

Pure perforator free sensory proximal ulnar artery perforator flap for resurfacing hand defects

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Abstract

Objective: This prospective study was performed to investigate the distribution of proximal ulnar artery perforating vessels through three-dimensional blood vessel reconstruction and examine the presence and consistency of the perforating vessels intraoperatively.

Methods: For anatomical guidance, three-dimensional blood vessel reconstruction was performed to determine the consistent presence of perforating vessels in the proximal ulnar artery. A free proximal ulnar artery perforator flap was then transferred in 17 patients to resurface skin defects on the hands. Color Doppler ultrasound was used to identify and mark the perforating vessels. Intraoperative evaluation was conducted to check for anastomosis of the perforating vessels at the marked sites and assess the vessel anastomosis conditions.

Results: No vascular crisis, flap necrosis, or wound infection occurred after surgery in 15 patients. Postoperative follow-up was conducted for 6 to 36 months. The appearance of the flap was satisfactory, the texture of the flap was soft, sensation was well restored, and hand function was not limited. The mean two-point discrimination of the flap was 7.6 ± 2.2 mm.

Conclusions: Free sensory proximal ulnar artery perforator flap transfer is a safe and reliable surgical technique with respect to restoration of both the appearance and sensory function of the hand.

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Keywords

Perforator flaps, perforator vessel, ulnar artery, perforator, skin defects, hand

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Introduction

Many methods are available for repairing skin and soft tissue defects in the hand, including skin grafts and the transfer of local flaps, propeller flaps, or free perforator flaps.¹ Because of the special anatomical characteristics of the hand, the surgical goals include not only wound coverage but also restoration of the hand sensation, appearance, stability, and wear resistance as well as reduction of donor morbidity.²

In recent years, many types of local flap transfer have been devised for the repair of small skin defects in the hand.³ Small skin defects in the fingers can be repaired using the V-Y advancement flap⁴ or digital artery perforator flap.⁵⁻⁷ Medium-sized skin defects in the ring and little fingers can be repaired using ulnar palmar perforator flap transfer.⁸ Medium-sized or large skin defects in the hand can be reconstructed by the forearm propeller flap⁹ and free perforator flap transfer.¹⁰ However, the current techniques for perforator flap repair of skin defects on the hand have several deficiencies. First, flaps raised from the dorsal and lateral forearm carry an abundant amount of hair, which affects the appearance of the palm and the finger pad after transfer. Second, during rotation of the propeller flap, the perforating vessel is twisted and the accompanying vein is easily compressed, which reduces the venous blood flow of the vascular pedicle and affects flap survival. Third, the vessel caliber between the hand and flap does not match in traditional free perforator flap transfer. Fourth, most flaps without

sensory reconstruction cannot attain reliable sensation recovery, which is very important for the hand and fingers. Finally, some patients develop secondary morbidities such as pain, dehiscence, scar contracture, and poor abrasion at the donor site. Thus, there is a particularly urgent need to establish a novel free sensory perforator flap transfer technique to reconstruct medium-sized or large defects in the hand.

The present study was performed to investigate the distribution of the proximal ulnar artery perforating vessels through three-dimensional (3D) blood vessel reconstruction and identify the presence and consistency of the perforating vessels intraoperatively. Accordingly, we herein propose a novel technique for free perforator flap transfer that not only considers restoration of both the appearance and sensory function of the hand but also balances the recipient outcome and donor morbidity.

Materials and methods

This prospective study was performed in accordance with the recommendations of the Ethics Committee of the Ningbo No. 6 Hospital, and written informed consent was obtained from all patients in accordance with the Declaration of Helsinki. The protocol was approved by the Ethics Committee of the Ningbo No. 6 Hospital.

