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## ABSTRACT

The optimal treatment option for Kienböck's disease is determined by the stage of the disease, ulnar variance, status of the lunate cartilage shell and presence of arthritic changes. The vascularized bone grafts are attractive treatment options for stage II and III according to Stahl-Lichtman classification. The purpose of this article is to present an overview for Kienböck's disease and describe our technique of the 4th extensor compartment artery vascularized bone graft for Kienböck's disease and its usefulness in the current concepts of treatment for Kienböck's disease.

KEY WORDS: Kienböck's disease, vascularized bone grafting, 4th extensor compartment artery

#### Introduction

Kienböck's disease, also known as idiopathic lunate osteonecrosis, has an etiology and pathogenesis that have not been absolutely determined even nowadays.

Interestingly regarding the historical background of the disease, it has been reported that even from 1843, before the advent of radiographs, Peste described collapse of the lunate bone in anatomic specimens and he attributed this finding to an acute, traumatic event. Later, Robert Kienböck an Austrian pioneer radiologist noted collapse and sclerosis of the lunate on radiographs and in 1910 he published the classic description in his publication "*Concerning traumatic malacia of the lunate and it's consequences*". He suggested "*distur-* bance in the nutrition of the lunate caused by the rupture of the ligaments and blood vessels" after repeated trauma as most prominent etiology and he also described the natural history with carpal collapse leading to secondary arthritis [1].

#### Pathogenesis

Osseous and vascular anatomic variations are considered predominant causative factors for idiopathic lunate osteonecrosis as they render the lunate blood supply vulnerable to trauma (acute or repetitive).

The arterial blood supply to the lunate is mainly delivered to the non-articular portion of both its dorsal and palmar aspect by 3-5 vessels on average. Howev-

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er, a 7% of specimens receives blood supply by a single palmar vessel. Also, in 30% of specimens there is limited intraosseous branching ("I," "X," or "Y" patterns have been described). Such lunate specimens with a single supply vessel or limited intraosseous branching are at increased risk for osteonecrosis [2]. Disruption of venous outflow has also been implicated in the etiology of Kienböck's disease [3]. Lunate morphology and variations in local osseous anatomy have also been theorized causative factors for lunate osteonecrosis. In cases with negative ulnar variance the increased height of the radius increases the force transmission across the radiolunate joint, predisposing to osteonecrosis [4]. Decreased radial inclination and a small size of lunate bone have both been implicated as factors in the development of Kienböck's disease, while recently, the trabecular microstructure of the lunate has also been examined [5]. The most pertinent interpretation is that the pathogenesis of Kienböck's disease is multifactorial and co-influenced by genetic, anatomic, mechanical, and metabolic factors [2].

#### Natural history

Idiopathic avascular lunate osteonecrosis is a progressive disorder and leads to a predictable pattern and continuum of pathologic changes from increased lunate radiodensity to lunate fragmentation, lunate collapse and finally progression to radiocarpal and midcarpal arthritis [6,7]. This is the natural history of Kienböck's disease if left untreated and it progresses throughout these stages over several years. However, while a predictable, progressively worsening pattern of lunate osteonecrosis occurs, clinical symptoms do not necessarily correlate with this pathoanatomic process. Each stage of the disease may be the first presentation of lunate osteonecrosis since not always all stages in every patient are painful [8]. The surgery's ability to alter the disease progression is also not well-defined [8,9].

#### **Classification systems**

Whereas several classification schemes have been suggested, the one that is most commonly used in the Stahl-Lichtman classification (the one developed by Lichtman et al after revisions on the system originally described by Stahl) [10]. At this scheme staging of Kienböck's disease depends on the radiographic findings. Staging is an important step in the evaluation of a patient with Kienböck's disease because the surgical management options are largely affected by the stage of disease.

# In stage I x-rays show normal density of the lunate with no sclerosis or collapse.

Magnetic resonance imaging may reveal diffuse decreased T1 signal. In stage II the lunate appears diffusely sclerotic on radiographs with no articular collapse or loss of lunate height. Fracture lines may appear. In stage III there is collapse of the articular surface. In stage IIIA carpal height and alignment remain normal, whereas in stage IIIB lunate collapse is accompanied by carpal instability, fixed scaphoid rotation, decreased carpal height and proximal capitate migration. In order to differentiate between stage IIIA and IIIB, a radioscaphoid angle greater than 60° was introduced to define carpal instability and stage IIIB [11]. Finally, stage IV is characterized by lunate collapse and radiocarpal or midcarpal arthritis.

