Title: Vascularized pedicled bone graft from the distal radius supplied by the anterior interosseous artery for treatment of ulnar shaft nonunion: An anatomical study of cadavers and a case report

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Abstract:

Background

A vascularized distal radius graft can be a reliable solution for the treatment of refractory ulnar nonunion. The aim of this study is to establish the anatomical basis of a vascularized bone graft pedicled by the anterior interosseous artery and report its clinical application, using cadaveric studies and a case report.

Methods

Fourteen fresh frozen cadaveric upper limbs were used. The branches of the anterior interosseous artery (the 2,3 intercompartmental supraretinacular artery and the fourth extensor compartment artery) were measured at the bifurcation site. The anatomical relationship between the anterior interosseous artery and motor branches of the posterior interosseous nerve was investigated. An anterior interosseous artery pedicled bone flap was used in a 48-year-old woman with refractory ulnar nonunion.

Results

There were two variations depending on whether the 2,3 intercompartmental supraretinacular artery branched off distally or proximally from the terminal motor branch of the posterior

interosseous nerve. The proximal border of the graft was located at an average of 10.5 cm (range, 6.5-12.5 cm) from the distal end of the ulnar head in the distal type (57%) and 17.5 cm (range, 9.5-21.5 cm) in the proximal type (43%). In the clinical application, successfully consolidation was achieved 4 months post-surgery. The patient had not developed any postoperative complications till the 2-year postoperative follow-up.

Conclusions

The anterior interosseous artery-pedicled, vascularized distal radius bone graft would be a reliable alternative solution for the treatment of an ulnar nonunion located within the distal one third of the ulna.

INTRODUCTION

Nonunion of the forearm sometimes occurs after an open injury, high-energy fractures, soft-tissue or vascular problems, and open surgery. Orthopedic surgeons often encounter ulnar shaft nonunion following ulnar shortening osteotomy owing to the absence of a dominant intramedullary vessel in the ulnar diaphysis[1], resulting in the deterioration of its vascularity after surgery. Conventional autogenous bone grafting can result in a high rate of union in cases with small bone defects;[2] however, a vascularized bone graft is indicated in cases with nonunion accompanied by segmental bony defects (larger than 6 cm) or in cases with massive soft-tissue or vascular problems[3]. Although free vascularized bone grafting has a risk of vascular complications[4 5], vascularized pedicled bone grafting can be a reliable alternative owing to less invasive surgery and reduction of vascular complications.

Sheetz et al.[6] demonstrated the arterial blood supply of the distal radius and ulna and discussed its potential use in vascularized pedicled bone grafts. In vascularized pedicled bone grafts from the distal radius, the 1,2 intercompartmental supraretinacular artery was used for the treatment of scaphoid nonunion and Preiser's disease[7 8], the fourth and fifth extensor compartment arteries were used for treating Kienböck's disease[9 10 11], and the fourth extensor compartment artery was used for carpometacarpal fusion in the treatment of carpal boss[12]. The anterior and posterior interosseous arteries were used in vascularized pedicled bone grafts for the treatment of diaphyseal nonunion of the ulna[13 14].

For the treatment of forearm nonunion, a posterior interosseous artery-pedicled, vascularized periosteal flap was useful and less invasive to the donor site[17]. The posterior interosseous artery, which runs along the dorsal aspect of the ulna, between the fifth and sixth compartments, is likely to be damaged in the diaphyseal nonunion of the ulna following an open fracture and ulnar shortening osteotomy. On the other hand, the anterior interosseous artery runs slightly away from the ulna and is more reliable for the treatment of recalcitrant nonunion of the ulnar diaphysis. However, there is insufficient information about the vascular anatomy of the dorsal metaphysis of the radius for transferring the pedicled distal radius vascularized graft to the ulnar diaphysis. Thus, the aims of this study were to investigate (1) the location and internal diameter of the branches of the anterior interosseous artery on the dorsal aspect of the distal radius (the 2,3 intercompartmental supraretinacular artery and the fourth extensor compartment artery), (2) the anatomical relationship between the anterior interosseous artery and motor branches of the posterior interosseous nerve, and (3) the range of distance that the anterior interosseous artery-pedicled, vascularized radius graft can reach. The authors then used this vascularized bone graft successfully to reconstruct a recalcitrant ulnar nonunion in a 48-year-old woman after plate removal following ulnar shortening osteotomy.

