Digital Artery Perforator-Based Propeller Flaps for Fingertip Defects: Clinical Evaluation and Reconstructive Considerations

Raafat Abd El-Latif Anani, Amr Nabil Emara Gafar, Ayman FIkry Mehanna, Hisham Aboalez Ibrahim

Department of Plastic and Reconstructive Surgery, Faculty of Medicine, Zagazig University

Corresponding Author: Amr Nabil Emara Gafar

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Abstract

Abstract

Background: Fingertip injuries are common hand trauma presentations and may cause functional, sensory, and aesthetic impairment when reconstruction is inadequate. Digital artery perforator-based propeller flaps provide local, vascularized, sensate-compatible tissue while preserving the main digital artery and avoiding staged procedures.This review evaluates the anatomical basis, reconstructive indications, surgical principles, clinical outcomes, advantages, limitations, and complications of digital artery perforator-based propeller flaps for fingertip defect reconstruction.

Conclusion: Digital artery perforator-based propeller flaps represent a reliable and versatile option for selected fingertip defects, particularly when preservation of finger length, pulp contour, durable coverage, and early functional recovery are required. Their success depends on accurate perforator identification, careful flap design, atraumatic pedicle handling, and prevention of venous congestion. Further comparative studies are needed to define standardized indications and long-term functional outcomes.

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Keywords: Digital Artery Perforator-Based Propeller Flaps, Fingertip Defect, Clinical Evaluation , Reconstructive Considerations

Introduction

The human fingertip is a specialized structure that allows for complex digit functions that are usually not fully appreciated until the function of one or more components has been lost. The fingertip is composed of skeletal elements (distal phalanx, tendons, and ligamentous structures), the nail complex or perionychium (germinal and sterile matrices, nail plate, sheaths, and skin folds), fibrous connective tissue network with the subcutaneous tissues, vascular network, nerves with end organs, and the nonparochial skin [1].

Fingertip injuries are typically classified based on the extent of tissue loss, bone involvement, and specific structures damaged (like the pulp and nail bed). Standardized systems help guide treatment—ranging from simple dressings to complex flap reconstruction [2].

In terms of restoration of useful functions to the hand, flap reconstruction is most relevant for amputations at the fingertip level. If one considers Swanson's classification of hand impairment, 50% of the function of a digit is lost when the finger is amputated distal to the distal interphalangeal joint [3,4].

Ideal wounds suitable for flap reconstruction in the fingers often have exposed joint, bone, tendon or nerve, or extensive combined defects. The defects may be found in an area in which a skin graft may be unstable and lead to wound breakdown [5].

The use of local perforator flaps in general gained a big popularity, due to some of their advantages: (1) Replacing like with like, (2) Donor site in the same area, (3) Possible complete or partial donor site primary closure, (4) Do not need microvascular sutures (microsurgical non-microvascular flaps), (5) Shorter operating time, (6) One stage surgery and (7) No need for extensive neurovascular dissection and makes unnecessary the sacrifice of the digital neurovascular bundle [6].

The use of DAP flaps in finger reconstruction is determined by both the size and the anatomical location of the defect. For smaller defects, especially those involving glabrous areas such as the fingertip pulp or palmar surface, reconstruction can be achieved using DAP flaps allowing the flap to be rotated or advanced to cover the defect effectively [7].

This review aims to evaluate the anatomical basis, surgical technique, indications, clinical applications, advantages, limitations, complications, and reconstructive considerations of digital artery perforator-based propeller flaps for fingertip defects.

The human fingertip is a specialized structure that allows for complex digit functions that are usually not fully appreciated until the function of one or more components has been lost. The fingertip is composed of skeletal elements (distal phalanx, tendons, and ligamentous structures), the nail complex or perionychium (germinal and sterile matrices, nail plate, sheaths, and skin folds), Fibrous connective tissue network with the subcutaneous tissues, vascular network, nerves with end organs, and the nonparochial skin [1].

The Skeleton

The distal phalanx has a head, a diaphysis and a base with articular surface. The dorsal cortex of the distal diaphysis and the head supports the nail plate and the underlying nail matrix. The head of the distal phalanx is an enlarged termination of the phalanx with a "U-shaped" tuberosity called the ungual process. The nail bed also firmly adheres to this distal expansion of the phalanx. In addition, the nail matrix is firmly adhered to the more proximal aspect of the distal phalanx via expansive fibers that serve to anchor the matrix to the base of the distal phalanx [8].

