Modified Innervated Radial Collateral Artery Perforator Flap for Repairing Digital Defects

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Abstract The authors presented their clinical experience and demonstrated surgical methods to reconstruct soft-tissue defects in the digit by using modified innervated radial collateral artery perforator flap. Surgical procedures that involved 12 modified innervated radial collateral artery perforator flaps were performed in 12 patients. Among the patients, two had defects in the thumbs, six had defects in the index fingers, whereas two had defects in the middle fingers, two had defects in the little fingers. The flaps ranged in size from 5.0×2.0 to 7.5×4.0 cm. The pedicle of the flap was divided and ligated below the level at which the radial collateral artery was divided into anterior and posterior branches. The recipient vessels were the proper digital artery and the palmar subcutaneous vein ($n=8$), the deep branch of the ulnar palm artery ($n=4$), and the venae comitantes.

Nerve suture was done between the posterior cutaneous nerve of the arm and the proper digital nerve of the digital. The cosmetic appearance of the donor and recipient sites and static two-point discrimination of the operated finger were evaluated in a follow-up visit. Postoperative venous congestion happened in two cases, and both succeeded after exploration. All flaps survived, and all donor sites were closed directly, leaving a linear scar. Follow-up time ranged from 12 to 28 months. Defatting of the flap was performed in two cases during the late postoperative period. Cosmetically acceptable results were achieved for the rest of the patients. The modified innervated radial collateral artery perforator flap is a good option for reconstructing soft-tissue defects in digits.

Keywords Radial collateral artery · Innervated · Soft-tissue defect · Microsurgery

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Introduction

Tissue loss accompanied with nerve injury in the digits presents a challenging reconstruction problem. Traditional repair often involves prolonged treatment with several surgical interventions that are frequently performed in staged procedures [1–5]. Ideally, these procedures should be conducted during a combined operation. Hence, a flap that includes a cutaneous nerve is required to restore flap sensation. Innervated flap coverage is preferable for such injuries. The radial collateral artery perforator flap can provide length, stability, and adequate sensibility for digit soft-tissue repair [6–10]. We reported a modified technique based on our experience in a series of 12 modified innervated radial collateral artery perforator flap procedures from the lateral arm for difficult digit defect repairs.

Patients and Methods

From September 2008 to January 2010, 12 patients with soft-tissue defects in the digits that resulted from crush injuries or motor vehicle accidents underwent reconstructive procedures that employed the modified innervated radial collateral artery perforator flap. Among the 12 patients, two had defects in the thumbs, six had defects in the index fingers, whereas two had defects in the middle fingers, two had defects in the little fingers. The patients included seven males and five females with ages ranging from 15 to 60 years at the time of surgery (Table 1). Five defects were localized to the left hand and seven to the right.

Operative Techniques and Postoperative Treatment

Nine flaps were transferred from the ipsilateral extremity, whereas three flaps were transferred from the contralateral extremity. Procedural sedation was carried out by intravenous administration via a tourniquet. The perforator was identified preoperatively by using an 8-MHz handheld Doppler. Flap elevation began from the posterior side and moved toward the anterior side through the supracutaneous tissue plane (Fig. 1a). Once the perforator was identified, the lateral intermuscular septum was divided. The intermuscular septum and a tiny ellipse of deep fascia cuff were preserved around the radial collateral vessel and its skin perforator on the skin flap. The posterior cutaneous nerves of the arm was identified and contained in the flap (Fig. 1b).

Finally, the entire flap was isolated. Then, the pedicle of the flap was divided and ligated below the level at which the radial collateral artery was divided into anterior and posterior branches, at an average distance of 4 cm proximal to the lateral epicondyle (Fig. 1c). Subsequently, peripheral fatty tissues from the dissected flap were pruned, and the bone segment was trimmed according to the dimensions of the defect.

Finally, the flap was insetted into the defect, followed by microsurgical anastomoses of posterior branch of the radial collateral artery (PBRCA) pedicles. All anastomoses were performed by using an end-to-end method. The recipient arteries were the proper digital artery at the level of the proximal finger crease ($n=8$) and the deep branch of the ulnar palm artery ($n=4$). Venous drainage occurred through the venae comitantes of PBRCA. The recipient veins were the dorsal subcutaneous vein at the level of the proximal finger crease ($n=8$) and the venae comitantes of the deep branch of the ulnar palm artery ($n=4$). Two vessels (an artery and a vein) were anastomosed in nine patients and three vessels (an artery and two veins) were anastomosed in the remaining three cases. For all the patients, the posterior cutaneous nerve of the arm is sutured to the digital nerve as far distally as possible (Fig. 1d). All donor sites were closed directly.

Postoperative monitoring was performed hourly for 3 days. Arterial and venous patencies were monitored clinically based

on the color of the flap. Postoperatively, supportive dorsal plaster of Paris was used to immobilize all patients for 1 week. After the plaster was removed, the patients underwent active and passive physical rehabilitation programs and began to achieve the maximum range of finger motion.

Ethical Considerations

All patients provided a written informed consent and were aware of the objective of the study. We obtained permission to perform the study from the Ethics Committee of the hospital district where the study was conducted.

Results

Postoperative venous congestion occurred in two cases, but both succeeded after exploration. The mean duration of the complete surgical procedure (from the introduction of anesthesia until the patient was taken out of the operating room) was 3.5 h (range 2.5 to 5.0 h). The flap ranged from 5.0×2.0 to 7.5×4.0 cm in size. The outcome was recorded for each patient, and the details of any adverse event or complication are listed in Table 2. All flaps survived and exhibited stable postoperative blood circulation.

The follow-up period ranged from 12 to 28 months, with an average of 15.8 months. Most of the reconstructed fingers resembled a replica of what was missing, with correct length and circumference, similar bulk and contour. Defatting of the flap was performed in patients 4 and 8 during the late postoperative period, whereas cosmetically acceptable results were achieved for the rest of the patients. The final function depended on the severity of the injury and the deformity. Patients who suffered from severe joint stiffness and complex injury before surgery only recovered partially because the active and passive arcs of motion of the involved joints were poor. The sensitivity of the reconstructed digit ranged from 8 to 11 mm (mean, 10 mm). Besides a linear scar, donor morbidity was negligible. An area of numbness was noted along the lateral arm at a location innervated by the posterior cutaneous nerve of the arm. This numbness decreased progressively within the first 4 months after surgery. The functional results for the arms where the flap was transferred were satisfactory.

Case Presentation

Case 2

A 28-year-old male patient sustained a strangulation injury from a drilling machine at his left index finger, leading to soft-tissue defects over the palmar aspect of the finger and severance of the underlying tendons, vessels, and nerves. The modified innervated radial collateral artery perforator flap with a size of

Table 1 Clinical data from the 12 patients who underwent digit reconstruction with modified innervated radial collateral artery perforator flap

Patient	Age (years)/sex	Etiology	Injured finger	Size of cutaneous flap (cm ²)	Op. time (h)
1	37/M	Motor vehicle accidents	Left index finger	5.5×2.0	4.5
2	28/M	Crush injuries	Left index finger	6.5×3.0	3.5
3	28/M	Crush injuries	Right little finger	7.5×4.0	4.5
4	60/M	Motor vehicle accidents	Right middle finger	6.5×3.0	5.0
5	15/F	Crush injuries	Right index finger	7.0×3.0	3.5
6	20/F	Motor vehicle accidents	Left middle finger	7.0×4.0	2.5
7	41/M	Crush injuries	Right thumb	7.0×3.5	2.5
8	32/F	Motor vehicle accidents	Right index finger	5.5×3.0	4.0
9	21/F	Crush injuries	Left little finger	6.5×2.5	2.5
10	39/M	Motor vehicle accidents	Left thumb	5.0×2.0	3.5
11	11/F	Crush injuries	Right index finger	5.5×3.5	2.5
12	56/M	Crush injuries	Right index finger	7.0×4.0	3.5

M male, F female

6.5 cm×3.0 cm was designed and harvested (Fig. 2a, b) and transferred to cover the defects (Fig. 2c), posterior cutaneous nerve of the arm was contained in the paddle and anastomosed with the radial proper palmar digital nerve of the index finger, and the donor site was closed directly (Fig. 2e). The flap survived completely and the sensory of the finger was rebuilt (Fig. 2d). The patient was followed up for 24 months, the flap survived smoothly, and no secondary debulking procedure was necessary (Fig. 2f), static two-point discrimination score of the flap and finger was 10 mm. The donor site healed uneventfully, and only linear scar was left (Fig. 2g).

Discussion

Industrialization has led to increased accidental hand injuries, such as avulsion and crush injuries, commonly together with

defects in proper digital nerves and blood vessels. Especially, it is clinically difficult to repair the wound and reconstruct nerve feeling in one stage using either pedicled or freed grafting of perforator flaps, because most of the flaps applied are not innervated, the anatomic basis and the traditional operative technique limit improvement of clinical outcomes of hand and finger reconstruction [4, 5, 11, 12].

The principal reconstructive methods currently involve island flaps vascularized by the digital artery or the posterior metacarpal artery [1]. These flaps enable repairs without the need for vascular anastomoses and have low operating risks. However, it can be difficult to repair more distal wounds and further scarring and functional compromise of the hand and fingers can result [2].

Perforator flaps are widely used to reconstruct a variety of soft-tissue defects at different sites including the skin or subcutaneous fat [13–15]. For digital defects, the most commonly

Fig. 1 Schematic diagram of digit reconstruction by using the modified innervated radial collateral artery perforator flap. **a** Flap elevation began from the posterior side to the anterior side through the supracutaneous tissue plane. The perforator was then identified. **b** The posterior cutaneous nerve of the arm was identified and contained in the flap. **c** The entire flap was completely isolated. **d** Schematic diagram of vessels and nerve anastomoses

Table 2 Postoperative follow-up data and complications of the 12 cases

Patient	Flap survival	Complication	Bone union (months)	Additional operation	S-2pd Test (mm)	Follow-up (months)
1	Complete	–	4	–	10	16
2	Complete	Blister	3	–	10	24
3	Wound dehiscence (postoperative 7 days)	–	5	Exploration	11	14
4	Complete	–	5	De-fatting	11	14
5	Complete	–	3	–	8	16
6	Complete	Blister	4	–	10	28
7	Complete	Blister, venous congestion	5	Exploration	11	14
8	Wound dehiscence (postoperative 12 days)	–	6	De-fatting	10	12
9	Complete	–	5	–	10	14
10	Complete	–	3	–	10	12
11	Complete	–	5	–	10	14
12	Complete	Blister	6	–	9	12

used perforator flaps are those raised from the ulnar or radial artery [3], but they have numerous disadvantages such as sacrificing the major artery and require several trimmings before a cosmetically and functionally satisfactory result is achieved; the donor site cannot be closed directly and needs skin grafts.

Besides, traditionally, the wound repairing of the hand and finger is emphasized, but sensory reconstruction is neglected. However, after flap reconstruction in the later operation, time delayed, especially when the flap is too bulky and needs second thinning; the clinical outcome of nerve grafting and reconstruction will be far from satisfactory. Therefore, the traditional flap operation has some limits.

Compared with these, the lateral arm flap has the advantages that are thinner and similar in texture to the finger, and it can be operated under the same tourniquet [16–18]. Moreover, the lateral arm flap is a versatile flap that can be used in numerous modifications. In its first description provided by Song et al. [19], this flap was presented as a simple skin flap that addresses the availability of cutaneous nerves for anastomosis. Katsaros et al. [20] reported using a lateral arm skin flap and considered it as a composite graft. However, they did not provide further anatomical details. In 1998, Harpf et al. [21] described a series of 72 lateral arm flaps, 70 of which were used as fasciocutaneous flaps. The anatomy of radial collateral arteries makes them suitable as free flap donor areas [22, 23]. Arnez et al. [24] published a study on three patients who underwent thumb reconstruction by using osteocutaneous neurosensory lateral arm free flaps. All these studies demonstrated that a lateral arm flap can be used successfully in hand surgical reconstructive procedures.

In our series, the modified flap has the additional benefits of enabling the reconstruction of skin sensory function using posterior cutaneous nerve of the arm contained in the flaps, and the skin flap is similar in texture to finger skin. This flap

can be created without additional trauma to the hand, and the donor site is relatively concealed. Furthermore, the cutaneous nerves in the flap can bridge digital nerve defects simultaneously during the flap transplantation.