MATERIALS AND METHODS

This study was approved by the ethics committees of our institutions. Fourteen fresh frozen cadaveric limbs (7 right and 7 left) from 8 cadavers were investigated. Of the 14 specimens, 10 were from men and 4 from women, with a mean age of 75 years (range, 51-95 years). The mean length of the ulna was 25.3 cm. A 14-gauge catheter was placed in the brachial artery, and 20 ml of silicone rubber compound (Microfil®; Flow Tech Inc.) was injected with the cadaveric limb under manual pressure. Anatomical dissection of the forearm was performed under 2.5× loupe magnification an hour after the injection.

Skin incisions were made on the dorsal compartment of the forearm. The extensor digitorum and extensor pollicis longus (EPL) were identified and retracted. The distal end of the ulnar head was defined as a point of reference and the proximal direction as positive. First, the location (cm) and the internal diameter (mm) of the bifurcation sites of the anterior interosseous artery on the dorsal metaphysis of the distal radius (the 2,3 intercompartmental supraretinacular artery and the fourth extensor compartment artery) were measured. Second, the anatomical relationship between the anterior interosseous artery and motor branches of the posterior interosseous nerve was investigated. Third, the distance of the most proximal border that the pedicled bone graft could reach was measured. The pedicled bone graft was harvested from the distal radius 1 cm proximal to the point of reference, and the transposition ratio was measured relative to the total ulnar length.

RESULTS

In all 14 specimens, the 2,3 intercompartmental supraretinacular artery, fourth extensor compartment artery, and posterior interosseous artery branched off from the anterior interosseous artery at 6.8 cm (range, 3.0-11.5 cm), 3.1 cm (range, 2.5-5.5 cm), and 3.8 cm (range, 2.5-7.0 cm) from the distal end of the ulnar head, respectively (Figure 1). The internal diameters of the 2,3 intercompartmental supraretinacular artery, fourth extensor compartment artery, and posterior interosseous artery were 0.82 mm (range, 0.43-1.20 mm), 0.48 mm (range, 0.27-0.84 mm), and 0.61 mm (range, 0.21-0.86 mm), respectively.

The posterior interosseous nerve was consistently identified on the radial side of the fourth extensor compartment artery and anterior interosseous artery. The motor branches of the posterior interosseous nerve crossed the anterior interosseous artery, and the locations of the bifurcation were at 5.9 cm (range, 3.5-8.0 cm) and 6.7 cm (range, 5.0-10.0 cm) in the extensor indicis proprius (EIP) and extensor pollicis longus (EPL), respectively. In all specimens, the terminal motor branch of the posterior interosseous nerve was a branch to the EIP (Figure 1).

The bifurcation pattern of the anterior interosseous artery had two variations depending on whether the 2,3 intercompartmental supraretinacular artery branched off distally or proximally from the terminal motor branch of the posterior interosseous nerve. The distal type accounted for 57% (8/14) of cases. In the distal type, the 2,3 intercompartmental supraretinacular artery, fourth extensor compartment artery, and posterior interosseous artery branched off from the anterior interosseous artery at 4.7 cm (range, 3.0-6.7 cm), 3.1 cm (range, 2.5-5.5 cm), and 4.0 cm (range, 2.5-7.0 cm), respectively (Figure 2) (Figure 4A) (Table 1). The proximal type accounted for 43% (6/14) of cases. In the proximal type, the 2,3 intercompartmental supraretinacular artery, fourth extensor compartment artery, and posterior interosseous artery branched off from the anterior interosseous artery at 9.5 cm (range, 5.5-11.5 cm), 3.2 cm (range, 2.5-5.0 cm), and 3.6 cm (range, 2.5-5.0 cm), respectively (Figure 3) (Figure 4B) (Table 1).

