



# The use of pedicled vascularized bone grafts in the treatment of scaphoid nonunion: clinical results, graft options and indications

Bedri Karaismailoglu<sup>1</sup>  
Mehmet Fatih Guven<sup>2</sup>  
Mert Erenler<sup>2</sup>  
Huseyin Botanlioglu<sup>2</sup>

- Scaphoid nonunion is a challenging situation for orthopaedic surgeons. Nonunion rate is especially high in proximal pole fractures of the scaphoid due to tenuous retrograde blood supply.
- The use of pedicled vascularized bone grafts for the treatment of scaphoid nonunion provides both good clinical and radiological outcomes.
- The preserved vascularity of the graft leads to better bone remodelling, less osteopenia, faster incorporation and better maintenance of bone mass compared to the conventional non-vascularized grafting.
- Pedicled vascularized bone grafts also allow the correction of the carpal alignment and humpback deformity of the scaphoid.
- Clinical and radiological results have been satisfactory and promising, making us anticipate that the role of vascularized bone grafting for the treatment of carpal diseases will increase.

**Keywords:** pedicled vascularized bone graft; scaphoid fracture; scaphoid nonunion

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## Introduction

The treatment of scaphoid nonunion is still a challenge for hand surgeons. Nonunion rate of scaphoid fractures varies between 5% and 15%.<sup>1</sup> Due to tenuous retrograde blood supply of the scaphoid, this rate can increase up to 30% in proximal pole fractures of the scaphoid.<sup>2</sup> The most prominent symptom of scaphoid nonunion is pain during wrist motion but if left untreated, it can cause osteoarthritis,

decrease in grip strength and limitation in wrist range of motion. The natural history of scaphoid nonunion progresses to scaphoid nonunion advanced collapse (SNAC) which is characterized by advanced collapse and progressive arthritis of the wrist leading to less favourable clinical results.<sup>3</sup> The aim of the treatment is to achieve union and restore normal carpal anatomy, stability and range of motion. Although multiple treatment options have been proposed for scaphoid nonunion, a consensus on the best treatment option has not been reached. The most commonly used treatment methods are conventional bone grafting, with or without internal fixation, and pedicled or free vascularized bone grafting. Conventional bone grafting is the most preferred method, but due to the limited osteogenic potential of non-vascular bone grafting (NVBG), the results might be suboptimal, and the union may not be achieved in a significant proportion of the patients. With improved understanding of the distal radius blood supply and advances in microsurgical techniques, the use of pedicled vascularized bone grafts (VBGs) has been increasingly applied to nonunion of the scaphoid bone.

Theoretically, VBGs have the advantage of preserving the living osteocytes and osteoblasts. Several animal models and clinical studies have shown the superior biologic and mechanical properties of VBGs.<sup>4,5</sup> Vascularized bone grafts can accelerate revascularization and union of the scaphoid nonunion.<sup>4</sup> Due to the preserved vascularity of these grafts, better bone remodelling, less osteopenia, faster incorporation and better maintenance of bone mass were expected compared to the conventional non-vascularized grafting.<sup>6</sup> Due to low union rates (< 50%) with NVBGs in proximal pole scaphoid nonunions with avascular necrosis, the use of VBGs as primary procedure is recommended in nonunions with avascular necrosis.<sup>7</sup>

The meta-analyses comparing NVBGs and VBGs in the management of scaphoid nonunions could not show a significant difference in union rates. In a 5246 patient meta-analysis by Munk and Larsen, the union rate for NVBG was reported as 80%, while it was 84% in patients treated with NVBG and internal fixation, and 91% in patients treated with VBG with or without internal fixation.<sup>8</sup> In a recent systematic review of 1602 patients by Pinder et al, the union rate was found to be 88% for NVBG and 92% for VBG.<sup>9</sup> But these differences were not statistically significant.

