ARTERIALIZED VENOUS FLAPS: A REVIEW OF THE LITERATURE

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The arterialized venous flaps are highly regarded in microsurgical and reconstructive surgeries based on advantages of ease of design and harvest without the need to perform deep dissection, no sacrifice of a major artery at the donor site, no limitation of the donor sites, and less donor-site morbidity. Many experimental investigations and clinical applications have been reported. However, their survivals are still inconsistent, and survival mechanisms remain controversial. In this review, we update the existing problems, experimental studies for survival mechanisms, clinical practices, and methods developed to improve their survivals. © 2010 Wiley-Liss, Inc. Microsurgery 30:472–478, 2010.

Venous flaps are those in which the primary blood supply enters and exits the flap through the venous system.[1] The exact vascular circuit or mechanism of physiologic nutrition, however, remains unclear. Compared with conventional arterial flaps, venous flaps have advantages, including ease of design and harvest without the need to perform deep dissection, no sacrifice of a major artery at the donor site, no limitation of the donor sites, and less donor-site morbidity with optimal postoperative contour compared with other free microvascular tissue transfers.[2–16]

Thatte and Thatte proposed a three-type classification system[17] of venous flaps. This classification, which was based on the vessels that enter and leave the flap as well as the direction of flow within these vessels, was detailed as follows: type I, unipedicled venous flaps; type II, bipedicled venous flaps; type III, arterialized venous flaps (AVFs), which are perfused by a proximal artery anastomosed with a cephalad end vein and drained by a distal vein. This classification system briefly illustrates the general modes of venous flaps, which were cited most commonly both experimentally and clinically.[18–23] In recent decades, there have still been other modified classifications brought forward by several other authors beyond this classification.[8,16,21,24]

Because of the unfavorable outcomes using type I and type II venous flaps,[8,23,25–29] clinical reports have been mostly focused on type III venous flaps, which are considered the most reliable of these three types.[3–7,9–11,12–16,20,23,30–40] Even so, there continues to be problematic with type III venous flaps limiting their widespread acceptance. A greater understanding of venous flaps through a review of the literature is difficult, given that most series are small and their approach to venous flap transplantation varied making results and conclusions difficult to correlate between studies. Regardless, the purpose of this review is to update the existing problems, their survival mechanisms, experimental and clinical practices, and methods developed to improve their survivals, of which type III venous flaps are mainly discussed.

SURGICAL TECHNIQUES

The donor sites for venous flaps undertaken clinically by far include: the distal volar forearm,[16,30,41] the dorsum of foot and medial aspect of low leg,[15,16,30] and the thenar and hypothenar.[12] The distal volar forearm is mostly used for the coverage of soft tissue defect in medium size, the dorsum of foot and lower leg mostly for the coverage of large size of soft tissue defect, whereas the thenar and hypothenar are usually used for resurfacing small size of finger defects.

The AVFs are raised with the conventional techniques but with only venous pedicles. The following concepts are regarded as guidelines for AVF design[42]: 1) avoid perfusing the afferent phase by applying the largest possible arterial flow; 2) lax configuration of the efferent phase, using at least two available receptor veins; and 3) flap designing over the diffuse venous plexus while attempting to include not only the pathway of a single vein. Furthermore, other two considerations are recommended when used in hand reconstruction, which is the optimal option for the application of AVFs: first, the afferent vein must be left close to the recipient artery to avoid pedicle kinking and second, the efferent veins must be longer to reach the recipient veins.

