

Reverse-Flow Radial Forearm Flap for Reconstruction of the Hand

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Soft-tissue injuries of the hand often require flap coverage to achieve primary wound closure and a good functional result. The use of the reverse radial forearm fasciocutaneous flap in the reconstruction of the hand is discussed. This flap offers thin, pliable, hairless skin and has proved very reliable because of its excellent vascular supply. The anatomy and vascular basis of this flap are presented along with its application in three patients.

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Open hand injuries often present a challenge to the plastic and reconstructive surgeon because of the maximal functional importance of the hand. Substantial skin loss requires immediate soft-tissue coverage with tissue of similar or as nearly similar quality as is obtainable under the circumstances [1]. Thus, we can achieve early wound closure, minimize wound infection and scarring [2], and finally attain a good functioning hand [3].

Skin grafts have only a limited use in such cases because graft take is dependent on the vascularity of the recipient bed. Skin grafting remains suitable for superficial defects, but more extensive damage involving deeper structures renders the wound surface unsuitable for rapidly vascularizing a graft. This relative avascularity, plus the exposure of vital structures such as bone, tendon, vessel, or nerve, which often accompanies hand trauma, presents the need of a flap consisting of skin and subcutaneous tissue with its own blood supply [2, 4].

Even in the acute stage of treatment, consideration should be given to the quality of this soft-tissue covering, bearing in mind the possibilities of subsequent reconstruction [2]. Small defects can be covered with local flaps, but larger defects required distant flaps until other methods were

used in the Military Hospital of China in 1981 [2, 3, 5, 6]. Actually, Yang and Chen described the flap as early as 1978 but their results were published in 1981 [6]. The radial forearm flap came to the attention of the Western world through the efforts of Song and his colleagues [7, 8] in 1982, and it has been named the Chinese flap [9]. Since then, the Chinese flap has gained great popularity among plastic surgeons, and several other articles have appeared in international literature about the versatility of this flap or a modification of it [3]. Muhlbauer, Biemer, Stock, Soutar, and Tanner were among the first to adopt, use, and modify this flap in the West [7, 10-13]. The radial forearm flap has been used for a variety of defects, such as facial [5, 7, 11, 13, 14], intraoral [15, 16], forearm [5, 17], elbow [18], hand [2, 12, 19-21], lower limb [2, 8, 11, 22], and penile reconstruction [9, 23, 24] and wherever there is a need for thin, pliable, hairless skin with a good vascular supply.

For the management of soft-tissue injuries of the hand, the Chinese flap was initially used to reconstruct contralateral hand injuries, but subsequently it was shown that it could be pedicled distally on the radial artery, venae comitantes, and the cephalic vein and used as a reverse-flow island flap to cover the ipsilateral hand [2, 10, 12, 19, 25].

The reverse-flow radial forearm flap has been established as a reliable source of thin, pliable, hairless skin in adequate quantity for the reconstruction of soft-tissue defects of the hand. The anatomical basis of this flap, its surgical elevation, the management of the secondary defect, and its clinical application in three patients are discussed.

Anatomical Basis

The radial forearm flap is a fasciocutaneous flap based on the radial artery and its two venae comitantes (sometimes the inclusion of the ce-

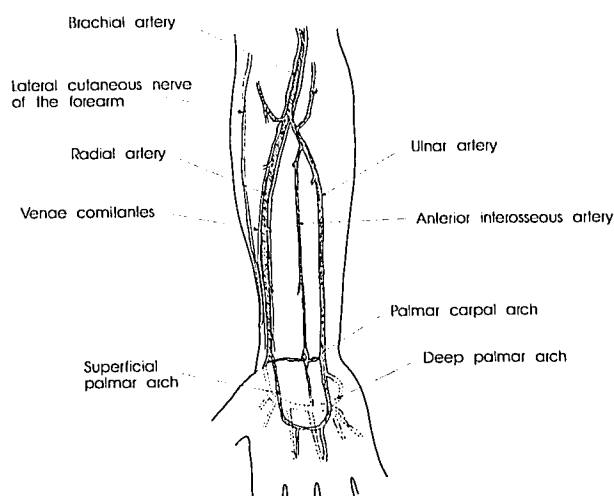


Fig 1. Vascular anatomy of the forearm.

phalic vein is rendered necessary to ensure adequate venous outflow) [2, 11].