The union rate with NVBG applications decreases to 40–67% in the presence of proximal pole avascular necrosis (AVN).<sup>10,11</sup> Two retrospective studies found better healing rate and faster recovery in proximal pole AVNs treated with VBG compared to NVBG.<sup>12,13</sup> Ribak et al achieved bone fusion in 89.1% of AVN patients treated with VBG, while this figure was 72.5% in the NVBG group. The difference was found to be statistically significant ( $p = 0.024$ ).<sup>12</sup> Caporrino et al achieved similar bone fusion rates in both groups but the union was 12 days earlier in VBG group ( $p = 0.002$ ).<sup>13</sup> In a meta-analysis by Merrell et al, in which 36 studies were included, the union rate in the presence of proximal pole AVN was found to be 88% after VBG, while it was found to be 47% in patients treated with NVBG ( $p < 0.0005$ ).<sup>14</sup>

There are also some VBG studies with less promising results,<sup>15–17</sup> but it is hard to evaluate the all studies together and draw a conclusion since the studies have different inclusion and exclusion criteria, different methods to evaluate union, vascularity and clinical outcome. Most of the studies have limitations such as small number of patients, uncertainty about the presence of arthritis and proximal pole AVN, and limited radiological and clinical follow-up. Since VBGs are preferred mostly in patients with proximal pole AVN or humpback deformity and in patients with failure of NVBG treatment, the patient groups might not be homogenous in studies comparing VBG and NVBG applications. Some studies comparing pedicled VBG and NVBG application in the management of scaphoid nonunions are summarized in Table 1.

The arthroscopic NVBG of scaphoid nonunions is also reported in the literature and the results are promising.<sup>18,19</sup> Kang et al reviewed 33 patients managed by arthroscopic bone grafting and reported a 97% union rate with favourable clinical outcomes.<sup>19</sup> Oh et al compared arthroscopic and open NVBG in the management of instable scaphoid nonunions. They achieved similar union rates in both groups (arthroscopic: 96.4%, open: 97.1%). The clinical outcomes were also similar at minimum two years follow-up, but carpal alignment was restored better in open grafting group.<sup>18</sup> Both studies excluded patients with proximal pole AVN for arthroscopic management. Therefore, the role of VBGs remains

important in the management of nonunions with AVN. Although the preliminary results are promising, more studies comparing the arthroscopic grafting to the available techniques are needed.

Although free vascularized grafts from sites like the supracondylar region of the femur, the base of the third metatarsal or iliac crest are available, pedicled vascularized grafts have advantages such as less donor-site morbidity and no need for microsurgical anastomoses. There are several options to use as a pedicled vascularized bone graft in the management of scaphoid nonunions. The most commonly used grafts include volar radial graft, 1,2 intercompartmental supraretinacular artery (ICSRA) and 4+5 extensor compartmental artery (ECA) graft. In this study, we will focus on pedicled vascularized bone grafts, review the latest literature available about clinical results, graft options and indications.

### Pedicled vascularized graft options

The first use of VBG was described by Roy-Camille.<sup>20</sup> He transferred the scaphoid tubercle with a pedicle from the abductor pollicis brevis muscle. Zaidenberg et al were the first to report the use and promising results of a distal radius VBG which was based on 1,2 intercompartmental supraretinacular artery.<sup>6</sup> This invention led surgeons to investigate the detailed anatomy of the distal radius for other possible pedicled VBGs. The vascular structures of the distal radius were introduced in detail by Sheetz et al in 1995.<sup>21</sup> Although some VBGs from ulna and metacarpals were defined, the use of distal radius VBGs in the treatment of scaphoid nonunions is supported further in the literature.<sup>6,22,23</sup>

The blood supply of VBGs provides great advantage in the healing process of the scaphoid. The most common indications for VBG application are previous unsuccessful NVBG application and avascular necrosis of the proximal fragment. But the recent literature also supports the use of VBGs as primary procedure in the treatment of scaphoid nonunion.<sup>7</sup> VBGs are contraindicated in the presence of radiocarpal joint degeneration.<sup>24</sup>

Several methods are described for VBG transfer from distal radius to scaphoid and they are mostly classified as dorsal or volar grafts. The best graft choice depends on the character and location of nonunion and the presence of a significant deformity dictating a specific surgical approach. Dorsal pedicled distal radius VBGs are used for proximal scaphoid nonunions, while volar grafts are preferred for nonunions in the waist region of the scaphoid and in nonunions with humpback deformity.<sup>6,25</sup> Table 2 includes commonly used pedicled VBG options, their indications and advantages. Table 3 summarizes the studies reporting outcomes of scaphoid nonunions reconstructed with pedicled VBG of the distal radius.