Most AVFs reported in the literature are performed in an antegrade perfusion fashion.[3–7,9–11,12–16,20,23,30–40] Woo et al.[16] presented three perfusion patterns in their series, including antegrade, retrograde, and mixed perfu-

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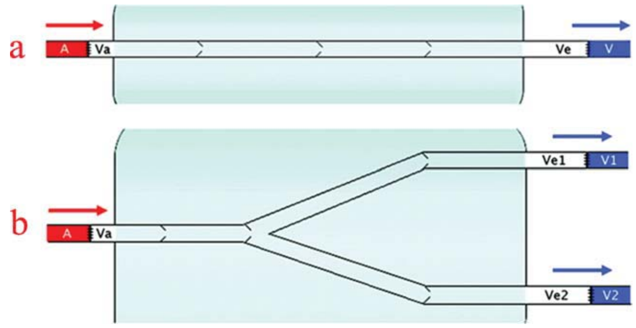

*Figure 1. Arterialized venous flap with antegrade perfusion pattern. (**a**) Through-valve type with a flow-through pattern. Red arrow shows the afferent arterial perfusion and blue arrow shows venous return. (**b**) Through-valve type with a Y-shaped pattern. Red arrow shows the afferent arterial perfusion and blue arrow shows venous return.*

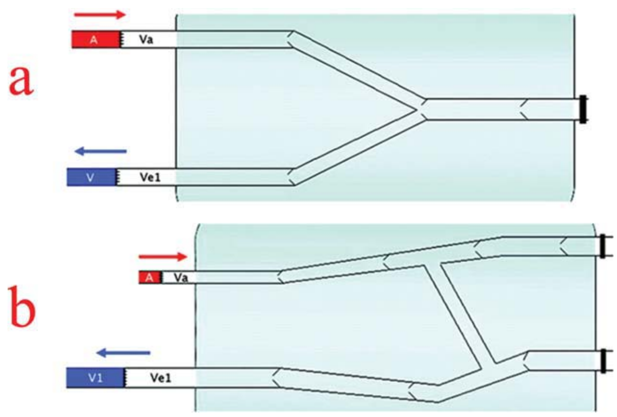

*Figure 2. Arterialized venous flap with retrograde perfusion pattern. (**a**) Against-valve with a reversed Y-shaped pattern. Red arrow shows the afferent arterial perfusion and blue arrow shows venous return. The black bar at the end indicates the ligation of the vein. (**b**) Against-valve with a H-shaped pattern. Red arrow shows the afferent arterial perfusion and blue arrow shows venous return. The black bar at the end indicates the ligation of the vein.*

sion patterns (Figs. 1–3), and no difference in flap survival was noted among them. However, controversies were put forward in an attempt to demonstrate that retrograde perfusion can enhance the perfusion of the flaps.[41,43] Koch et al.[41] used the retrograde AVFs to resurface the skin and soft-tissue defects with success. Their results suggest that retrograde perfusion enhances blood flow in the periphery of AVFs and gives good results in terms of flap survival, especially on the upper extremity. However, few further investigations were found in literature using the retrograde AVFs for clinical reconstruction.

CLINICAL APPLICATIONS AND COMPLICATIONS

During the last decades, many clinical attempts have been performed in the application of type III venous flaps

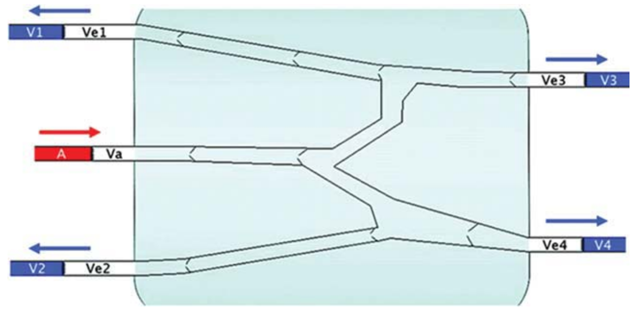

Figure 3. Arterialized venous flap with mixed perfusion pattern. Red arrow shows the afferent arterial perfusion and blue arrow shows venous return.

as a result of unreliable outcomes of early clinical studies using type II venous flaps.[2,44] In 1987, AVFs were first used clinically by Yoshimura et al.,[45] and they confirmed that AVFs were more reliable in their series.