The anatomy and vascular basis of the radial forearm flap (Figs 1, 2) have been extensively described by other authors [2, 3, 8, 19, 26]. We would only like to point out some interesting details. First, being a fasciocutaneous flap, the radial forearm flap is supplied by a fascial vascular plexus and is formed by numerous small branches of the radial artery [27]. Second, it is well established that the hand and fingers derive their blood supply mainly from the ulnar artery by means of the deep palmar arch [9, 11, 19, 28–32]; therefore, ligation of the radial artery itself will not affect the circulation of the hand provided the ulnar artery is intact [19, 33, 34]. Third, when the radial forearm flap is used as an island flap, pedicled distally, the normal arterial flow is reversed and the flap relies on a retrograde flow by the ulnar artery via the palmar arch, provided again that the ulnar artery is intact. A similar reverse flow is required to ensure venous drainage [2, 3].

Surgical Considerations

Allen's test or an ultrasonic Doppler meter testing, or both, should be performed preoperatively to rule out anatomical variations and to establish the presence of a good ulnar artery [8, 19]. Then a pattern of the area to be reconstructed is prepared, and a skin flap large enough to cover the

defect is outlined on the forearm (see Fig 6b), taking the distal part of the radial artery as its axis [8, 11, 19]. There are no limitations to the shape of the flap, and it can be elevated from anywhere on the volar surface of the forearm; we prefer using the mid- or distal forearm because the skin and fascia are thinner and of better quality than in the proximal forearm, and they also permit the inclusion of bone, tendon, or nerve to the flap [3, 8, 19, 35]. The radial and ulnar artery, the superficial veins (mainly the cephalic vein) and the lateral cutaneous nerve of the forearm are mapped out on the skin (see Fig 6b) [8, 32]. The operation is best performed with a pneumatic tourniquet [3, 6, 8, 11]. The plane of dissection (see Fig 2) should reach the undersurface of the deep fascia to ensure that both the radial artery and fascial plexus are included in the flap, making it a fasciocutaneous flap [2, 3, 8, 11]. The margins of the flap are incised down to the deep fascia, taking care to spare the subcutaneous veins, which we believed were not necessary to be included in our flaps. The flap is easily elevated starting from the ulnar border where the fascia is thicker [3]. The lateral intermuscular septa and the deeper branches of the radial artery to muscles and tendon sheaths should be ligated and divided to allow elevation of the flap [2, 11]. The radial artery and venae comitantes are ligated and transected at the proximal end of the flap, and the flap is elevated on this pedicle consisting of the radial artery and venae comitantes (Fig 3), leaving behind exposed muscles and tendons covered with paratenon (see Figs 6c, 6d) [36]. At this point, the tourniquet should be released to assess the viability of the flap [8, 11]. Care should be taken while dissecting the radial artery from the radius because its attachment is very strong; it is held by a dense, fibrous septum that needs to be divided very close to the bone. If this is not separated, then it becomes a cause of kinking of the artery, jeopardizing the flap's blood supply [6]. If we wish to increase the flap's arc of rotation further up to the fingertips, then the radial artery should be dissected free in the anatomical snuffbox and the flap and its pedicle passed underneath the abductor pollicis longus and extensor pollicis brevis [19, 37]. If the flap is to be used on the fingertips, then it should be based on an exteriorized pedicle because digital

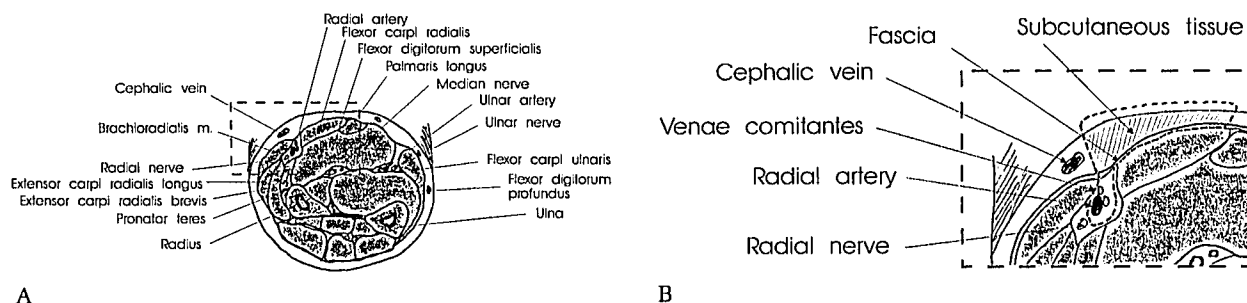


Fig 2. Anatomy of the forearm. (A) Transverse section at the level of the mid-forearm. (B) Enlarged section of the transverse anatomy (plane of flap dissection).