The most proximal border of the arc, where the pedicled bone graft was harvested from the distal radius 1 cm proximal to the point of reference and rotated as a pivot point of the vascular pedicle at the terminal motor branch of the posterior interosseous nerve, was located at an average of 10.5 cm (range, 6.5-12.5 cm), and the transposition ratio was an average of 0.41 (range, 0.30-0.51) in the distal type. In the proximal type, when the fourth extensor compartment artery was used as a single pedicle, the proximal border of the arc was located at an average of 10.8 cm (range, 5.5-14.5 cm) and the transposition ratio was an average of 0.4 (range, 0.26-0.59). Conversely, when the 2,3 intercompartmental supraretinacular artery were used as a single pedicle, the proximal border was located at 17.5 cm on an average (range, 9.5-21.5 cm) and the mean transposition ratio was 0.70 (range, 0.43-0.87).

CASE REPORT

A 48-year-old woman presented with recalcitrant right ulnar nonunion after plate removal following ulnar shortening osteotomy. At the first visit to our clinic, the flexion-extension was 95°, pronation 80°, and supination 80°. the visual analog scale (VAS) score for wrist pain was 50. The patient-rated wrist evaluation (PRWE) score was 52 points. The radiograph showed ulnar nonunion with a 5-mm bone defect at 5 cm proximal to the wrist (Figure 5). Computed tomography images showed a 3-cm dorsal cortical bone defect (Figure 6).

The operation was performed under 2.5× loupe magnification and tourniquet control. An S-shaped incision was made in the dorsal aspect of the forearm, the fourth extensor compartment was opened, and the extensor digitorum communis and EIP were retracted radially. The fourth extensor compartment artery and posterior interosseous nerve were exposed; the 2,3 intercompartmental supraretinacular artery branched 5 cm proximal to the end of the ulnar head, which was classified as the distal type. In the nonunion site, the cortical bone of the dorsal aspect was damaged in the previous operation, and a bony defect measuring 3 cm existed. The intramedullary canal was filled with scar tissue. After scar tissue resection in the nonunion site, the vascularized pedicled bone graft (1×3 cm), including both the 2,3 intercompartmental supraretinacular artery and the fourth extensor compartment artery, was transplanted and fixed with plate and screws (Figure 7).

A long-arm cast was applied for 2 weeks, followed by a short forearm cast for 2 weeks. Radiography revealed that bone consolidation was achieved after 4 months, without any restriction of the range of motion of the wrist (Figure 8). No paralysis of the posterior interosseous nerve was observed postoperatively. Two years after the surgery, the range of flexion-extension, pronation, and supination was 105°, 70°, and 80°, respectively. The VAS and PRWE scores improved to 20 and 35 points, respectively.

DISCUSSION

The current anatomical study revealed that the location of the fourth extensor compartment artery and terminal motor branch of the posterior interosseous nerve branching site was less variation. On the other hand, the location of the 2,3 intercompartmental supraretinacular artery bifurcation site showed variation. Pagnotta et al.[14] reported the use of a vascularized bone graft from the distal radius, pedicled with the fourth extensor compartment artery, for the treatment of a 2-cm ulnar bone defect. Andro et al.[13] reported the clinical application of a vascularized bone graft from the distal radius with the 2,3 intercompartmental supraretinacular artery as a single pedicle. In these reports, the vascularized pedicled bone graft was elevated with a single pedicle; however, the combination of both pedicles can reliably nourish the dorsal distal radius. Especially in the distal type, harvesting the vascularized pedicled bone graft with both pedicles is recommended in the clinical setting (Figure 9A).

In the proximal type, the 2,3 intercompartmental supraretinacular artery branches off more proximally from the terminal branch of the posterior interosseous nerve. As the dissection of the EIP and EPL was required for elevating the combination pedicles, the surgeons had to select either of the two (Figure 9 BC). As fewer nutrient branches to the distal radius were reported with the 2,3 intercompartmental supraretinacular artery than with the fourth extensor compartment artery[6 16], the graft pedicled with the 2,3 intercompartmental supraretinacular artery could be assumed as a periosteal flap. However, the length of the 2,3 intercompartmental supraretinacular artery pedicle was longer than that of the fourth extensor compartment artery pedicle. Especially in the proximal type, the vascularized bone graft pedicled with the 2,3 intercompartmental supraretinacular artery alone was useful, because the graft was extended 40% to the distal side of the ulna and harvested without the risk of posterior interosseous nerve damage.