Stage IIIC was described later and includes a coronal fracture of the lunate. Due to poor clinical outcome it was suggested that a coronal lunate fracture, regardless of carpal stability, should be treated with a salvage procedure [12].

Bain et al used diagnostic arthroscopy and developed an articular-based classification system for Kienböck's disease. These authors suggested that treatment should be designed based on the findings of the articular cartilage pathology during wrist arthroscopy [13].

#### **Treatment principles**

The appropriate treatment strategy for Kienböck's disease depends on the Stahl-Lichtman stage, type of ulnar variance, coexistence of arthritic changes and whether the articular cartilaginous shell of the lunate is intact [14]. Besides, the clinical presentation of the patient should be considered because not seldom radiographic findings do not correlate with patient symptoms [8]. Therefore, although the radiographic stage directs treatment options, on the other hand the presence of abnormal x-ray findings alone does not necessarily mandate surgical intervention. Consequently, the need for treatment and the most appropriate treat-

ment option is dictated by thorough assessment of patient's characteristics, symptoms and their severity, functional deficits and the aforementioned radiological parameters and staging. Treatment options range from conservative measurements (immobilization) to surgical interventions.

# Surgical treatment can be categorized into 3 broad categories:

**Mechanical**: aim to unload the lunate: joint leveling procedures (radial shortening/wedge osteotomy) [15-21], capitate shortening osteotomy that can be combined or not with vascularized bone graft (VBG) [22-25], arthroscopic core decompression of the lunate [26], and metaphyseal core decompression of the radius or ulna [27].

**Biological:** aim to revascularize the lunate: direct implantation of an arteriovenous pedicle [28-30], pisiform transfer [31], pronator quadratus pedicle flap [32], index metacarpal [33], pedicled dorsal distal radius [34], and revascularization with free iliac or medial femoral condyle bone grafting [35].

**Salvage:** wrist denervation, lunate excision [36], lunate replacement [37], proximal row carpectomy [38], limited [39, 40] or total wrist fusion [41], and total wrist arthroplasty.

#### Lunate revascularization

Lunate revascularization is performed by transferring vessels or vascularized autogenous tissue (free or pedicled) from a donor site to the necrotic lunate bone. Implantation of arteriovenous bundles (an artery and its venae comitantes) [28] or vascularized bone flaps (grafts, VBG) have been used in Kienböck's disease.

Revascularization and remodeling of surrounding avascular and necrotic bone is promoted and accelerated by a VBG. One of the advantages of VBG is that they act relatively independently of the recipient host bed as they are implanted with their own blood supply [42]. One of the main differences with non-vascularized grafts is that more than 90% of the osteocytes survive the transplantation procedure [43], and recipient site revascularization occurs much more rapidly because the bone resorption and creeping substitution of necrotic bone mechanisms that take place with non-vascularized grafts, do not occur with VBGs [43]. The lack of this resorption phase before revascularization results in superior and faster structural strength during the first six weeks after implantation when VBGs are used [42]. During this initial period these grafts still require mechanical stability while they incorporate into the host bed.

Revascularization procedures with VBG in the treatment of Kienböck's disease are suggested in cases that the lunate cartilage shell is intact (without fracture or fragmentation) and there is absence of carpal arthritis [44,45]. Under these circumstances, it is also ideal procedure in ulnar neutral or positive variance patients where radial shortening is contraindicated. One of the most important parameters for success of vascularized bone grafting in Kienböck's disease is to have a pedicle of sufficient length to reach the host site without excessive tension [46]. The VBG must have nutrient vessels supplying both cortical and cancellous bone and receive sufficient blood flow to maintain its viability and through this to promote revascularization of the recipient site, ie the necrotic lunate. With these principles strictly adhered to, a number of VBG based on a variety of pedicles from dorsal or palmar aspect of the wrist [31,34,47-52] have been devised in the treatment of Kienbock's disease with most important: (1) 4+5 extensor compartment artery (ECA) bone graft, (2) second or third metacarpal base bone grafts, (3) 2,3 intercompartmental supraretinacular (ICSRA) or 1,2 ICSRA bone grafts, (4) pisiform bone graft, (5) volar bone grafts from the distal radius, and also (6) free pedicle bone grafts from the medial femoral condyle and the iliac crest [29,30,32,35,45,53-57].