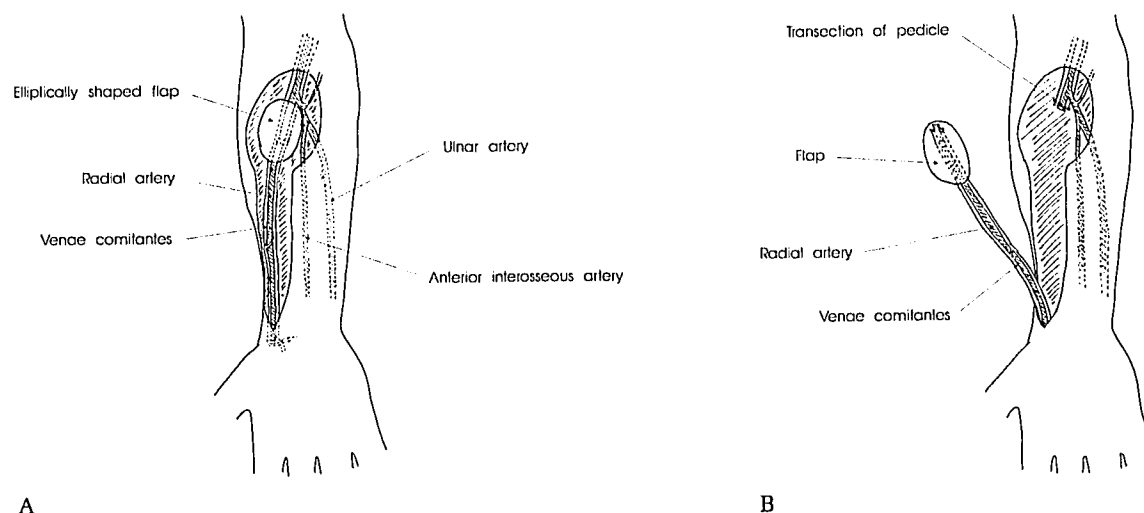


Fig 3. (A) Flap incision plus anatomical elements of the forearm flap. (B) Flap elevation.

subcutaneous space is too small to allow passage of the pedicle to the fingertips [38]. The flap and its pedicle are wrapped in warm saline-moistened gauze until the recipient site is prepared. If a narrow elliptical flap is used (see Fig 6c), then the donor site is closed directly. If this is not possible, it is covered with a split-thickness skin graft, which is one of the drawbacks of this flap [8, 11].

Patient Histories

Patient 1

A 20-year-old sailor presented to us with a large skin defect on the dorsum of the left hand, which was crushed by a trapdoor on a warship (Fig 4A). After thorough debridement, a reverse-flow radial forearm flap was raised from the left forearm and brought to the dorsum of the hand. The donor site was closed using a split-thickness skin graft.

After 1½ years, the patient has an aesthetically acceptable skin cover and his hand is fully functional (Fig 4B).

Patient 2

A 21-year-old man was involved in an automobile accident that led to extensive soft-tissue injury to the dorsum of the left hand with skin necrosis and avulsion of the extensor tendons to the middle, ring, and little fingers (Fig 5A). The trauma site was thoroughly debrided, and after tendon restoration, the wound was covered in one stage using a reverse-flow radial forearm flap from the left forearm (Fig 5B). The donor site was covered using a split-thickness skin graft.

Patient 3

A 60-year-old woman presented to our clinic with a squamous cell carcinoma of the second web space of the right hand (Fig 6A). A reverse-