A few previous studies have investigated the use of the vascularized pedicled ulnar graft to treat forearm nonunion. Berrera-Ochoa et al.[17] described that the posterior interosseous artery provided a mean of 13 periosteal branches to the area 15 cm distal to the whole ulna. They used a posterior interosseous artery periosteal flap to treat a patient with nonunion of the radius. Kamrani et al.[18] reported the use of a vascularized ulnar graft pedicled by the posterior interosseous artery in 9 patients with forearm nonunion. They described that the vascularized ulnar graft is indicated for nonunion in the middle or proximal one-third of the ulna. The current authors consider the vascularized ulnar graft unsuitable for use for the treatment of nonunion within the distal one-third of the ulna, because the posterior interosseous artery runs along the distal ulnar shaft and may be damaged by previous trauma or graft harvesting. Thus, the authors applied the anterior interosseous artery-pedicled, vascularized bone graft from the distal radius for the treatment of distal ulnar nonunion.

CONCLUSIONS

The anterior interosseous artery-pedicled, vascularized bone graft from the distal radius can be a reliable alternative for the treatment of ulnar nonunion located within the distal one third of the ulna.

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FIGURE LEGENDS

Fig. 1

Schema of vascular patterns of the anterior interosseous artery branches (thick solid lines) and the posterior interosseous nerve (double lines) in all specimens

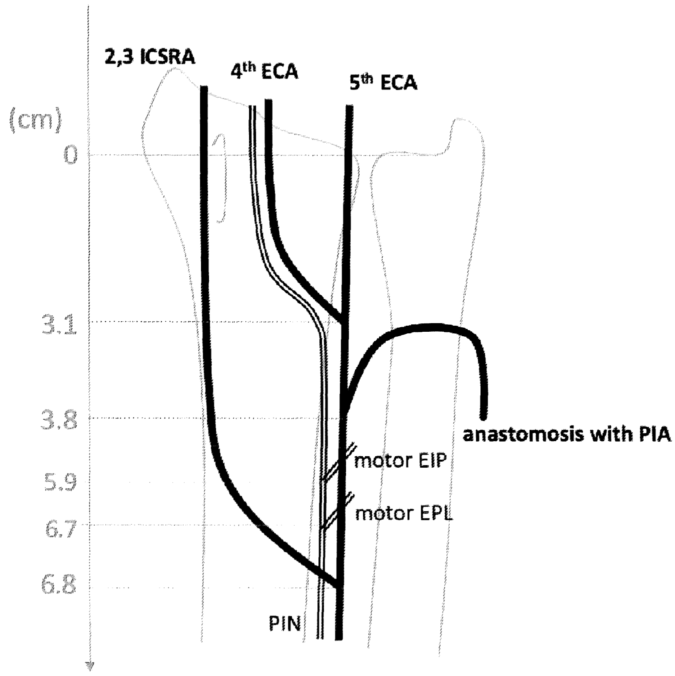

Fig. 2

The vascular pattern of anterior interosseous artery branches in the distal type. The 2,3 intercompartmental supraretinacular artery (†). The fourth extensor compartment artery (*). The anastomosis of posterior interosseous artery (§). The last motor branch of the posterior interosseous nerve (¶).

Fig. 3

The vascular pattern of the anterior interosseous artery in proximal type. The interosseous membrane was removed, and the EPL tendon is dissected. The 2,3 intercompartmental supraretinacular artery (†). The fourth extensor compartment artery (*). Anastomosis of the posterior interosseous artery (§). The last motor branch of the posterior interosseous nerve (¶).