The perforator dissection technique minimizes donor morbidity. Including the deep fascia within the lateral arm flap is conventionally regarded as essential to flap success. However, a modified suprafascial harvesting technique was used in the present study to improve cosmetic outcome and reduce donor-site morbidity. Reserving a tiny ellipse of soft-tissue cuff around the perforator is essential. Although fatty tissues were further pruned in all 12 patients after elevation, two patients complained of bulking, and thus, defatting the flap was performed for these patients during the late postoperative period. The muscles remained intact upon elevating the skin paddle on the suprafascial plane. The operative procedure was also meticulous. Third, dissecting the pedicle in a traditional manner is tedious because of a multitude of large branches that require ligation. Certain aspects of the reconstruction technique used in this study can render a favorable option relative to previously published methods. Given that very small vessels (<1 mm) can be anastomosed with a high rate of success, harvesting a flap by using an extensive proximal exposure incision to find vessels that are sufficiently large for anastomoses becomes unnecessary [25, 26].

The caliber of the arteries in our series ranged from 1.0 to 1.5 mm (mean 1.2 mm). We always identified two venae comitantes accompanying the artery. The caliber of the large vena comitans ranged from 1.2 to 1.6 mm (mean 1.3 mm), whereas that of the small one ranged from 0.8 to 1.4 mm (mean 1.1 mm). Thus, the caliber of the posterior branch of the radial collateral vessels fits the recipient site well. We decreased the operative time required to harvest the vessel pedicle and still maintained a high success rate in repairing

Fig. 2 The modified innervated radial collateral artery perforator flap for reconstructing defects in index finger. **a** Design of the modified innervated radial collateral artery perforator flap. **b** The flap was completely elevated and shown at the recipient site. **c** The flap was transferred to

the injured hand. **d** The skin flap exhibited good color and texture match with the recipient site 2 weeks postoperative. **e** The donor site was closed directly. **f** Appearance of the index finger 6 months postoperative. **g** Appearance of the donor site on the arm 6 months postoperative

vessels within the range of 1 mm. Furthermore, the radial artery, which provides the dominant arterial blood supply to the hand [27, 28], was preserved.

Although majority of the flaps in our series were elevated on one perforator, comprehensive knowledge on all useful perforators in the middle and distal territories of the arm and elbow is important because it provides surgeons with more options when choosing a flap location, thus increasing adaptability during an operation. Multiple perforators can also be used efficiently.

However, this flap also exhibits several shortcomings, including the variation of perforators, the requirement of a learning curve, and sometimes, the necessity for a second venous drainage. Applying a Doppler probe may help find perforator variation [27, 29].

This study has several limitations. First, this research is retrospective in nature; therefore, it is prone to the same biases and limitations of data collection as other reviews. Second, the number of patients evaluated was relatively small. We limited our initial study to patients who were reluctant to receive prolonged treatment with several surgical interventions and toes damage but still require a good cosmetic outcome. Finally, this procedure requires a microsurgical technique. The anatomical variability and discontinuity of the radial collateral artery in the mid-lateral arm may alter the surgical plan [20].

Although anatomic variation was not observed in the present series, the continuity of the radial collateral artery in the mid-lateral arm should be explored preoperatively by using a Doppler to rule out anatomic variations. Despite

these limitations, our preliminary results imply that the modified innervated radial collateral artery perforator flap can restore sensation and provide a good therapeutic option to address soft-tissue defects in the hand.

Conclusions

The modified innervated radial collateral artery perforator flap may become a valuable option for repairing digital composite defects. Avoiding the sacrifice of a main artery of the hand and a short pedicle can reduce morbidity and operation time associated with this procedure.