As an alternative method to conventional flaps, AVFs have been mostly used for the closure of small defects. In 1988 and 1990, Inoue and Maeda addressed that almost a 95–100% success rate was achieved in their series who sustained small skin defects (1.0 × 1.0 cm–3.0 × 12.0 cm) of the hand using AVFs.[4,5] Similar results were achieved by Galumbeck and Freeman[6] and Iwasawa et al.[12]

Several successful clinical series using AVFs for coverage of relatively larger defects have also been reported.[10,11,31,34] Yilmaz et al.[10] designed an AVF in size from 6 × 8 cm to 10 × 12 cm for the coverage of various defects. Four of five flaps totally survived with 30% partial necrosis in one flap. Overall clinical results were successful. Woo et al.[11] reported 12 AVFs ranging from 3 × 6 cm to 14 × 9 cm in size to resurface the skin defects of the hand. All flaps survived well except three cases sustained about 10% partial necrosis.

The AVF has also been attempted on several special applications in managing difficult clinical challenges. We have succeeded in resurfacing an upper extremity stump with a venous flap from the amputated part, avoiding additional procedures for staged reconstructions.[32] In our practice, the AVF was also used to reconstruct two separate dorsal digital defects with a syndactylizing venous free flap simultaneously and achieved excellent functional and cosmetic result.[46] Avulsion injuries of the hand or degloving injuries of fingers are some of the most intractable clinical scenarios. This flap was applied to salvage the avulsed palmar tissue with good results.[39] We used an AVF to reconstruct a ring avlusion injury with success,[47] and salvage of other degloved fingers with this flap was also reported.[13,33,36] Besides, it can serve as composite flaps not only for the coverage of skin defects but also for the reconstruction of tendon and nerve defects.[3,4,9,14,34]

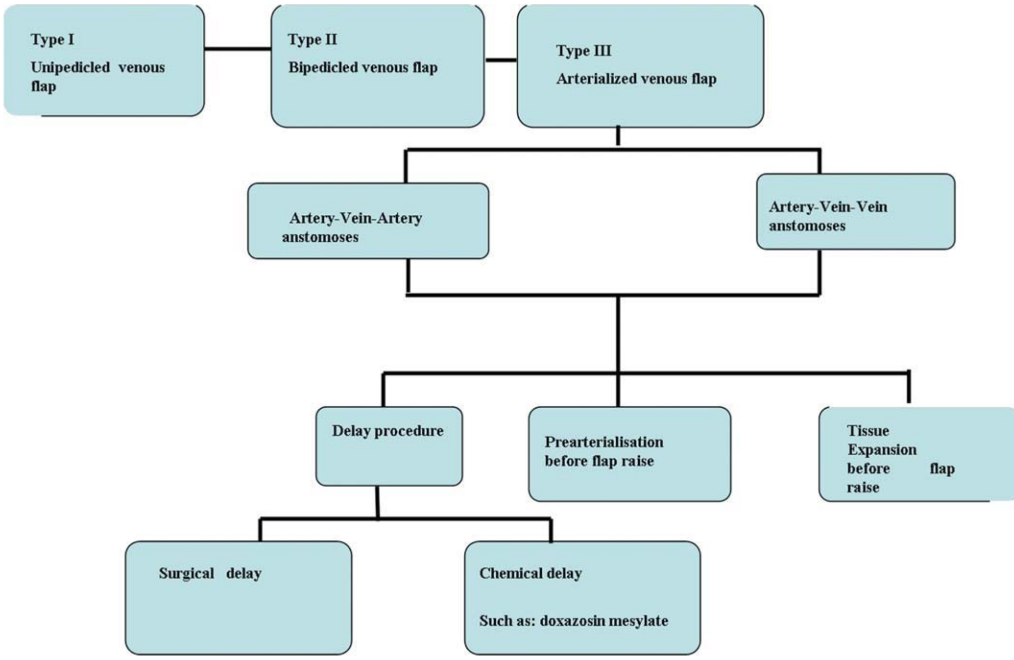

Figure 4. Algorithm of venous flaps and improvement of survival.

