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ORIGINAL ARTICLE • WRIST - MICROSURGERY

MR angiogram confirms sustained blood flow in 1,2 ICSR artery of vascularized bone grafting in scaphoid nonunion treatment

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Abstract

Purpose To evaluate the functioning of 1,2 intercompartmental supraretinacular artery (ICSRA) in vascularized bone grafting (VBG) of scaphoid nonunions with avascular necrosis of proximal pole.

Materials and methods Fourteen patients with scaphoid nonunion were treated operatively with 1,2 ICSRA VBG. Viability of the pedicle artery was evaluated by MR angiography with intravenous contrast agent.

Results In 13 out of 14 patients, the 1,2 ICSR artery was found to be patent and functional. Revascularization of scaphoid proximal pole was revealed in all cases, and nonunion healing was confirmed as well.

Conclusion 1,2 ICSRA VBG in scaphoid nonunion is an effective surgical technique. It combines the advantages of bone grafting and vascular supply via the transferred pedicle artery which seems to be functional postoperatively if a meticulous operative technique is used.

Keywords Vascularized bone grafting · Scaphoid nonunion · 1,2 Intercompartmental supraretinacular artery · MR angiography

Introduction

Scaphoid nonunion occur in up to 15% of scaphoid fractures and often result from delayed treatment, inadequate immobilization, displacement of the fracture, or proximal pole involvement in the setting of avascular necrosis (AVN) [1–4]. The management of the scaphoid nonunion remains a challenge, and several techniques for reconstruction have been developed [5, 6].

Transfer of vascularized bone grafts (VBG) is among the techniques that provide both bone replacement and vascularity and is the treatment of choice nowadays when the fracture includes a fragment with avascular necrosis [7, 8]. Zaidemberg et al. [9] described 1,2-ICSRA-radius flap, which is a vascularized bone graft from the dorsoradial aspect of the distal radius.

Effectiveness of this particular vascularized bone graft (VBG) has been studied well and despite the demanding operative technique, many surgeons worldwide use it as a treatment of choice in scaphoid nonunion [10–12]. The viability of the bone graft and especially artery's function postoperatively is undoubtedly the keystone of successful revascularization of the proximal pole of the scaphoid and therefore the treatment of the nonunion.

Revascularization of the whole scaphoid had been studied by the use of MRI pre- and postoperatively [13]. Normalizing of bone marrow signal indicates such a process in accordance with fracture healing, but many authors doubt that this is a result of a still patent pedicle artery. These authors state that thrombosis of the vessel is inevitable after the vascularized bone graft transposition and the success of the procedure is based just on the concomitant surgical trauma.

We studied the viability of the pedicle artery postoperatively in scaphoid nonunions treated by 1,2 ICSRA VBG using magnetic resonance angiogram (MRA) examination with intravascular contrast fluid, demonstrating the existing

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arterial blood flow and patency of the vessel postoperatively. The MRA findings were compared with the clinical and radiographic findings of bone healing.

Materials and methods

Fourteen patients, who underwent a surgical procedure with transfer of a vascularized bone graft based on the 1,2 ICSR artery, were evaluated for patency and function of the artery. The average age of the patients was 33 years (range 24–36). Twelve were men, and two were women. Manual workers were 4 of the 14 patients (28.6%), and in 5 patients the dominant hand was injured. Twelve of the patients were initially treated conservatively, and two were treated operatively. All patients had a painful wrist with limited motion and considerable loss of grip strength. Three patients had a poor Mayo wrist score, and none had an acceptable function. The time elapsed, until scaphoid nonunion was treated by transfer of a vascularized bone graft, was in average 4.9 years (range 2–13 years).

Surgical technique for the transfer of the vascularized bone graft had been described previously in the literature [14–16]. All procedures were carried out under axillary block anesthesia, tourniquet control, and binocular loupes magnification. The 1,2 ICSR artery was identified and dissected along with corticocancellous bone graft from the distal metaphysis of the radius (Fig. 1). Bone graft was of 10 mm depth, and the vessel was dissected together with a strip of periosteum and fascia of 5–6 mm in width, to avoid avulsion or kinking of pedicle. Vascularized bone graft was interposed in the scaphoid after bone edges of the nonunion were cleaned with a rongeur until healthy cancelous bone was encountered. 1 or 2 K-wires were used to transfix the graft on place. Donor site was filled with bone allograft. A long-arm cast including the thumb metacarpophalangeal joint was applied for 6 weeks. At that time, the K-wires were also removed. A short-arm thumb spica cast was then applied for an additional period of 2–4 weeks [14].

Scaphoid union was determined according to the criteria proposed by Dias and by the assessment of trabeculae crossing the nonunion site. Preoperative and postoperative radiographs were reviewed [14, 15, 17].