**Table 1.** Summary of studies comparing outcomes of non-vascular bone grafting and vascularized bone grafting in the treatment of scaphoid nonunions

| Authors, year                         | Study type                  | Patients                      | Union rate (%)                   | Comments   |
|---------------------------------------|-----------------------------|-------------------------------|----------------------------------|--|
| Merrell et al, 2002 <sup>14</sup>     | Meta-analysis (7 studies)   | 64 pts (NVBG: 34 VBG: 30)     | NVBG: 47% VBG: 88% p < 0.0005    | All included patients had proximal pole AVN. The authors concluded that a vascularized graft may be preferable for patients with AVN of the proximal fragment or with a previously failed surgery.                                       |
| Munk et al, 2004 <sup>8</sup>         | Meta-analysis (147 studies) | 5246 pts                      | NVBG: 80.0–84.0% VBG: 91.0%      | VBG cases were almost exclusively cases with prior surgery and/or proximal pole AVN. The authors reported a significant increase in the union rate when adding blood supply to the bone graft (VBG).                                     |
| Pinder et al, 2015 <sup>9</sup>       | Meta-analysis (48 studies)  | 1514 pts (NVBG: 993 VBG: 571) | NVBG: 88.0% VBG: 92.0%           | Sixty-eight per cent of studies using VBG included cases of AVN, compared with 40% of NVBG series.   |
| Braga-Silva et al, 2008 <sup>44</sup> | Prospective randomized      | 80 pts (NVBG: 45 VBG: 35)     | NVBG: 100.0% VBG: 91.4%          | Thirteen patients in the vascularized group and eight patients in the non-vascularized group had a sclerotic proximal pole fragment on preoperative X-ray.   |
| Ribak et al, 2010 <sup>12</sup>       | Prospective randomized      | 86 pts (NVBG: 40 VBG: 46)     | NVBG: 72.5% VBG: 89.1% p = 0.024 | Considering only patients with scaphoid nonunions and proximal pole fragment, there was bone healing in 19 of 21 patients in the VBG group (90.5%), but in just 11 of 16 patients in the NVBG group (68.8%).                             |
| Caporrino et al, 2014 <sup>13</sup>   | Prospective randomized      | 75 pts (NVBG: 40 VBG: 35)     | NVBG: 80.0% VBG: 88.6% p = 0.312 | The VBG group reached bone union earlier by 12 days (p = 0.002), but union rates were similar (p = 0.312). There was also less ulnar deviation in the VBG group (p = 0.03). There were no other differences between intervention groups. |

Note. NVBG, non-vascular bone grafting; VBG, vascularized bone grafting; AVN, avascular necrosis; pts, patients.

*Dorsal pedicled VBGs of the distal radius*

Dorsal pedicled VBGs of the distal radius are the most commonly performed VBGs for scaphoid nonunions due to their proximity to the scaphoid. They are preferred in difficult cases such as displaced proximal pole fractures, avascular necrosis (AVN) of proximal fragment, chronic nonunions and nonunions which have failed to heal despite NVBG treatment.<sup>24,26</sup> But their use is limited in cases with humpback deformity since it is hard to correct the deformity with dorsal approach and grafts.<sup>10</sup> Dorsal VBGs of the distal radius are based on four pedicles which are the 1,2 and 2,3 intercompartmental supraretinacular artery located between 1,2 and 2,3 extensor compartments and 4+5 extensor compartmental arteries arising from the dorsal branch of the anterior interosseous artery. In an anatomical study by Sheetz et al in which they included 41 cadavers, 1,2 and 2,3 intercompartmental supraretinacular artery, and 4+5 extensor compartmental arteries were present in 94%, 100%, 100%, 100% of the cadavers respectively.<sup>21</sup> Dorsal grafts have advantages such as anatomic reliability of dorsal vascular network, no need for vascular anastomosis, dissection and treatment through the same incision and relatively simple technique compared to volar grafts.<sup>2</sup>

