Arterialized venous flow-through flaps in the reconstruction of digital defects: case series and review of the literature

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Abstract

Background Arterialized venous flow-through (AVFT) flaps are useful in reconstructing small soft tissue defects. Currently, no guidelines exist for the use of AVFT flaps for reconstructing soft tissue defects in the digits of the hand. We retrospectively reviewed our experience with AVFT flaps and developed a selection process for vascular anastomoses.

Methods We reviewed the use of AVFT flaps in a series of ten consecutive patients requiring reconstruction of small soft tissue defects of the fingers.

Results Between 2006 and 2012, ten consecutive digital reconstructions were performed using AVFT flaps. Flap sizes ranged from 5 to 13.5 cm². Initial congestion was seen in all flaps and resolved within 3–7 days. Leeches were utilized in two cases. All cases achieved good functional results. Three illustrative cases from our series of ten are presented, each demonstrating key decision-making factors in selecting recipient and flap vessels for anastomosis.

Conclusions AVFT flaps appear congested post-operatively, resolving in days to weeks, and resulting in healthy coverage of digital soft tissue defects with good functionality. We suggest a selection process for the use of AVFT flaps in digital soft tissue reconstruction, based on dorsal vs. volar and

proximal vs. distal defect location, and the flap's inherent venous architecture.

Keywords Arterialized venous flow-through flaps · Hand & digital reconstruction · Hand & digital soft tissue defects · Venous flaps

Introduction

Venous flow-through flaps, first described by Nakayama et al. [1] in 1981, have more recently been advocated for the use in the reconstruction of small soft tissue defects of the fingers and hand [2]. The use of a small venous flap can restore circulation and soft tissue coverage to the disrupted surfaces of an injured digit, not otherwise amenable to skin grafts. Other advantages include relative ease of harvest, multiple potential superficial donor sites, minimal donor site morbidity, and single-stage reconstruction [3]. While other flaps, i.e., cross-finger flap, kite flap, or other free flaps, could be used for digit reconstruction, venous flaps are attractive options because they provide thin tissue, potential for vascular reconstruction, and minimal donor site deficit.

Although the use of venous flow-through flaps has increased, their exact physiology remains unclear. Studies have demonstrated more complex patterns of flow-through venous flaps, and with this knowledge, nomenclature describing venous flow-through flaps has evolved. In a recent review, Goldschlager et al. [4] proposed a modification of the classification system originally established by Chen in 1991 [5]. The more recent model takes into account the number of afferent and efferent flap vessels used, as well as the complex branching of intra-flap veins and shunt restriction.

However, much of the literature describing these flaps cautions that they are prone to venous congestion and ischemia during the early post-operative period. As a result, this

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class of flaps has experienced limited use in clinical practice and is not commonly selected as a first choice for soft tissue injuries to the hand and digits.

There has been much discourse on how to improve problems with congestion, edema, and ischemia post-operatively. Despite concerns, there are many reported successful outcomes using venous flow-through flaps that range from 89 to 100 % success rates [2, 3, 6–10]. There are no standard recommendations for the use of venous flow-through flaps in the coverage of digital soft tissue defects.

The current study retrospectively reviewed ten consecutive patients who underwent reconstruction of digital defects using arterialized venous flow-through (AVFT) flaps performed by the senior author (JA). The authors address the established nomenclature and propose a suggested selection method for the use of AVFT flaps in digital soft tissue reconstruction.

Materials and Methods

A retrospective review of traumatic finger defects repaired with arterialized venous flow-through flaps by the senior author (JA) between 2006 and 2012 was conducted. The venous flap vascular anastomoses performed were either digital artery to afferent flap vein and efferent flap vein to digital vein (Chen type III) or digital artery to afferent flap vein and efferent flap vein to digital artery (Chen type IV). All flaps were harvested from the distal volar forearm.

Results

Between 2006 and 2012, the senior author performed ten consecutive digital reconstructions using AVFT flaps. The size of AVFT flap skin islands ranged from 5 to 13.5 cm². In seven cases, a single vein through the flap served as both the inflow and outflow conduits. In the other three cases, a separate efferent vein within the same flap was utilized as the outflow vessel. The latter choice was based on the inherent vascular availability (digital artery or vein(s)) of the tissue surrounding the defect and the venous architecture of the flap itself. All flaps were noted to experience transient congestion post-operatively. Congestion lasted for 3–7 days and was managed conservatively in eight patients, with elevation, rest, and warm room temperature maintenance (80° F). Leeches were utilized in two cases for 5-day duration. All cases of congestion resolved. Post-operatively, patients were anticoagulated with unfractionated intravenous heparin at 300–500 units/h for 5 days, as well as 325 mg of daily oral aspirin for 30 days. There were no complete flap losses. In three of the cases, there was a partial necrosis at the edges of the flap (<1 cm²); all successfully managed with topical

wound care. Wound healing in these three cases occurred by 2 weeks time.

Indications for using digital venous flow-through flaps varied. In five cases, there was exposure of a vital structure (i.e., tendon, bone, and/or joint surface), making the wound not amenable to skin grafting. In four cases, there was loss of vascular continuity, and the AVFT flap served to restore blood flow distally to the digit. Finally, in one case, the indication for using an AVFT flap was late flexion contracture after trauma. After release of the scar, the AVFT flap provided the needed volar skin and soft tissue to restore full extension to the digit.

Three illustrative cases from our series of ten are presented, each demonstrating key decision-making factors in selecting recipient and flap vessels for anastomoses. A suggested selection method is presented for the use of AVFT flaps in hand digital reconstruction.

Selected Cases

Case 1

A 28-year-old right-hand-dominant male sustained a traumatic injury to his right index finger while cutting a board with a table saw (Fig. 1a). He sustained extensive dorsal soft tissue injury with exposure of the extensor tendon and middle phalanx bone. At the time of presentation, the patient did not want surgical intervention and was hopeful that conservative treatment would allow for adequate healing. Therefore, his wound was cleansed and dressed. After a delay of 2 weeks, granulation tissue was starting to cover the exposed structures; however, there was still exposure of both tendon and bone. He was then taken to the operating room for right volar forearm AVFT flap to fill the dorsal soft tissue defect. The planned flap was pre-marked on the volar forearm and measured 2 cm×5 cm. Two parallel veins on the volar forearm were included in the flap. With the use of the operating microscope, the flap was elevated, preserving these two inflow and two outflow veins (Fig. 1b). After reversing the flap and securing it to the defect, a single end-to-end inflow anastomosis with 9-0 nylon suture was performed between the radial digital artery proximal to the level of injury and one flap inflow vein. The distal end of this vein was then clipped. The second, parallel, flap vein was used as the outflow vessel. The distal end of this vein was anastomosed to a dorsal digital vein with 9-0 nylon interrupted suture, while the proximal end of this vein was clipped (Fig. 1d). The flap was therefore classified as a Chen type III venous flap with separate (discontinuous) inflow and outflow vessels, but does not fit any of the Goldschlager modifications. After releasing all clamps, excellent inflow and outflow were noted, and the flap color was good. Total tourniquet time for the case was 94 min. The donor site for the flap was closed primarily. The hand was splinted in a neutral position, with a window for flap monitoring.

Fig. 1 Case 1. **a** Original wound. **b** AVFT flap donor site. **c** Inset AVFT flap. **d** Schematic view of inset AVFT flap (red arterial inflow, blue flap's vein, dashed blue inherent venous architecture of flap, transverse line across blue line clip). **e** Three days post-operatively. **f** Six weeks post-operatively. **g** Twelve weeks post-operatively in extension. **h** Twelve weeks post-operatively in flexion

At 3 days post-op, the flap was very swollen with mild evidence of congestion, which resolved on its own over the next 5 days. By 3 months, the flap had contoured well to the dorsum of the digit (Fig. 1g, h). The patient regained full range of motion.