Table 1. Clinical Applications

Authors	Year	Case no.	Sizes (cm)	Congestion rate (%)	Partial necrosis rate (%)	Complete necrosis rate (%)
Inoue and Maeda[4]	1988	8	1 × 2–2 × 4	–	12.5	0
		7	3 × 10–4 × 15	–	28.6	42.3
Inoue et al.[5]	1990	22	1 × 1–3 × 12	–	18.2	4.5
Nishi[23]	1994	24	1.0 × 1.0–4.5 × 8.5	–	20.8	12.5
Galumbeck and Freeman[6]	1994	4	4 × 6–5 × 9	100	0	25
Iwasawa et al.[12]	1997	15	2 × 3	–	6.7	6.7
Yilmaz et al.[10]	1996	5	6 × 8–10 × 12	–	20	0
Woo et al.[11]	1996	12	3 × 6–14 × 9	100	25	0
Klein et al.[49]	2000	34	–	–	23	30.8
De Lorenzi et al.[15]	2002	40	1.5 × 2–3 × 15	100	45.2	7.5
Koch et al.[41]	2004	13	2 × 1–11 × 7	46.2	15.4	0
Woo et al.[16]	2007	154	10–25 cm^2	N/A	5.2	1.9
Kong et al.[30]	2008	44	1 × 1–5.5 × 4.5	63.6	13.6	11.3
Average					19.5	11.9

However, many problems have also been encountered using this flap in clinical settings, especially in several relatively large series[4,15,23,30,48,49] except for Woo et al.'s report[16] (Table 1). Inoue and Maeda[4] demonstrated that failure rates were from 20 to 50% in their series.[4,48] De Lorenzi et al.[15] noted that postoperative congestion was present in all flaps, and partial necrosis rate was as high as 42.5% with a total flap necrosis rate of 7.5% in their practice.

EXPERIMENTAL STUDIES

Because high occurrence rate of partial flap necrosis and prolonged healing or secondary procedures, further investigation is needed for this nonconventional flap. Several animal models have been developed for experimental studies (Table 2).

The first animal model used to study venous flaps was the rat reported by Nakayama et al. in 1981.[1] The flap was designed using the superficial inferior epigastric vein distally and a branch of the lateral thoracic vein proximally served as the venous system. The AVF model was established with the anastomosis between the epigastic vein in the flap and the femoral artery in the distal side. Lenoble et al.[50] described another venous flap, which was sited transversely between the left and right epigastric venous systems.

Table 2. Animal Models of Venous Flaps

	Site	Proximal vein	Distal vein	Type of venous network
Rat	Abdomen	Superficial epigastric vein	Superficial epigastric vein	Nonflow-through
	Thoraco-abdomen	Lateral thoracic vein	Superficial epigastric vein	Nonflow-through
Rabbit	Ear	Central vein	Central vein	Flow-through
	Abdomen	Lateral thoracic vein	Superficial epigastric vein	Nonflow-through
Dog	Leg	Saphenous vein	Saphenous vein	Flow-through
Swine	Leg	Cephalic vein	Cephalic vein	Flow-through

Rabbits are the most common animal model used for the study of venous flaps.[51–64] The rabbit ear has served as a model for venous flaps.[51–60] Its reliable anatomic characteristics have provided additional rationale for the selection of this model, making this flap a genuine flow-through venous flap. Another model for the venous flap in rabbits was illustrated by Xiu and Chen.[58] The venous flap was tailored along the axis of the thoracoepigastic veins as a flow-through venous flap.

