

Clinical applications of venous flaps in the reconstruction of hands and fingers

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Abstract In recent years, the venous flap has been highly regarded in microsurgical and reconstructive surgeries, especially in the reconstruction of hand and digit injuries. It is easily designed and harvested with good quality. It is thin and pliable, without the need of sacrificing a major artery at the donor site, and has no limitation on the donor site. It can be transferred not only as a pure skin flap, but also as a composite flap including tendons and nerves as well as vein grafts. All these advantages make it an optimal candidate for hand and digit reconstruction when conventional flaps are limited or unavailable. In this article, we review its classifications and the selection of donor sites, update its clinical applications, and summarize its indications for all types of venous flaps in hand and digit reconstruction.

Keywords Venous flaps · Classifications · Hand and digit reconstruction · Microsurgery

Introduction

The hands and fingers have many functional and cosmetic features that pose limits on the options that are available to

treat soft tissue injuries, especially when deep structures are exposed. Classically, soft tissue injuries have been treated by using various types of skin flaps such as cross-finger flaps, dorsal metacarpal flaps, neurocutaneous island units, advancement flaps, kite and flag flaps, and reversed radial forearm flaps [1–5]. The adequacy of these flaps is dependent on the ability to establish a conventional vascular pedicle with an afferent arterial inflow, a capillary system, and an efferent venous outflow. In hands and fingers, however, these flaps are associated with remarkable donor site morbidity. They are not only limited, if not lacking, in the number of suitable donor sites, but they are also restricted by the size, orientation, location of defect, number of digits requiring reconstruction, as well as the length of pedicle necessary for the reconstruction.

A promising alternative in managing such scenarios is represented by the venous flap, defined as a composite flap of skin and subcutaneous veins, which relies on the venous system alone for flap perfusion. Unlike conventional arterial flaps, venous flaps do not sacrifice an artery of the donor site nor do they require deep dissection. This results in an easier procedure as well as a decrease in morbidity of the donor site. In addition, they are thinner and more pliable because they consist only of skin, venous plexus, and subcutaneous fat. They can also be transferred simultaneously as a composite flap to reconstruct the defects of affected tendons and vessels [6–16]. These advantages make venous flaps an ideal indication for the repair of soft tissue defects in hands and fingers, especially when local and other conventional flaps are not available.

The venous flap was first introduced in an experimental study by Nakayama et al. [17] in 1981. Possible mechanisms for the survival of the venous flaps are based on three main theories. These include “A–V shunting” [18] or retrograde flow from the venous system to the arterial system

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via paralyzed arterial–venous shunts, “reverse flow” [19] or a “to and fro” intermittent flow with perfusion of the blood from the flap vein to the capillary and then back to the vein, and finally “capillary bypass” [20] or flow through the venous system without entering the arterial side until neovascularization. There is no conclusive evidence and therefore no consensus regarding the exact mechanism for venous flap survival. However, it is probable that a combination of the aforementioned factors is responsible for perfusion of venous flaps [21]. Ever since the early reports of Honda et al. [6] and Yoshimura et al. [22] were published on the clinical use of venous flaps in the replantation of amputated digits, there have been many descriptions of the applications of venous flaps on various types of hand and finger reconstruction [6–16, 22–29, 31–40, 42–58]. However, because of its unconventional perfusion pattern and inconsistent survival in some cases [23–27], the clinical application of venous flaps is still under further investigations. This article reviews the clinical applications of various venous flaps reported in literature and evaluates their values in hand and finger reconstruction.

Classifications of venous flaps utilized in the reconstruction of hands and fingers

In literature, the classification of venous flaps employed in hand and finger reconstruction was first introduced by Chen et al. [28] in 1991. In their original report, venous flaps, which were used for the coverage of hand wounds over exposed bones, joints, and tendons, were classified into four types: type I, a free venous flap with total venous perfusion where both ends of the vein were anastomosed with two veins; type II, a pedicled venous flap with total venous perfusion where one end of the vein was intact and the other end was anastomosed to an adjacent vein; type III, a free venous flap of arterialized venous perfusion with an afferent A–V fistula where the distal anastomosis was an artery to a vein and the proximal anastomosis was a vein to a vein; type IV, a venous flap with total arterialized venous perfusion in which both ends of the vein were connected to arteries. The authors also proposed another possible type of pedicled venous flap, in which the proximal end of the vein was intact as a pedicle and the distal end of the vein was anastomosed to an artery, but they did not utilize this type in their series.