Case 2

A 12-year-old right-hand-dominant male sustained severe crush injury to the left index finger from a wood splitter (Fig. 2a). The zone of injury was centered on the ulnar and volar surfaces, at and just proximal to the proximal interphalangeal (PIP) joint. There was a comminuted intra-articular fracture of the distal portion of the proximal phalanx. When seen at an outside hospital 4 days after the accident, pinning of the fracture and laceration closure were performed. Post-operatively, he was noted to have loss of blood flow to the index

finger distal to the PIP joint. Pins and sutures were removed, and when blood flow to the finger did not improve, the patient was transported urgently to our institution. On our exam, blood flow had recovered, with appreciable Doppler signal on the radial side of the index finger, distal to the injury. However, the finger had a mottled appearance and sensation distal to the zone of injury on both sides of the digit was absent. There was a 1.5 cm × 3 cm area of nonviable soft tissue on the ulnar aspect of the digit.

Initially, the patient was admitted to a warm room, with the hand immobilized and elevated, and 325 mg of oral aspirin was given. However, minimal improvement in perfusion of the digit was noted after 24 h. An operative plan was made which included an AVFT flap interposed at the injured ulnar digital artery, restoring perfusion to the distal finger and bringing soft tissue to close the volar and ulnar wounds. At this time, the patient was brought to the operating room. The proximal phalanx fracture was percutaneously pinned with two 0.028-in. K-wires. Examination of the ulnar digital neurovascular bundle revealed a contused but intact digital nerve, but the artery was transected. The proximal and distal ends of the ulnar digital artery were identified and debrided, noting a 3-cm gap. A 1.5 cm × 3 cm flap was planned on the volar forearm overlying a superficial vein and harvested under the microscope (Fig. 2b). After reversing the orientation of the vein, end-to-end anastomosis was performed to digital artery, both proximally and distally. Immediately after releasing the clamps, the flap and digit both appeared well perfused with good capillary refill and Doppler signal (Fig. 2c). This flap was classified as a Chen type IV arterialized venous flow-through flap with a continuous central vein and arterial inflow and outflow (Goldschlager *C1P0*). Total tourniquet time for the case was 60 min. IV heparin was started at 300 units/h in the operating room and continued for 5 days. Aspirin was continued for 30 days.

By post-operative day 5, the flap was clearly congested, and by day 7, superficially sloughed the distal one-eighth. This area fully reepithelialized with topical wound care over the next 2 weeks. With occupational therapy, the patient went on to a full recovery with good PIP joint flexion and extension and recovered sensation throughout the distal finger. He had a persistent 15° extensor lag at the PIP joint. Figure 2 demonstrates the operative and post-operative results.

Case 3

A 44-year-old right-hand-dominant male sustained a traumatic injury to his right index finger while cutting a board with a table saw (Fig. 3a). He sustained extensive dorsal soft tissue injury with exposure of the terminal extensor tendon and DIP joint. At the time of presentation, the wound was irrigated and debrided with the plan for definitive repair.

Fig. 2 Case 2. **a** Original wound. **b** AVFT flap donor site. **c** Inset AVFT flap. **d** Schematic view of inset AVFT flap (red arterial inflow and outflow, blue flap's vein, dashed blue inherent venous architecture of flap). **e** Five days post-operatively. **f** Three weeks post-operatively. **g** Eight weeks post-operatively in extension. **h** Eight weeks post-operatively in flexion

The patient was taken to the operating room and a right volar forearm AVFT flap measuring 2 cm×4 cm was designed overlying a single superficial vein. With the use of the operating microscope, the venous flow-through flap was elevated superficial to the forearm fascia to include the superficial vein. After reversing the flap and securing it to the defect, a single end-to-end inflow anastomosis with 9-0 nylon suture was performed between the radial digital artery proximal to the level of injury and the afferent end of the flap vein. An outflow anastomosis was similarly created between the efferent end of the flap vein and a dorsal digital vein. The flap was classified as a Chen type III arterialized venous flow-through flap with a single (continuous) vein for both inflow and outflow (Goldschlager *CIP0*) (Fig. 3c). After releasing all clamps, excellent inflow and outflow were noted, and the flap color was good. Total tourniquet time for the case was 60 min. The donor site for the flap was closed primarily. The hand was

splinted in a neutral position, and the patient was started on daily aspirin for 30 days and IV heparin at 500 units/h for 5 days.