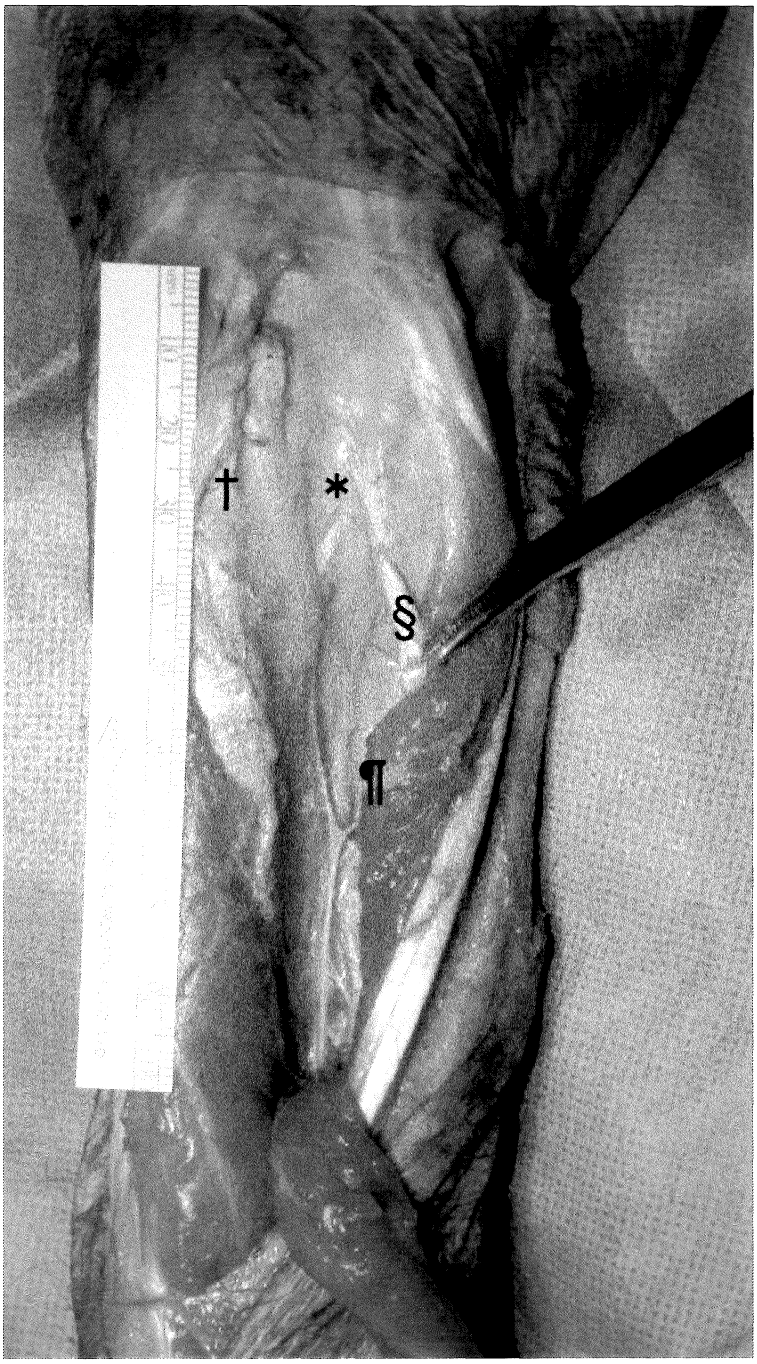

Fig. 4

Thick solid lines showed branches of the anterior interosseous artery.

Double lines showed posterior interosseous nerve

(A) Schema of the vascular patterns of the distal type.

(B) Schema of the vascular patterns of the proximal type.