In 1994, Fukui et al. [29] proposed another four-type classification system of venous flaps in hand and finger reconstruction. These two four-type classifications further elaborated on the common three-type classification of venous flaps in plastic and microsurgery surgery by Thatte et al. [30] (Table 1). Recently, Woo et al. [31] refined the classification of arterialized venous flaps used in hand and

Table 1 Classifications of venous flaps

Thatte et al. [30] (1993)	Chen et al. [28] (1991)	Fukui et al. [29] (1994)	Perfusion patterns
Type I	–	Type A	V(pedicled)–V(flaps)
Type II	Type I	Type B1	V(free)–V(flaps)–V(free)
–	Type II	–	V(Pedicled)–V(flaps)–V(free)
Type III	Type III	Type B2	A(free)–V(flaps)–V(Free)
–	Type IV	Type B3	A(free)–V(flaps)–A(Free)

V vein, A artery

finger reconstruction into three types. Their classification takes into consideration the presence of an intravenous valve, the venous network of the donor site, the location, and the number of veins at the recipient site. Type I is a “through and along-valve” type, which mimics similar blood flow as in a standard vein graft with a straight or Y-shaped pattern. Type II is against-valve, which is arterial inflow against the valve through the afferent vein with a reversed Y- or H-shaped venous network. In type III venous flaps, venous flow drains through efferent veins against intravenous valves. They suggested that type I, II, and III could be utilized for the coverage of small, medium, and large defects, respectively.

Pedicled venous flap

In the hand and finger, a pedicled venous flap is produced by preserving a draining vein of the flap, cutting the arterial branches entering the flap, and then transferring it. Two types of pedicled venous flaps were developed in this clinical setting: unipedicled (Thatte et al., type I) and bipedicled venous flaps (Chen et al., type II) [28, 30].

The unipedicled venous flap was first performed in the reconstruction of hand and both palmar and dorsal digital defects by Foucher and Norris [32] in 1988. A total of 23 patients were treated with pedicled venous flaps. Of the 23 flaps, there was one case of total flap loss (4.3%), two cases of superficial loss (8.6%), and one partial flap loss (4.3%). They concluded that it was not suggested that the venous dorsal digital island flap should replace the more conventional reconstruction for hand and digital defects, but that it adds to the hand surgeon’s armamentarium when dealing with more awkward defects. Also, a dorsal pedicled venous flap can be transferred through either the web space or between the metacarpals to the palmar surface with less donor site morbidities. In 1989 and 1993, Fukui et al. [33, 34] presented their experiences using the unipedicled venous flaps for the reconstruction of traumatic skin defects on digits. Their results suggest that the successful survival

of these flaps depends partly on revascularization from the recipient bed, and the draining vein should not be dissected more than 5 cm [29]. Xiu et al. [35] and Cil et al. [36] also succeeded using this type of flap in hand and finger reconstruction. They recommended that a well-planned distally based venous flap was a useful option for the coverage of the defects from proximal phalangeal soft tissue burn defects of the finger and web space burn contracture of the hand.

The bipediced venous flap (Chen's type II) was first reported by Amerante et al. [37] in 1988, in which through flow was re-established by a simple venous anastomosis for the coverage of the skin defects after scar excision on hand. Although 100% survival was achieved in Chen's study [28], the authors still deemed that this type of venous flaps should not replace traditional flaps if possible. Due to the low perfusion state in the venous network, they suggested that the tissue should be handled with care in order to preserve the tenuous vascularity and recommended Dextran postoperatively. Another technique introduced by Inada et al. [38] might be considered as a modification of this type of pedicled venous flap in the treatment of poorly perfused skin defects on the lateral aspect of the fingers. They developed the sliding venous flap, which can be moved to the defect by utilizing the elasticity of the dissected dorsal veins on the same finger. This technique was applied in six cases with excellent results, but the indications for this technique were limited to those with only slight injury on the dorsum of fingers.