#### Vascular anatomy of dorsal distal radius

Several vascularized bone grafts that can be used to treat carpal pathology had already been described such as those from volar radius/pronator quadratus muscle-bone graft, from second metacarpal, and the pisiform. In 1994 in their landmark study for arterial blood supply of distal radius and ulna, Sheetz and colleagues identified several vascular pedicles and based on these, several novel reverse flow pedicled VBG from the dorsal distal radius that could serve as additional graft sources for the hand surgeon when treating Kienböck's disease [53]. These new graft sources had some advantages that made them promising and

attractive: the reliable nutrient vessel blood supply, the relative technical ease of harvest and single surgical incision for both harvest and implanting, and finally the long pedicle length.

The study of Sheetz et al showed that the arterial blood supply of dorsal distal radius is provided by four longitudinal vessels, it is robust and constant [53]. These constant longitudinally oriented arteries supply nutrient vessels to the dorsal distal radius and have consistent relationships to adjacent anatomic landmarks. Furthermore, three dorsal arterial arches provide significant anastomotic connections to these four longitudinal arteries, allowing each of them to serve as a distally based and retrograde-flow pedicle graft.

The posterior division of anterior interosseous artery and the radial artery are the primary sources of antegrade blood flow to the distal dorsal radius. Four arteries arise from them, supply the dorsal radius with nutrient branches, and give rise in the design of pedicle grafts. These four arteries are named according to their relationship with the extensor compartments and the extensor retinaculum. Two of them lie superficially to the extensor retinaculum, and are located between extensor tendon compartments giving nutrient branches to underlying bony tubercles between these compartments. These are the 1,2 and 2,3 intercompartmental supraretinacular arteries (1,2 ICSRA and 2,3 ICSRA), that they pass between 1st-2nd and 2nd-3rd extensor compartments respectively. The other two longitudinal arteries are deeper, and they lie within the floor of respective extensor compartments in the radial side of it, named the 4th and  $5^{\rm th}\, extensor\, compartmental arteries$ (4th ECA and 5<sup>th</sup> ECA).

The 1,2 ICSRA is present in 94%, it is the smallest of the four vessels with mean internal diameter 0.3 mm and originates from the radial artery approximately 5 cm proximally to the radiocarpal joint. It runs beneath the brachioradialis muscle and lie on the extensor retinaculum before entering the anatomic snuffbox to anastomose with the radial artery and/or the radiocarpal arch. It is usually used as a graft to scaphoid due to its superficial location and limited arc of rotation.

The 2,3 ICSRA is present 100% of the time and originates from the anterior interosseous artery or the posterior division of the anterior interosseous artery. It lies superficial to the extensor retinaculum, lies on Lister's tubercle and anastomoses with the dorsal intercarpal arch, the dorsal radiocarpal arch or the fourth ECA. It gives nutrient branches deep into cancellous bone and has similar mean internal diameter (0.35 mm) but greater arc of rotation than the 1,2 ICSRA, thus being appropriate graft source also for Kienböck's disease except from scaphoid nonunions.

The fourth ECA initiates from the posterior division of the anterior interosseous artery or its 5th extensor compartment branch and distally anastomoses with the dorsal radiocarpal and dorsal intercarpal arch. It lies on the radial aspect of the fourth extensor compartment and locates directly adjacent to the posterior interosseous nerve. It gives rise to numerous nutrient arteries to the distal dorsal radius that penetrate deeply into cancellous bone.