The basic technique is shown in Figure 1. First, anatomical guidance was conducted; that is, 3D blood vessel reconstruction of

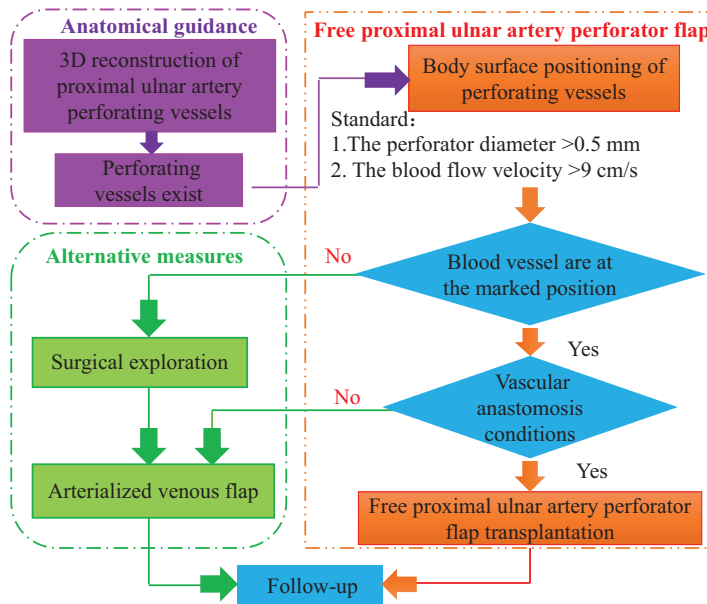


Figure 1. Process of skin defect repair on the hand using free proximal ulnar artery perforator flap transplantation.

four upper limb samples was performed, and the consistent presence of perforating vessels of the proximal ulnar artery was investigated. Second, preoperative ultrasonography was performed to screen for proximal ulnar artery perforating vessels that met the anastomosis conditions, and their position was marked with circles on the skin surface.¹¹ Next, a flap was raised to determine whether the perforator was at the marked position, and the vascular anastomosis conditions were assessed. If the perforating vessel was identified with the marked position and the vascular anastomosis conditions were met, free proximal ulnar artery perforator flap transfer was performed. If the perforating vessel was not in the marked position and could not be found at a nearby location through additional dissection, or if the vascular anastomosis condition was not met (e.g., the caliber of the perforator was too small for successful anastomosis), the alternative

procedure of converting the same flap paddle to a free arterialized venous flap transfer technique was adopted.

Four fresh adult upper limb specimens were provided by the teaching laboratory of the Wenzhou Medical University Department of Human Anatomy. Gelatin–lead oxide was perfused through the femoral artery, and the specimen was subjected to a trigger scan. After the scan, data were transmitted to a workstation for 3D image reconstruction of the ulnar artery. The scanning instrument was a 64-row spiral computed tomography machine (SOMATOM Definition AS; Siemens Healthineers, Erlangen, Germany).

The 3D reconstruction of the four upper limb samples showed that a large, consistent ulnar artery perforating vessel was present at approximately one-third of the line formed from the pisiform bone and the medial epicondyle of the humerus. One of the 3D reconstructions of the ulnar artery

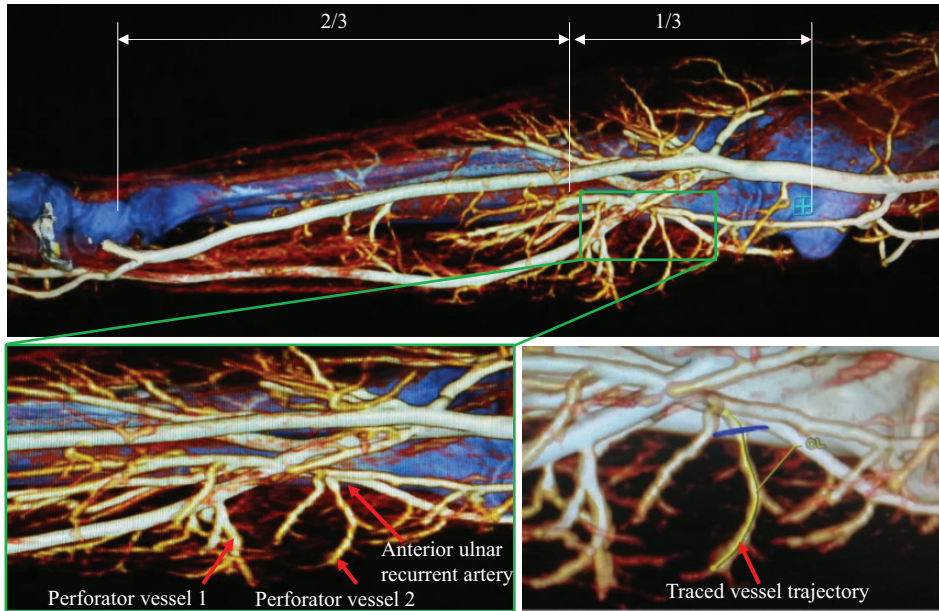


Figure 2. Three-dimensional reconstruction of proximal ulnar artery perforating vessels. (a) Blood vessels of the forearm. (b) Proximal ulnar artery perforating vessels. (c) Tracing of perforating vessels.