A visual analog scale (VAS) was used for the assessment of pain before surgery and at the latest follow-up. Function was assessed with the Mayo modified wrist score and the Disabilities of the Arm, Shoulder, and Hand Score (DASH) by questionnaires employed both before and after surgery.

MR angiography was performed in all 14 patients who were treated for scaphoid nonunion with 1,2 ICSRA VBG. Magnetic resonance angiogram (MRA) using a 3 T (Tesla) magnetic resonance imaging (MRI) scanner was the method of choice to reveal not only pedicle patency and perfusion but scaphoid's proximal pole revascularization also.

Results

Patients were examined with an MR angiography in an average postoperative time of 9 months (range 5 months to 2 years). 1,2 ICSR artery was depicted in 13 out of the 14 scaphoids, and dye intake in the area of preexisting nonunion due to arterial supply was revealed in all 14 patients. In the MR angiography, both the natural vascularization of the scaphoid from the distal pole and the 1,2 ICSR artery were recognized (Figs. 2, 3). The course of the pedicle was confirmed not only in three levels (coronal, axial, and sagittal) but also by using 3D MPR (multi-planar

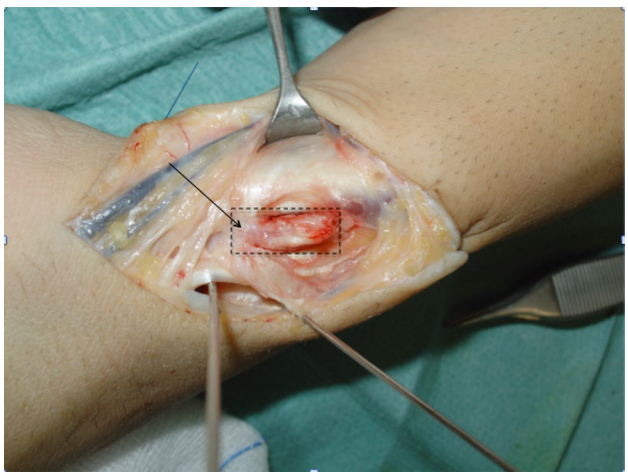

Fig. 1 1,2 ICSR artery is identified and dissected along with corticocancellous bone graft from the distal metaphysis of the radius

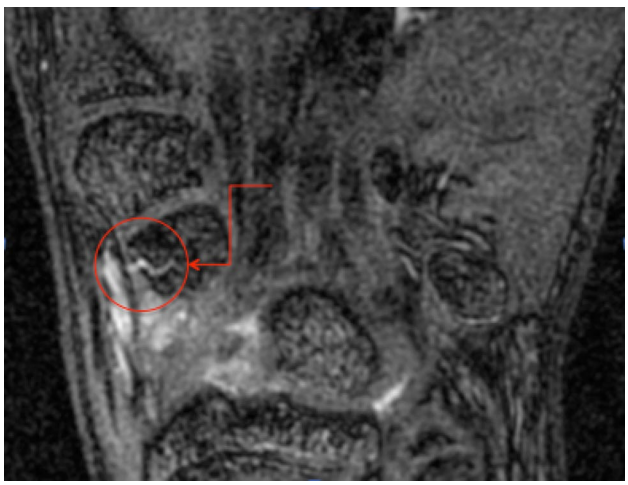

Fig. 2 Scaphoid blood supply from volar radial artery branch (normal vascularization) in MR angiography

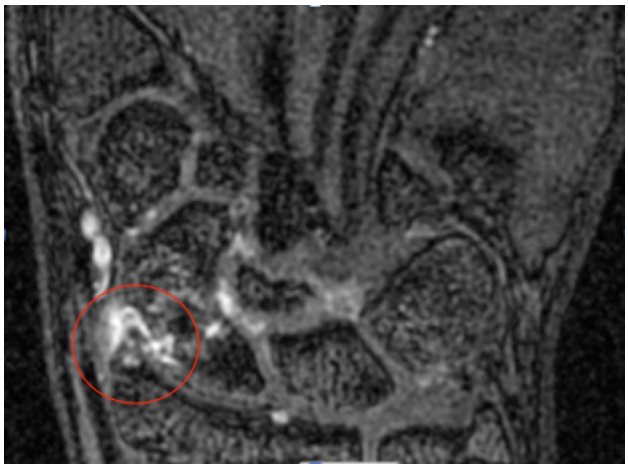

Fig. 3 Blood supply provided to the scaphoid by the transferred 1,2 ICSRA pedicle (MR angiography)