There are also several other animal models undertaken as venous flap models, which were not widely used in experimental studies, including the dog saphenous or cephalic venous flaps[62,63] and the swine pedicled buttock venous flap.[64]

MECHANISMS OF FLAP SURVIVAL

Venous flaps differ from conventional flaps in that the classic Harvesian model of arterial inflow-capillaries venous outflow is replaced by the venous inflow-capillary network-venous outflow.[1,17] There are considerable controversies on the real nature of their survivals accompanied with their advent. Investigations on the blood supply of venous flaps mostly focus on type I and type II venous flaps.[62,65,66]

The work of Noreldin et al. and Shalaby and Saad indicated that the perivenous areolar tissue, which contains small arteries, is vital to the survival of type I venous flaps in rats.[66,67] Whereas, the results of Xiu and Chen showed that the similar perivenous areolar tissue was purely venous and had no fine arteries with the vein in the rabbit, and the role of perivenous areolar tissue is strictly to protect and nourish the vein itself. They otherwise proved that the profuse venous network in type II venous flaps and early invasion of new blood vessels are the mainstays of venous flap survival.[58] Another hypothesis of "to-and-fro" flow[62] was also introduced as the single venous channels, providing both perfusion and drainage to the flap tissue, and the "to-and-fro" flow in the single vein was also observed.[58] Many authors demonstrated that the early invasion of new blood vessels is essential to venous flap survival, and the low perfusion of venous flaps enhances the invasion of new vessels.[58,68]

Whatever hypotheses of its survival mechanisms were put forward, the fundamental basis is that venous blood itself could be taken as the sole nourishing source at the early stage contributing to the support of its early survival in type I and type II venous flaps.[17,38,62] Apparently, venous blood has a lower pO_2 and accordingly is likely to be less nourishing in terms of energy metabolism of tissue. Therefore, the survival mechanism of type III venous flaps should not be compared with that of type I and type II venous flaps in terms of blood flow. Three main theories have been postulated as to the physiology of the venous flap. These include "arterio-venous shunting"[69] or retrograde flow from the venous system to the arterial system via paralyzed arterial–venous shunts, "reverse flow"[62] or flow from the venules into the capillaries, and "capillary bypass"[56] or flow through the venous system without entrance into the arterial side until neovascularization. AVFs are possibly supported by a combination of mechanisms until peripheral neovasclarization occurs.

Improvement of the Flap Perfusion

One of the unsolved problems regarding the AVF is that the flap was nourished by arterial inflow through the venous network, causing a larger volume of blood directly flowing out through an arteriovenous shunt, and the flap was subsequently undernourished by insufficient blood flow.[4,70,71] With the purpose of increasing the perfusion of the flap, Moshammer et al.[43] studied the circulation in retrograde AVFs in the forearms of fresh human cadavers. As expected, their investigation showed that better results were achieved in the retrograde perfusion pattern, indicating that blood circulation in the periphery of AVFs can be enhanced by retrograde arterialization. Koch et al.[41] published the follow-up clinical application of the retrograde approach with a 100% (13/13) success rate. While Woo et al.[16] recently also published their clinical series using their antegrade approach with a 98% (151/154) success rate and a 5.2% (8/154) partial loss rate. These studies show that either antegrade or retrograde approach can result in success rates comparable to conventional microvascular transplants.

Angiogenesis by Expansion Procedure

It is now well established that tissue expansion causes angiogenesis in a variety of standard flaps.[72,73] In an experimental study using rabbits, Shin et al.[74] stated that expansion of the AVF resulted in more than a threefold increase in survival area of the preexpanded group compared to the nonexpanded group.

The possible mechanisms to explain how tissue expansion increases the survival of venous flaps were considered as follows[75]: first, dilatation of the venous network after tissue expansion may increase the survival of venous flaps by providing a better drainage of the harmful metabolites; second, tissue expansion may improve the survival of venous flaps by increasing their arterial blood supply due to increase of the number and size of perivenous arterioles. However, further study using expansion is still needed before it is widely accepted in clinical applications.

Surgical Delay

Surgical delay procedures have been researched and applied clinically in traditional flap transfers to extend the expected survival length of a flap, to define the survival of a flap of uncertain viability, and to improve the circulation of an established flap of expected viability.[76,77] Byun et al. revealed that a 14-day delay procedure significantly increased the survival area of AVFs in a rabbit model.[54] Subsequently, Cho et al. also proved that the combination of surgical and chemical delay with doxazosin mesylate procedures would be more effective than any of the single delay procedures in increasing the survival of AVFs, and the delay period could be shortened.