perforating vessel is shown in Figure 2. The ulnar artery radiates from the radial artery at the level of the radial head and runs down along a curved path, branching along the way (Figure 2(a)). Eight perforating vessels radiate from the ulnar artery and the anterior ulnar recurrent artery (Figure 2(b)). We traced the ulnar artery perforating vessels (yellow curve in Figure 2(c)) and measured the length and diameter of the proximal ulnar artery perforating vessel based on the traced trajectory. Finally, the mean length was measured as 4.30 ± 0.90 cm, and the mean diameter was measured as 0.71 ± 0.15 mm. Based on these anatomical guidance assessments, we concluded that the proximal cutaneous perforating vessels of the ulnar artery were present and stable.

The technique of pure perforator free sensory proximal ulnar artery perforator flap transfer is shown in Figure 3. Color Doppler ultrasound (iU22; Philips,

Best, Netherlands) was used to detect the proximal ulnar artery perforating vessels before surgery. Perforating vessels with a caliber of >0.5 mm were screened and marked on the skin surface, and their blood flow velocity was simultaneously recorded (Figure 3(a)).

With the position marked using preoperative color Doppler ultrasound, the line joining the medial epicondyle of the humerus and the lateral margin of the pisiform bone was used to design the flap. Aided with tourniquet control in the proximal arm after exsanguination, the flap was incised first at the lateral margin, the superficial fascia was bluntly separated, and the superficial veins and cutaneous nerve of corresponding length in the flap were found and retained based on the coaptation requirements in the region. Next, we determined whether the position of the perforating vessel matched the marked position (Figure 3(b)).

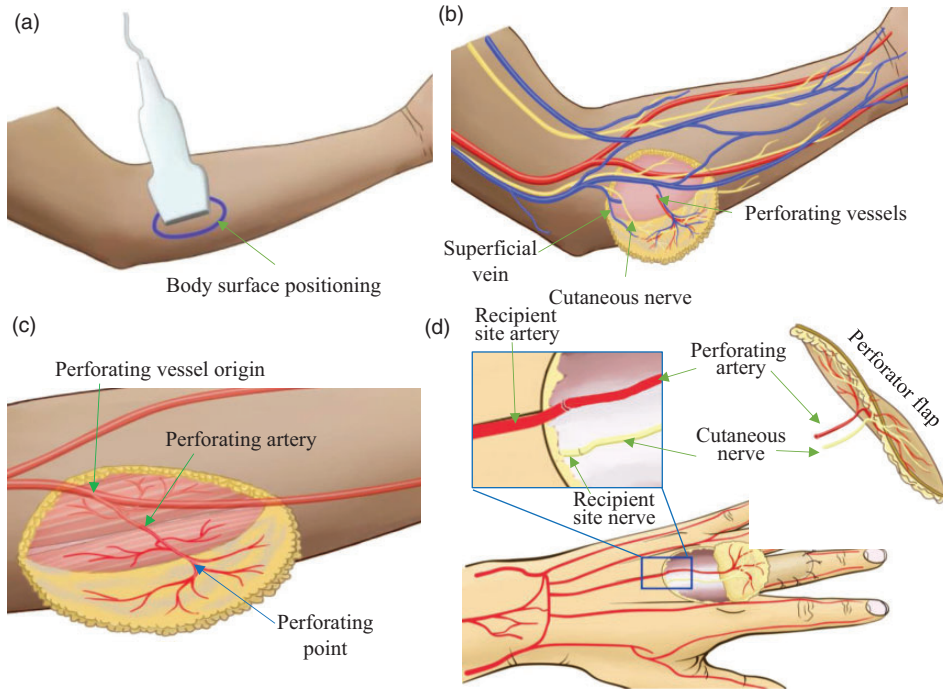


Figure 3. Schematic representation of a pure perforator free proximal sensory ulnar artery perforator flap. (a) Surface positioning of a perforating vessel. (b) Flap incision to determine whether the perforating vessel is at the marked position. (c) Anatomy of the perforating vessel to assess the vascular anastomosis condition. (d) Free proximal ulnar artery perforator flap transplantation.

