Predictable Pattern Digital Artery Perforator Flap: An Alternative Concept in Digital Reconstruction

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Abstract

Background: The proper digital arteries as any other axial vessel give rise to multiple cutaneous perforators either volar or dorsal along their course. Their identification is performed with Doppler flowmetry. The vasculo-cutano-tendino-osseous complex (VCTOC), which was described by the senior authors, was responsible for the vascularization of all digital anatomic structures (extensor apparatus, skin, periosteum). Their consistent appearance to well measured distances from the digital joints led the way to the present clinical study for highlighting this described anatomy in-vivo and demonstrating the predictability in digital artery perforator (DAP) flap harvest. **Methods:** From November 2012 to March 2014, fifteen patients underwent reconstruction with a predictable pattern digital artery perforator flap (PPDAP), based on the previously described VCTOC mapping, for digital lesions secondary to tumor extirpation. Flaps were designed as V-Y advancement or propeller type. Postoperative control concerned flap viability and digital function. **Results:** Seven males and 8 females underwent elective surgery using PPDAP flaps for digital defects following tumor extirpation. The diameter of the defect ranged from 0.5 to 1.5 cm. The vast majority of the lesions were identified on the right hand, the index, the ring finger and the distal phalanx. All flaps survived without signs of venous congestion. No functional digital problems were observed during follow up (mean of 77 months). A minor wound dehiscence presented in one patient. **Conclusions:** Authors introduced the concept of a “predictable pattern” in the surgery of perforator flaps in the digits. These flaps are reliable and could be a valuable reconstructive option.

Keywords: digital artery perforator flap, vascular cutaneo-tendino-osseous complex, extensor apparatus, dorsal perforators, predictable pattern, Doppler device

Introduction

The description of perforator flaps by Koshima and Shoeda¹⁶ in the late 1980s marked a new era for reconstructive surgery. It was demonstrated that by sparing of the underlying muscle and main vessel, decreased morbidity of the donor site along with an improved aesthetic outcome could be achieved.

Later on Wei and Mardini^{22,35} with their pioneering work introduced the concept of free-style perforator flaps, opening a new dimension in this recent field. A hand-held Doppler device allowed mapping of any clinically significant perforating vessels in every region of the human body offering limitless possibilities to the reconstructive surgeon.

Koshima et al¹⁷ described the digital artery perforator (DAP) flap based on cutaneous perforators originating from the proper digital arteries, which are amenable to numerous free-style perforator flap design options using preoperative Doppler imaging.

Almost at the same time the senior authors in a detailed anatomical work concerning the arterial blood supply of the extensor apparatus of the fingers¹⁸ described the vascular cutaneo-tendino-osseous complex (VCTOC). These complexes (see Tables 1 and 2), based on perforators originating from the proper digital arteries, vascularize not only the extensor apparatus, but also all anatomical elements of the fingers. Their pattern of origin was mapped in detail in relation to their distances from digital articulations (see Figures 1 and 2).

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Table 1. Mapping of VCTOC “Predictable Pattern” Appearance—Distance From the Digital Articulations (Radial Side).

Articulations	Fingers (radial side)				Mean
	Index	Middle	Ring	Small	
	Mean (range)	Mean (range)	Mean (range)	Mean (range)	
MCP	1.3 cm	1.4 cm	1.2 cm	1.3 cm	1.3 cm
(distal)	(1.2-1.8)	(1.2-1.8)	(1.0-1.3)	(0.7-1.8)	
PIP	1.2 cm	1.3 cm	1.3 cm	1.3 cm	1.3 cm
(proximal)	(1.0-1.5)	(1.0-1.5)	(1.1-1.5)	(1.2-1.5)	
PIP	0.9 cm	0.8cm	0.8 cm	0.7 cm	0.8 cm
(distal)	(0.7-1.7)	(0.7-1.0)	(0.7-1.1)	(0.6-0.9)	
DIP	1.0 cm	1.1 cm	1.2 cm	1.2 cm	1.1 cm
(proximal)	(1.0-1.2)	(1.0-1.3)	(0.7-1.5)	(0.9-1.5)	

Note. VCTOC, vascular cutaneo-tendino-osseous complex; MCP, metacarpophalangeal; PIP, proximal interphalangeal; DIP, distal interphalangeal.

Table 2. Mapping of VCTOC “Predictable Pattern” Appearance—Distance From the Digital Articulations (Ulnar Side).