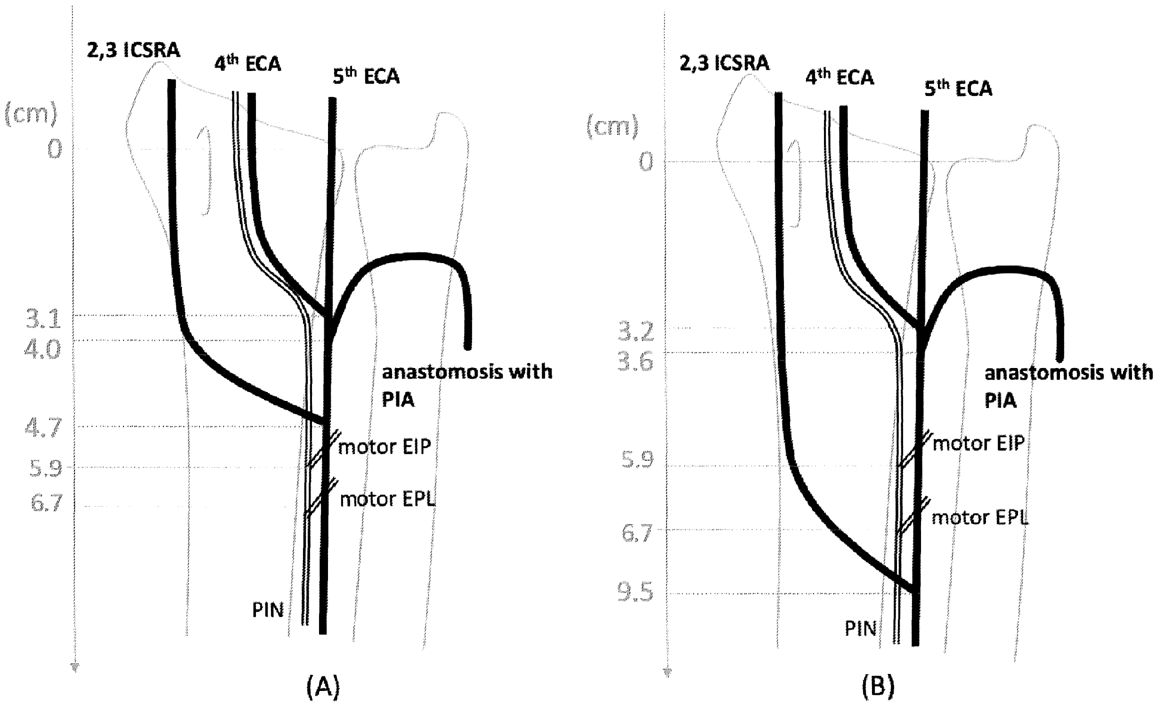

Fig. 5

Preoperative radiograph showed 5-mm bone defects at 5 cm proximal to the wrist

Fig. 6

Computed tomography images showed a 5-cm dorsal cortical bone defect

Fig. 7

The vascularized bone graft with a 2,3 intercompartmental supraretinacular artery and fourth extensor compartment artery