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References

- Chen C, Tang P, Zhang L et al (2013) Repair of multiple finger defects using the dorsal homodigital island flaps. *Injury* 44(11): 1582–1588
- Schmitt T, Talley J, Chang J (2012) New concepts and technologies in reconstructive hand surgery. *Clin Plast Surg* 39(4):445–451
- Ignatiadis IA, Mavrogenis AF, Avram AM et al (2008) Treatment of complex hand trauma using the distal ulnar and radial artery perforator-based flaps. *Injury* 39(Suppl 3):S116–S124
- Foucher G, Delaere O, Citron N et al (1999) Long-term outcome of neurovascular palmar advancement flaps for distal thumb injuries. *Br J Plast Surg* 52(1):64–68
- Krishnan KG (2001) Sensory recovery after reconstruction of defects of long fingertips using the pedicled V flap. *Br J Plast Surg* 54(6): 523–527
- Chaput B, Faisan D, Espie A et al (2013) Radial collateral artery perforator (RCAP)-based propeller flap: “discussion”. *Ann Chir Plast Esthet* 58(4):379–381
- Zhang PH, Zhang MH, Xie TH et al (2013) Repair of wound on hand or foot due to electrical burn using free lateral upper arm perforator flap. *Zhonghua Shao Shang Za Zhi* 29(5):424–426
- Sauerbier M, Germann G, Giessler GA et al (2012) The free lateral arm flap—a reliable option for reconstruction of the forearm and hand. *Hand (N Y)* 7(2):163–171
- Brunetti B, Tenna S, Segreto F et al (2013) Lateral arm reconstruction with posterior radial collateral artery perforator based flap. *J Plast Reconstr Aesthet Surg* 66(6):875–876
- Depner C, Erba P, Rieger UM et al (2012) Donor-site morbidity of the sensate extended lateral arm flap. *J Reconstr Microsurg* 28(2):133–138
- Smith KL, Elliot D (2000) The extended Segmuller flap. *Plast Reconstr Surg* 105(4):1334–1346
- Kim KS, Yoo SI, Kim DY et al (2001) Fingertip reconstruction using a volar flap based on the transverse palmar branch of the digital artery. *Ann Plast Surg* 47(3):263–268
- Yoshimatsu H, Yamamoto T, Iwamoto T et al (2014) Toe digital artery perforator flap for coverage of defects on the toe. *J Plast Reconstr Aesthet Surg* 67(2):284–286
- Suzuki S, Koshima I (2011) Digital artery perforator flap for reconstruction of fingertip after resection of melanoma in situ. *Hand Surg* 16(3):395–398
- Koshima I, Yamamoto T, Narushima M et al (2010) Perforator flaps and supermicrosurgery. *Clin Plast Surg* 37(4):683–689
- Chen HC, el Gammal TA (1997) The lateral arm fascial free flap for resurfacing of the hand and fingers. *Plast Reconstr Surg* 99(2):454–459
- Lanzetta M, Bernier M, Chollet A et al (1997) The lateral forearm flap: an anatomic study. *Plast Reconstr Surg* 99(2):460–464
- Sun RM, Wang JD, Li Q, et al (2013) Anatomical study of improved lateral arm free flap. *Zhonghua Er Bi Yan Hou Tou Jing Wai Ke Za Zhi*. 48(1): 37–41
- Song R, Song Y, Yu Y (1982) The upper arm free flap. *Clin Plast Surg* 9(1):27–35
- Katsaros J, Schusterman M, Beppu M et al (1984) The lateral upper arm flap: anatomy and clinical applications. *Ann Plast Surg* 12(6): 489–500
- Harpf C, Papp C, Ninkovic M et al (1998) The lateral arm flap: review of 72 cases and technical refinements. *J Reconstr Microsurg* 14(1):39–48
- Haas F, Rappl T, Koch H et al (2003) Free osteocutaneous lateral arm flap: anatomy and clinical applications. *Microsurgery* 23(2):87–95
- Hennerbichler A, Etzer C, Gruber S et al (2003) Lateral arm flap: analysis of its anatomy and modification using a vascularized fragment of the distal humerus. *Clin Anat* 16(3):204–214
- Kindred E (1976) Planning keeps wards, wings safe. *Occup Health Saf* 45(2):24–26
- del Pinal F (2004) The indications for toe transfer after “minor” finger injuries. *J Hand Surg (Br)* 29(2):120–129
- Koshima I, Inagawa K, Urushibara K et al (2000) Fingertip reconstructions using partial-toe transfers. *Plast Reconstr Surg* 105(5): 1666–1674
- Iida Y, Numata T, Shiba K et al (2002) Hemodynamic changes of the hand after radial forearm flap harvesting. *Ann Plast Surg* 49(2):156–160
- Meland NB, Core GB, Hoverman VR (1993) The radial forearm flap donor site: should we vein graft the artery? A comparative study. *Plast Reconstr Surg* 91(5):865–870, discussion 871
- Taylor GI, Doyle M, McCarten G (1990) The Doppler probe for planning flaps: anatomical study and clinical applications. *Br J Plast Surg* 43(1):1–16