Articulations	Fingers (ulnar side)				Mean
	Index	Middle	Ring	Small	
	Mean (range)	Mean (range)	Mean (range)	Mean (range)	
MCP	1.3 cm	1.2 cm	1.3 cm	1.2 cm	1.2 cm
(distal)	(1.2-1.8)	(0.7-1.6)	(0.7-1.3)	(0.7-1.6)	
PIP	1.4 cm	1.4 cm	1.4 cm	1.5 cm	1.4 cm
(proximal)	(1.2-1.8)	(1.2-1.5)	(1.2-1.5)	(1.2-1.5)	
PIP	0.7 cm	0.7cm	0.7 cm	0.8 cm	0.7 cm
(distal)	(0.6-1.0)	(0.6-0.9)	(0.6-0.9)	(0.7-1.1)	
DIP	1.0cm	1.2 cm	1.1 cm	1.1 cm	1.1 cm
(proximal)	(1.0-1.2)	(0.7-1.5)	(0.9-1.5)	(0.8-1.3)	

Note. VCTOC, vascular cutaneo-tendino-osseous complex.

Figure 1. Perforators’ origin (arrows) from the digital artery (arrowhead) in relation to its measured distance from the MCP (distally) and PIP (proximally) joints on the radial side of a left index finger.

Note. Dotted red line, joint; red cross, projection of the perforator origin on the dorsal aspect of the finger.

Figure 2. Perforators’ origin (arrows) from the digital artery (arrowhead) in relation to its measured distance from the PIP joint (dotted red line) proximally and distally, on the ulnar side of a left middle finger.

Note. Red cross, projection of the perforator origin on the dorsal aspect of the finger.

Subsequently, the purpose of this study was to determine the feasibility of designing and harvesting “predictable pattern” DAP (PPDAP) flaps, highlighting the anatomy *in vivo*, standardizing the procedure to make flap dissection reproducible and safe, thus eliminating the need for preoperative Doppler imaging.

Material and Methods

Patients

All adult patients who presented with a finger lesion to the Plastic and Reconstructive Department of a single tertiary hospital, from November 2012 until March 2014 were included in the study. Patients younger than 17 years of age, patients with a history of trauma over the area to be reconstructed, and those who did not consent to participate in the study were excluded. Medical co-morbidities did not exclude patients from participation in this study. The flap was either islanded in a V-Y manner or rotated in a propeller fashion. Postoperatively, the flap was monitored for any color or temperature change and capillary filling time.

The primary outcome measure was flap survival, and secondary outcome measures included aesthetic result (in terms of color match, contour match, donor site morbidity) and functional outcome (in terms of complete wound closure without any of distortion of adjacent structures). Approval from University Medical School Ethics Committee was obtained.

The sociodemographic profile of the patients, pathology and site of the defect, flap orientation, complications encountered, and outcome in terms of flap success or otherwise, color match, contour match, donor site morbidity, and functionality were all recorded. The data were subjected to statistical analysis.

Anatomy

The arterial supply of the extensor apparatus of the fingers was studied by the senior authors. It was found that the vascularization concerning the proximal third is segmental and 2 systems were responsible for it: the dorsal metacarpal network and the VCTOC. The remaining two thirds (middle and distal) were supplied by the VCTOC. These complexes are perforators derived from the proper digital artery, disposing a main trunk and whose branches vascularize the skin, the extensor apparatus, and the underlying periosteum of the fingers.¹⁸

Their location has been demonstrated to be constant in either side (both radial and ulnar) in relation to the digital joints (MCP, PIP, and DIP). These measurements allowed for the identification of perforators' origins with safety, designing DAP flaps in a predictable pattern without the use of a Doppler device.

Surgical Technique

All dissections were performed with digital block anesthesia, digital tourniquet, and under $\times 3.5$ loupe magnification. The safety margins of the lesion were marked first. Then the dissection was realized as follows:

A. PPDAPs in a V-Y manner

Using a ruler and a skin marker, the origin of the perforator from a joint, closer to the location of the defect, was marked dorsally (see Figure 3a). This mark was based on the results of the detailed vascular mapping (see Tables 1 and 2) from our previous study.¹⁸ Subsequently, the PPDAP flap was designed on the mid-lateral side of the digit. Following lesion extirpation, the flap was incised along with a vertical incision dorsally, which corresponded to the projection of the VCTOC origin, facilitating its dissection (see Figure 3b). Next, skin flaps were raised volarly and dorsally and stabilized with silk stay sutures. Then the flap was raised proximal to distal, filling the defect in a V-Y manner (see Figure 3c).