The Perionychium

The perionychium, or nail complex, is a highly specialized structure that is critical to normal digit function. The anatomy of the perionychium includes the nail bed (sterile and germinal matrices), the paronychium, the eponychium, the nail fold, and the hyponychium. The nail plate itself is a hard, kertinaceous three-layered structure formed by contributions from multiple components [9].

The Nail Plate

The nail plate itself is a hard, durable, translucent keratinous protective shell for the dorsal finger tip that provides counterpressure to the pulp, increases the sensory abilities of the digit, increases the ability of the digits to manipulate the environment, protects the nail bed, and splints the phalangeal tuft. It has three histologic layers,The most dorsal or superficial layer is thin and provides its sheen and polished appearance. The middle layer is thick. The ventral or deep layer is irregular with longitudinal striations. The majority of the nail is manufactured by the germinal matrix (dorsal and intermediate matrces) [1].

Fibrous and Ligamentous Network

The extraordinary fibrous structure provides the distal digit its significant anatomical support. The DIP joint is composed of both ligaments and tendons, while robust ligamentous and fascial reinforcement fastens the nail bed and skin to the concealed bone. Together, all of these different complex units of anatomy and the network they compose interrelate and contribute to the support of the joint and the unified distal digit [1].

The tip is organized by radially extending fascial bands from the ungual tuberosity out to the tip dermis that separate the fibrous subcutaneous fat into conical or wedge-shaped compartments. This arrangement makes the fatty and bulky padding of the fingertip very stable to pressure and shear to allow for stable manipulation of the environment by the fingertip while simultaneously allowing for dissipation of pressure or force [1].

Vascular Anatomy of the Fingers

Excluding the Thumb, The proper digital arteries arise as the branches of common digital arteries. The neurovascular bundles of each digit are distributed radially from the center of the palm. The ulnar digital artery is larger in the index and middle fingers and the radial vessel is almost always larger in the ring and small fingers. The common digital vessel to the third web space divides into branches that are large on both sides of the web space [10].

Volar Branches of the Digital Arteries

According to Strauch and De Moura (1990), the palmar subcutaneous tissue receives its blood supply from palmar branches that arise from the proper digital arteries. These branches form anastomoses with their counterparts within the subcutaneous tissue. The proper digital arteries are interconnected by three major volar transverse arches: the proximal, middle, and distal arches. The middle and distal arches are approximately 1.5 times larger than the proximal arch. Their positions are consistent: the proximal arch aligns with the C1 pulley, while the distal arch corresponds to the C3 pulley, lying deep to the flexor tendons. These transverse connections between the digital arteries serve as the foundation for distally based vascular island flaps. The distal arch is formed when the two digital arteries curve centrally to join just distal to the insertion of the flexor digitorum profundus tendon [11].

In 2006, Koshima and colleagues studied the perforating branches of the digital arteries and their terminal arterioles within the subdermal layers. They introduced the term “digital artery perforators” to describe these branches, which pierce the thin fascia and subcutaneous fat to deliver multiple small arterioles into the subdermal layer. Additionally, a dense network of perforating arterioles and venules connects these perforators throughout the subcutaneous tissue along the midlateral line of the fingers [12].

Dorsal Branches of the Digital Artery

The dorsal branches have a regular repetitive pattern at the proximal and middle phalanges Strauch and de Moura (1990) described four vessels: (1) A condylar vessel supplying the condylar area of the metacarpal and proximal phalanx, respectively; (2) A metaphyseal vessel supplying the metaphysis of the proximal and middle phalanx, respectively; (3) Dorsal skin vessels; and (4) Transverse palmar arch vessels (palmar branches), supplying the proximal and middle palmar arches, respectively. These dorsal branches arising from both proper digital arteries supply the skin over the dorsum of the finger (Dorsal digital artery perforator flap) [11].