The first report with 1,2 intercompartmental supraretinacular artery pedicled VBGs was by Zaidenberg et al and they achieved union in all of their 11 patients at an average of six weeks.<sup>6</sup> This technique is still popular in the literature and so many surgeons have reported their clinical outcomes after application of this type of graft (Fig. 1). Even though most of the studies have claimed excellent outcomes with union rates close to 100% at average of

6–12 weeks, some studies have also reported low union rates down to 27%.<sup>17,26,27</sup> Steinmann et al achieved 100% union in their 14 patients including four with proximal pole AVN at an average of 11 weeks.<sup>26</sup> Waitayawinyu et al included 30 cases of proximal pole AVN in their patient series, and union was achieved in 28 patients at an average of five months. They also had significant improvement in grip strength, functional outcomes and scaphoid height–length ratio.<sup>27</sup> In contrast, some authors reported suboptimal results in patients with proximal pole AVN. Boyer et al had 60% union rate in their patients with proximal pole AVN, but the patients with nonunion had a previous failed NVBG procedure, so the authors attributed their poor outcomes to history of previous failed surgery.<sup>16</sup> Similarly, Straw et al had poor outcomes with 1,2 intercompartmental supraretinacular artery pedicled VBG. They reported 27% union rate in their 22 patients and explained this low rate as being due to the high proportion of patients with avascular necrosis (16 of the patients had proximal pole AVN).<sup>17</sup> Straw et al used K-wires for the fixation and they removed the K-wires after eight weeks whether union was achieved or not. Therefore, one of the reasons behind the low union rate might be inadequate stabilization as proposed by Payatakes and Sotereanos.<sup>28</sup>

In one of the largest patient series, Chang et al achieved a 71% union rate in their 48 patients. When they analysed the patients in detail, they found that 10 of the patients with failure had either humpback deformity or carpal instability preoperatively, which constitutes a contraindication for a dorsal VBG procedure.<sup>10</sup> Therefore, the indications must be carefully evaluated and the treatment decision should be made accordingly. Dorsal rectangular

**Table 2.** Common pedicled vascularized bone grafting options, indications, advantages and surgical considerations

| Type   | Indication   | Advantages   | Pedicle             | Advantages and surgical considerations   |
|--------|--|--|---------------------|--|
| Dorsal | <ul style="list-style-type: none"> <li>Displaced proximal pole fractures</li> <li>Avascular necrosis of proximal fragment</li> <li>Chronic nonunions and nonunions failed to heal despite non-vascular bone grafting treatment</li> <li>Proximal scaphoid nonunions</li> </ul> | <ul style="list-style-type: none"> <li>Anatomic reliability of dorsal vascular network</li> <li>Relatively simple technique compared to volar grafts</li> </ul>  | 1,2 ICSRA           | <ul style="list-style-type: none"> <li>Adequate length for transfer to both proximal and distal non-unions despite the short rotation arc</li> <li>Styloidectomy might be required to avoid kinking and tension in the pedicle</li> </ul>  |
|        |  |  | 2,3 ICSRA           | <ul style="list-style-type: none"> <li>Adequate length without tension</li> <li>Wider rotation arc providing easier access to volar carpus</li> </ul>  |
|        |  |  | 4+5 ECA             | <ul style="list-style-type: none"> <li>An important option for the treatment of Kienböck's disease</li> <li>The large pedicle length also allows reaching to proximal scaphoid</li> <li>It is also a valuable option in the treatment of proximal pole nonunion of the scaphoid</li> </ul> |
|        |  |  | Capsular-based      | <ul style="list-style-type: none"> <li>Simple dissection and graft harvesting</li> <li>Prevents vessel kinking</li> <li>The location of this graft provides easy access to both lunate and the proximal pole of the scaphoid</li> </ul>  |
| Volar  | <ul style="list-style-type: none"> <li>Humpback deformity</li> <li>Dorsal intercalated segment instability</li> <li>Waist nonunions of the scaphoid</li> </ul>   | <ul style="list-style-type: none"> <li>Effective in restoring carpal geometry</li> <li>Protects the blood supply of the scaphoid which is dominant on the dorsal side</li> <li>Does not cause a significant loss in wrist extension</li> </ul> | Volar carpal artery | <ul style="list-style-type: none"> <li>Lies between the palmar periosteum of the radius and the distal part of the superficial aponeurosis of the pronator quadratus</li> </ul>  |
|        |  |  | Pronator quadratus  | <ul style="list-style-type: none"> <li>Less risk with vascular manipulation since they are based on the rich anastomoses between anterior interosseous, radial and ulnar artery branches</li> </ul>  |

Note. AVN, avascular necrosis; ICSRA, intercompartmental supraretinacular artery; ECA, extensor compartment artery.

graft usage in patients with humpback deformity leads to persistence of the deformity with malunion or nonunion. Larger volar VBGs are more appropriate in this group of patients.

Average pedicle length of the 1,2 intercompartmental supraretinacular artery was found to be 22.5 mm (range: 15–31 mm) by Waitayawinyu et al.<sup>29</sup> Its length is adequate for transfer to both proximal and distal nonunions despite the short rotation arc. But sometimes styloidectomy might be required to avoid kinking and tension in the pedicle.<sup>30</sup> Although less commonly performed, 2,3 intercompartmental supraretinacular artery pedicled VBGs also have promising results.<sup>31,32</sup> Woon Tan et al reported a large series with 52 patients with 92.3% union rate at an average of 14.5 weeks.<sup>2</sup> Its adequate length without tension and wider rotation arc providing easier access to the volar carpus, makes the 2,3 intercompartmental supraretinacular artery a valuable option in the treatment of scaphoid nonunions with or without proximal pole AVN.

The location of pedicle and graft makes 4+5 extensor compartmental artery pedicled VBG a great option for the treatment of Kienböck's disease, but the large pedicle length also allows this VBG to reach the proximal scaphoid. Therefore, it is also a valuable option in the treatment of proximal pole nonunion of the scaphoid. The pedicle can be reached using a dorsal approach on the 4th extensor compartment. With a 0.49 mm diameter, the 5th extensor compartmental artery is the largest

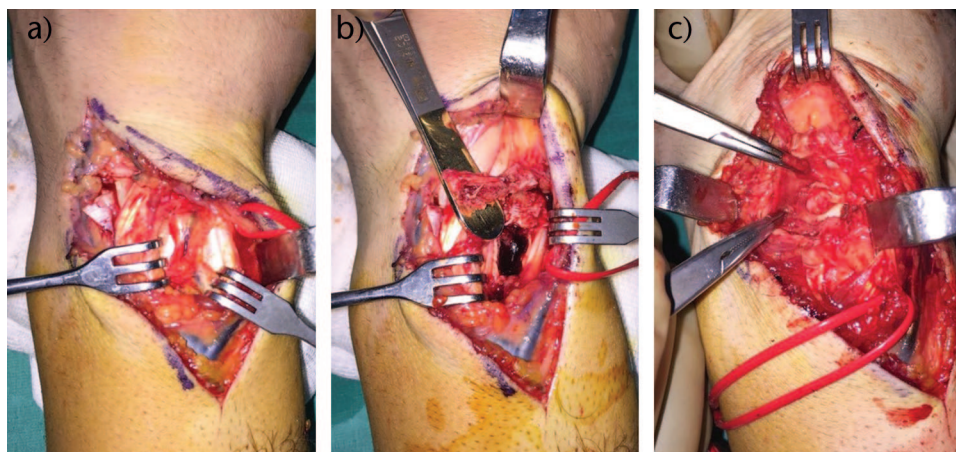
among the dorsal arteries used as a pedicle, providing better blood supply. But it does not provide a nutrient artery to the graft, which is why it is used mostly with the 4th extensor compartmental artery if a long pedicle is needed.<sup>21</sup>

To simplify the pedicle dissection and prevent vessel kinking, Sotereanos et al described a dorsal VBG from the distal radius based on the joint capsule.<sup>25</sup> Anatomical studies have shown the reliable vascularization of this graft by the 4th extensor compartmental artery with a 0.4 mm diameter.<sup>21</sup> Sotereanos et al reported an 80% union rate in three months, increased grip strength and range of motion, in their 10 patients series with proximal pole AVN. They did not determine any donor site morbidity and the violation of the dorsal extrinsic ligament did not cause any clinical or radiological instability.<sup>25</sup> The simple dissection and graft harvesting is the main advantage of this technique. The location of this graft provides easy access to both lunate and the proximal pole of the scaphoid<sup>28</sup> Özalp et al achieved union in 8 of 9 patients treated with 4+5 extensor compartmental artery pedicled VBG at an average of 9.5 weeks.<sup>33</sup> The vascularity of the 4+5 pedicle is not reliable in patients with previous dorsal approach surgery, or in patients with a significant trauma history to the dorsal wrist. Like 1,2 intercompartmental supraretinacular artery pedicled VBGs, 4+5 extensor compartmental artery pedicled VBGs are not able to correct significant humpback deformities.