B. Propeller PPDAP

In the same way, the origin of the perforator related was marked dorsally, according to the detailed mapping (see Tables 1 and 2 and Figure 4a). The flap was designed dorsally. Following lesion resection and flaps' incision, skin flaps were developed. Key point of the dissection is to ensure that the subcutaneous tissue margins should slightly exceed those of the skin paddle, to achieve an optimal venous return (see Figure 4b). Next, the flap was harvested distal to proximal. Rotation of the flap from 45 to 90 degrees followed, filling the defect (see Figure 4c-e).

Skin closure was realized with 4-0 Nylon. Sutures were removed on the 10th postoperative day. Digital immobilization was applied during a 5-day period.

Physical Therapy

A rigorous program of physical therapy was applied to every patient for a 3-week period immediately after suture removal, including massage of the wound, and passive and active range of motion.

Results

Fifteen patients underwent elective surgery for defects that concerned 15 fingers secondary to tumor extirpation. Their age ranged from 21 to 77 years (mean 56 years) with a gender distribution of 7 males and 8 females. Post-resection defect diameter ranged from 0.5 to 1.5 cm

Figure 3. Surgical technique: (a) This is a 56-year-old female patient, presenting a granuloma in the ulnar side of the third phalanx, secondary to accidental insertion of a foreign body 4 months ago. A PPDAP flap was opted in a V-Y manner. Using a ruler and a marker, the flap was marked dorsally, based on the detailed mapping of the previous anatomical work, with the origin of the VCTOCs' main trunk (perforator) from the digital joint closest to the defect (here the DIP). (b) According to the mapping, the perforator originates at 1.1 cm proximal to DIP. Following extirpation of the lesion, the PPDAP was incised along with a dorsal vertical incision, corresponding to the projection of the VCTOC origin. Development of the flaps volarly and dorsally follows. (c) Raising of the flap proximal to distal and filling of the defect. Note. PPDAP, predictable pattern digital artery perforator; VCTOC, vascular cutaneo-tendino-osseous complex.

(mean 0.95 cm; SD 0.35). Median follow-up was 6.9 months (ranging from 1 to 18 months). Pathology included different etiologies, which are presented in Table 3 along with other details.

Concerning the location, 9 lesions were identified on the right hand (9/15 or 60%), while the index and ring finger were mostly affected (5/15 or 33.3% of the cases) followed by the other digits. Moreover, the distal phalanx was affected in more than half of the lesions (8/15 or 53.3%).

A total of 15 PPDAPs flaps based on the VCTOC detailed measurements were utilized to reconstruct the defects. The vast majority of them were V-Y advancement flaps (11/15) and the remaining (4/15) were propeller. Details concerning the location (digit, phalanx, side either radial or ulnar, etc) are presented in Table 4.

All flaps survived without venous congestion-related problems. A minor wound dehiscence presented in one immunocompromised and diabetic patient healed by secondary intention. Color, contour match, donor site morbidity, and functional outcome were remarkable in all cases.

Characteristic clinical case is depicted in Figure 5.

Discussion

An alternative concept was presented in DAP flap surgery. Traditionally, perforators' detection necessitates preoperative use of a Doppler device. However, mapping of the distances of the digital perforators' origins from digital joints provides the anatomical tool for a "predictable pattern" of detection. Depending on the site of the defect, the appropriate perforator is selected using a plain ruler and a marker without the need for any other device. Thus, a PPDAP flap can be designed and utilized for reconstruction. Subsequently, the surgeon becomes able to design the suitable flap expanding the freedom of the free-style flaps.

Venous return in fingers is quite different compared with other anatomic locations. There are no committant veins following proper digital arteries. Lucas²¹ described the pattern of venous drain of the digits in a manner of ladder dorsally, communicating with oblique anastomosing veins to a similar pattern volarly. Sukop et al³¹ studied further this system describing its valvular apparatus. Signs of venous congestion were not observed postoperatively in our series.

Figure 4. Surgical technique: (a) This 55-year-old patient presented with an ulcerated pyogenic granuloma at the level of the PIP. A PPDAP flap was used to treat the problem. Based on the mapping the perforators' origin is marked at 1.4 cm proximal to the joint. The flap is designed dorsally. (b) Following lesion resection, flap and skin incision, a surrounding subcutaneous tissue larger than the skin island is preserved in an effort to ensure better venous return. (c) The flap is rotated around 45° to fill the defect. Immediate postoperative result. (d, e) Postoperative result 18 months later. Satisfactory functional and aesthetic outcome has been achieved with full ROM. Note. PPDAP, predictable pattern digital artery perforator; PIP, proximal interphalangeal; ROM, range of motion.