Prearterialization

The concept of prearterialization used for AVFs was first introduced by Nakayama et al.[1] Briefly, prearterialization was achieved by performing an arteriovenous fistula of the vein within the flap at the donor site for different periods of time before harvesting the AVFs. Thereafter, prearterialization procedure as another promising technique was investigated to improve the survival of larger AVFs.[20,35,53,78]

Fukui et al. used this technique by a 2-week prearterialization to prevent congestion and necrosis of AVFs using the model of rabbit ear with success.[53] However, if a 1-week prearterialization was performed, only slightly better results than in the standard AVFs were achieved.[79] Wungcharoen et al.[78] also noted that at least 14 days of prearterialization was reliable for flap survival. A reasonable prearterialization period may play an important role on the improvement of the AVFs.

CLINICAL MODIFICATIONS

On the basis of the results of experimental studies, Kamei and Ide[71] developed a modified pedicled venous flap with arterialized technique, in which arterial blood flows through a vein and returns to the venous system through the pedicle. They used this technique to reconstruct skin defects with pedicled AVFs in three cases. Two cases survived completely, and one sustained partial superficial necrosis and healed eventually without further management. This technique can provide a flap to cover a relatively larger defect, with no shunt formation and with a high success rate.

As to the retrograde procedure, although some experimental studies achieved better outcomes when compared with the antegrade procedure, the application of this procedure is still controversial. Inoue and Tamura reported one complete flap loss in their series, which they attributed to retrograde flow due to a planning mistake.[3] Nakayama et al. addressed that blood flow against the valves is a hazard to flap circulation.[80] In contrast, Woo et al. noted no problems with competent valves in the afferent and efferent vein when flaps were perfused retrogradely.[11,81]

As for the expansion procedure, Woo and Seul presented a small series of preexpanded AVFs to cover the defects of the head and neck measuring between 10 × 12 cm and 12 × 15 cm, and uneventful healing was achieved in all three reported cases.[81] It is obvious that preexpanded AVFs require a two-stage operation, prolonging the treatment in addition to the insertion of the expander, which introduces potential complications. However, preexpansion confers many advantages over conventional AVFs, such as easier and less time-consuming dissection, less donor-site morbidity, custom-made design of the flap, and a thin, well-textured flap.[81]

AVFs using delay procedures were attempted by Cho et al.[38] They reported a series of 15 flaps using surgical or surgical–chemical delay procedure with only one flap loss. Their results suggest that except for a disadvantage of two-stage operation, the delayed AVF may develop a larger flap than can be obtained with a pure venous flap or AVF and increase the survival rate of the AVF, which permits the possibility of using a composite flap besides all the advantages of the pure venous flap.

Prearterialization technique in venous flaps has also been used in clinical reconstructions. Ueda et al. noted that almost completely survival of four venous flaps in size ranged from 7 × 13 cm to 9 × 13 cm with this procedure was achieved to repair skin defects of the hand.[37] Wungcharoen et al. also presented their experience of resurfacing the skin defects using this technique in eight patients.[35] Flap survival was between 93 and 100% of the surface area. Their results seem promising in repairing relatively large defects in selected cases with the AVFs by this technique.

CONCLUSIONS

Based on many experimental and clinical studies conducted, AVFs can expand the armamentarium of plastic surgeons for reconstruction of various defects in selected cases. Survival inconsistence and partial loss of these flaps may be solved by techniques, such as surgical delay procedure, prearterialization technique, surgical expansion, and application of growth factors[19] after meticulously preoperative planning. The algorithm for improvement of AVFs is shown in Figure 4. Further experimental and clinical investigations are still needed to clarify the mysteries in reconstructions with AVFs.

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