If consistency was confirmed, retrograde dissection along the perforator vessel was performed.

After raising the flap thoroughly with only the vessel pedicle connected to the source artery, the blood supply of the flap and the pulse of the perforator vessel were assessed intraoperatively. Papaverine was dripped around the perforator vessel to help avoid vasospasm (Figure 3(c)). A good blood supply of the flap and strong pulse of the perforator vessel indicated that no injury had occurred during dissection and that the anastomosis conditions had been met; in such cases, free proximal ulnar artery perforator flap transfer was performed. Otherwise, if the blood supply of the flap and pulse of the perforator vessel were poor, an arterialized venous flap using

the same skin paddle was harvested as a backup.

Either an end-to-end or end-to-side method could be adopted to anastomose the vessels between the flap and the recipient site with the help of supermicrosurgery techniques. The cutaneous nerve of the flap and the sensory nerve in the recipient area were also coaptated. Finally, the wound was recovered by the flap (Figure 3(d)).

All patients were followed up to assess the appearance of the flap, including its color, texture, and other details. The two-point discrimination of the flap was measured to assess flap sensation recovery. Any subjective hypersensitivity or cold intolerance of the flap and any numbness or tingling at the donor site were also surveyed.

Results

Seventeen patients with skin defects of the hand were admitted to our hospital from May 2014 to January 2018 (Table 1). The patients' average age was 40 years. The right hand was affected in nine patients and the left hand was affected in eight patients. Ten skin defects involved one finger, three defects involved two fingers, three defects involved the dorsal hand, and one defect involved the palm. The area of the defects ranged from 2.5×5.0 to 7.0×3.0 cm.

The blood velocity of the perforator arteries as evaluated by color Doppler ultrasound ranged from 9 to 16 cm/s, with an average of 12 cm/s. All 17 flaps survived and all donor sites were closed directly, with only a concealed linear scar remaining. Proximal ulnar artery perforator flap transfer was performed in 15 patients, and no complications occurred. An arterialized venous flap was used as an alternative backup in two patients. Swelling and blistering of the two flaps developed postoperatively, but both flaps survived after conservative treatment.

Postoperative follow-up was conducted for 6 to 36 months, with an average of 20 months. In all 17 patients, the flap was pliable and there was no obvious limitation in hand joint activity. The color of the flap was similar to that of the surrounding tissue in the recipient site, there was no obvious hair growth, and the overall appearance was good. The mean two-point discrimination in the flap was 7.6 ± 2.2 mm. None of the patients reported hypersensitivity or cold intolerance in the flap or obvious numbness, tingling, or other abnormal subjective sensations in the donor site of the medial forearm skin. However, reduced pinprick algesia was found around the skin of the donor site scar compared with the healthy side.

Patient No. 13 (Table 1) developed a skin defect in the left index finger after a crush injury, and a free sensory proximal

ulnar artery perforator flap was transferred to repair it. During the operation, end-to-end anastomosis was performed between the perforating artery and the radial proper digital artery of the index finger, and end-to-end anastomosis was performed between a flap superficial vein and a volar digital vein. The cutaneous nerve in the flap was coaptated with the radial proper digital nerve of the index finger in an end-to-end fashion. The donor site was closed primarily, leaving only a concealed linear scar. The flap survived and healed uneventfully (Figure 4). The 1-year postoperative follow-up examination showed that the flap had a good shape, the two-point discrimination was 6 mm, and there was no limitation in the range of motion of the index finger.

