fracture side and non-affected hands. In addition, on the last follow-up visit, patients completed the modified Mayo wrist score *(11)*, which comprises five multiple-choice questions. The total score ranges from 0 to 100 points, with higher scores indicating a better result. An excellent result is defined as 90–100 points, good is 80–89, fair is 65–79 points, and poor is less than 65 points.

Radiographic evaluations were scheduled at 2, 4, and 6 weeks postoperatively, and monthly thereafter, as needed until the final follow-up. At each follow-up, the wrist was examined for snuffbox tenderness, and three radiographic views of the scaphoid (anteroposterior, lateral, semipronated oblique) were taken. Union was considered to have occurred when there was no tenderness at the fracture site, and there was evidence of trabeculae crossing on at least three views. We used the Nattrass index, which measured the carpal height and carpal height ratio *(12)*. The third metacarpal axis continued to the distal radial articular surface. Carpal height was considered the distance between the base of the third metacarpal and the point of intersection of

the metacarpal axis with the radiocarpal joint. The scapholunate angle is the angle between the long axis of the scaphoid and the mid axis of the lunate on the lateral view. All radiological parameters were evaluated by same author using the picture archiving and communication system (PACS) (Extreme PACS).

NCSS (Number Cruncher Statistical System) 2007 (Kaysville, Utah, USA) was used for statistical analysis. Student's t-test was used for comparison of two groups of variables with normal distribution, and the Mann-Whitney U test was used for comparison of two groups of variables that were not normally distributed. The Wilcoxon signed-rank test was used for intragroup comparisons of variables that did not show normal distribution. Pearson chi-square test, Fisher-Freeman-Halton test, and Fisher's exact test were used to compare the qualitative data, with the significance level set a priori at $p < .05$ A p value less than 0.05 was considered to be statistically significant.

RESULTS

Overall, 40 patients who met the inclusion criteria were identified. Pronator quadratus vascularized pedicled muscle flap was used in 16 patients (group 1), and autologous bone graft was used in 24 patients (group 2). No statistically significant intergroup differences were observed regarding age (group 1: 24.40 ± 6.09 vs. group 2: 28.33 ± 7.02, $p = 0.082$). Twelve patients in group 1 and six patients in group 2 had fracture on their dominant side. Group 1 had 15 patients had symptomatic waist and ten patients had proximal third scaphoid nonunion. In group 2, ten patients had symptomatic waist and six patients had proximal third scaphoid nonunion. Notably, 15 patients (93.3%) in group 1 and 19 patients (79.2%) in group 2 achieved bone union ($p = 0.376$). Four of twelve patients in group 2 with avascular necrosis (AVN) and one of eight in group 1 with AVN were not able to achieve union. Group 2 (34%) had higher nonunion rate than group 1 (12%), albeit with no statistically

Table I. – Demographics data of the patients

		Patients with autologous bone graft (n=24)	Patients with Pronator quadratus vascularized pedicled muscle flap (n=16)	p Value
Age (year)	Min-Max	16-40	16-36	[a]0.082
	Mean ± SD	28.33 ± 7.02	24.40 ± 6.09	
Dominant Side; n (%)	No	12 (50%)	10 (62.5%)	[d]0.436
	Yes	12 (50%)	6 (37.5%)	
Fracture Side	Waist	15 (58.3%)	10 (62.5%)	[d] 1
	Proximal	9 (25%)	6 (37.5%)	
Avascular Necrosis (AVN); n (%)		12 (50%)	8 (50%)	[d]0.839
Bone Union; n (%)		19 (79.2%)	15 (93.75%)	[e]0.376
Bone union patients with AVN; n (%) (n=20)		12/8 (66.7%)	8/7 (87.5%)	[e]0.603
Time to union (week)	Min-Max	10-16	8-14	[a]0.214
	Mean ± SD	12.79 ± 1.47	12.07 ± 1.77	
Time from injury to surgery (month)	Min-Max	11-80	12-60	[b]0.434
	Mean ± SD	30.42 ± 17.36	24.87 ± 11.43	

[a]Studen t Test, [b]Mann Whitney U Test, [c]Fisher Freeman Halton Test, [d]Pearson Chi-Square Test, eFisher's Exact Test.
SD: Standard deviation; Min: Minimum; Max: Maximum

significant differences (p = 0.29). The mean time to union was 12.79 ± 1.47 weeks in group 1 and 12.07 ± 1.77 weeks in group 2. No significant intergroup differences were observed regarding the demographic data (Table I).

The mean flexion-extension and radial-ulnar deviation arcs were significantly higher on the non-affected side than the fracture side in both groups (p < 0.001 and p < 0.001). No intergroup differences were noted regarding the postoperative mean wrist flexion and ulnar deviation arcs. However, the extension and radial deviation arcs were significantly higher in group 1 than group 2 (p = 0.011, p = 0,003). The range of motion value is summarized in Table II.

No intergroup differences were observed regarding the mean grip strengths and key pinch strengths. However, the strengths were significantly higher on the non-affected side than the fractured side in both groups (p < 0.001 and p < 0.001) (Table III).

VAS scores decreased from 6.38 ± 0.88 to 2.17 ± 0.87 in group 1 and 6.53 ± 0.52 to 1.87 ± 0.64 (p < 0.001) in group 2. The decrease in postoperative VAS scores compared with preoperative VAS scores was statistically significant (p < 0.001 and p < 0.001). The Mayo wrist score was 79.54 ± 7.63 (range: 68–93) in group 1 and 80.93 ± 7.40 (range: 60–92) in group 2. The postoperative Mayo wrist score and VAS scores between both groups were compared, and no statistically significant differences were observed (p = 0.578, p = 0.689).

The scapholunate angle decreased from 57.08 ± 7.36 to 43.50 ± 7.51 in group 1 and 56.00 ± 9.67 to 46.33 ± 6.94 in group 2. The decrease in postoperative scapholunate angle was statistically

Table II. – Comparison of clinical result between both groups

			Patients with autologous bone graft (n=24)	Patients with Pronator quadratus vascularized pedicled muscle flap (n=16)	p Value
Flexion Degrees	Non-affected side	Min-Max	70-80	70-80	0.058
		Mean ± SD	76.25 ± 4.48	78.67 ± 3.52	
	Fracture side	Min-Max	40-80 (60)	40-70 (70)	0.914
		Mean ± SD	63.54 ± 8.66	62.67 ± 9.61	
Comparison of non-affected and fracture side			0.001**	0.001**	
Extension Degrees	Non-affected side	Min-Max	45-80 (60)	50-70 (60)	0.298
		Mean ± SD	58.13 ± 8.32	60.67 ± 5.63	
	Fracture side	Min-Max	30-60 (50)	20-50 (40)	0.011*
		Mean ± SD	48.33 ± 9.05	39.33 ± 9.98	
Comparison of non-affected and fracture side			0.001**	0.001**	
Radial Deviation	Non-affected side	Min-Max	15-25 (20)	15-25 (20)	0.960
		Mean ± SD	20.63 ± 3.06	20.67 ± 3.20	
	Fracture side	Min-Max	10-20 (15)	10-20 (15)	0.003**
		Mean ± SD	16.67 ± 3.51	13.00 ± 3.16	
Comparison of non-affected and fracture side			0.001**	0.001**	
Ulnar Deviation	Non-affected side	Min-Max	25-35 (30)	20-30 (30)	0.065
		Mean ± SD	29.58 ± 2.04	27.33 ± 4.17	
	Fracture side	Min-Max	20-30 (25)	15-30 (20)	0.404
		Mean ± SD	25.21 ± 2.32	24.00 ± 5.41	
Comparison of non-affected and fracture side			0.001**	0.059	

*p<0,05. **p<0,01. SD: Standard deviation; Min: Minimum; Max: Maximum

Table III. – Comparison of radiological and clinical results

			Patients with autologous bone graft (n=24)	Patients with Pronator quadratus vascularized pedicled muscle flap (n=16)	P value
Scapholunate angle	Preoperative	Min-Max	40-70 (60)	35-70 (60)	0.844
		Mean ± SD	57.08 ± 7.36	56.00 ± 9.67	
	Postoperative	Min-Max	35-60 (40)	30-60 (50)	0.097
		Mean ± SD	43.50 ± 7.51	46.33 ± 6.94	
Grip strengths	Non-affected side	Min-Max	28-70 (50)	25-65 (44)	0.128
		Mean ± SD	49.50 ± 10.34	44.27 ± 9.22	
	Fracture side	Min-Max	22-58 (42)	12-53 (35)	0.115
		Mean ± SD	42.00 ± 9.89	35.73 ± 12.06	
Key pinch strengths	Non-affected side	Min-Max	11-27 (16.5)	14-22 (17)	0.816
		Mean ± SD	17.75 ± 4.36	17.13 ± 1.92	
	Fracture side	Min-Max	11-23 (14)	11-20 (15)	0.873
		Mean ± SD	15.33 ± 3.77	14.53 ± 2.56	

SD: Standard deviation; Min: Minimum; Max: Maximum

significant when compared with the preoperative scapholunate angle ($p < 0.001$ and $p < 0.001$) (Table III). However, no statistically significant difference was observed regarding postoperative measurement ($p = 0.097$). The Nattrass ratio was significantly increased postoperatively compared with the preoperative measurement in both groups. However, no statistically significant differences were noted regarding the postoperative measurement ($p = 0.318$)