The dorsal branching vessels originating from the proper digital artery in the middle phalanx of finger are constant. The dorsal branching vessels at the level of DIPJ (Distal interphalangeal joint) give rise to 2 to 3 subungual arcades that vascularize the nail bed. The superficial arcade of the nail bed lies most proximally, just dorsal at the level of the DIPJ [13].

Venous Drainage of the Digits

There are two networks of veins: dorsal and palmar. The dorsal system is larger and more constant than the palmar one. Each of these systems resembles a ladder and are interconnected by lateral anastomotic and commissural veins. In a series of dissections Lucas 1984 found a constant vein that terminated over the dorsal midline of the distal phalanx to arborize over the surface of the nail matrix. The veins running longitudinally along the nail margins were also constant. The longitudinal palmar veins do not travel with the arteries. They are situated more superficially and have a more random pattern, traveling in and out of Cleland and Grayson ligaments. In some, there are deep longitudinal veins on the palmar side along the tendon sheath receiving branches from the vincula system [10].

Vascular Anatomy of the Thumb

The thumb has two arterial systems, The palmar and the dorsal systems. There are two proper digital arteries on the palmar surface: the ulnar digital artery and the radial digital artery. In 90% of individuals, the radial digital artery originates from the princeps pollicis artery while, in 10% of all cases it is seen to originate directly from the superficial palmar branch of the radial artery. The ulnar digital artery is larger in diameter and its origin is variable. In 50% of cases, it originates from the princeps pollicis artery in the other 50% of the population, it may arise from the superficial palmar arch of the radial artery [14].

Dorsal Arteries of the Thumb

The thumb has a dorsal radial and a dorsal ulnar artery. The origin of these dorsal arteries of the thumb is variable. Typically, they arise from the first dorsal metacarpal artery, which itself is a branch of the dorsal branch of the radial artery before it enters the palm. The dorsal ulnar artery originates either from the first dorsal metacarpal artery or as direct branches from the dorsal branch of the radial artery. Rarely they may originate from the princeps pollicis artery. These arteries are absent in 30% of the population [10].

Kosuke Shintani et al 2016 conducted color Doppler ultrasonography for Planning digital artery perforators flaps They mapped perforators from the digital artery of the radial and ulnar sides at the level of proximal and middle phalanges [15].

Fingertip Injury Classification

fingertip injuries are typically classified based on the extent of tissue loss, bone involvement, and specific structures damaged (like the pulp and nail bed). Standardized systems help guide treatment—ranging from simple dressings to complex flap reconstruction [2].

The most common classification systems for fingertip injuries and amputations include:

1. Allen Classification (For Amputations)

This is the most frequently used system, classifying injuries based on the level and structures involved at the tip of the finger: [2].

Allen’s classification of fingertip injuries:

1. Type I-loss of only the pulp of the finger;
2. type II, pulp and nail loss without bone fragment in the distal amputated fingertip;
3. type III, partial loss of the distal phalanx plus corresponding loss of the pulp and nail;
4. type IV, loss proximal to the germinal matrix

2. PNB Classification (Pulp, Nail, Bone)

This system provides a highly descriptive 3-digit number to accurately document the severity of damage to the three core components of the fingertip:

- Pulp (P): Graded on tissue loss and involvement.
- Nail (N): Evaluates damage to the nail plate and nail bed.
- Bone (B): Assesses phalangeal fractures or loss of bone [16].

3. Tamai Zones (For Replantation Feasibility)

This system classifies the zone of injury based on the distal phalanx (the fingertip bone) to dictate whether surgical replantation is an option:

• Zone I: Occurs distal (farther out) to the bone, with preservation of most of the nail bed and germinal matrix.
• Zone II: Located distal to the lunula (the white crescent at the base of the nail) and typically involves exposed bone [17].

4. Classification by Mechanism

Injuries are also grouped by how they happened, which heavily dictates the surgical approach:
• Crush injuries: Often caused by getting the finger caught in a door or hit with a hammer, typically resulting in complex, comminuted fractures.
• Lacerations: Clean cuts or star-shaped (stellate) tears from household or work tools.
• Amputations: Complete or partial severing of the soft tissue and bone [18].