**Table 3.** Summary of studies reporting outcomes of scaphoid nonunions reconstructed with pedicled vascularized bone grafts of distal radius

| Authors, year                          | Pedicle  | Number of patients | Mean age | Cases with AVN | Union rate (%) |
|--|--|--------------------|----------|----------------|----------------|
| Zaidenberg et al, 1991 <sup>6</sup>    | 1,2 ICSRA  | 11                 | 26       | (Not reported) | 100.0%         |
| Boyer et al, 1998 <sup>16</sup>        | 1,2 ICSRA  | 10                 | 31       | 10             | 60.0%          |
| Straw et al, 2002 <sup>17</sup>        | 1,2 ICSRA  | 22                 | 32       | 16             | 27.0%          |
| Steinmann et al, 2002 <sup>26</sup>    | 1,2 ICSRA  | 14                 | 28       | 4              | 100.0%         |
| Waitayawinyu et al, 2009 <sup>27</sup> | 1,2 ICSRA  | 30                 | 24       | 30             | 93.0%          |
| Tu et al, 2008 <sup>32</sup>           | 1,2 ICSRA (20 pts)<br>2,3 ICSRA (52 pts)           | 72                 | 38       | 50             | 90.0%          |
| Chang et al, 2006 <sup>10</sup>        | 1,2 ICSRA  | 48                 | 24       | 24             | 71.0%          |
| Lim et al, 2013 <sup>45</sup>          | 1,2 ICSRA  | 21                 | 34       | 21             | 85.7%          |
| Caporrino et al, 2014 <sup>13</sup>    | 1,2 ICSRA  | 35                 | 26       | 0              | 88.6%          |
| Hirche et al, 2014 <sup>46</sup>       | 1,2 ICSRA  | 28                 | 29       | 18             | 75.0%          |
| Rahimnia et al, 2018 <sup>47</sup>     | 1,2 ICSRA  | 41                 | 26       | 26             | 73.0%          |
| Braga-Silva et al, 2008 <sup>45</sup>  | 1,2 ICSRA  | 35                 | 26       | (Not reported) | 91.4%          |
| Malizos et al, 2017 <sup>43</sup>      | 1,2 ICSRA (93 pts)<br>Volar carpal artery (47 pts) | 140                | 26       | 42             | 99.3%          |
| Özalp et al, 2015 <sup>33</sup>        | 1,2 ICSRA (49 pts)<br>4+5 ECA (9 pts)              | 58                 | 28       | 32             | 86.2%          |
| Woon Tan et al, 2013 <sup>2</sup>      | 2,3 ICSRA  | 52                 | 38       | (Not reported) | 92.0%          |
| Mathoulin et al, 1998 <sup>35</sup>    | Volar carpal artery                                | 17                 | 29       | (Not reported) | 100.0%         |
| Werdin et al, 2014 <sup>48</sup>       | Volar carpal artery (45 pts)<br>1,2 ICSRA (9 pts)  | 54                 | 29       | 47             | 68.5%          |
| Hamdi et al, 2011 <sup>49</sup>        | Volar carpal artery                                | 26                 | 32       | 1              | 88.5%          |
| Gras et al, 2011 <sup>7</sup>          | Volar carpal artery                                | 111                | 30       | 0              | 93.7%          |
| Dailiana et al, 2006 <sup>36</sup>     | Volar carpal artery                                | 9                  | 25       | 1              | 100.0%         |
| Kawai et al, 1988 <sup>38</sup>        | Pronator quadratus                                 | 8                  | 24       | (Not reported) | 100.0%         |
| Lee et al, 2015 <sup>40</sup>          | Pronator quadratus                                 | 27                 | 24       | (Not reported) | 100.0%         |
| Noaman et al, 2011 <sup>39</sup>       | Pronator quadratus                                 | 45                 | 24       | 25             | 95.5%          |
| Sotereanos et al, 2006 <sup>25</sup>   | Capsular-based                                     | 13                 | 26       | 10             | 76.9%          |

Note. AVN, avascular necrosis; ICSRA, intercompartmental supraretinacular artery; ECA, extensor compartment artery; pts, patients.

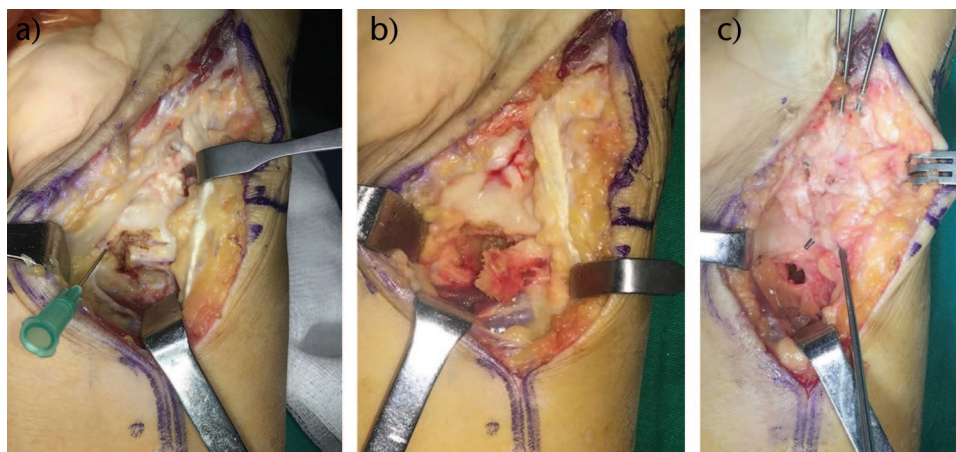


**Fig. 1** (a) The approach for dorsal pedicled radial vascularized bone graft (VBG). (b, c) Harvesting of dorsal distal radius VBG based on the 1,2 intercompartmental supraretinacular artery and its application to scaphoid nonunion.

*Volar pedicled VBGs of the distal radius*

The inability of dorsal radius VBGs to correct humpback deformity triggered a search for more appropriate donor sites. Kuhlmann et al were the first to report their results with volar radius VBGs.<sup>34</sup> Volar distal radius VBGs are based on radial carpal artery (Fig. 2a). The radial carpal artery has a 0.5–1.0 mm diameter and gives a few periosteal and cortical perforating branches.<sup>34</sup> The graft is elevated from the palmar and ulnar side of the distal radius (Fig. 2b). Palmar approach and volar grafts are preferred

in most cases with waist nonunions of the scaphoid. Both graft harvesting and application to the scaphoid can be made from the same incision (Fig. 2b, Fig. 2c). When appropriately configured, volar grafts are also more effective in restoring carpal geometry by correcting the parameters such as intrascaphoid angle, scapholunate angle and revised carpal height ratio. That is why they are also preferred in the presence of humpback deformity.<sup>28</sup> Previous surgery with volar approach and significant trauma to this region are relative contraindications for the use of volar



**Fig. 2** (a) The approach for volar pedicled radial vascularized bone graft (VBG). (b) Harvesting of volar distal radius VBG based on the radial carpal artery. The graft is elevated from the palmar and ulnar side of the distal radius. (c) The fixation of the VBG with K-wires.

pedicled VBGs. Free vascularized bone grafts from the iliac crest or medial femoral condyle are the other alternatives to correct humpback deformity.<sup>15</sup>

The results of volar radius VBGs for scaphoid nonunion are promising. Mathoulin and Haerle used volar radius VBGs in 17 patients with waist nonunion of the scaphoid. Ten patients had failed previous surgery. The authors achieved union in all patients at average an 8.6 of weeks.<sup>35</sup> In a study with 24 months postoperative follow-up of waist nonunions, Dailiana et al reported union in all of their nine patients with the use of volar radius VBGs. Union was achieved at an average of 9 weeks. They also determined that scapholunate angle and carpal height were significantly corrected and complete pain relief was obtained.<sup>36</sup> They claimed that palmar approach is the best way to visualize the waist region of the scaphoid. It protects the blood supply of the scaphoid which is dominant on the dorsal side and it does not cause a significant loss in wrist extension. Derby et al proposed that the high union rates in these studies can be attributed to the patient groups which did not include any patients with AVN.<sup>37</sup>