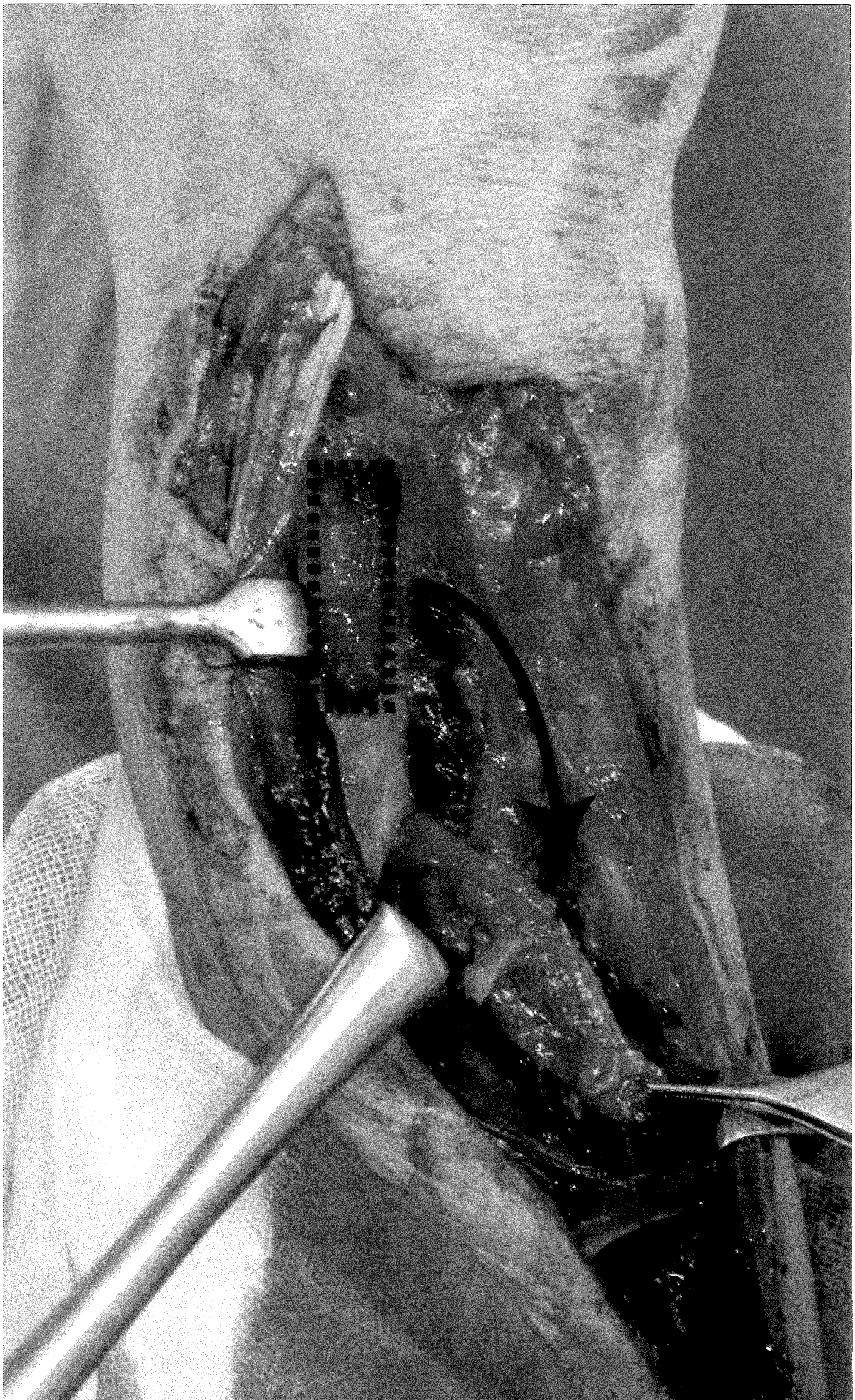

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Fig. 8

Postoperative plain radiographic images

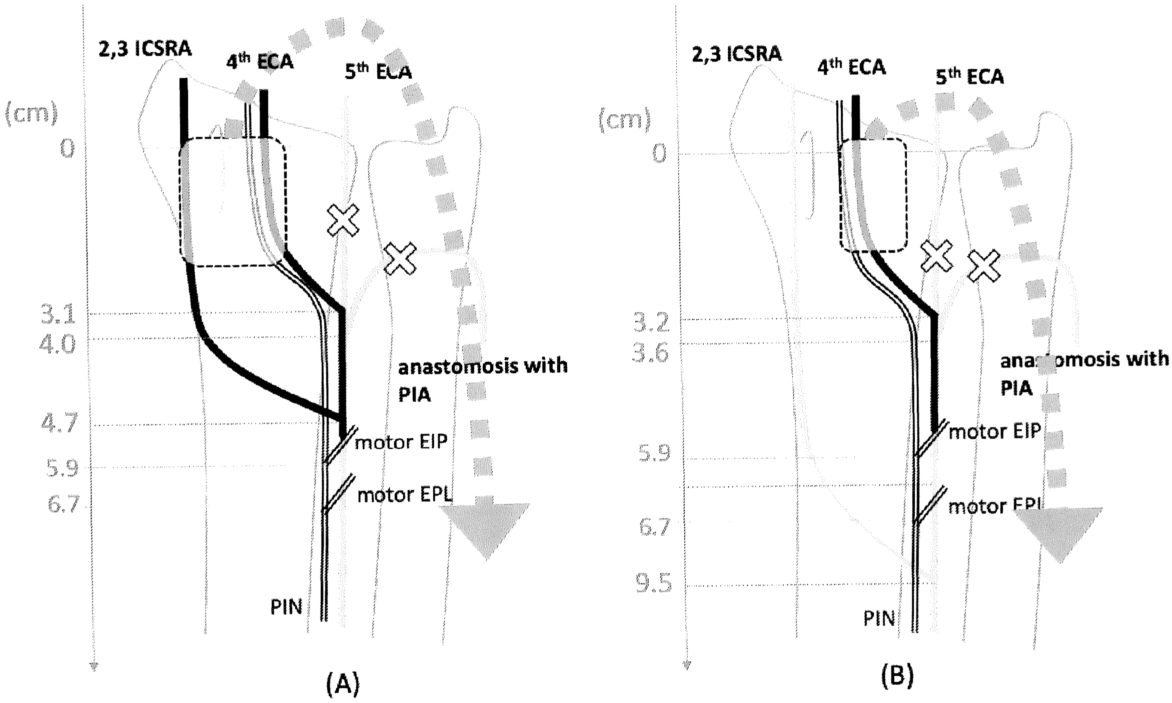
Fig. 9

Thick solid black lines showed pedicles. Double lines showed posterior interosseous nerve. Grey colored square showed bone graft. X-mark showed ligation site.

