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ORIGINAL PAPER

Pedicled vascularized bone grafts compared with xenografts in the treatment of scaphoid nonunion

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Abstract

Introduction Fractures of the scaphoid account for 60–70% of all wrist bone fractures. The results of treatment in terms of bone healing vary depending on the type and location of the fracture, the time elapsed since the injury, the type of surgical treatment. Nonunion occurs in 5–15% of the cases on average. The purpose of this paper is to compare the surgical techniques and results of treating scaphoid nonunion (SNU) with osteoplastic xenografts of bovine origin or a vascularized autograft of the distal part of the dorsal radius.

Methods We compare two groups of patients with symptomatic SNU, treated surgically with either a vascularized graft ($n = 15$) or a xenograft of bovine origin ($n = 15$). In the presurgical stage, the demographic characteristics of the patients, the time elapsed between injury and surgery, and classification of the injury (Schonberg, Herbert–Fisher, and Geissler–Slade) were recorded. One year following surgery, bone healing, total duration of the treatment, complications, the Mayo wrist score, and answers to the DASH questionnaire were analyzed.

Results No statistically significant differences between the two groups of patients were observed for bone healing (86.7% vs 80%) or functional results. A highly significant difference was observed with respect to duration of the surgical intervention in favor of xenografts.

Conclusion The xenograft method is simple and relatively acceptable, providing good results in terms of healing and functionality.

Keywords Scaphoid nonunion · Vascularized bone graft · Bone grafting · Xenograft

Introduction

Fractures of the scaphoid bone occur prevalently in young men, in cases of wrist extension greater than 95° under a low intensity energy force [1, 2]. Nonunion of fractures is seen in 5–15% of the cases on average [2–4].

The scaphoid bone bridges the proximal and distal rows of the wrist bones. Almost 80% of the scaphoid bone surface is covered with cartilage. There are several ligament attachments and one dominant nutritive artery, which is a branch of the radial artery. Interosseal vascularization of the proximal bone pole (70–80%) originates from the radial artery branch which enters the bone along the dorsal ridge at the level of the waist. Given such anatomy, after a fracture there is a risk of vascular insufficiency and consequential development of avascular necrosis [5], particularly of the upper bone pole [1]. Delay in diagnosis leads to a variety of adverse outcomes such as delayed union, nonunion, decreased grip strength, smaller range of motion, and osteoarthritis of the radiocarpal joint [6]. Risk factors for the development of SNU are as follows: displacement of a fragment larger than 1 mm, fractures at the level of the upper pole, delayed treatment, inadequate immobilization, and associated instability of the wrist. Osteonecrosis occurs in 3% of fracture cases, particularly of the upper pole [3].

Initially, SNU may be asymptomatic [7, 8], but over time pain occurs due to development of intercarpal and radiocarpal arthrosis. Even though a significant number of clinical algorithms for treatment of SNU can be found in the literature, optimal treatment of SNU remains a challenge for surgeons

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[1], particularly when there is a very small and sclerotic proximal fragment [9]. Thus, the results of surgery in terms of SNU healing vary depending on the type and location, the time elapsed since the injury, the type of surgical treatment, and the occurrence of complications (avascular necrosis, humpback deformity, arthrosis), which range from 80 to 100% [10].

Treatment of SNU most often involves the use of bone grafts [11] with internal fixation; K wires and screws with a variety of compression forces are available for scaphoid fixation [5, 12–14]. An ideal bone graft facilitates bone healing, increases bone density (ensuring greater stability), and is compatible with the essential bone mass, involving no morbidity for the donor site. Ideal bone graft material should have osteoconductivity, osteoinductivity, and osteogenesis characteristics [15]. Bone grafts—most commonly used—are nonvascularized and vascularized autografts (from the patient), allografts (cadaveric, or from bone bank), and xenografts based on tissue engineering, representing biocompatible substances. The gold standard is the application of autografts [16], because only autografts possess all three above properties, while allografts and xenografts have just one or two of the three features of an ideal bone graft [17].

Autografts have optimum osteogenetic properties, featuring strong osteoinductive and osteoconductive characteristics, without immune response or disease transmission risks. Xenografts show osteoinductive and osteoconductive properties, and they are widely available. However, a xenograft loses its osteogenetic and partly its osteoinductive abilities during processing of the antigenic characteristics in order to prevent an immune response and infection transmission. Xenograft bones are harvested from a different species. Commonly attainable bone xenografts are derived from coral, bovine, and porcine sources. A major risk with xenografts is the potential transmission of zoonotic diseases. Xenograft bones also lose their osteogenic and some osteoinductive characteristics [18]. When organic substances are extracted from bovine bone, the remaining xenograft structure has fine pores like natural bone a chemical compound or microstructure [19]. High osteoconductivity and a very low resorption rate have been demonstrated. Implanted collagen material is absorbed by enzymatic and phagocytic activity of host tissue and promotes early ingrowth of vascularity and cell producing elements. This induces early healing of defects and new bone formation. Its advantages include absorption, good tissue compatibility, a porous structure encouraging spongiosa ingrowth, and adjustability of cube shape to the bone cavity. Over the past few years attempts have been made to upgrade xenografts by ensuring further compatibility of their characteristics [16].

Among the options, different clinical studies demonstrated that the recombinant bone morfogenic protein (BMP) enhances biological processes which achieve fusion in the treatment of fractures and nonunions [20, 21].

To improve the outcome after surgical treatment of, especially, proximal scaphoid nonunion, different operative methods have been developed. One of them is a pedicled vascularized bone graft of the distal radius, but Stevanovic state that even with conventional bone grafts very good results can be obtained [11]. Arteria *carpi transversa palmare* for surgical procedures of the wrist was first described in 1987 by Kuhlman [22]. Zeidemberg and coworkers then introduced a dorsal pedicled bone graft based on the 1, 2 intercompartmental supraretinacular artery (1, 2 ISCRA) [23]. The first clinical implementation of a pedicled vascularized bone graft from the palmar distal radius was performed by Mathoulin and Haerle [24].

Indications for the use of a pedicled vascularized bone graft from the distal part of the radius are the presence of a small or avascular proximal pole fragment and recurrence of scaphoid nonunion after previous surgery.

Scaphoid nonunion, if not treated, can lead to a scaphoid nonunion advances collapse (SNAC) and progressed degenerate changes. In that cases, different surgical options are available, such partial fusion [25] and proximal row carpectomy [26].

Purpose of the paper

The purpose of this report is to present the surgical techniques and results of treating SNU with osteoplastic xenografts of bovine origin in comparison with distal radius vascularized pedicle bone grafts.

Materials and methods

Thirty patients with SNU symptoms were treated between 2009 and 2017 at the Hand Surgery department of the Clinic for Orthopedic Surgery and Traumatology, Clinical Center of Serbia. The patients were divided into two groups of 15 subjects with respect to the graft used for SNU treatment. The first group received a xenograft and the second group a vascularized bone graft. The study did not include patients with osteonecrosis of the proximal pole and arthrosis (intercarpal or radiocarpal).

In the presurgical stage, the demographic characteristics of the patients, the time elapsed between injury and surgery, and classification of the injury according to Schernberg, Herbert–Fisher, and Geissler-Slade [1] were recorded. All patients in both groups underwent surgery in a bloodless operative field.

For the first group, the volar approach was applied, with incision radially from the tendon of the muscle *flexor carpi radialis* (FCR) and the scaphoid tuberculum, with longitudinal section of the wrist joint capsule and volar radiocarpal ligament. After identifying the nonunion site, a cavum was created by means of a curette in the proximal and distal

fragments reaching down to healthy tissue. The rim was used only in cases of more pronounced bone sclerosis. The fragments were stabilized with two Kirschner wires placed longitudinally along the longitudinal axis of the bone, under x-ray control. The cavum was then filled with the xenograft. The bone substituent applied was a porous collagen matrix implant of bovine origin, purified from antigens, fatty cells, minerals, enzymes, and other non-collagen components (Osteovit®-B.Braun Melsungen AG, Melsungen, Germany).[1] We used one to three cubelets 1.5 × 1.5 × 0.5 cm in size, depending on the size of the cavum prepared. This was followed by reconstruction of the capsule and the volar radiocarpal ligament. After releasing the tourniquet, haemostasis was carefully performed and the wound was closed in layers. A forearm plaster immobilization for the wrist and thumb was applied.

For the second group of patients, two types of vascularized bone grafts were applied, depending on the nonunion location. When nonunion followed fracture of the proximal pole, the dorsal approach was used including a dorsal capsule-based graft (fourth extensor compartment artery capsule-based graft -4ECA), whereas in cases of pseudoarthrosis at the level of the waist and more distally, the volar approach was applied with a volar carpal artery bone graft (Volar radius VBG-radial carpal artery) [3, 24, 27]. Two Kirschner wires were used for fixation, just as in the first group of patients.

A precise record was kept of the duration of the surgical intervention for each patient, from the moment of starting the incision until suture of the wound, expressed in minutes.

The post-surgical protocol was the same for both groups. Postsurgical cast immobilization lasted for a period of two to four months, while Kirschner wires were removed after three months on average. Early physical therapy was introduced immediately after the surgery, by applying a 50-Hz pulse electromagnetic field (PEMF) for 30 minutes, in order to stimulate healing. After removing the immobilization, all patients continued with physical therapy and rehabilitation. In the postsurgical stage, early complications were monitored (migration of Kirschner wires and wound infection), as well as later complications (radiocarpal arthrosis, intercarpal arthrosis, deformity of the scaphoid bone in the form of a hump, the need for a second surgical intervention).

Functional results in all the patients were assessed at the one year follow-up using the Mayo wrist score [28] and the DASH (Disabilities of the Arm, Shoulder and Hand) questionnaire [29]. The Mayo wrist score assesses the presence and intensity of pain, the range of movement, and hand grip strength (expressed in percentage points compared with the noninjured hand), as well as functional status in terms of performance of activities. The results are valued on the basis of a score: 90–100 excellent, 80–90 good, 60–80 satisfactory, and less than 60 poor [27]. The DASH questionnaire involves 30 questions analyzing the patient's ability to carry out everyday activities that he/she performed over the past week, irrespective of which hand is used [29]. Scaling was ranked from 0 indicating the least disability to 100 indicating the greatest disability.

This research was conducted in accordance with the Helsinki Declaration, and statistical analyses were performed using SPSS 16.0 for Linux®. In all analyses the significant level was set at 0.05.

Results

The present study comprised 30 patients. The basic characteristics and presurgical data for both groups are shown in Table 1. Most patients in each group were males (15/14), and the mean age was 23.27/21.53 years. According to Schernberg and Geissler Slade classifications, the majority of SNU were type III. There were no differences between the two groups except for time before surgery, which was significantly longer in the group receiving a xenograft.

The treatment results for both groups of patients are shown in Table 2. Healing was established by radiography in 80% of the patients with a xenograft and in 86.7% of those with a vascular graft. No statistically significant differences were observed regarding the healing rate, the incidence of postoperative complications, and the functional outcome. Thus, the incidence of post-surgical complications was similar in both groups (chi-square = 0.600; $p = 0.439$). None of the patients in either group complained of post-surgical pains in the wrist joint and all resumed their previous activities. Their main complaint was reduced sporting ability due diminished wrist joint dorsiflexion. The t test revealed no significant difference regarding Mayo wrist score values between the groups ($t = 0.533$; $p = 0.598$). The Mann–Whitney test showed no significant difference in the DASH score values ($U = 105$; $Z = 0.332$; $p = 0.740$). However, there was highly significant divergence between the two groups of patients regarding duration of the surgery (t test; $p < 0.01$). Patients who received a xenograft experienced a shorter operation time than those given a vascularized graft (58.00 ± 8.61 vs 100.66 ± 7.03 min) (Fig. 1).

Discussion

Most of the patients in our study were males (96.66%), and the overall mean age was 22.4 years. Similar data were recorded by others. In Aibinder and coworkers' investigation male made up 86% and the average age was 24 years, while in that of Chang et al. male patients accounted for 80.85% and the average age was 24 years [30, 31].

[1] The study was not financed by the provider.

Table 1 Baseline characherictics. Presurgical data about the two groups of patients

Variables	Xenograft ($N = 15$)	Vascularized graft ($N = 15$)	p
Sex			.500
Men	15 (100%)	14 (93.3%)	
Women	0 (0%)	1 (6.7%)	
Age	23.27 ± 5.70	21.53 ± 3.81	.336
Time before the surgery (months)	14.20 ± 15.93	11.53 ± 9.64	.004
Schernberg classification			
I	3 (20.0%)	2 (13.3%)	.725
II	5 (33.3%)	4 (26.7%)	
III	6 (40.0%)	9 (60.0%)	
IV	1 (6.7%)	0 (0%)	
Herbert–Fisher classification			
D1	9 (60.0%)	5 (33.3%)	.660
D2	6 (40.0%)	10 (66.7%)	
Geissler–Slade classification			.286
II	2 (13.3%)	1 (6.7%)	
III	9 (60.0%)	10 (66.7%)	
IV	4 (26.7%)	4 (26.7%)	

Numerous SNU osteoplasty techniques using different surgical approaches, osteofixation implants [12, 13], and different graft types are described in the literature, but it is demanding surgical problem [31, 32]. A whole range of grafts applied and the results obtained by different authors can be found in the report of Munk and Larsen [33]. Shin and Bishop introduced vascularized grafts which significantly advanced SNU treatment [3]. The use of reverse flow pedicled vascularized bone grafts from the dorsal distal radius makes it possible to transfer bone with a preserved circulation and viable osteoclasts and osteoblasts. Therefore, instead of replacement with nonvital bone and revascularizing it, we have primary bone healing (Fig. 2).

The metanalysis of Merell et al. revealed that vascularized grafts can ensure bone healing in 88% of SNU cases, compared with up to 47% for non-vascularized grafts [7]. However, such favourable results regarding healing of SNU with vascularized grafts are not always obtained. Thus, Straw et al. found that bone healing was established in only 27% of patients [34]. Sixteen out of the 22 cases involved the avascular proximal scaphoid pole, which was a factor contributing to poor results employing conventional grafts [7]. In our series, SNU healing after vascularized grafts was 86.7%. Similar results were obtained by others. Thus, Jaminet et al. observed union of a pedicled graft from the distal radius in 91.3% of cases by the palmar approach and 81.1% by the dorsal approach. The grafts were

Table 2 Results of surgical treatment of patients in both groups

Variables	Xenograft ($N = 15$)	Vascularized graft ($N = 15$)	p
Surgery duration in minutes	58.00 ± 8.61	100.66 ± 7.03	< .01
Healing			.50
Yes	12 (80.0%)	13 (86.7%)	
No	3 (20.0%)	2 (13.3%)	
Total duration of treatment (months)	6.00 ± 2.45	6.00 ± 1.51	.626
Complications			
Arthrosis	4 (26.7%)	4 (26.7%)	
Hump	1 (6.7%)	0 (0%)	
Shearing	1 (6.7%)	0 (0%)	
Total	6 (40%)	4 (26.7%)	.439
Mayo score			.598
Excellent	9 (60.0%)	10 (66.7%)	
Good	4 (26.7%)	3 (20.0%)	
Satisfactory	2 (13.3%)	2 (13.3%)	
DASH questionnaire	1.19 ± 1.53	1.91 ± 3.42	.740

used for avascular necrosis of the proximal pole or in a second operation after previous unsuccessful surgery [35]. Moreover, the union rate after a conventional iliac graft was 96.3%. Aibinder et al. recorded union rates of 79% for 1, 2 ISCRA vascularized grafts, 71% for iliac grafts, and the best results for grafts from the medial femoral condyle (89%) [30]. In the study of Waitayawinyu et al. the union rate was 93% with an average healing time of 5.1 months [36].

One method for surgical treatment of SNU reserved for certain cases with cystic SNU without hump form deformity is arthroscopic assisted osteoplasty [1]. In this method, a spongial bone graft is inserted percutaneously by dorsal approach at the pseudoarthrosis location. In 2013, Bumbaširević et al. presented a technique of SNU treatment involving the application of an external apparatus according to Ilizarov without the use of grafts. Bone union was achieved in all 15 cases. [37, 38]

Our patients had similar demographic characteristics in both groups. All pseudoarthroses were symptomatic, i.e., the dominant symptom was pain. In the presurgical stage, the patients were not diagnosed with any avascular necrosis, carpal collapse, and deformity in the form of a hump or arthrosis.

There is no agreement in the definition of radiological union after scaphoid fracture surgery. Nonunion was defined as a fracture that had not united within 12 weeks of the acute injury based on plain radiographs or computed tomography (CT) scans [39]. One review found that the radiological features of union are the absence of bridging trabeculae [40] or the absence of a complete gap between the fracture fragments on any image, as well as no evidence of loosening of the fixation screw or wires [41]. CT scanning allows a more reliable assessment of union, but the presence of a screw or wires may distort the images and make this difficult. In our study all patients underwent x-ray follow-up at six, 12, and 24 weeks post-operatively. Scaphoid union was determined if trabeculae across the nonunion site were present on all projections. When healing could not be definitely confirmed or excluded by x-rays a CT was performed. The use of conventional radiographs in the assessment of fusion in SNU treatment is found in other reports. [4, 9, 13, 14, 30, 35, 42]. Viability could be estimated on MRI [4, 5].

No statistically significant differences between our two groups of patients were identified for the Mayo wrist and

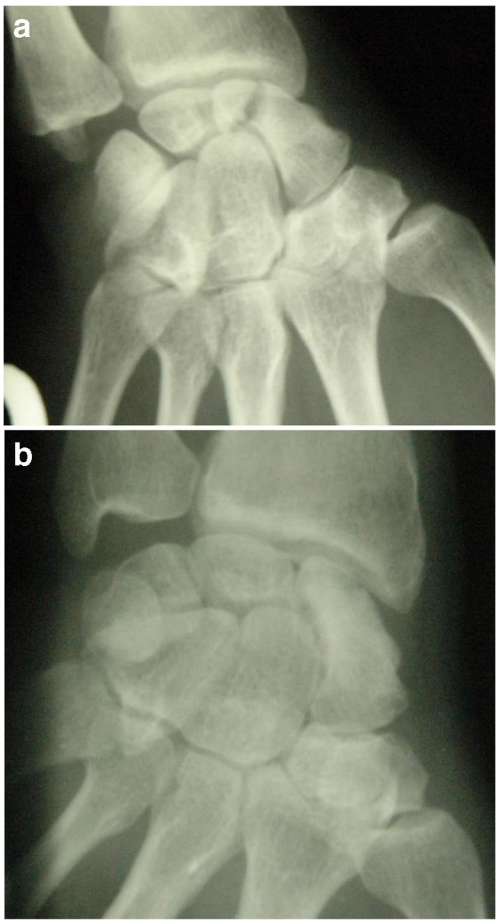

Fig. 1 **a** Pre-operative radiograph SNU treated with xenograft. **b** Postoperative radiograph SNU treated with xenograft

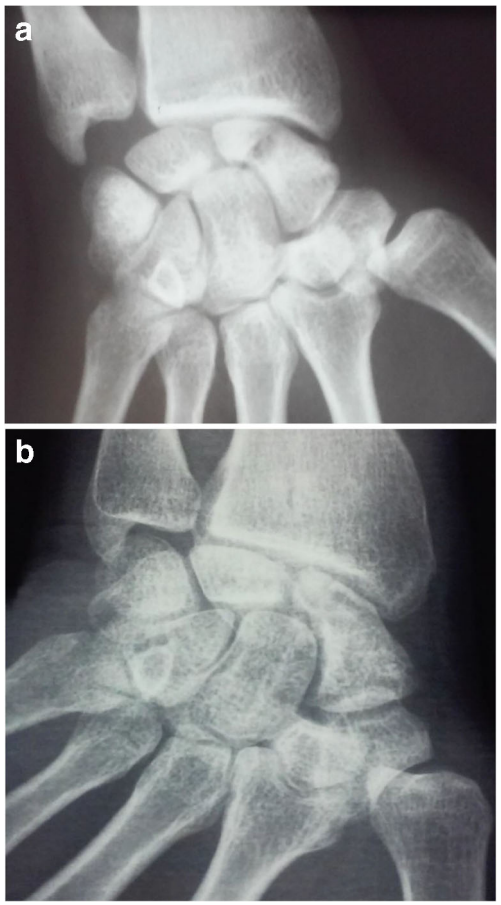

Fig. 2 **a** Pre-operative radiograph SNU treated with vascularized bone graft. **b** Postoperative radiograph SNU treated with vascularized bone graft

DASH scores. The Mayo wrist score was excellent in 60.0%/66.7% cases, numerically 88.6/89, while DASH scores were 1.19/1.91. After using vascularized grafts in the treatment of SNU Raihimni et al. obtained an average Mayo score of 83 and 21 for DASH, while Alluri et al. achieved 85.6 for the Mayo score and 11.47 for DASH [43, 44]. Better results were obtained by Sander and colleagues where the Mayo score was 94.1 while DASH was 7.4 [45].

The only and highly significant difference found by us was for duration of the surgical intervention, in favor of a shorter time required for xenografts. A shorter duration of operative procedure we find in study of Bilic et al., in cases where allogenic bone was used, compared with cases where autologous iliac graft was used [20].

Xenografts are used in clinical practice in orthopaedic surgery for filling the defects of the fracture of the distal radius [46]. We have also applied a xenograft to correct the defect of the donor site after lifting the vascular graft from the distal radius. Xenografts taken from an individual of one species and transplanted to an individual belonging to another species may be derived from corals or of porcine or bovine origin. The problem with bovine products is the possibility of transmission of zoonosis and infection, such as bovine spongiform encephalopathy. In our clinical practice, we have had no complications of this kind [16, 46]. Kujala et al. used a composite implant of native bovine bone morphogenetic protein and biocoral in the treatment of scaphoid nonunion. Preliminary results for ten cases were not promising, as only two wrists showed complete union [47]. In contrast to this the use of human morphogenic protein by Jones and associates produced excellent results [48]. The xenograft osteoplastic technique is a simple and rapid method. It can be performed by a single surgeon, without special technical conditions (sophisticated instruments). There is no involvement of a donor site, which reduces duration of the surgery and the possibility of post-surgical complications (donor site morbidity).

Although vascular bone grafts have often been shown to provide better healing rates, they are technically more demanding [49] and carry a risk of donor-site morbidity. The disadvantages that have been referred are restricted bone quantity and extended duration of the surgery. However, the application of vascularized grafts is a technically more demanding method. It requires a trained assistant and a much longer time for performing the surgery, as well as certain technical preconditions. Moreover, the donor site leaves a bone defect which requires a certain period to heal.

Conclusion

Bone grafting is one of the most commonly used options to treat nonunion. Autografts remain the gold standard. Allografts, xenografts, and tissue-engineered-based grafts all have shortcomings. With xenograft the acceptable results was obtained. New strategies such as gene therapy, polytherapy using scaffolds, healing promotive factors and stem cells, and finally three-dimensional printing are in preliminary stages but may offer new exciting alternatives in the near future.

The xenograft osteoplastic method is simple, rapid, and relatively acceptable, providing good results in terms of healing and functionality. When used in appropriate cases it is a suitable method for treating SNU.

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