The fifth ECA originates from the posterior division of the anterior interosseous artery and is the largest of the four dorsal vessels (mean internal diameter 0.49 mm). It locates at the radial side of the floor of the fifth extensor compartment, it passes through the 4,5 septum and anastomoses with the dorsal radiocarpal arch, the dorsal intercarpal arch, the 2,3 ICSRA, the fourth ECA, and the oblique dorsal artery of the distal ulna. The advantages of the 5th ECA include its multiple anastomoses, its large diameter, the ulnar location that puts it away from capsulotomy incisions that are usually required to expose carpal bones and render it a desirable source of retrograde blood flow. On the contrary a relative disadvantage is that the fifth ECA seldom provides direct antegrade nutrient branches to the dorsal distal radius as compared to the other three dorsal arteries. For this reason, a respective VBG that is used is not a 5th ECA based VBG but rather a 4th +5th ECA VBG due to the proximal anastomosis or common origin with the 4<sup>th</sup> ECA.

A series of transverse arterial arches that locate distally to these compartmental and intercompartmental arteries and lie across the dorsum of the wrist, provide the distal anastomotic network for the ICS-RA and ECA and give the retrograde blood flow for the respective VBGs. These include the dorsal intercarpal arch, the dorsal radiocarpal arch and the dorsal supraretinacular arch. The dorsal intercarpal arch is the most important than the others and anastomo-

ses with the 1,2 ICSRA, 2,3 ICSRA, the fourth ECA, and the dorsal radiocarpal arch thus being important and vital element of several potential grafts. On the other hand the dorsal radiocarpal arch has limited usefulness as a potential source of retrograde arterial flow due to its tendency to course deep to dorsal capsule and by its small caliber ulnarly which both make dissection difficult and adequate blood flow inconsistent.

All these characteristics of nutrient branches coming from the longitudinal vessels to the dorsal distal radius, and the distal anastomoses coming from the transverse arches allows to harvest relevant distally based or reverse flow VBG from the distal radius following proximal vessel ligation. The arc of rotation of each harvested VBG is a factor to take in consideration respecting their applicability.

#### Our surgical technique

In this article we present our surgical technique using a 4<sup>th</sup> ECA VBG for treatment of stage II and III (Stahl-Lichtmann classification) Kienbock's disease. In contrast to 4+5 ECA pedicle bone grafting that is considered the most reliable form of revascularization, the 4<sup>th</sup> ECA avoids the more extensive dissection and the higher risk of pedicle kinking due to the long pedicle of 4+5 ECA. On the other hand, special considerations regarding the capsulotomy are provided in order to secure the preservation of retrograde blood flow.

#### Indications

We use the 4th ECA VBG for stage II and for stage IIIA disease. Stage IIIB disease has been considered contraindication for vascularized bone grafting, however it is recently recommended that the most important factor in determining feasibility of vascularized bone grafting is the status of the articular cartilage shell of the lunate [1]. In our cases with an intact cartilage shell of the lunate and absence of marked arthritic changes, vascularized bone grafting from the 4<sup>th</sup> ECA is a viable option. In cases with ulna neutral or positive variance, in which joint leveling is contraindicated, VBG is also an appropriate method to revascularized bone grafting as an adjunctive procedure to radial shortening.

#### Contra-indications

Contraindications for the procedure include stage IV disease and lunate fracture with fragmentation of the cartilage shell. Coronal fracture (IIIC) is also a relative contraindication although fixation with a screw in the acute setting has been proposed [45]. Previous surgery at the dorsal wrist through extensor retinaculum or wrist arthroscopy via the 4–5 portal are relative contraindications for using this graft, due to potential prior violation of the underlying 4<sup>th</sup> ECA vascular pedicle or the retrograde blood flow.

#### Surgical technique

Under axillary nerve block, the patient was placed in supine position, and pneumatic tourniquet is inflamed at 250 mmHg of pressure after exsanguination has been performed from the wrist and proximally to enable visualization of the vessels during the operation.

If the status of lunate articular cartilage is under question, wrist arthroscopy can be performed to evaluate the lunate cartilage and the cartilage of the rest of the carpus, but the 4-5 portal and ulnar midcarpal portals are not used to prevent from possible damage to the 4<sup>th</sup> ECA and anastomotic branch from dorsal intercarpal arch.

A longitudinal dorsal wrist incision is made in line with the third metacarpal starting from its base and extending towards the distal forearm (**Fig 1**). Deep dissection is made with opening of the extensor retinaculum and creating two flaps to expose the fourth extensor compartment. The fourth ECA is located radially in the floor of the 4th compartment, radial to the posterior interosseous nerve (**Fig 2A**). It is traced and localized more proximally because later it will be ligated at this proximal site (**Fig 2B**) although it's not necessary to trace it up to its proximal origin from the posterior division of anterior interosseous artery.

After the localization of the fourth ECA, the approach to the dorsal surface of lunate bone is performed. At this stage before doing the capsulotomy it should be kept in mind that the blood flow on which the 4<sup>th</sup> ECA vascularized bone graft will be based is retrograde from the dorsal carpal arches, with the dorsal intercarpal arch (d ICA) being the most important [53]. With respect to this vascular anatomy that has been well-described, we propose a capsulotomy that

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*Figure 1.* A standard longitudinal dorsal wrist incision is made in line with the third metacarpal starting from its base and extending towards distal forearm.

spares the retrograde blood flow (Fig 3 and 4). The capsulotomy should be performed over the lunate and a capsular flap is created with its base ulnarly. This facilitates the visualization and exposure of lunate bone. Depending on the surgeon's preference, the somatometric characteristics of the patient and the location and extend of lunate necrosis, a rectangular or an angled-shape (or "L") capsulotomy are described (Fig 3, 4). The basic principle is to avoid compromising the anastomotic branch between the d ICA and the 4<sup>th</sup> ECA that is directly at the site of capsulotomy. The safest way to do it for both capsulotomies (rectangular and angled-shaped) is to perform the longitudinal cut centered over the lunate or slightly radially on the lunate but not too far radially in order to protect the anastomotic branch between the d ICA and the 4th ECA. In this way we create a flap that is ulnarly to the anastomotic branch (Fig 3A, 4A). However, since the d ICA and its anastomotic branch is located superficially to the capsule (in contrast to the dorsal radiocarpal arch that has the tendency to course deep to the dorsal capsule) [53] an alternative approach is to raise an ulnar based flap with the longitudinal cut more radially than the anastomotic branch (this offers much more visualization of the lunate) but only in the case we visualize the anastomotic branch that lies superficially on the capsule. In this case we raise a flap and the anastomotic branch is also raised with it on its superior surface (Fig 3B, 4B, 5, 7). The extension of the transverse limbs of our flap ulnarly (Fig 3C, 4C) as well as the extension of the longitudinal cut distally (i.e how wide the flap will be in proximal-distal dimension) (Fig 3D, 4D) although they should be avoided when possible,





**Figure 2.** A. The fourth ECA and venae comitantes are visualized on the radial aspect of the floor of the 4th compartment, lying radially to the posterior interosseous nerve B. The fourth ECA is traced and localized more proximally because later it will be ligated at this proximal site although it's not necessary to trace it up to its proximal origin from the posterior division of anterior interosseous artery. (R, radially; U, ulnarly; P, proximally; D, distally)

however, they do not put in risk the viability of the VBG since the retrograde blood flow follows the pathway from radial artery to the d ICA and from this to the 4<sup>th</sup> ECA (the radial half of the d ICA) [53]. This risk of extending the transverse limbs more to gain visualization could be fatal for a radially based flap, and this is one of the reasons that we do not recommend a radially based capsular flap. Other reason that a radially based flap should be avoided and not recommended is that it requires a cut to the ulnar side (since the base would be on radial side), which possibly affect part of the dorsal radiocarpal ligament.

After the capsulotomy has been completed the lu-



### The optimal rectangular-shape ulnar-based capsulotomy

**Figure 3.** The aim of capsulotomy is to protect the dorsal intercarpal arch (dICA) that is located across the proximal border of the distal carpal row and the anastomotic branch that allows retrograde blood flow from the dICA to the 4th extensor compartmental artery (ECA) and thus to the vascularized bone graft that receives nutrient branches from the 4th ECA. The main path for this "network of retrograde blood flow" that will keep the VBG "alive" as shown in the anatomic study by Sheetz et al is the dark red pathway coming from the radial artery, through the d ICA and finally to the 4th ECA.

- A. Knowing this arterial blood anatomy, the capsular flap can be one of the following a rectangular-shaped and ulnar-based flap. Ideally the longitudinal cut is at the center of lunate or at the radial lip of it but not far radially to protect the anastomotic branch between the d ICA and the 4th ECA, so the longitudinal cut and the whole flap remains ulnarly to the anastomotic branch protecting it.
- B. The advantage of the d ICA and its anastomotic branch compared to the dorsal radiocarpal arch is that the former lies more superficially to the capsule whereas the latter tends to course deep to the capsule. Therefore in cases we can control and visualize the route of the anastomotic branch we can raise carefully the flap including on its superficial surface the anastomotic branch. In this case the longitudinal cut can be performed more radially "including" in our capsular flap the anastomotic branch.
- C. Due to the very limited space available when such capsulotomy is performed, the extension of the limbs of capsulotomy (either longitudinal or transverse limbs of the cut) may be extended from the surgeon to allow lunate visualization. In the ulnar-based flap this may be forgiving due to the specific "pathway of retrograde blood flow" shown by Sheetz et al. If the transverse cuts extend far ulnarly this may not sacrifice the retrograde blood flow, since the anastomotic branch is radially.
- D. Similarly, in some cases the flap may be wider (large longitudinal cut in the proximo-distal direction) to allow visibility accordingly to the extent of lunate necrosis. Although this should be avoided as it has the risk to cut the d ICA if this is not clearly seen, the blood flow will again be preserved for the VBG through the radial half of the d ICA that is the main "pathway" for the reverse blood flow (red arrow).

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The optimal angle-shape ulnar-based capsulotomy

**Figure 4.** Similarly, the same principles for the retrograde blood flow and for the optimal capsulotomy (A) apply for an angle ("L") shape ulnar-based capsulotomy flap. The choice of a rectangular or an angle shape capsulotomy depends on the surgeon's preference, the somatometric of the patient (rectangular shape can be easier performed in larger wrists) and the extent and localization and the lunate necrosis. Again, an optimal (A) capsulotomy is described, but also one with longitudinal cut more radially than the anastomotic branch in cases we can visualize this vessel, protect it, and raise it with the flap. In cases that the limbs of capsulotomy extend more ulnarly (C) and more distally (D) depending on the intraoperative need for visualization, this may not disturb the pathway of retrograde blood flow.

nate is inspected (**Fig 5**) to examine the cartilage shell especially if arthroscopy was not performed at the beginning of the operation. If the cartilage shell is intact, without fragmentation and without arthritic changes, we proceed with the VBG. The necrotic bone tissue of the lunate is removed through a dorsal window using a burr and curette under direct visualization, while also fluoroscopic image may also be used to facilitate this step. (**Fig 6A,B**). At this stage we proceed to the scaphocapitate pinning (using two K-wires that will be kept for 6-8 weeks) to unload the lunate.

As next step, the bone graft is raised. The graft is centered approximately 10-11mm proximally to the radiocarpal joint overlying the 4th ECA because at this point the graft includes most of the nutrient vessels [53]. The size of the graft should coincide the dimensions of the excavated area of the lunate that will be filled (**Fig 7A**). The 4th ECA is ligated proximally and the graft is elevated with sharp osteotomes (**Fig 7B**).

At this point release of the tourniquet is required to confirm the viability of the graft through the retrograde blood flow. Then the graft is implanted in a press fit manner in the lunate cavity (**Fig 8**). If necessary cancellous bone graft can be inserted into the lunate to fill an excessive void prior to graft insertion.

The wrist capsule is slightly repaired avoiding using too many sutures both to avoid postoperative stiffness and also to minimize the risk to struggle the pedicle. The flap of extensor retinaculum is replaced, and a long-arm postoperative hand splint is applied.

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*Figure 5.* A rectangular-shaped ulnar-based capsulotomy with longitudinal cut more radially than the anastomotic branch according to pattern described in fig 3B has been performed (left wrist) and the lunate is inspected directly below.

(*R*, radially; *U*, ulnarly; *P*, proximally; *D*, distally)

#### Results

The radiologic outcome of the patient with stage II Kienböck's disease that is presented in this surgical technique paper is shown at **Figure 9**. Revascularization of the lunate is evident on magnetic resonance imaging with intravenous contrast agent. The patient showed improvement of pain and Mayo wrist score, as well as grip strength (from 60 to 80% of unaffected side) and wrist range of motion (from 70 to 90% of unaffected side) at 15 months follow up.