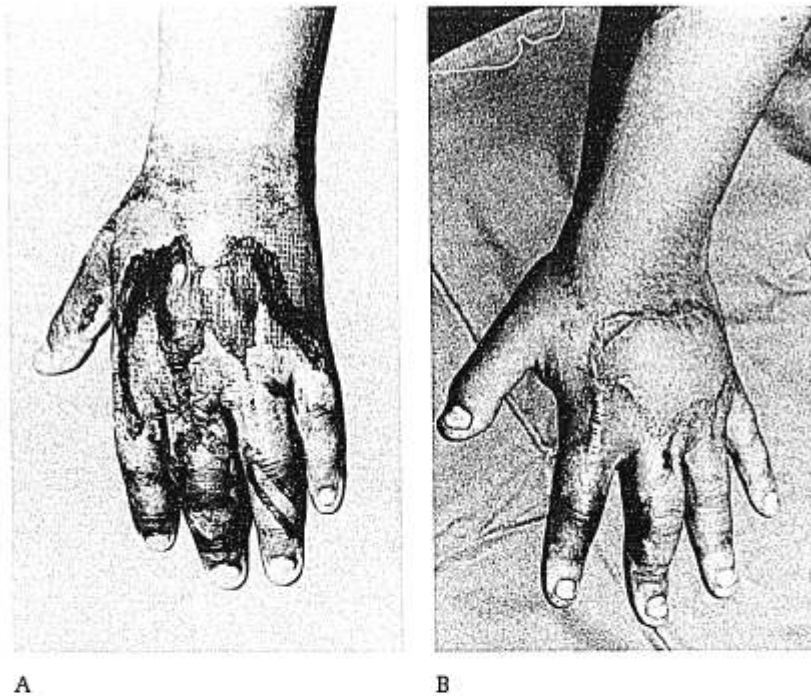


Fig 4. Patient 1. (A) Dorsal crash injury of the right hand. (B) Result 1½ years postoperatively with the reverse forearm flap.

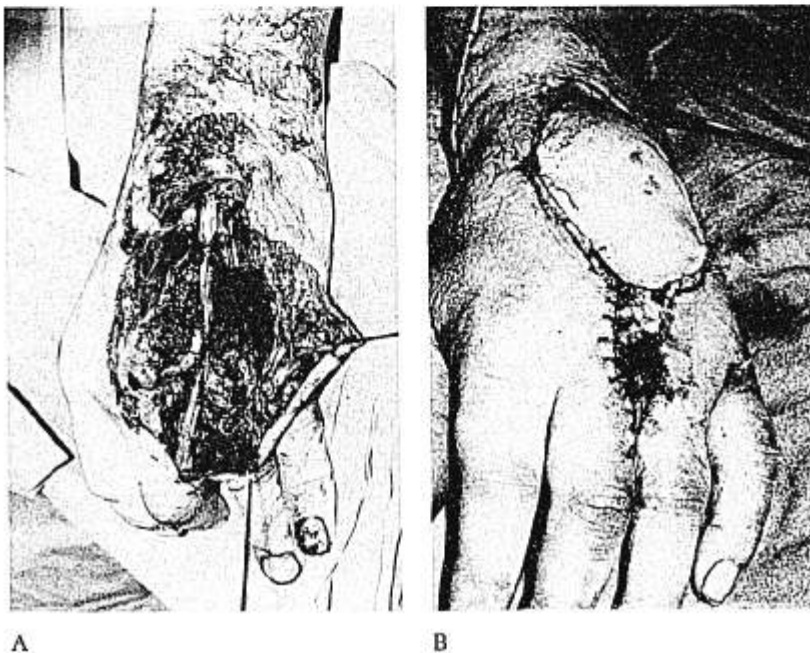


Fig 5. Patient 2. (A) Dorsal hand trauma after surgical debridement and exposure of extensor tendons. (B) Immediate postoperative result.

flow radial forearm flap was raised and inset (Fig 6B–F). The donor site was closed primarily.

Discussion

The management of severe hand injury involving substantial skin loss has always been a challenging problem to the plastic surgeon. The goals of

treatment continue to be minimal sacrifice of tissue with maximal functional and aesthetic results [31].

In the past, soft-tissue defects of the hand required the use of distant flaps like the groin flap [4, 39, 40], the hypogastric flap, the thoracoepigastric and deltopectoral flaps, the lateral thoracic flap, the cross-arm flap, and the medial arm flap [4, 18]. These methods required the attach-