Patient No. 14 (Table 1) developed a skin defect in the left hand after a thermal crush injury. The size of the skin defect in the left palm was 9.0×2.5 cm. The patient underwent free sensory proximal ulnar artery perforator flap transfer. The flap was 9.5×3.0 cm in size, and its perforating artery was anastomosed in an end-to-side manner with the superficial palmar arch artery. End-to-end anastomosis was performed between the perforating vein and the accompanying vein of the palmar arch. End-to-end coaptation of the cutaneous nerve in the flap with the palmar cutaneous nerve was also performed. The flaps survived and healed uneventfully after surgery. The 1.5-year postoperative follow-up examination showed that the color, texture, and sensation of the flap were close to those of the surrounding tissue, and there was no obvious contracture in the palm. The two-point discrimination was 8 mm (Figure 5).

Discussion

It remains a great challenge to find an effective method of repairing skin defects in the hand with a good postoperative

Table 1. Patient profiles.

Patient No.	Sex	Age (years)	Injury mechanism	Recipient site	Size of defect (cm ²)	Pedicle length (cm)	AVF	Sensible flap	Complications	TPD (mm)
1	M	54	Crush	Thumb	5.2 × 2.5	5.4	Y	Y	Purple discoloration and blistering	6
2	M	30	Crush	Thumb	5.1 × 2.4	3.9	N	Y	N	5
3	M	46	Crush	Thumb	4.9 × 2.9	5.5	Y	Y	Purple discoloration and blistering	7
4	M	59	Crush	Index and middle fingers	5.1 × 3.5	7.0	N	Y	N	5
5	M	17	Crush	Dorsal hand	6.8 × 3.6	2.5	N	Y	N	13
6	M	59	Crush	Thumb	5.3 × 2.5	4.5	N	Y	N	8
7	F	53	Crush	Dorsal hand	6.0 × 3.8	3.0	N	Y	N	10
8	F	35	Crush	Thumb	4.7 × 3.6	2.5	N	Y	N	7
9	M	58	Crush	Index finger	4.0 × 3.0	3.6	N	Y	N	8
10	F	24	Crush	Middle and ring fingers	4.8 × 3.2	4.1	N	Y	N	9
11	M	30	Crush	Index finger	7.0 × 2.9	3.2	N	Y	N	11
12	F	17	Thermal crush	Middle finger	5.0 × 3.1	4.3	N	Y	N	7
13	F	42	Crush	Index finger	5.2 × 3.5	3.2	N	Y	N	6
14	F	33	Thermal crush	Volar hand	9.0 × 2.5	3.9	N	Y	N	8
15	F	44	Crush	Ring finger	6.1 × 2.9	2.0	N	Y	N	6
16	M	39	Crush	Index and middle fingers	5.5 × 3.2	5.4	N	Y	N	6
17	F	47	Crush	Index finger	5.8 × 3.2	6.3	N	Y	N	7

M: male, F: female, N: no, Y: yes, AVF: arterialized venous flap, TPD: two-point discrimination.

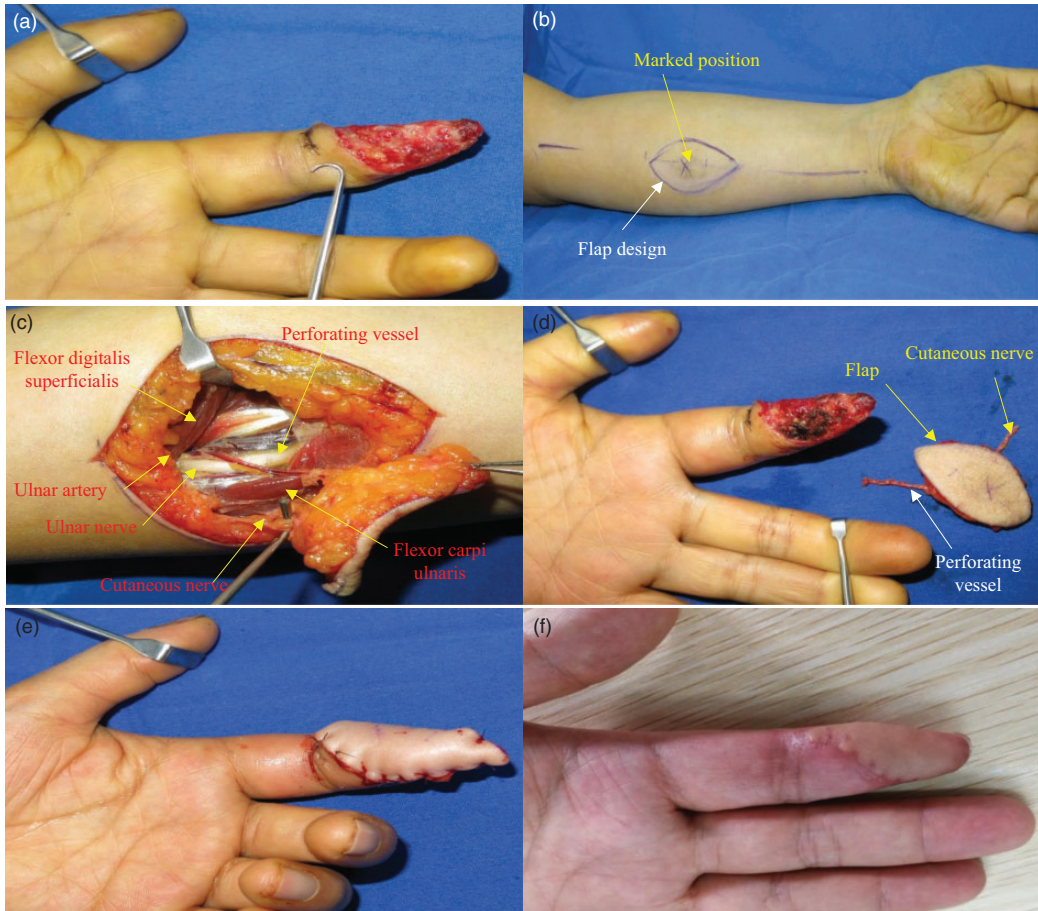


Figure 4. Free proximal ulnar artery perforator flap repair of fingertip skin defects. (a) Left index finger skin defect. (b) Flap design. (c) Anatomy of a perforating vessel. (d) Flap transplantation. (e) Wound coverage. (f) One-year follow-up.

appearance, reliable sensation recovery, and maintenance of a balance between the recipient outcome and donor morbidity.^{5,8,9,12} We have herein proposed a free flap transfer technique with anastomosis of the perforator vessels and coaptation of cutaneous nerves, and we successfully repaired the hand skin defects in 15 patients using this technique. This technique improved the shape of the hand, the reliability of transfer, and the sensation recovery of the flap. The three main innovations of our technique are as follows. First, using

the pure perforator vessels nourished the flap more effectively than the traditional method, which uses part of the ulnar artery. The anastomotic reliability of small vessels (<0.5 mm) with supermicrosurgery techniques was conformed in our study. Second, the branches of the medial antebrachial cutaneous nerve in the superficial fascia of the flap are closely aligned with the superficial veins and perforating vessels, which are easy to find and are suitable for sensation reconstruction. Third, the superficial fascia of this flap is rich in superficial



Figure 5. Free proximal ulnar artery perforator flap repair of skin defects in the palm. (a) Donor site flap design. (b) Preservation of superficial veins and cutaneous nerves. (c) Intraoperative measurement of perforator length. (d) End-to-side anastomosis of flap perforator and superficial palmar arch. (e) The 1.5-year follow-up.

veins, which can either be used to improve the venous backflow or be used as an alternative backup for harvesting an arterialized venous flap with the same skin paddle of the proximal ulnar artery perforator flap.

We strongly recommend positioning the perforators as close as possible to the proximal one-third during the proximal ulnar artery perforator flap transfer. The ratio of musculocutaneous perforators to intermuscular perforators in our study was 4:11, which is consistent with the literature.¹³ The proximal ulnar artery perforating vessels are mainly inserted into the skin through the gap between the flexor carpi ulnaris and the flexor digitorum superficialis; the vascular pedicle is long enough for hand reconstruction. The proximal one-third of the forearm is mainly composed of intermuscular perforators,¹³ the position of which is relatively shallow, and their perforating vascular pedicles are easily dissected.