Flaps' design in a V-Y fashion in the mid-lateral side of the finger lowers the morbidity of the donor area offering a good postoperative outcome. V-Y advancement flap, since the first description by Esser¹³ and its modification by Zook,³⁸ was recognized as a reliable reconstructive option in the management of various defects for several decades.^{2,11,29,32} Limited mobility was a problem, which was solved with the elaboration of the perforator concept.³⁷

Other DAP Series

Koshima¹⁷ in a series of 5 patients first described and used the term *DAP* providing the guidelines for its utilization. Detection of the perforator was performed with a Doppler device.

Mitsunaga et al²⁵ reporting on a series of 13 DAP flaps for fingertip and finger stump reconstruction presented his

experience following traumatic finger amputations. He supercharged them in 2 cases. Partial skin necrosis was noted in 2 flaps.

Kawakatsu and Ishikawa¹⁴ in a small series of 3 patients described first the utilization of dorsal DAP to reconstruct distal dorsal defects. Perforators were detected using a hand-held Doppler device. Flaps designed in a V-Y or rotation manner. No viability problems reported. However, they mentioned an uncertainty in the matching of the marked vessels with the perforators arising from the propria digital artery.

Ozcanli et al,²⁷ in their series of 17 patients, reported on an innervated version of these flaps (innervated—IDAP) covering fingertip defects. Flaps were drawn in a triangular or custom-shaped configuration and used as propeller flaps. However, the pedicle included not only the perforator but

Table 3. Demographic Data.

Demographic data	Value
Patients (n)	15
Fingers (n)	15
Age (year)	
Mean	56
Range	21-77
Gender; n (%)	
Male	7 (46.7)
Female	8 (53.3)
Diagnosis (%)	
Pyogenic granuloma	20
Fibrokeratoma	20
Wart	6.7
Mucous cyst	13.3
Fibroma	13.3
Giant cell tumor	13.3
Annular granuloma	6.7
Pseudorheumatoid nodule	6.7
Type of flap; n (%)	
V-Y	11 (73.3)
Propeller	4 (26.7)
Hand; n (%)	
Right	9 (60)
Left	6 (40)
Digit; n (%)	
Index	5 (33.3)
Middle	3 (20)
Ring	5 (33.3)
Little	2 (13.3)
Phalanx; n (%)	
Proximal	4 (26.7)
Middle	3 (20)
Distal	8 (53.3)
Follow-up (months)	
Mean	6.9
Range	1-18
Flap-related complications	MWD (1/15)
Donor site complications; n (%)	0 (0)

Note. MWD, minor wound dehiscence.

also the final segment of the propria digital artery and the digital nerve located in the vicinity of the defect. All flaps had survived. Compared with conventional DAP flaps, IDAPs can cover larger lesions providing sensation. In addition, as their supply is based on a pedicle including a segment of the digital artery and perforators, no effort for their detection is necessitated. The theoretical question is whether IDAPs could be considered as “true” perforator flaps.

Basat et al⁴ utilized DAPs into a smaller series of 5 patients as a reliable option for fingertip amputation

reconstruction. Perforators were identified and selected intraoperatively, while DAPs were rotated 180° to fill the defect. Donor area was reconstructed with full-thickness skin grafts. Authors reported on one case of a partial skin necrosis.

Other DAP-Like Series (Included Studies Using the Dorsal Branch of the Propria Digital Artery in a Different Manner)

Kin and Wang¹⁵ described their experience in the treatment of fingertip defects into 4 fingers in 3 patients using a flap based on the dorsal branch of the propria digital artery at the middle finger. These branches are identified intraoperatively based on the anatomic studies of Braga-Silva.^{7,8} They used the term *predictable* during the identification procedure. However, it is rather a vague report without any additional explanation.

Li et al,²⁰ in a series of 3 cases, presented an innervated reverse island flap supplied by the end dorsal branch of the propria digital artery, at the PIP level, for fingertip defects. The perforator was identified between the proximal crease of the PIP and the distal third of the middle phalanx. As the treated defects were large, the donor site was covered with a full-thickness skin graft. All flaps survived.

Xianyu et al³⁶ reported their experience in the reconstruction of the fingertips in a series of 7 patients, using an innervated fasciocutaneous homodigital laterodorsal flap supplied by the dorsal branches of the propria digital artery. Flaps were designed over the laterodorsal side of either the proximal or the middle phalanx of the digit depending on the size and the shape of the defect. Dissection proceeded proximal to distal over the paratenon of the extensor apparatus. The dorsal branch of the digital nerve was identified and dissected. The identification of the perforator (dorsal branch) was based on the anatomical work of Bene et al²⁴ and the previous work of Li et al.²⁰ Venous drainage was realized through the surrounding perivascular fat and the cutaneous veins. Flaps were rotated 80° to 160° around the pedicle to fill the defect, while the donor area was covered by a full-thickness skin graft. No complications or venous congestion-related problems were reported.