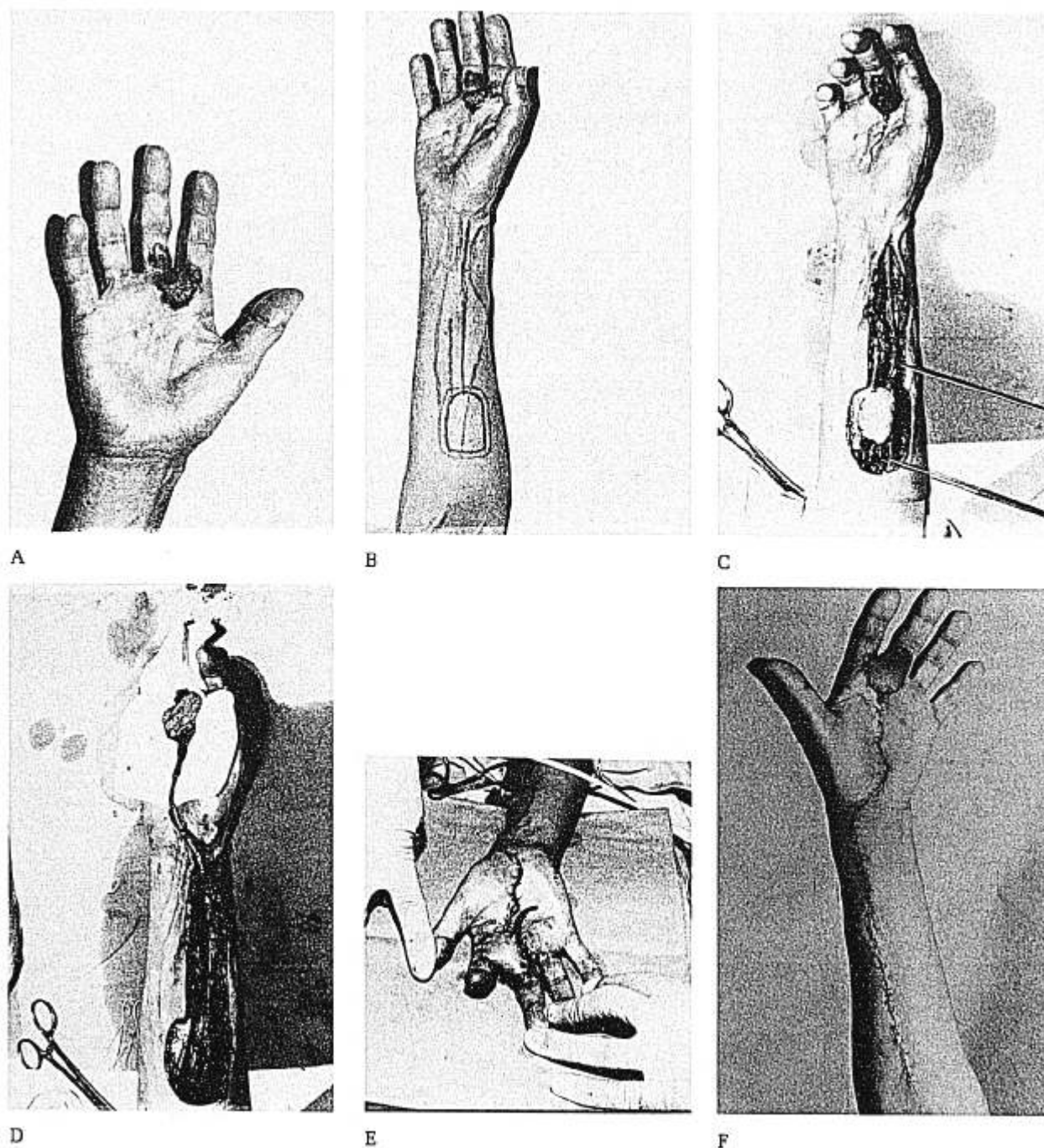


Fig 6. Patient 3. (A) Squamous cell carcinoma of the second web space of the right hand. (B) Reverse forearm flap design. (C) Flap incision. (D) Flap elevation and transposition. (E) Immediate postoperative result. (F) Result 2 weeks postoperatively.

ment of the injured limb to another part of the body with an avoidable restriction in its mobility. In addition, post-traumatic edema was difficult to control, a staged procedure was required, and, because of the division of the pedicle of the flap, the latter no longer contributed to the vascularity of the injured limb [2].

With the free flaps developed later, like the dorsalis pedis flap, the free groin flap, and the latissimus dorsi musculocutaneous flap, to name a few, single-stage flap transfer became possible [11]. The injured limb remains free from abnormal attachments to the body, which allows for better control of edema and early mobilization.

Furthermore, the soft-tissue cover actively contributes to the vascularity of the hand. The main disadvantage of free flaps lies in the technical difficulties and microsurgical equipment and expertise required [2].