We achieved a good overall postoperative appearance using the herein-proposed flap transfer technique. This technique has several advantages. First, the skin color, patterns, and texture of the flap are close to those of the hand, and there is significantly less hair than in the rest of the forearm. Second, the donor site is rich in tissue. A deep or extended finger defect, which requires a large amount of tissue for recovery, can fully regain its postoperative appearance. Additionally, using a microdissection technique, a super thin and pliable skin flap can be raised for reconstruction of the back of hand or the fingers. Third, an advantage over foot flaps is that the operation can be completed under the same brachial plexus block anesthesia and controlled using the same tourniquet. Finally, the donor site can be directly closed without an additional skin graft, which significantly reduces the morbidity at the donor site. At the same time, the linear scar is concealed and the appearance is acceptable.

This study has some limitations. A supermicrosurgery technique is required

for this pure perforator flap transfer technique. Additionally, the learning curve of color Doppler ultrasound for the detection of perforators is long and experience-dependent. Finally, our anatomic 3D study can only provide general information about the distribution of the proximal ulnar artery perforator vessels because of the insufficient number of samples.

The proximal sensory ulnar artery perforator flap can be used to resurface a palmar defect of a digit with a good appearance and reliable sensory recovery. However, according to the principle of "replacing like with like," the durability and thickness of the dermis are less optimal than those achieved by the medial plantar perforator flap. In this study, patients with a palmar digit defect were preoperatively advised to undergo treatment with the latter flap, but none of them received our advice after balancing the advantages and disadvantages of the two kinds of flaps. Therefore, as noted in the reports by Shen et al.¹⁴ and Liu and Zheng,¹⁵ a perforator flap raised from the forearm as the donor area can still be an appropriate choice to repair a digital palmar skin defect in terms of balancing the recipient outcome and donor morbidity. The coaptation of cutaneous nerves in our flaps with nerves at different positions in the hand promotes sensory recovery. The nerves were coaptated with the proper digital nerve in nine patients, with the dorsal digital nerve in seven, and with the palmar nerve in one. To reconstruct the sensory function in the recipient site, the cutaneous nerves are carried when raising the flap. The nerve coaptation can be performed in an end-to-end or end-to-side manner.¹⁶ After the original cutaneous nerve in the flap is severed and re-coaptated, regenerated firing of nerve fibers will occur after 1 month, activity will be restored after 2 to 3 months, new re-matching will occur after 4 months,¹⁷ and the density of the neural network in the central area of the flap will reach normal levels

after 6 to 8 months. The 17 patients in our study were followed up for 6 to 36 months after the operation. The mean two-point discrimination in the flap was 7.6 ± 2.2 mm; this was close to the two-point discrimination reported by Yan et al.,¹⁸ showing that the flap technique described in this paper significantly improves sensory reconstruction and is reliable.

In Patients 1 and 3 in our study, the small perforating vessels were damaged by over-stretching during flap dissection. When the flap and its perforator vessels were assessed intraoperatively, we found that the blood supply of the flap was poor, even after the use of papaverine around the pedicle. Therefore, these two flaps were converted to an arterialized venous flap.¹⁹ The arterialized venous flap is a type of non-physiological flap. It is not the first choice among reconstructive surgeons because of its shortcomings. Venous blood flows in a direction opposite to that of the normal blood flow, and the pressure of venous blood cannot easily break through the retrograde valve; this affects reflux,²⁰ making the entire tissue flap prone to swelling.^{21,22} Although this flap can be used to reliably reconstruct sensation, its characteristics in the later stage (including color, texture, and flexibility) are far less optimal than those of a physiological flap. Nevertheless, from the viewpoint of avoiding additional damage to the donor site, the arterialized venous flap can serve as an acceptable backup plan. When the perforating branch is damaged or is an anatomic variant, we can use the same skin paddle to convert the flap into an arterialized venous flap instead of harvesting a new flap from another donor site.

Author contributions statement

Conceived and designed the study: Jiadong Pan, Liping Wang, Xin Wang. Performed the surgery: Jiadong Pan, Miaozhong Li. Performed patient follow-up: Yaopeng Huang. Wrote original draft

of the manuscript: Jiadong Pan, Miaozhong Li, Jianghui Dong, Xin Wang, Liping Wang. Reviewed and edited the manuscript: Miaozhong Li, Jianghui Dong, Liping Wang. All authors read and approved the final manuscript.

Declaration of conflicting interest

The authors declare that there is no conflict of interest.

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