DISCUSSION

The primary aim of the scaphoid nonunion surgery is to achieve bone union and restore scaphoid alignment. Notably, several factors influence the outcome, such as the fixation device, fracture location, type of bone graft, patient's age, smoking history, fracture displacement, and degree of instability. Even though vascularized bone grafting is an effective treatment option for scaphoid nonunion with AVN, it does not always provide a desirable surgical outcome. Several vascularized bone graft techniques have been described in the literature, such as the use of 1,2 intercompartment supraretinacular artery graft, pedicled grafts based on the ulnar or palmar carpal artery, pedicled grafts from the index finger or thumb metacarpal, implantation of a vascular leash from the second dorsal intermetacarpal artery in combination with bone grafting, free vascularized bone grafts from the iliac crest or the medial femoral supracondylar region, and pronator quadratus pedicled vascularized bone grafts *(12-14)*. Notably, three previous studies have used the pronator quadratus pedicled vascularized bone grafts for scaphoid nonunion treatment. However, no study has compared this technique with another bone graft technique. In this study, we compared the union rate and clinical outcome of the autologous bone graft versus pronator quadratus vascularized pedicled muscle flap in the treatment of scaphoid nonunion besides comparing the results in patients with AVN in both groups.

Several studies have compared vascularized and non-vascularized bone grafts in patients with scaphoid nonunion. Merrell et al. *(15)* determined that the rate of union using the vascularized bone graft in patients with AVN of the proximal fragment was 88% among 34 patients and that of using non-vascularized wedge graft was 47% among 30 patients for scaphoid nonunion treatment. In another study, Ferguson et al. reported with 5464 cases with scaphoid nonunion outcomes after reviewing 144 studies. In that study, they reported that union rates in vascularized and

non-vascularized bone grafts were 84% and 80%, respectively while the union rate with vascularized bone graft was 74% compared with 62% with non-vascularized bone graft in patients with AVN *(16)*. However, Caporrino et al. compared vascularized and non-vascularized bone grafts for scaphoid fractures and concluded that the rate of the union was similar, although the vascularized bone graft group reached bone union earlier *(17)*. In our study, 15 of the 16 (93.3%) patients in group 1 and 19 of 24 (79.2%) patients in group 2 achieved bone union ($p = 0.376$). Moreover, 4 of 12 patients in group 2 with AVN and 1 of 8 in group 1 with AVN were not able to achieve union. Group 2 (34%) had a higher nonunion rate than group 1 (12%), albeit with no statically significant differences ($p = 0.29$).

The first series was described by Kawai and Yamamoto *(18)* in 1988, and the second series by Noaman et al. *(19)* for the treatment of scaphoid nonunion. They evaluated 8 and 45 cases of scaphoid fracture nonunion and demonstrated excellent radiographic union rate (100% and 95%) and range of motion of the wrist after treatment, respectively. The third series was presented by Sang Ki Lee in 2015, which operated 27 patients (20 men and 7 women) and observed that all scaphoid nonunions united at an average of 11.5 weeks *(20)*. In our series, 16 patients were treated with pronator quadratus vascularized pedicled muscle flap compared with 24 patients with the autologous bone graft. Notably, the union was achieved in 19 patients of the autologous bone grafting group with a union rate of 79%. In contrast, the union was achieved in 14 patients of the vascularized pronator quadratus pedicled muscle graft group with a union rate of 93%. The mean time to union was 12.48 ± 1.62 weeks, ranging from 8 to 16 weeks. The mean time to union was 12.79 weeks in the autologous bone graft group and 12.07 weeks in the vascularized pronator quadratus pedicled muscle graft group.

Nonetheless, this study had some limitations. First, this was a retrospective and non-randomized study. The surgical techniques have performed based on the surgeon's preference. Therefore, preoperative clinical information was not evaluated, and no comparisons were performed of the postoperative range of motion, grip and pinch strength value and preoperative values. Nevertheless, more detailed data can be obtained if a prospective randomized controlled trial could be performed. Second, the sample size was relatively small. Third, the follow-up time was relatively shorter, and a longer follow-up period is needed to adequately assess the arthritic changes, which are among the most common complications.

CONCLUSION

The non-vascularized iliac bone grafts provided a similar rate of union and excellent clinical outcomes in patients with scaphoid nonunion compared with the pronator quadratus vascularized pedicled muscle flap. However, the pronator quadratus vascularized pedicled muscle flap is undoubtedly superior to non-vascularized bone grafting in the treatment of scaphoid nonunion with AVN. The vascularized pedicled muscle flap is not required patients without AVN.

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