The development of the radial forearm flap has made available a large amount of local tissue for the reconstruction of the injured hand. The flap is reliable, is relatively easy to raise, and does not require any microsurgical equipment and expertise, and surgery is confined to the injured limb [2, 31, 41–43]. It offers a large donor area with skin of excellent quality (thin, pliable, hairless), with only a small amount of subcutaneous tissue, which makes it extremely versatile and adaptable. Furthermore, the possibility of including nerve, tendon, bone, or even muscle [44, 45] to the flap makes the flap an invaluable tool in hand reconstruction [8, 11, 18, 19, 24, 31, 46].

The forearm flap is quite different from the other flaps traditionally used (random, axial, and musculocutaneous) because its blood supply originates directly from numerous cutaneous branches arising from the radial artery and forming a rich fascial vascular network. Normally, only a small portion of the radial artery's blood reaches the skin of the forearm through the small cutaneous branches, but after formation of a forearm flap, all blood from the radial artery is directed to the cutaneous branches, greatly increasing the flow of blood to the skin. This sudden increase in blood flow forces open all the denervated capillaries, which gradually return to normal by the seventh postoperative day. This extraordinary rich blood supply probably accounts for the high success rate attained [8]. One could object that, by severing the continuity of the radial artery, the hand's blood supply is jeopardized [47]. The fact is that the main blood supply of the hand comes through the ulnar artery and the deep palmar arch, whereas the radial and interosseous arteries are potential nutrient arteries of the hand. Provided that the ulnar artery is intact and well functioning, there are no functional or vascular consequences to the hand [9, 11, 19, 28–31].

When the forearm flap is used as an island flap pedicled distally, its blood supply is based on a retrograde flow through the deep palmar arch [2, 3, 9, 11, 29, 30]. Allen's test or an ultrasonic

Doppler meter testing, or both, should, therefore, be performed preoperatively to rule out anatomical variations and to establish the presence of a good ulnar artery [8, 19]. The radial artery is almost constantly present, and there have only been two cases described in which it was absent [19].

Venous return has also been established to be retrograde through the venae comitantes (deep veins). The venae comitantes have numerous valves (every 1–3 cm), which are often at the same level between the two comitantes or to within a centimeter of being so. This makes unavoidable the question of how immediate reverse flow through the veins can occur. Between the two venae comitantes are anastomoses, and it has been suggested [48] that these cross-connections bypass the venous valves and thus allow reverse flow. If this were the case, normal forearms would have edema and cutaneous ulceration [27]. Although it cannot be affirmed that bypassing never occurs in the vascular pedicle, at some stage its venous blood has to flow back through previously competent valves.

There are three factors that make this backflow possible. First, when a distally based radial forearm flap is raised, the deep veins are denervated; second, venous pressure in these veins is increased after ligation of their proximal ends; and third, the veins are kept filled by blood from the wrist and hand.

Each of these three factors alone or even two of them together are not sufficient to allow backflow, but if all three factors occur simultaneously, as in a distally based radial forearm flap, then immediate reverse flow through a venous valve will occur [27, 48–51]. This finely balanced combination of three necessary factors may explain why some distally based flaps become edematous [2, 20, 52] or even require additional venous drainage by means of an anastomosis of their superficial veins to a forearm or hand subcutaneous vein [2, 17].

The only real disadvantage of this flap is that the donor site can be closed primarily only if the flap is narrow and elliptically shaped. If the flap is larger, then a split-thickness skin graft is required [2, 8, 11, 19, 46].

The cosmetic result is quite acceptable, especially if the donor site is confined to the volar

aspect of the forearm [2, 8, 11, 19, 53]. Numerous methods have been devised to accelerate donor-site wound healing [54]; these methods promote either enhancement of skin-graft adherence such as oversewing of forearm muscles above exposed tendons [5, 55, 56] or the use of prolonged immobilization [5, 57], or they eliminate the need for a skin graft altogether, using a V-Y advancement of a local ulnar artery forearm flap [58, 59] or skin expansion [24, 56].

In conclusion, we submit that the reverse radial forearm flap has several advantages over its alternatives for soft-tissue coverage of the hand, and it should be the plastic surgeons' first choice in several cases. First, it should be used in emergency operations after extensive soft-tissue loss in the hand, when immediate coverage is required, because the operation is fast, is technically easy, and offers good vascularization to the injured and potentially infected limb. Second, it is useful in situations in which the patient has concomitant injuries, because the operation, besides being fast, does not involve other parts of the body and allows the patient to be free of abnormal attachments. Third, it should be used in selected cases because the operation is reliable, is technically easy, and does not require "mutilation" of the other hand or abnormal attachments discomforting the patient. