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RESEARCH ARTICLE

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Vascularized ulnar periosteal pedicled flap for forearm reconstruction: Anatomical study and a case report

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Abstract

Purpose: Through an anatomical review, the aim of this study is to define the ulnar periosteal branches of the posterior interosseous vessels (PIV). In addition, we report the clinical utility of a vascularized ulnar periosteal pedicled flap (VUPPF), supplied by the investigated PIV, in a complex case of radial nonunion.

Methods: Ten upper limbs latex colored from fresh human cadavers were used. Branches of the PIV were dissected under 2.5× loupe magnification, noting the periosteal, muscular, and cutaneous branches arising distal to the interosseous recurrent artery. The VUPPF was measured in length (cm) and width (cm).

Results: The PIV provided a mean 12.8 periosteal branches to the ulna distributed along the most distal 15 cm, with a mean distance between branches of 1 cm, allowing for the design of a VUPPF which measured a mean 12 cm in length and 1.7 cm in width. We used a VUPPF of 7.8 cm in length and 2 cm in width to treat extensive nonvascularized bone graft nonunion with a defect of 2 cm of the left radius in a 6-year-old girl, secondary to previous Ewing's Sarcoma reconstruction. Successfully consolidation was achieved 6-months after surgery. The patient did not present post-operative complications. At 2-years of follow-up after surgery, active supination was 80° and pronation 0° (due an incomplete interosseous ossification); grip strength was 80% that of the opposite hand. The patient had resumed all her daily activities.

Conclusions: VUPPF may be considered a valuable and reliable surgical option for forearm reconstruction in complex clinical scenarios.

Conflict of Interest: The authors, their immediate family, and any research foundation with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

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1 | INTRODUCTION

There is no large study on pediatric nonunion of forearm in children. Open injury, high-energy fractures, soft-tissue or vascular problems, open surgery, older age group, presence of infection, and inadequate immobilization are contributory to pediatric bone nonunion (Song & Kim, 2003). Although several treatment options have been described for complex cases of forearm nonunion in children, there are no definite guidelines. The traditional methods for treating or preventing complex bone nonunion in pediatric patients as electrical stimulation, prolonged casting, bone grafting, or osteotomy of the involved bone

TABLE 1 Anatomical study of ulnar periosteal branches based on PIV

	Periosteal branches		Septocutaneous perforator branches	Muscular branches	
Number	Mean: 12.8		Mean: 7.3	Mean: 13.1	
	Range: 11–14		Range: 6–10	Range: 10–15	
Distance between branches (cm)	Mean: 1		Mean: 1.6	Mean: 0.8	
	Range: 0.2–2.5		Range: 0.4–4.2	Range: 0.5–1.8	
Distribution (Number)	Medial	Mean: 7.7		Extensor	Mean: 7.5
		Range: 5–10		Digiti Minimi	Range: 5–10
	Lateral	Mean: 5.1		Extensor	Mean: 5.5
		Range: 4–8		Carpi Ulnaris	Range: 4–8

and plate fixation are usually insufficient (Fernandez, Eberhardt, Langendörfer, & Wirth, 2009; Song & Kim, 2003). Vascularized bone grafting appears to be more successful than other treatments (Mathoulin, Gilbert, & Azze, 1993). Vascularized periosteal flaps have been reported as very effective for treating or preventing complex bone nonunion in pediatric patients, owing to their high angiogenic and osteogenic potentials (Qi et al., 2008; Soldado et al., 2012a, 2015). We anatomically studied how the posterior interosseous vessels (PIV) vascularize the ulnar periosteum to assess the potential for developing a new vascularized periosteal pedicled flap to manage selected cases of radius nonunion with less donor-site morbidity and less technically demanding. Afterwards, we used this VUPPF successfully to reconstruct complex nonunion of the radius in a 6-year-old girl with a nonvascularized fibular auto-graft post Ewing's Sarcoma resection.

2 | MATERIALS AND METHODS

For this study, 10 upper limbs from fresh human cadavers were used. In all specimens, we performed anterograde arterial injection of colored natural latex through the brachial artery at the level of the elbow. Branches of the PIV were dissected under 2.5× loupe magnification, noting the periosteal, muscular, and cutaneous branches arising distal to the interosseous recurrent artery, which was identified in all specimens. The distance (cm) of the periosteal branches to ulnar styloid and the distribution of the branches (medial/lateral) were also noted. The VUPPF was measured in length (cm) and width (cm).

3 | RESULTS

The anatomical findings are depicted in Table 1. The PIV were located in all dissections in the septum between the extensor carpi ulnaris (ECU) and extensor digiti minimi (EDM) muscles; and their origin from the common interosseous artery was confirmed. The PIV emerged in the posterior compartment under the supinator muscles. The PIV provided periosteal branches arising both from their medial (60%) and lateral (40%) side, also running transversely across the periosteum of the ulna dorsally. Periosteal branches were found to be distributed solely along the most distal 15 cm of the ulna with a mean distance between branches of 1 cm (range 0.2–2.5 cm). There was a mean 12.8 periosteal branches. Before harvesting, the periosteal flap measured a mean 15 cm in length (range 13.5–16.5 cm) and 2 cm in width (range 1.8–2.2 cm). Postharvest, the periosteal flap measured a mean 12 cm in length (range 11.5–13 cm) and 1.7 cm in width (range 1.5–1.9 cm), because of elastic retraction (Figure 1).

4 | CASE REPORT

We present the case of a 6-year-old girl previously treated for an Ewing's sarcoma of the left radius. The patient initially underwent a wide 10 cm midshaft excision of the radius, through a volar approach, with immediate use of a nonvascularized fibular auto-graft fixed with a proximal locking compression plate (LCP). Both graft and host junction consolidation was obtained. However, the patient sustained a fracture of the distal part of the graft 6 months postoperatively, secondary to upper limb trauma. Six months after the fracture, radiographs showed a severely angulated atrophic nonunion of the fracture, (Figure 2). Clinical examination revealed very limited, painful forearm rotation (Figure 3) and 20° of pronation and 10° of supination. Grip strength was 30% that of the opposite hand.

Nine months after the fracture, the patient underwent a second operation. For this, the patient was placed in a decubitus supine position and a mid-arm tourniquet applied. Nonunion was exposed using the volar Henry approach. The proximal LCP and screws were then removed. Sclerotic bone was debrided and excised at the nonunion site. Radius angulation was corrected creating a defect of 2 cm at the nonunion site. This defect was bridged with a 2.7 mm locking reconstruction plate (Synthes GmbH, Switzerland). No bone graft was added to the nonunion site. Finally, the nonunion was covered with a VUPPF obtained through a posterior approach. Periosteal flap vascularization was from the PIV and constructed in a retrograde fashion.

The harvesting technique used for the VUPPF followed most of the standard steps used to obtain a reverse posterior interosseous flap (Akin, Ozgenel, & Ozcan, 2002; Cheema, Lakshman, Cheema & Durrani, 2007; Costa & Soutar, 1988; Kamrani, Mehrpour, Sorbi, Aghamirsalim, & Farhadi, 2013; Penteado, Masquelet, Romana, & Chevrel, 1990). The

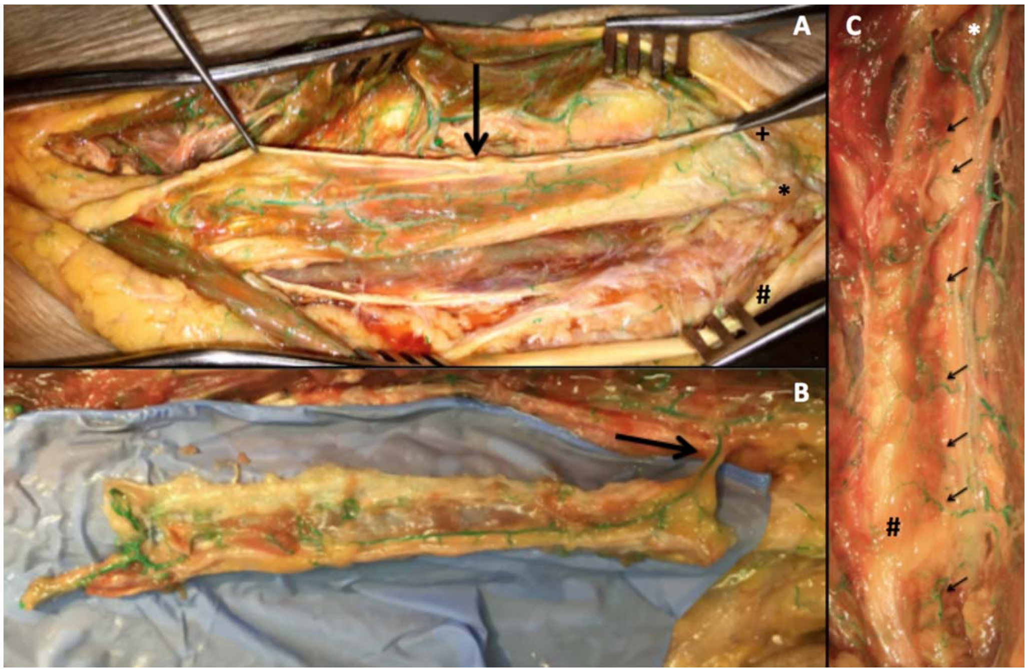

FIGURE 1 Posterior compartment of the forearm dissection. A, Periosteal branches originating in the PIV in the septum (black arrow) between the ECU (#) and EDM muscles were found running transversely across the periosteum of the dorsal aspect of the ulna. (+) Ulnar head. (*) Ulnar styloid. B, After harvesting the vascularized ulnar vascularized periosteal flap (VUPPF), supplied by the PIV (black arrow), and designed as a pedicled flap in a retrograde fashion. C, Detail of periosteal branches (black arrows) arising from the PIV to the ulna (#)

elbow was flexed to a right angle and the lateral epicondyle and distal radio-ulnar joint marked on the skin. The line that joined these two points formed the axis of the flap. A longitudinal skin incision was created on the posterior forearm and extended distally as far as the distal radio-ulnar joint, so as to expose the vascular pedicle. At the wrist, the PIVs anastomosis with the perforating branch of the anterior interosseous artery was identified. The posterior interosseous nerve also was identified and protected. PIV and their branches to the ulna's periosteum were exposed between the ECU and EDM muscles. Along its course, cutaneous and muscular branches of PIV

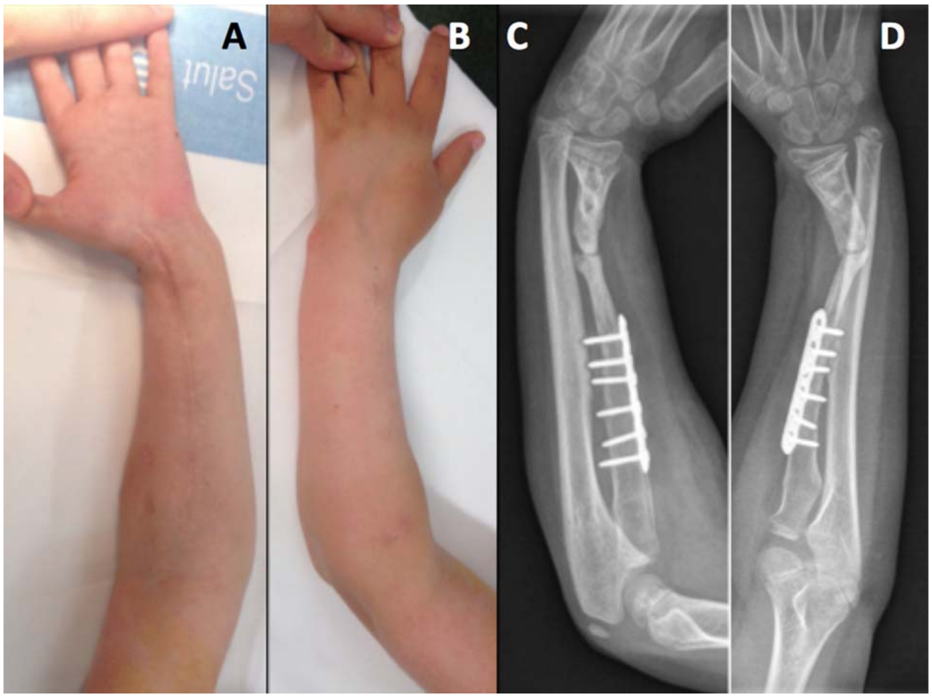

FIGURE 2 Preoperative radiographs and clinical image of complex radial nonunion and residual dorsal-radial angulation of the radius

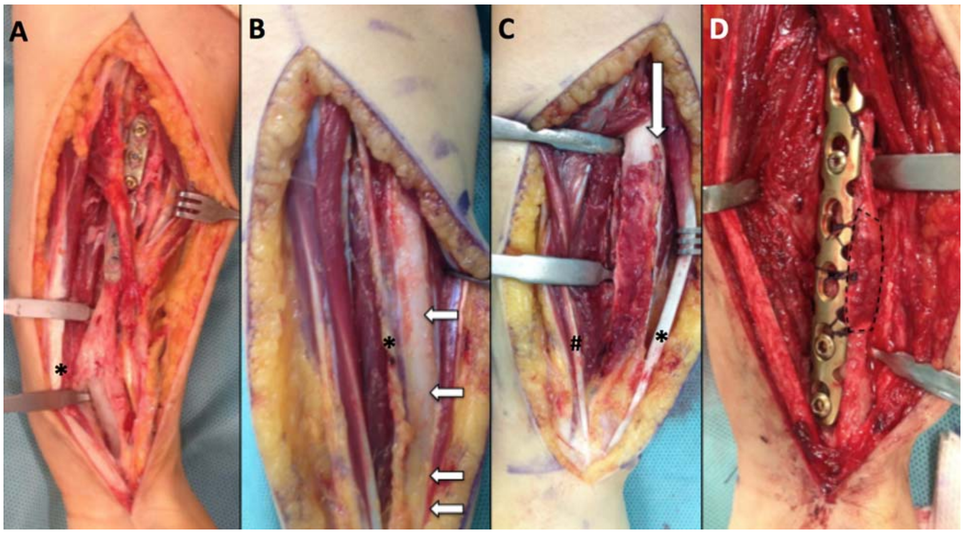

FIGURE 3 Forearm reconstruction. A, Volar forearm approach to expose extensive nonvascularized bone graft nonunion of the left radius (*). B, Periosteal branches (white arrows) from the PIV (*) before detachment from the ulna. C, VUPPF (white arrow) after detachment from the ulna, with previous transfer to the radius. (#) Extensor digiti minimi muscle. (*) Extensor carpi ulnaris muscle. D, Correction and fixation of radius nonunion with a LCP plate, and longitudinal placement of the flap (discontinuous black line) to bridge the nonunion

were ligated. A rectangular periosteal flap and PIV were elevated from proximal to distal using a periosteal elevator. Finally, distal release of the periostium at the level of the ulnar neck was performed; the distal vascular anastomotic arch also was released from the interosseous membrane. Then an intraoperative assessment to ensure the blood supply of the periosteal flap was performed. Placement of the flap was longitudinal to bridge the nonunion. The length of the flap before detachment was 10.3 cm and 2.2 cm in width, and 7.8 cm in length and 2.0 cm in width after harvesting (Figure 4). An above-the-elbow plaster cast was applied but removed 2 weeks postoperatively, replaced by a removable forearm splint, after which the patient underwent daily physiotherapy to enhance the patient's wrist and forearm range of motion.

Periosteal callus ossification was initially observed 6 weeks after surgery on a computed tomography scan. A nonunion healing was achieved at 6 months, while complete remodelation was observed at 12 months. Despite release of the distal periostium at the level of the ulnar neck, the patient developed ossification that did not completely bridge the interosseous space.

Two years postoperatively, the patient showed 80° of supination, 0° for pronation (Figure 5). Grip strength was 80% that of the opposite hand. The patient had resumed all her usual daily activities.

FIGURE 4 Radiographic evolution after the VUPPF. A, Anteroposterior and B, lateral radiographs at 2 months of follow-up revealing initial periosteal callus ossification. C, Anteroposterior and D, lateral radiographs at four months of follow-up showing a reduced gap at the nonunion site. E, Anteroposterior and F, lateral radiographs at 6 months of follow-up showing a nonunion junction (white arrows) and an incomplete interosseous ossification (black arrow)

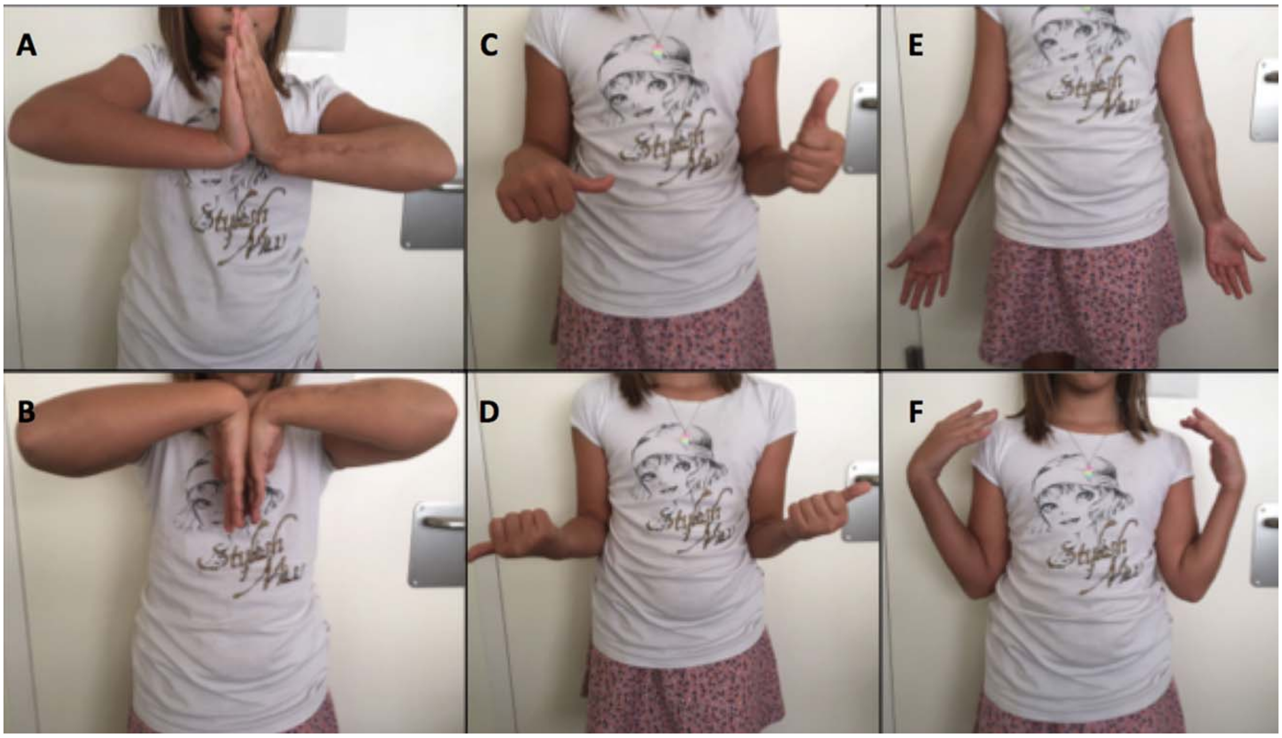

FIGURE 5 Active wrist and forearm range of motion postoperatively: A, 60° for extension, B, 70° for flexion, C, 0° for pronation, and D, 80° for supination, E, with full elbow extension, and F, flexion