Revascularization techniques have shown promising results for Kienböck's disease. Even among different VBG sources from the dorsal wrist and hand, functional outcomes, pain relief, and improvement in range of motion are favorable and comparable [1,34,57,58]. The good clinical results may be preserved for some patients even though radiographic progression of lunate and carpal height collapse have been reported after VBG in 0-15% of patients [45].

A detailed understanding of the vascular anatomy of the dorsal distal radius allows the surgeon to raise VBG for treating Kienböck's disease. The use of 4+5 ECA vascularized bone graft was introduced by Moran et al to promote revascularization and remodeling of the necrotic lunate and is now the most commonly proposed and used method for lunate revascularization in Kienbock's disease when indicated [34]. This



*Figure 6. A*, *B* Necrotic bone tissue of the lunate is removed through a dorsal window using a burr under direct visualization. Fluoroscopic image may also be used. *(R, radially; U, ulnarly; P, proximally; D, distally)* 

technique requires ligation of the posterior branch of the anterior interosseous artery. The retrograde flow from the fifth ECA is then directed into the fourth ECA in an orthograde direction. In this way the pedicle that is used is of large diameter and pretty long to assess the host site, while its ulnar location in the wrist allows capsulotomy to be performed without any risk to injure necessary vessels [34,59,60]. However, we realized some shortcomings when performing this technique as also reported in the literature [61]: the time required for surgical dissection is relatively long, while the longer pedicle sometimes has the risk of kinking. Although comparison of different dorsal distal radius VBG sources for treatment of Kienböck's is limited and we do not know from any comparative study if these differ in their subjective and objective outcome measures, however we have noted that some of these

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Figure 7.

- A. The graft is centered approximately 10-11mm proximally to the radiocarpal joint overlying the 4th ECA because at this point the graft includes most of the nutrient vessels (Sheetz). The size of the graft should coincide the dimensions of the excavated area of the lunate that will be filled.
- B. The 4th ECA is ligated proximally and the graft elevation is completed with sharp osteotomes. The pattern 3B of capsulotomy can be seen, and the anastomotic branch that provides the retrograde blood flow from d ICA to the VBG is seen on the superior aspect of the capsular flap.

(R, radially; U, ulnarly; P, proximally; D, distally)



*Figure 8.* The graft is implanted in a press fit manner in the lunate cavity.

- A. A necessary turn is required and this is a possible weak point in the technique. The proximity of the pedicle to the final host site may balance this risk. However, we try to avoid more pressure on the pedicle by avoiding closing this part of the capsular flap at the end.
- B. The VBG in its final position in the lunate bone.
- (*R*, radially; *U*, ulnarly; *P*, proximally; *D*, distally)

challenges that may arise from the use of 4+5 ECA may be eliminated by use of the  $4^{th}$  ECA.

We showed that the fourth ECA technique may present some challenges regarding the capsulotomy and requires a good understanding of the vascular anatomy that provides the retrograde arterial flow to the graft that is raised from the dorsal distal radius. According to this regional anatomy [53] we propose

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*Figure 9.* The radiologic outcome of the patient with stage II Kienböck's disease presented in this surgical technique paper is shown. Revascularization of the lunate is evident on magnetic resonance imaging with intravenous contrast agent 6 months postoperatively. No progression of the disease is noted.

the types of capsulotomy that spare this anastomotic branch, and they can be selected and performed in conjunction with other factors as the patient's somatometric characteristics, the surgeon preference and experience, and the capability to assess the lunate through a rectangular or angled-shaped capsular window in each case. Further clinical long-term results may reveal if the use of 4<sup>th</sup> ECA is a viable alternative to the 4+5 ECA VBG.

#### Conclusions

The surgical technique of the  $4^{\rm th}$  ECA vascularized

bone grafting for Kienböck's disease is presented. Careful patient selection according to indications and meticulous and precise surgical technique may deteriorate the progression of disease and allow for revascularization of the necrotic lunate. The technique does not prevent from using another treatment option in the future if the disease progresses. Further clinical results are required to evaluate this technique in the long term.

#### Conflict of interest

The authors declared no conflicts of interest.

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