Anatomical and Functional Considerations of Fingertip Reconstruction

Leading Side of Fingers (“High Premium” and “Low Premium” Territories)

One vital principle is the appreciation that not all areas of the hand are of equal functional value. Observation of the hand in action soon reveals that all digits have leading and trailing aspects. While one would not suggest that any part of the hand is of lesser importance, in reconstructive terms these could also be considered “high premium” and “low premium” territories [3].

Once this principle is accepted, one can start to assess the functional significance of a specific defect and the availability of suitable methods of reconstruction:

1. High premium areas require the best possible reconstruction, preferably sensate, glabrous pulp skin taken, if possible, from the same digit.
2. Injury to a low premium area may be reconstructed acceptably and reliably with relatively nonspecialized cover, such as a skin graft or an insensate skin flap.
3. Low premium areas can be considered for transfer to high premium areas, preferably on the same digit, as for instance the reconstruction of ulnar pulp in the thumb using radial pulp. These observations are proposed as factors to be considered and are certainly not absolute [3].

Anatomical and Functional Considerations, Current Flaps, and Digital Artery Perforator Flaps

Reconstruction of fingertip defects requires careful respect for scar placement, tissue matching, digit length, sensation, durability, and vascular reliability. Littler’s principle emphasizes that scars inevitably contract; therefore, incisions should be planned along lines that do not shorten during flexion, extension, or other functional movements of the digit. A properly designed scar should not restrict mobility or create deformity [19]. Similarly, the “like with like” principle remains fundamental in fingertip reconstruction. The ideal reconstructive tissue should match the missing tissue in thickness, pliability, durability, texture, and sensory potential. Finger coverage should be thin and mobile, while palmar and pulp skin should be glabrous, stable, and resistant to pressure. Whenever possible, adjacent local tissue is preferred because it provides the closest match to the lost fingertip components [20].

The choice between amputation and length preservation depends on the severity of injury. When the distal digit is severely crushed, with disruption of the nail complex and/or distal interphalangeal joint, amputation with local skin closure may be appropriate [3]. However, length preservation is important because distal fingertip loss has considerable functional consequences. According to Swanson’s classification, amputation distal to the distal interphalangeal joint may still result in loss of approximately 50% of digit function [4]. Therefore, flap reconstruction is particularly relevant for fingertip-level amputations where preservation of length, pulp contour, and durable sensation is required.

Several soft tissue coverage options are available for fingertip reconstruction. Healing by secondary intention is useful in selected small defects and in children. Mennen and Wiese reported complete healing using semi-occlusive dressings, with an average two-point discrimination of 3.6 mm, indicating satisfactory tactile recovery [21]. Skin grafts may be considered in limited situations, although they should be used cautiously in fingertip reconstruction. Lister recommended full-thickness skin grafts on the functional side of the finger for more durable cover and split-thickness skin grafts on the non-functional side to allow contraction and recruitment of surrounding sensate skin [22]. Composite grafts have variable success, and reported outcomes should be interpreted carefully, especially when based on questionnaires rather than direct clinical assessment. Smoking and graft placement proximal to the eponychial fold are associated with higher failure risk [5]. Skin flaps are preferred when exposed bone, tendon, joint, nerve, or unstable graft beds are present [5].

Traditional flap options remain important in fingertip reconstruction. Homodigital flaps include V-Y advancement flaps, bilateral lateral V-Y flaps, and homodigital island flaps. The V-Y advancement flap was originally described by Tranquilli-Leali and later popularized by Atasoy et al. A triangular full-thickness flap is designed with its base at the amputation edge and apex toward the distal interphalangeal crease. The flap advances over exposed bone while preserving the neurovascular bundles, and the donor defect is closed in a Y configuration [23]. Bilateral lateral V-Y flaps add rotation to advancement, increasing mobility and allowing coverage of larger fingertip defects in different amputation planes [24]. Homodigital neurovascular island flaps use dorsal finger skin to reconstruct pulp defects that cannot be closed by volar V-Y advancement [25].