A vascularized graft from the volar radius based on the pronator quadratus is also defined. Kawai and Yamamoto were the first to report their results with this graft type in 1988. They reported 100% union in eight patients.<sup>38</sup> Noaman et al also used pronator quadratus pedicled grafts and they found a 95% union rate in their 45 patients.<sup>39</sup> Lee et al applied this graft with headless compression screw in the presence of humpback deformity or dorsal intercalated segment instability. They achieved 100% union rate and good functional results.<sup>40</sup> Pronator quadratus pedicled grafts carry relatively less risk with vascular manipulation since they are based on the rich anastomoses between anterior interosseous, radial and ulnar artery branches.

## Surgical pearls

Meticulous surgical technique and extreme attention to detail are required for the success of the procedure. Pedicled VBG application has a long learning curve and operation time decreases as more experience is gained. Tourniquet application should be made after a few minutes' elevation of the extremity. Prolonged elevation or Esmarch's bandage application should be avoided since they might prevent the visualization of small vessels in the distal radius. Fibrous tissue and necrotic bone must be excised independently from the approach and the type of graft. The surgeon should have full knowledge of the microvascular anatomy of the distal radius and alternatives to pedicled graft options. Dissection should be under loupe magnification and pedicle should be protected with a sleeve of fascia or periosteum to prevent kinking. If the pedicle kinks after the placement of the graft, the blood supply of the graft might diminish or become disrupted completely.

Preoperative planning of the graft size and intraoperative adaptation of graft size to the defect area are required to restore scaphoid height and correct humpback deformity. The graft should be placed as a full thickness intercalary segment, not as an inlay graft bridging the nonunion. K-wires can be placed to each segment as a joystick to distract the nonunion area, overcome the difficulty in graft placement and correct the humpback deformity.<sup>6,41</sup> The graft should be prepared in trapezoidal shape to correct dorsal angulation of the scaphoid. It is reported that the deformity and nonunion may persist when dorsal rectangular inlay grafts are applied in cases with humpback deformity of the scaphoid.<sup>42</sup>

Implant choice might change according to the size of the fragments, the stability of the fracture the and

surgeon's choice. Headless cannulated compression screws are associated with higher union rates and should be preferred when technically applicable.<sup>10,14</sup> Non-cannulated mini-screws or K-wires can be used if the small size of the proximal fragment does not allow the usage of cannulated screws. But it should be kept in mind that both screws and K-wires might damage the construct and disrupt the inner vascular bed of VBG. The authors recommend four to six weeks of cast immobilization and a return to normal activities should only be allowed when the solid union has been detected.<sup>28,43</sup>

## Conclusion

Although technically difficult, pedicled VBGs provide higher union rates in the presence of proximal pole AVN with the help of revascularization of the avascular proximal pole and correction of carpal alignment. Dorsal pedicled distal radius VBGs are the most commonly performed VBG for proximal scaphoid nonunions, but due to their limited capacity for deformity correction, volar grafts are preferred for nonunions in the waist region of the scaphoid with humpback deformity. Larger prospective and comparative studies with properly designed patient groups are required to investigate the possible superiority of available pedicled VBG options.

### AUTHOR INFORMATION

<sup>1</sup>Ayancik State Hospital, Department of Orthopaedics and Traumatology, Sinop, Turkey.

<sup>2</sup>Istanbul University – Cerrahpasa, Cerrahpasa Medical Faculty, Department of Orthopaedics and Traumatology, Istanbul, Turkey.

Correspondence should be sent to: Mehmet Fatih Guven, Istanbul Universitesi – Cerrahpasa, Cerrahpasa Tıp Fakültesi, Ortopedi ve Travmatoloji Anabilim Dalı, Kocamustafapasa Cad. No:53, Fatih, Istanbul, Turkey.  
Email: mfguven@yahoo.com

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