(A) Schema of the combination of the fourth extensor compartment artery and 2,3 intercompartmental supraretinacular artery pedicled vascularized bone graft in the distal type.

(B) Schema of the fourth extensor compartment artery pedicled vascularized bone graft in the proximal type.

(C) Schema of the 2,3 intercompartmental supraretinacular artery vascularized bone graft in the proximal type.


2,3 ICSRA
4th ECA
5th ECA
(cm)
0
3.1
4.0
4.7
5.9
6.7
anastomosis with PIA
motor EIP
motor EPL
PIN
(A)
2,3 ICSRA
4th ECA
5th ECA
(cm)
0
3.2
3.6
5.9
6.7
9.5
PIA
motor EIP
motor EP
PIN
(B)

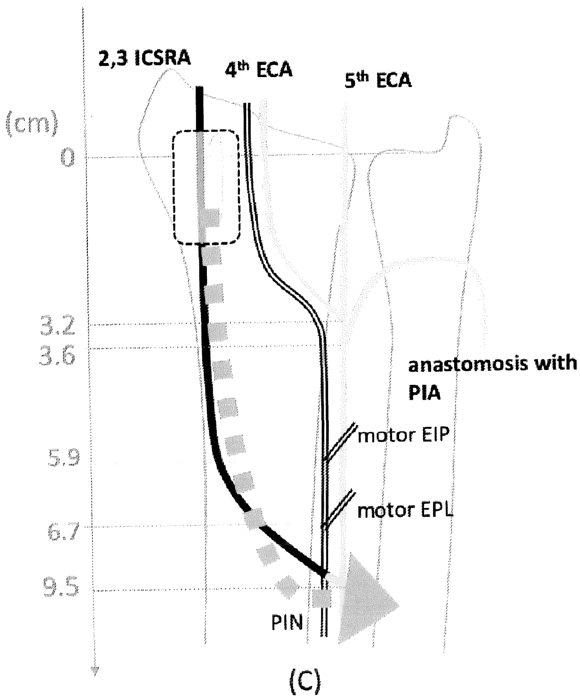

2,3 ICSRA
4th ECA
5th ECA
(cm)
0
3.2
3.6
5.9
6.7
9.5
anastomosis with PIA
motor EIP
motor EPL
PIN
(C)

Table 1 The AIA Branches Characteristics

	2,3 ICSRA		Fourth ECA		Last PIN motor branch	Anastomosis with PIA	
	Location (cm)	Diameter (mm)	Location (cm)	Diameter (mm)	Location (cm)	Location (cm)	Diameter (mm)
Distal type	4.7 (3.0-6.7)	0.80 (0.43-0.95)	3.1 (2.5-5.5)	0.50 (0.30-0.84)	5.7 (4.0-7.0)	4.0 (2.5-7.0)	0.71 (0.57-0.86)
Proximal type	9.5 (5.5-11.5)	0.88 (0.57-1.2)	3.2 (2.5-5.0)	0.48 (0.27-0.80)	6.2 (3.5-8.0)	3.6 (2.5-5.0)	0.51 (0.21-0.84)
Total	6.8 (3.0-11.5)	0.82 (0.43-1.2)	3.1 (2.5-5.5)	0.48 (0.27-0.84)	5.9 (3.5-8.0)	3.8 (2.5-7.0)	0.61 (0.21-0.86)

All data shown in average (range)

AIA: anterior interosseous artery
ICSRA: intercompartmental supraretinacular artery
ECA: extensor compartment artery
PIN: posterior interosseous nerve
PIA: posterior interosseous artery