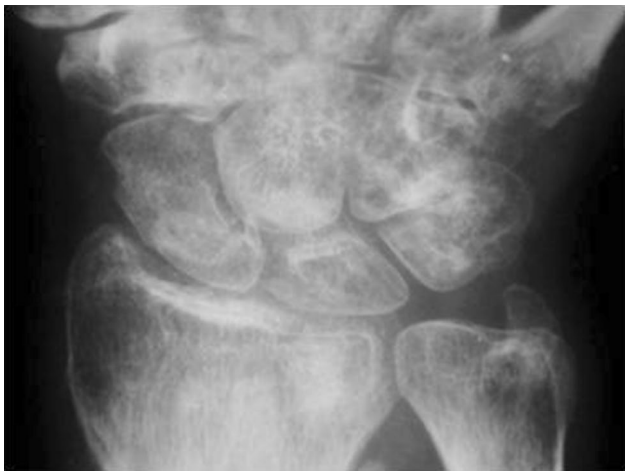

Fig. 4 Vascularized graft has been incorporated 6 months postoperatively

reconstruction) view. Moreover, in one patient, 1,2 ICSRA pedicle was recognized and found clearly patent during surgical exploration due to open trauma injury at the site.

After surgical treatment with 1,2 ICSRA VBG, all scaphoid nonunions united at an average period of 10 weeks (Fig. 4). VAS pain score, Mayo modified wrist score, and DASH score were improved significantly. At the last evaluation, five patients had an excellent score, and no one had poor function. The measured functional improvement according to DASH score was greater than 17 points, which is considered clinically significant [18]. There was also major improvement in pain that was evaluated with the visual analog scale (from 6.1 to 0.8).

Discussion

The management of the scaphoid nonunion remains a challenge, and several techniques for reconstruction have been developed in the last 80 years. Pedicle vascularized bone grafts from the distal radius have been proposed as an alternative after the poor results that non-vascularized bone grafts demonstrated in these cases given the fact that pedicle continues to be functioning. Serious debates arise from this matter between supporters and scrutinizers of the technique, and there is only to be answered whether pedicles do work in these cases. The purpose of our study was to examine in particular whether the 1,2 ICSR artery remains functional after the transfer in vascularized bone grafting of scaphoid nonunion. As far as we know, there is no other study dealing with this specific issue. Indirect confirmation of persistent vascular supply after Zaidenberg's flap technique is well documented in various studies that examine bone marrow quality after scaphoid's union. We examined directly the function of the pedicle artery by MR angiography with intravenous contrast agent.

VBGs in the treatment of scaphoid nonunion offer substantial advantages over conventional grafts because circulation and cell viability are maintained in the graft promoting revascularization and remodeling of surrounding avascular bone. Bone blood flow measurements and quantitative histomorphometric analysis of osteoid, new bone, and osteoblast-covered surface demonstrate significantly superior blood flow and remodeling in these avascular segments with the use of vascularized inlay grafts. A meta-analysis found that vascularized bone grafting achieved an 88% union rate versus a 47% with non-vascularized bone grafting in scaphoid nonunion with avascular necrosis [19, 20].

Despite the fact that there are other vascularized flaps that may be even more effective, the majority of hand surgeons tend to use the 1,2 ICSRA-radius flap [21]. Zaidenberg et al. described this vascularized bone graft from the dorsoradial aspect of the distal radius in 1991. It relies on the ascending irrigating branch of the radial artery that Sheetz and Bishop have defined as the 1,2 ICSRA [22].

Reported union rates range from 27 to 100%. Successful application of the vascularized bone flap gives satisfactory results reaching union rates of 100%. Zaidenberg et al. (100%), Waitayawinyu et al. (93%), and Malizos et al. (100%) have achieved and published such results for scaphoid union [9, 10, 23–25]. On the other hand, other investigators such as Chang et al. (71%), Boyer et al. (60%), and Straw et al. (27%) have reported significantly less satisfactory outcomes [26–28]. Precision in surgical technique is extremely important for avoiding mechanical complications with the graft and internal fixation. Patient

selection, smoking, and previous scaphoid procedures are other important factors for varying union rates [23, 26].

In addition, grip strength is another important wrist function parameter and criterion of success. There are also different results in published data (72–99%). Malizos et al. measured grip strength at 82% and Dailiana et al. at 86% compared to the contralateral hand [10, 29]. There are also different findings between dominant and non-dominant hand and of course, better results in scaphoid unions than nonunions. However, grip strength after successful 1,2 ICSRA VBG is not fully restored as well as active range of wrist motion [9, 23, 27, 30].

Analyzing the healing of proximal pole scaphoid nonunions after 1,2 ICSRA VBG and stable internal fixation, there is a correlation between the rate of healing and the revascularization of avascular proximal pole. Nonunion fibrous tissue works as a barrier to traditional bone grafting methods, even if it is augmented with internal fixation. The use of pedicled vascularized bone grafts that help ischemic bone revascularization should improve the union rate, and time to union as well [7, 31].