Free venous perfusion flap

Free venous perfusion flaps (Chen's type I) were first introduced by Tsai et al. [39] in 1987. In their series, 15 patients who underwent replantation/revascularization of a single digit with substantial defects in the dorsal soft tissue were reconstructed with free venous flaps. The flaps were transferred by venous anastomoses at both ends with dorsal superficial veins of the recipient digits. The flaps from the dorsal aspect of an uninjured digit had a survival rate of 100% with no partial necrosis, while the flaps from a forearm or dorsal foot donor site failed. Their original experience advocates the advantages of using venous free flaps, especially in the replantation or revascularization of a digit. Not only does this technique provide for venous drainage, but it also provides flap coverage and avoids complications, such as vessel occlusion or hematoma formation, associated with skin grafting over a venous anastomosis, with subsequent loss of the skin graft. However, the total success rate was only 73.3%. Also, in 1989, Fukui et al. [33] successfully reconstructed the skin defects on the dorsal side of the finger and hand with this flap in two cases. They proposed

that the following conditions be regarded as essential: the use of a venous flap with a rich venous network; the preservation of many "flow-through" veins; and the anastomosing veins of the "flow-through" flap with recipient veins where high efferent venous pressure exists and differential pressure is observed.

It is common sense that indications for V–V flaps are skin defects of small dorsal areas of the fingers. It can also be used for skin defects in the dorsal area of the hand, if the number of veins anastomosed is increased [25, 40]. Kantarci et al. [40] presented seven cases using this flap on the hand. Five small flaps survived uneventfully (71.4%), while the other two larger flaps sustained complete necrosis. It has been reported that the width of this type of flap must be 1.0–2.0 cm or less with a single flow-through vein for survival and that the rate of survival of this flap is lower than that of the other types [41]. However, the width of these flaps can be increased and their indications can be expanded if the number of anastomosed veins is increased [25]. Nonetheless, few investigations using this type of venous flap achieved more than 80% of survival rate [25, 39, 40] and, recently, no more clinical reports on this type of venous flaps have been retrieved from literature.

Free arterial perfusion (arterialized) venous flap

Venous flaps with arterial inflow (Chen's type III, IV) have been found to be more reliable than those with venous inflow [22, 24, 28, 42]. Therefore, arterialized venous flaps have been mostly adopted for the reconstruction of hand and digit injuries [7–16, 23, 24, 26, 27, 43–60]. The arterialized venous free flap was first developed by Nakayama et al. [17] in 1981. It has been widely used since Yoshimura et al. [22] successfully performed it clinically in 1984. It is a versatile technique for reconstruction of complex defects of the hand and the digit.

Resurfacing of soft tissue defects only on hand and digit

Arterialized venous flaps have been mostly used for the closure of small defects. Yoshimura et al. [22] first introduced the arterialized venous flap (A–V–V, Chen's type III) in 1987. Thirteen arterialized venous flaps measuring from 1.3 cm × 3.1 cm to 6.0 cm × 1.0 cm were utilized to resurface the skin defects on fingers in 11 cases. Of the 13 digits treated, complete survival was achieved in 12 (92.3%) and 1 sustained partial superficial necrosis. Later, they presented another larger series of these flaps for the coverage of skin defects on the hands in 22 patients, of which an A–V–A type of venous flap was used in 12 patients and an A–V–V type in 10 patients [24]. The size of the flaps

ranged in size from 1.0 cm × 1.0 cm to 3.0 cm × 12.0 cm. As much as 17 were completely successful, 4 were partially successful and 1 resulted in complete failure. Then in 1991, Chen et al. [28] performed four cases of A–V–V type and seven cases of A–V–A type of venous flaps with 100% survival for the coverage of skin defects on hands and digits. Recently, we succeeded in resurfacing an upper extremity stump with a 9 × 6-cm venous flap harvested from a non-replantable part after partial hand amputation. The flap provided durable coverage and avoided additional procedures for coverage and staged tendon reconstructions [42]. In our experience, we realize that choosing a relatively small afferent vein for arterial perfusion is helpful for the success of a large venous flap, and using at least two efferent veins for drainage is also essential for the survival of the large venous flap.

This flap has also been considered as a potential reconstructive option for large dorsal digital defects with exposed bone, joint, and/or extensor tendons when local flaps are inadequate or unusable. In 1996, Yilmaz et al. [43] designed an arterialized venous flap utilizing the venous network of the forearm and applied this flap in five patients with two cases of skin defects on the hand ranging in size from 6 cm × 8 cm to 10 cm × 12 cm and both totally survived. Also in the same year, Woo et al. [44] presented 12 cases of relatively large skin defects of the hand that were reconstructed with the A–V–V fashion venous flap ranging in size from 6 cm × 3 cm to 14 cm × 9 cm. Although the flaps showed remarkable edema and multiple bullae on their surface postoperatively, partial necrosis of the flap only developed in three cases. Then in 2004, Nakazawa et al. [45] presented successful reconstruction of four cases with severe and extensive contractures of the palm using large arterialized venous flaps. The flaps, measuring from 5 cm × 13 cm to 9 cm × 17 cm, were applied in an A–V–V fashion. All four flaps showed complete survival with uneventful clinical courses and none of them required a defatting procedure after the operation. Recently, Hyza et al. [46] also described their experience with 13 venous free flaps in 12 patients with large dorsal digital defects. Their survival rates for these flaps are comparable to the published data.

Multiple skin defects of digits due to trauma or burns pose challenging reconstructive problems. Traditional therapeutic options for salvaging these digits were problematic, limiting their clinical applications to the treatment of injury [47–49]. Inoue and Suzuki [47] extended the scope of applications in 1993. Five patients with multiple skin defects of the hand were treated with A–V–V type of venous flaps. Four flaps survived uneventfully (80%) and one showed 30% partial necrosis. In 2005, Hyza et al. [48] reported a patient who sustained volar and dorsal defects of the middle finger, which were covered simultaneously with

a bilobed arterialized venous free flap from the left forearm. The flap was composed of two paddles, which were connected by a subcutaneous bridge containing a subcutaneous venous network. The flap survived completely with temporary mild venous congestion. An excellent functional and cosmetic result was reached. In our practice, we also treated a patient who sustained multiple finger injuries on the hand using a venous flap. After thorough debridement, two dorsal defects of the middle and ring fingers were covered simultaneously with a single arterialized venous free flap from the right forearm. The flap was used to create a dorsally syndactylized digit, which survived completely and was subsequently divided longitudinally [49]. In our point of view, the key point for the coverage of multiple defects in fingers with this flap is to select the proper donor site, in which a sufficient diffuse venous plexus and lax configuration, including at least two separate pathways for anastomosing with the recipient vessels, could be ensured. Thus, either the syndactylized or bilobed arterialized venous free flap with an early division is a useful option for the simultaneous coverage of multiple skin defects of digits and can achieve excellent functional and cosmetic results [48, 49].

Reconstruction of skin and vascular defects on hand and digit

Due to the anatomical nature of venous flaps, the best scenario for the clinical use of the arterialized venous flap occurs when both revascularization and skin coverage are needed [6–12]. In 1984, Honda et al. [6] first developed the clinical application of the arterialized venous flap as a composite skin and subcutaneous vein graft in the replantation of six amputated digits, which was complicated by the loss of skin and veins and with the exposure of bone and tendon. Complete survival of the skin graft was achieved in two digits and partial necrosis occurred in three. Then in 1989, Nishi et al. [7] presented seven cases of arterialized venous flaps for the treatment of both skin and digital arterial defects. The flaps were applied to cover the skin defect as well as to restore blood circulation. Almost complete survival of the flaps was achieved in all cases. In 1999, Koch et al. [12] reported the first case of successful coverage of a skin and soft tissue defect, including revascularization with an arterialized venous flap bridging both arterial and venous defects in a finger avulsion injury. Similarly, several subsequent case reports using arterialized venous flap to cover the soft tissue defect and restore digital circulation achieved satisfactory results [8–11], indicating that this procedure was a well-established technique to provide not only flap coverage for exposed bone and tendon, but also a one-stage procedure for digits in need of revascularization and skin coverage.