5 | DISCUSSION

In this article, we have described the anatomy of a novel pedicled periosteal flap, harvested from the dorsum of the ulna using the posterior interosseous vessels' axis. The VUPPF was successful at achieving bone consolidation without bone grafting, while treating a complex radius nonunion.

The PIV axis has been described as a means to obtain cutaneous, fascial, or ulnar bone flaps. Our procedure is similar to what has been described previously for adult patients in whom radial nonunion was treated with vascularized ulnar bone flaps supplied by the PIV (Akin, Ozgenel, & Ozcan, 2002; Kamrani, Mehrpour, Sorbi, Aghamirsalim, & Farhadi, 2013). Our technique might be considered a modification of the previous one that has been adapted for the pediatric population, focusing solely on periosteum rather than bone. The rationale for this is that vascularized periosteal flaps yield faster consolidation than vascularized bone flaps (Cheema, Lakshman, Cheema, & Durrani, 2007). This can be explained by the abundance of osteogenic stem cells that are located in the cambium layer (Finley, Wood, and Acland, 1979; Soldado et al., 2012a,c, 2016).

Our technique is in line with several recently described vascularized periosteal graft in children which showed to be very effective in enhancing bone union in remarkably unfavorable scenarios in children (Qi et al., 2008; Soldado et al., 2012a,b,c, 2015). No need for nonunion site bone grafting was necessary with these flaps, as was done in our case (Diaz-Gallardo et al., 2015; Finley et al., 1979; Soldado et al., 2012a,c, 2015, 2016). A periosteal callus would fill the bone gap that eventually evolves into cortical union.

We disregarded nonbiological surgical techniques and opted for a vascularized procedure, owing to the serious clinical scenario of our patient. Alternative biological procedures might include a free vascularized periosteal or bone graft but a local pedicled vascularized periosteal flap for forearm nonunion offers several advantages relative to a free flap including less donor-site morbidity; an operative field being limited to one upper extremity; there being no need to sacrifice either of the main forearm vascular axes (Akin et al., 2002; Andro, Richou, Schiele, Hu, & Le Nen, 2011; Kamrani et al., 2013; Pagnotta, Taglieri, Molayem, & Sadun, 2012; Shahryar Kamrani, Farhoud, Nabian, & Farhadi, 2015) and, finally, being technically less demanding.

One potential disadvantage of the pedicled VUPPF for forearm nonunion might be the risk of radioulnar synostosis. In fact, our patient developed incomplete interosseous ossification. Nonetheless, her final active range of motion, on prono-supination, was 80°.

We found the anatomy of the PIV axis to be similar to that described in previous studies (Cheema et al., 2007; Costa & Soutar, 1988; Kamrani et al., 2013; Penteado, Masquelet, Romana, & Chevrel, 1990). However, limited information exists regarding the ulnar periosteal branches. Contrary to what was reported by Penteado et al. (1990), we found that the PIV has an important part to play in supplying the dorsal aspect of the ulnar periosteum, including a mean 12.8 periosteal branches along the distal 15 cm of the ulna.

Regardless of the limitations inherent in a single case report, we feel that the technique we have just described can be used successfully to manage selected cases of radius nonunion with a small bone gap.

6 | CONCLUSION

The VUPPF may be an alternative to conventional nonvascularized and free vascularized bone/periosteal grafting procedures, to treat radius nonunion with a small bone gap in children, since only the findings from anatomic study and a single are not enough to make a strong conclusion. This technique needs further investigation by application in a larger series of cases.

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