Obviously, such a result can be achieved only in cases of preserved arterial flow in the pedicle of vascularized bone graft. Average pedicle length of 22.5 mm is sufficient for the placement of vascularized bone grafts into the proximal pole of the scaphoid, but there are several factors that can influence the success of this VBG transposition. Knowledge of the area anatomy, identification of 1,2 ICSR artery, meticulous dissection and transposition of the pedicle with no elongation or twisting and even, an appropriate positioning of the wrist peri- and postoperatively are prerequisites for a healthy, vascularized bone graft [32]. 1,2 Intercompartmental supraretinacular artery must remain functional postoperatively to promote revascularization of the proximal pole of scaphoid. Many authors have questioned this claiming that intraoperative manipulations drive to thrombosis of the vessel. However, there is research over the issue with published results which confirm that vascularized bone graft remains viable after being transferred to the recipient site and aids in active revascularization of proximal pole of scaphoid and nonunion healing by providing vessels into avascular bone and vascular osteogenic tissue [13, 19, 33–35].

Evaluation of the vascular status of proximal pole of scaphoid after 1,2 ICSRA VBG transfer can be safely achieved by MRI as Dailiana et al. and Anderson et al. have shown (13,34). MRI can be utilized for the evaluation of union after surgery and particularly with the use of vascularized bone grafts as effectively as it has been employed to assess factors influencing healing in nonunion treated with internal fixation. The postoperative contrast-enhanced MR images have been proven valuable in all patients, in assessing the viability of the graft, demonstrating directly the partial or complete enhancement of its bone marrow [13, 34, 36]. While CT scan can successfully reveal bone consolidation or nonunion at the fracture site, sclerosis of proximal pole cannot be strongly correlated with avascular necrosis. MRI can appropriately assess the lack of vascularity preoperatively and revascularization of proximal pole of scaphoid postoperatively as well. Positive revascularization of the proximal pole of scaphoid is defined as normalized bone marrow signal intensity on all MR imaging sequences and the absence of pseudoarthrosis. On the other hand, failure of revascularization is defined as persistent postoperative pseudoarthrosis with AVN of proximal pole of the scaphoid [34, 37, 38]. The third postoperative month was selected to obtain the first postoperative MRI assuming that there was adequate time for the surgery-related tissue injury to subside and for bone union to occur. Additional MRI investigation was performed in the 6th and the 12th postoperative month to confirm graft incorporation and viability of the whole scaphoid [13, 34]. Considering that postoperative MRI may become a technically demanding procedure due to artifacts from the use of metal instruments and Kirschner wires, even after their removal, contrast-enhanced MRI particularly was the only means to depict the viability of both the graft and the proximal segment [13, 39].

Both CT and MR angiography can reveal blood flow in vessels even of small caliber and despite continuous motion of the arteries. MR angiography can be done with or without intravenous contrast agent relying on magnetic properties and quantum spin characteristics of hydrogen protons (mainly in water), while CT angiography is basically an X-radiation study, which utilizes an iodinated intravenous contrast agent.

Image slices have 3D properties (CT better than MRI) and contrast sensitivities that allow tissue characterization (MRI better than CT). As with all imaging techniques, both tools are subject to artifacts that limit information content.

MRA examinations are of course time-consuming and more expensive; but while CT angiography provides strictly anatomic information, MR angiography can reveal function, perfusion, and viability.

In our series, functioning of 1,2 ICSR artery was revealed in 13 out of 14 patients who underwent MRA examination. The absence of arterial blood flow in 1 patient was the result either of the imaging technique inaccuracy or due to poor surgical technique. On the other hand, increased contrast enhancement was evident in all patients confirming the effectiveness of 1,2 ICSRA VBG technique in revascularization and consolidation of scaphoid nonunion. Even if inconspicuous pedicle artery (1 of 14 cases) is considered inactive, healing of the nonunion can be explained by the effectiveness of non-vascularized bone grafting techniques that also are proposed and widely used in the treatment of scaphoid nonunion.

Conclusion

1,2 ICSRA-vascularized bone grafting is a reliable choice in the treatment of scaphoid nonunion. Scaphoid healing is the result of the structural reconstruction by embedding of bone graft in conjunction with revascularization of the avascular proximal pole succeeded by blood supply of the transferred artery despite the fact that many authors doubt artery's patency. In our study, viability of the pedicle artery was confirmed by MR angiography with intravenous contrast agent reasserting 1,2 ICSRA VBG as an effective surgical technique in scaphoid nonunion.

Compliance with ethical standards

Conflict of interest All the authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript. Ioannis K. Antoniou, Efstratios D. Athanaselis, Christos Rountas, Antonios Koutalos, Zoe Dailiana, Konstantinos N. Malizos, and Sokratis E. Varitimidis declare that they have no conflict of interest.

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