Reconstruction of skin and tendon defects on hand and digit

The combined loss of skin and tendon of the finger is a common and challenging problem. These injuries have been mostly managed with a regional or distant flap, with tendon grafting done as a secondary procedure. This involves a multistage procedure, requiring a considerable amount of time and resulting in significant donor site morbidity. In 1991, Inoue and Tamura [13] first introduced a novel technique of composite free flap and tendon transfer using an arterialized venous flap containing the palmaris longus tendon to repair finger injuries involving the skin and both flexor and extensor tendons in four patients. The final range of motion was disappointing in their serial study, with an average of 10°. Further trials of this technique conducted in four more patients, however, achieved encouraging results after refining the indications of the procedure [15]. In addition, in 1994 Chen et al. [14] reported three cases of combined skin and tendon loss on the dorsum of the finger that were reconstructed with the same procedure and achieved satisfactory results. Their investigations demonstrated that the technique was feasible and offered a good treatment modality for the small, but complex, defects on the dorsum of the finger using a one-stage operation.

In 1999, Cho et al. [16] introduced a similar technique, which was applied to reconstruct the defects of skin and multiple extensor tendons. They reported on two patients whose acute soft tissue and tendon defects in the hand were treated with a dorsalis pedis tendocutaneous arterialized venous flap. One patient sustained a soft tissue defect on the dorsum of the right hand, including the absence of the extensor pollicis longus and the extensor digitorum communis of the index finger, and the other sustained a soft tissue defect on the dorsum of the right hand with the absence of the extensor digitorum communis tendons of the index and middle fingers. Two weeks after the surgical delay on the donor site, a venous flap, including the extensor digitorum longus tendons of the second and third toes, was transferred to the recipient site. Excellent results were achieved both esthetically and functionally. Although this technique is a two-stage operation with donor site scarring and weak extension of the toes, a larger arterialized venous flap can be obtained than when using a pure venous flap or arterialized venous flap. This technique can also increase the survival rate, and multiple tendon grafts can be harvested simultaneously.

Innervated arterialized venous flap

Sensation is vital to hand function and it is always optimal to resurface a skin defect and reconstruct the sensation

simultaneously whenever possible. Takeuchi et al. [50] used innervated arterialized venous flaps from the dorsum of the foot in two patients with traumatic finger degloving injuries. Sensation was preserved by anastomosing branches of superficial peroneal nerves with the digital nerves. All the flaps provided successful coverage over the denuded fingers. Good sensation and nearly full range of motion of the fingers were obtained. Kayıkçioğlu et al. [51] also reported two cases using this technique and achieved satisfactory sensory recovery with 4–6 mm static two-point discrimination. They concluded that the innervated arterialized venous flap was a useful method that provided functional and cosmetic coverage for digit reconstruction. However, Kushima et al. [52] revealed that sensory recovery was satisfactory even without nerve repair in the application of arterialized venous flaps. Their study hypothesized that sensory recovery after arterialized venous flap transfer on hand and digit was donor site dependent without nerve repair. In their series, soft tissue loss of fingers was repaired in 22 patients using 25 arterialized venous flaps harvested from the thenar, hypothenar, or forearm regions. Good sensory recovery was obtained for the thenar and hypothenar venous flaps, while moving two-point discrimination was not recorded during the follow-up period in the group using forearm venous flaps.

Meanwhile, due to the special nature of venous flaps, arterialized venous flaps have been utilized not only in the reconstruction of common soft tissue defects on the hand [7–16, 23, 24, 26, 27, 43–49], but also in the treatment of complicated soft tissue defects on the fingers [50–58].

Reconstruction of circumferential injuries

Circumferential defects of the digits are uncommon, but present a challenging problem to the surgeons. There are many reconstructive options that are available for the management of this injury. However, the use of simple skin grafts tends to cause tendon adhesions, limiting the range of motion. The use of local skin flaps, such as a cross-finger flap, is limited by the considerable skin loss that is naturally found in a defect that is circumferential in nature. Other options include the use of a reversed forearm flap or some free tissue transfers resulting in limited donor sites available, as well as donor morbidity. Takeuchi et al. [50] first described the technique of the reconstruction of digit avulsion injuries with arterialized venous flaps in a wrap-around fashion in 2000. Chia et al. [53] similarly achieved excellent contour and full range of motion with this flap on a resurfaced digit featuring a circumferential injury. In our series, venous flaps [54] were also used in the reconstruction of ring avulsion injuries. Eight flaps and digits survived without partial necrosis. The soft tissue envelope

was supplied in all cases and the total active motion (TAM) ranged from 160° to 210°. We consider that a proper length of the afferent and efferent veins is another key factor for success. It is suggested that the afferent vein must not be too long to avoid pedicle kinking, while the efferent one must be sufficiently long so as to reach the recipient veins without tension. Based on all these results, the arterialized venous flap has proven itself to be a reliable solution for the complex circumferential avulsion injury, which requires simultaneous soft tissue and digital vessel reconstruction.

Fingertip reconstruction

Fingertip injuries also pose a challenging reconstruction problem. Various skin flaps have been used in the reconstruction of fingertip defects. In repairing pulp tissue loss, local flaps are the first choice from the point of view of sensory recovery and skin texture. In cases where local flaps are not suitable, regional flaps harvested from elsewhere in the hand, such as the cross-finger flap or the thenar flap, are applied. However, these methods require long immobilization, multiple operations, and lengthy hospitalizations. Iwasawa et al. [55] introduced a new fingertip reconstruction procedure with arterialized venous flaps from the thenar or hypothenar regions. In their study, 13 of the 15 flaps survived completely. All the flaps that survived exhibited stable coverage and good texture at follow-up. These flaps are not sensory flaps; however, they exhibited useful sensory recovery within 6 months of operation. This showed that the thenar and hypothenar skin is durable with appropriate texture for replacement of fingertip defects. Kayıkçioğlu et al. [51] also achieved satisfactory outcomes in their series using this procedure. They concluded that the arterialized venous flap, which provides functional and cosmetic coverage, may be a good alternative for repairing fingertip defects in selected cases.

Nowadays, the reconstruction of a missing or deficient nail is still a challenging procedure for plastic surgeons. The vascularized free graft is becoming increasingly reliable, and it is now considered to be the best method [56]. However, preparation of the vascularized nail graft is rather difficult and tedious. To simplify this procedure, Nakayama et al. [57] developed a new method to reconstruct the finger nails using the principles from the arterialized venous flaps in 1990. Three patients underwent successful transplantation of the great toenails to their index fingers utilizing the venous system of the nail graft for perfusion by anastomosing the two venous pedicles with the recipient digital artery and dorsal vein. Then in 1999, Patradul et al. [58] reported ten cases of nail loss reconstructed with the same

procedure. Nine flaps survived completely and one had partial necrosis. All showed excellent esthetic and functional results except for one case with minimal deformity in the growth of the nail. They suggested that this procedure is easy, reliable, and a useful alternative for the reconstruction of nail loss.

Several concerns on arterialized venous flaps regarding the reconstruction of hand and digit

The arterialized venous flap is an unconventional flap in that the classic Harvesian model of arterial inflow–capillaries–venous outflow is replaced by the venous inflow–capillary network–venous outflow. The physiological basis for its survival is not entirely understood. Due to its atypical pattern as a skin flap, its progress is not easily predictable [59]. Many attempts have been proposed for improving the success of arterialized venous flaps in the hand and digit.

Surgical principles

Generally, the following concepts are regarded as the guidelines for the design of arterialized venous flaps [41]: (1) avoiding perfusing the afferent phase by using the largest possible arterial inflow; (2) provide lax configuration of the efferent phase, using at least two available receptor veins; (3) design flap over the diffuse venous plexus while attempting to include not only the pathway of a single vein. Furthermore, the following principles are of great importance for success: firstly, the afferent vein must be left close to the recipient artery to avoid pedicle kinking; and secondly, the efferent veins must be longer to reach the recipient veins.

About flap sizes and donor sites

Inoue and Maeda [23] mentioned that, in the use of arterialized venous flaps to reconstruct skin defects of the digits, success appeared to be influenced by the donor site and size of the flap. When a small flap from the forearm was used, the success rate was almost 100%. However, there was a 50% success rate when a large flap from the leg was used [23]. The influence of donor site on the survival of arterialized venous flaps may be attributed to the configuration of venous network of different donor sites. Of all the popular donor sites for arterialized venous flaps (Table 2), it is believed that the configuration of the dorsal skin of digits and hypothenar or thenar is more favorable than that of the volar forearm [33, 55], while the donor site of the lower

Table 2 Donor sites

Author	Donor site	Case	Size	Survival rate (including partial survival) (%)
Kong et al. [26] (2008)	Volar forearm	35	1 × 1 cm–5.5 × 4.5 cm	88.6
	Thenar area	8		
	Dorsum of foot	1		
Woo et al. [31] (2007)	Volar forearm	93	Small ≤10 cm ²	98.1
	Thenar area	37	Medium 11–24 cm ²	
	Dorsum of foot	16	Large ≥25 cm ²	
	Medial aspect of low leg	8		
Koch et al. [62] (2004)	Volar forearm	10	2 × 1 cm–11 × 7 cm	100
De Lorenzi et al. [68] (2002)	Volar forearm	37	1.5 × 2.0 cm–15 × 3 cm	92.5
	Medial aspect of low leg	3		
Reynoso et al. [59] (2000)	Volar forearm	37	Around 15 cm ²	91.9
Kayikcioglu et al. [51] (1998)	Dorsum of digit	8	–	87.5
Kantarci et al. [40] (1998)	Volar forearm	12	2 × 2 cm–3 × 15 cm	100
	Dorsum of foot	1		
Iwasawa et al. [55] (1997)	Hypothenar and thenar	15	2 × 3 cm in average	93.3
Nishi [25] (1994)	Volar forearm	5	1.0 × 1.0 cm–4.5 × 8.5 cm	87.5
	Dorsum of foot	19		
Karacalar et al. [69] (1994)	Volar forearm	13	1 × 1 cm–3 × 9 cm	92.3

leg, in which there is a poor venous network, is considered the last choice for venous flaps [23]. Recently, Kakinoki et al. [60] performed a retrospective analysis of the free arterialized venous flaps that were utilized in 51 patients to identify prognostic factors that correlate with flap necrosis. Multivariate analysis showed that the size of the flap was the factor that correlated statistically with a successful result after a flap operation. They found that the arterialized venous flaps that were less likely to develop necrosis of the skin generally had a surface area less than 767 mm².

About two types of arterialized venous flaps

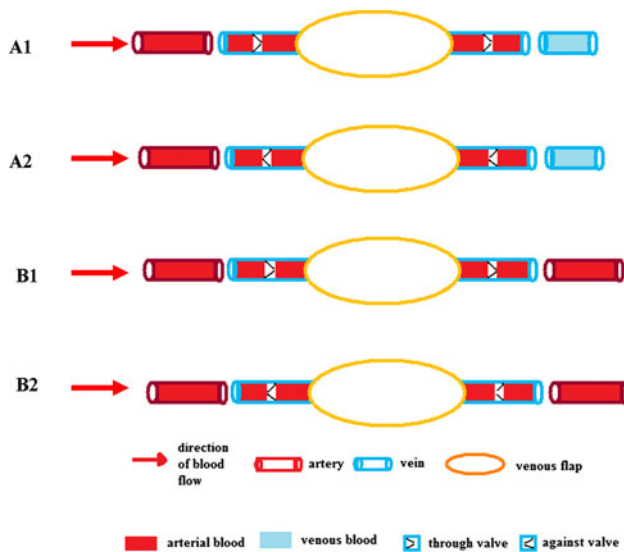
Of the two types of arterialized venous flaps, Chen's type III (A–V–V) and type IV (A–V–A), the results from an investigation by Nishi et al. [25] showed that type IV was likely to be more favorable than type III. Based on most of the literature that was reviewed, however, no significant difference in flap survival rate was noted despite that the statistical analysis was precluded (Table 3). The A–V–A type is mostly used for skin coverage and providing a conduit for arterial flow when the vessel is injured. The A–V–V type can be used regardless of the location of the soft tissue defect and therefore has been more widely used. It has been used in many situations including multiple digits, fingertip, finger shaft injuries, web space, and circumferential soft tissue defects [43–60].

About flow direction of arterialized venous flaps

Most arterialized venous flaps reported in the literature are performed in an antegrade perfusion fashion [6–16, 22–31, 39–60]. However, controversies were put forward in an attempt to demonstrate that retrograde perfusion can enhance the perfusion of the flaps [61, 62]. An experimental study with flaps from human cadavers indicated that blood circulation in the periphery of arterialized venous flaps can be increased by retrograde arterialization [61]. Koch et al. [62] utilized the retrograde arterialized venous flaps to resurface the skin and soft tissue defects, ten of which were located on the hand, and three on the lower leg. There was venous congestion with superficial epidermolysis in six flaps, but not in the other seven. All flaps survived except for partial skin necrosis that occurred in two of the lower extremity flaps. Their results suggest that retrograde perfusion enhances blood flow in the periphery of arterialized venous flaps and gives good results in terms of flap survival, especially of the upper extremity. They speculated that if blood flows through the flap in the original anatomic direction, the venous valves do not impose any resistance to blood flow. As a result, the greater part of blood flows through the flap's central vein only and the flap's periphery will be in danger of insufficient perfusion leading to partial necrosis [62]. However, few further investigations were found in literature using the retrograde arterialized venous flaps in the reconstruction of hand and digit, and so caution should be taken for clinical applications. The arterialized venous flaps utilized by far in hand and