The patient did well post-operatively and had transient congestion that lasted for 4 days which was managed conservatively with elevation, rest, and warm room temperature maintenance (80° F). At 2 years post-operatively, he had good function with mild stiffness at the DIP joint (Fig. 3d). The flap contoured well to the dorsum of the digit.

Discussion

Nomenclature

The nomenclature of venous flow-through flaps can be confusing, due largely to the diversity of venous anatomy and myriad subsequent flap designs. In addition, descriptive terminology for proximal and distal is opposite of arterial terms (e.g., proximal venous is located distal on the digit, while proximal arterial is located proximal on the digit). Venous flow-through flaps may be anastomosed to recipient site arteries or veins at either the afferent or efferent ends of the flap. Further complicating matters, the flap can be designed as free or pedicled. Additionally, some authors describe using efferent veins that are not directly continuous with the afferent vein, either due to the underlying venous architecture (i.e., parallel bridging veins) [6] or selective venous ligation to diminish shunting (i.e., shunt restriction) [2]. Disruption of shunting is felt by some authors to be critical in preventing poor flap perfusion [2, 9]. We did not perform restrictive shunting in any of our cases.

As the understanding of venous flow-through flaps has grown, the initial classification scheme, described by Chen et al. in 1991 [5], has been updated. Goldschlager et al. modified the Chen classification of venous flow-through flaps [4]. Using the Goldschlager model, the flaps employed in our current series all use arterial inflow (*arterialized*) with either venous (type III) or arterial (type IV) outflow. Seven of the ten cases in this series were *CIP0*, signifying a single “central” vein acting as both the afferent and efferent conduits within the flap, whereas the other three cases were flaps using a central inflow vein and a separate (potentially discontinuous) outflow vein.

Congestion and Necrosis of Arterialized Venous Flow-Through Flaps

One limitation many authors have noted with venous flow-through flaps is the tendency for congestion and edema, with possible subsequent partial or complete flap necrosis [6]. This can complicate the post-operative course and requires close

Fig. 3 Case 3. **a** Original wound. **b** Inset AVFT flap. **c** Schematic view of inset AVFT flap (*red* arterial inflow, *blue* flap's vein, *dashed blue* inherent venous architecture of flap). **d** Two years post-operatively in flexion

monitoring of color, temperature, and blood flow through the flap. Recent modifications in flap design, such as retrograde shunts, parallel veins, shunt restriction, and multiple outflow vessels have been used to address these problems and are discussed extensively in the literature [2, 6, 9, 11–13]. Woo et al. noted a case of severe edema and discoloration after performing an AVFT flap. Flap swelling was found to be most pronounced during the first post-operative week, slowly resolving thereafter [9]. A period of congestion followed by resolution was confirmed by De Lorenzi et al., who described a 10–14-day recovery period for resolution of flap congestion [3]. Lin et al. reported similar findings in 40 % of cases and noted that congestion and tissue loss was focused at the afferent end of affected flaps [2].

Additionally, Woo et al. found that when the number of outflow vessels increased, flap survival improved [9, 13]. Despite the use of multiple outflow veins, Woo still reported some necrosis in 7 % of patients during the early post-operative period. Partial or complete necrosis occurred more commonly when operating under less than ideal circumstances, such as a chronically infected or open wounds, or largely avascular recipient sites [9].

In our series of ten patients, some degree of AVFT flap congestion and edema was seen in all cases. In seven cases, a single vein through the flap served as both the inflow and outflow conduits. In the other three cases, a separate efferent vein within the same flap was utilized as the outflow vessel. Perhaps due to the relatively small flap sizes used in our series (2.5 cm×2 cm to 4.5 cm×3 cm), the congestion seen was transient. Wound healing issues observed were minor,

occurring within a time frame consistent with that reported above, and in all cases required local wound care only.