Heterodigital and distant flaps provide additional reconstructive options. The cross-finger flap is a reliable method for fingertip amputation coverage, particularly when local homodigital tissue is insufficient [26]. The thenar flap, first described by Beasley as a laterally based flap, is designed along the thenar crease and inset into the injured finger after elevation with subcutaneous tissue and fascia [27]. Thumb reconstruction requires special consideration. The Moberg flap is useful for thumb-tip defects and is elevated through midlateral incisions with dorsal dissection to the flexor tendon sheath, allowing up to approximately 2 cm of advancement [28]. The first dorsal metacarpal artery flap is a fasciocutaneous flap based on the first dorsal metacarpal artery or its dorsal digital branches and may be used as a neurosensory flap for thumb reconstruction [29].

Digital artery perforator (DAP) flaps represent a modern refinement in local fingertip reconstruction. Their anatomical basis depends on constant dorsal perforators arising from the bilateral digital arteries and connected by vessel chains. Hu et al. measured perforator locations and diameters and demonstrated that dorsal digital artery perforators, such as P1 and P2, are linked through a vascular chain. In the thumb, the flap can be designed slightly toward the dorsal lateral aspect. Through a volar incision, dorsal perforators of the radial digital artery and their connecting vessel chain can be identified. After ligation of unnecessary proximal perforators, the flap may remain based on a distal perforator and rotate up to approximately 160° to cover a pulp defect [30]. This supports the design of dorsal digital artery perforator chain-based propeller flaps along the dorsal lateral finger [30].

The design of a DAP flap depends on the location of the defect. For radial skin defects or central defects of the thumb, ring finger, or little finger, the flap is usually designed on the dorsal radial aspect. For ulnar defects or central defects of the index or middle finger, it is designed on the dorsal ulnar aspect. Because thumb anatomy differs from that of the second to fifth fingers, separate design principles are used [30]. In thumb reconstruction, the flap is planned along the dorsal digital nerve. The incision is usually started from the volar side and deepened to the fascia. Perforators and their vessel chains are identified, and an intact perforator near the wound edge is selected as the pedicle. The flap position may be adjusted according to perforator location. The flap is elevated while protecting the extensor aponeurosis, vessel chain, and surrounding fascia. The selected perforator should be visible but not fully skeletonized to avoid injury. After tourniquet release confirms perfusion, the flap is rotated by the smallest possible angle, preferably not exceeding 180° [30].

For the second to fifth fingers, the flap is designed over the dorsal lateral aspect, commonly near the distal proximal phalanx. Elevation begins from the volar side, and the dorsal perforator is identified beneath the deep fascia. If the selected perforator is small or damaged, dissection proceeds proximally to locate a more reliable perforator. The remaining unnecessary perforators are ligated, and the flap is rotated into the defect. Donor-site skin grafting may be required. Any fibrous band compressing the vascular pedicle during rotation should be released to prevent vascular compromise [30].

DAP flaps offer several advantages. They replace "like with like," use tissue from the same region, may allow partial or complete donor-site closure, avoid microvascular anastomosis, shorten operative time, permit one-stage reconstruction, and preserve the main digital neurovascular bundle [6]. Compared with free flaps, failure is often less severe because partial superficial loss may still allow coverage of exposed structures, followed by granulation and skin grafting [30]. However, limitations include small flap size, short pedicle length, need for meticulous perforator dissection, donor-site aesthetic concerns, and risk of venous congestion or partial necrosis [25,26]. DAP flaps are indicated for small to medium fingertip defects, especially involving glabrous pulp or palmar tissue, and are useful when local anesthesia, early return to work, or avoidance of staged procedures is desired [7,27]. Contraindications include large defects, previous scarring, vasospastic disease, heavy smoking, diabetic arteriopathy, degloving injury, or extensive soft tissue trauma that may damage perforators [27].

Conclusion

In conclusion, digital artery perforator-based propeller flaps provide a reliable, local, and anatomically sound option for reconstruction of selected fingertip defects. They follow the principles of “like with like” reconstruction, preserve the main digital artery, avoid microsurgical anastomosis, and allow one-stage coverage with acceptable functional and aesthetic outcomes. Their value is greatest in small to medium defects requiring durable coverage, pulp contour restoration, and early functional recovery. However, success depends on accurate perforator identification, careful flap design, atraumatic pedicle handling, minimal rotation tension, and prevention of venous congestion. Large defects, severe crush injuries, previous scarring, and vascular comorbidities should be considered carefully before choosing this flap.

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