Table 3 Survival status of two types of arterialized venous flaps

Authors	Type	No	Complete survival (%)	Partial survival (%)	Necrosis (%)
Inoue et al. [23] (1988)	A–V–A	6	5 (83.3)	1 (17.7)	0
	A–V–V	2	2 (100)	0	0
Inoue et al. [24] (1990)	A–V–A	12	9 (75)	2 (16.7)	1 (8.3)
	A–V–V	10	8 (80)	2 (20)	0
Chen et al. [28] (1991)	A–V–A	7	7 (100)	0	0
	A–V–V	4	4 (100)	0	0
Fukui et al. [29] (1994)	A–V–A	1	1 (100)	0	0
	A–V–V	6	4 (66.7)	2 (33.3)	0
Nishi [25] (1994)	A–V–A	15	11 (73.3)	3 (20)	1 (6.7)
	A–V–V	9	5 (55.5)	2 (22.2)	2 (22.2)
Iwasawa et al. [55] (1997)	A–V–A	3	2 (66.7)	1 (33.3)	0
	A–V–V	12	11 (91.7)	0	1 (8.3)
Kantarci et al. [40] (1998)	A–V–A	9	8 (88.9)	1 (11.1)	0
	A–V–V	4	4 (100)	0	0
Reynoso et al. [59] (2000)	A–V–V	37	24 (64.9)	10 (27)	3 (8.1)
De Lorenri et al. (2002) [59]	A–V–V	40	33 (82.5)	7 (17.5)	0
Kong et al. [26] (2008)	A–V–V	44	39 (88.6)	5 (11.4)	0
Average	A–V–A	53	43 (81.1)	8 (15.1)	2 (3.8)
	A–V–V	12	95 (76.6)	23 (18.6)	6 (4.8)

**Fig. 1** The classifications of the arterIALIZED venous flaps used in hand and finger reconstructions

finger reconstructions are classified into four types in terms of perfusion patterns (Fig. 1).

About pre-arterialization and surgical delay techniques

Many strategies for the improvement of arterIALIZED venous flap survival have been addressed experimentally, such as

the surgical delay procedure [21, 63], pre-arterialization [64, 65], expansion procedure [66], etc. In the reconstruction of hand and digit, Ueda et al. [67] employed the pre-arterialization technique to repair large skin defects due to third-degree burns on the dorsum of the hand using arterIALIZED venous flaps in four patients. Two weeks after plasty of an arteriovenous (A–V) shunt between the greater saphenous vein and dorsalis pedis artery, the arterIALIZED venous flap was transferred using the greater saphenous vein as the pedicle. The size of the flaps utilized ranged from 7 cm × 13 cm to 9 cm × 13 cm. Three patients survived uneventfully and one survived with superficial necrosis of about 10% of the flap at the borders. In 1999, Cho et al. [16] successfully treated two cases of composite large skin and tendon defects on hand with the arterIALIZED venous flap using the surgical delay procedure. Using these techniques, a larger arterIALIZED venous flap can be obtained and a higher survival rate of the flaps can be expected except for the disadvantage as a two-stage manipulation.

Conclusions

The venous flap is ideal for the reconstruction of the small defects of hand and digit. It is easily designed and harvested with good quality. It is thin and pliable, without the need to sacrifice a major artery at the donor site and with no limitation on the donor site. It can be transferred not only as

a pure skin flap, but also as a composite flap including tendons and nerves as well as vein grafts. The arterialized venous flaps are more reliable than other types and are suggested to be the optimal choice for the management of hand and digit defects. The volar aspect of the forearm and the nar area are relatively better donor sites. The survival status of the arterialized venous flaps is acceptable; however, these cannot completely replace the conventional flaps in the reconstruction of the hand and digit.

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