Pelissier and Casoli et al,²⁸ in their series of 27 patients, were the first who described pedicled island reverse flaps based on the dorsal branches of the propria digital artery to cover different digital defects. Previous well-conducted anatomical studies^{3,5,12,23,26,30,33} provided the robust anatomical background for the design of such flaps. Authors did not identify the perforator during pedicle dissection. Depending on the donor site, these flaps were able to rotate even 180° around the pivot point. No problems of venous congestion were reported.

Table 4. Analysis of Cases Treated With the PPDAP Flap.

Location	No. of cases	Mean lesion diameter (SD), cm	Flap type (propeller/V-Y)	Hand (right/left)	Mean age (SD), years	Sex (male/female)
Digit						
Index	5	0.90 (0.37)	2 propeller/3 V-Y	2 right/3 left	57.8 (19.1)	4 male/1 female
Middle	3	1.10 (0.30)	3 V-Y	2 right/1 left	53.6 (13.8)	3 female
Ring	5	1.00 (0.41)	2 propeller/3 V-Y	4 right/1 left	54.6 (19.5)	2 male/3 female
Little	2	0.75 (0.35)	2 V-Y	1 right/1 left	60.0 (5.6)	1 male/1 male
Phalanx						
Proximal	4	1.12 (0.41)	1 propeller/3 V-Y	3 right/1 left	60.8 (15.2)	2 male/2 female
Middle	3	1.20 (0.26)	2 propeller/1 V-Y	2 right/1 left	53.3 (17.2)	1 male/2 female
Distal	8	0.77 (0.27)	1 propeller/7 V-Y	4 right/4 left	55.0 (17.1)	4 male/4 female
Side 1						
Volar	3	1.13 (0.23)	2 propeller/1 V-Y	2 right/1 left	57.3 (16.7)	1 male/2 female
Dorsal	12	0.90 (0.36)	2 propeller/10 V-Y	7 right/5 left	56.0 (16.2)	6 male/6 female
Side 2						
Ulnar	11	0.94 (0.35)	2 propeller/9 V-Y	7 right/4 left	55.2 (16.1)	5 male/6 female
Radial	4	0.97 (0.38)	2 propeller/2 V-Y	2 right/2 left	58.7 (16.7)	2 male/2 female

Note. PPDAP, predictable pattern digital artery perforator.

Figure 5. Characteristic clinical case: (a) A 54-year-old female patient presented with a mass at the ulnar side of the third phalanx of the right ring finger. A PPDAP flap was opted for reconstruction. Retrieving the mapping of the perforators' origin, a VCTOC originating at 1.1 cm proximal to DIP was selected, and the flap was designed accordingly in a V-Y manner. (b) Following tumor extirpation, the flap was dissected. (c) Immediate postoperative result. (d) Postoperative result 3 months later with a pleasant aesthetic outcome.

Note. PPDAP, predictable pattern digital artery perforator; VCTOC, vascular cutaneo-tendino-osseous complex.

General Statements

The term *digital artery perforator flap* was first described by Koshima¹⁷ and later by Blondeel et al⁶ at the latest edition of their book concerning the perforator flaps.

The VCTOC concept, expanding and completing classical anatomic knowledge related to dorsal digital vascularization, offers a reliable tool in the design of DAP flaps. Accurate measurements allow the design of predictable pattern flaps depending on the location of the defect. Thus, preoperative Doppler identification was not deemed necessary, while at the same time reconstructive surgeon disposes a wide choice of possibilities in the design of flaps. Subsequently, the principle of free-style perforator flaps^{9,10,19,34,37} enriches, avoiding accuracy problems related to Doppler sonography.^{1,24} The V-Y pattern has the inner problem of lesser mobility compared with the propeller flap. However, the selection of the appropriate perforator closer to the defect area could resolve this problem.

Conclusions

An alternative concept was introduced in digital reconstruction. Predictable pattern flaps provide new possibilities enhancing reconstructive armamentarium with more options.

Ethical Approval

This study was approved by our institutional review board.

Statement of Human and Animal Rights

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008.

Statement of Informed Consent

Informed consent was obtained from all individual participants included in the study.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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