Selection of Arterialized Venous Flow-Through Flap Vascular Anastomoses

One central question when using AVFT flaps for digital reconstruction is which type of flap to use. There is no one correct answer to this question. However, we propose a straightforward selection process to address the selection of donor and recipient anastomoses, based anatomically on location: dorsal vs. volar and proximal vs. distal to the mid-shaft of the middle phalanx (or the interphalangeal joint of the thumb) (Fig. 4). The mid-shaft of the middle phalanx is a convenient and generally recognizable landmark, which correlates approximately with the division between flexor tendon injury zones 1 and 2. The rationale for this selection is simple: distal and dorsal to the middle portion of the middle phalanx, arterial targets for the efferent limbs are likely too small to be dependably useful, and the need for additional distal blood flow is minimal. Conversely, the negative effects of shunting directly to the outflow vein will be less problematic distally, where the caliber of the efferent recipient site vein is likely to be small. The flap's inherent venous architecture can be utilized to augment flow through and/or out of the flap, with potential benefits to flap survival.

When the digital wound is located volar and proximal to the mid-shaft of the middle phalanx, a type IV flap with arterial inflow and outflow (i.e., interposition) should be used. This suggestion maximizes arterial inflow and reestablishes in-line continuity of the digital artery. If the flap has an

Fig. 4 Selection of arterialized venous flow-through flap vascular anastomoses. *A-V* indicates inflow artery to inflow flap vein; *V-V* indicates outflow flap vein to digital vein; *V-A* indicates outflow flap vein to distal arterial target; *a* indicates dependent on inherent flap architecture (“central” or “peripheral” flap veins present) and wound geometry (availability of recipient digital artery or vein(s))

additional peripheral efferent vein, orientation of the flap in a way that provides coverage, while simultaneously allowing a second efferent anastomosis (between the flap vein and a dorsal vein), is an option available to the surgeon.

When the digital defect is located volar and distal to the mid-shaft of the middle phalanx, a type III AVFT flap with venous outflow to a dorsal vein should be utilized. This suggestion is based on the small size of arterial outflow targets distal to the mid-shaft of the middle phalanx. Therefore, dorsal venous outflow becomes the more viable option.

When the digital defect is located dorsal and proximal to the mid-shaft of the middle phalanx, a type IV or type III flap can be used, utilizing arterial inflow and either flap vein to recipient site artery or vein, depending on local flap venous architecture and recipient site targets. Consideration should be given to the potential for deleterious venous shunting if the flap’s efferent vein is anastomosed to a large dorsal venous recipient vein for outflow. Selective ligation of flap veins may also be an option to combat shunting.

Digital defects, located dorsal and distal to the mid-shaft of the middle phalanx, are best treated with type III flaps, utilizing digital arterial inflow and dorsal venous outflow, based on the small size of arterial outflow targets in this area (similar to volar distal defect repair).

Conclusion

Traumatic injuries to the hand can expose vital structures, such as tendon, bone, and neurovascular elements. We suggest a selection process for the use of AVFT flaps in digital soft tissue reconstruction, based on dorsal vs. volar and proximal vs. distal defect location, and the flap’s inherent venous architecture. With volar defects proximal to the mid-shaft of the

middle phalanx, an arterialized venous flow-through interposition flap is most suitable. Volar or dorsal defects distal to the mid-portion of the middle phalanx are best treated with digital artery to flap vein inflow and flap vein to digital vein outflow. Dorsal proximal defects are best addressed with artery to vein inflow and flap vein to recipient vein or artery outflow, depending on flap venous architecture and wound geometry.

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Conflict of Interest Jared W. Garlick declares that he has no conflict of interest.

Isak A. Goodwin declares that he has no conflict of interest.

Keith Wolter declares that he has no conflict of interest.

Jayant P. Agarwal declares that he has no conflict of interest.

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 This study was submitted to our institutional IRB and received exempt status.

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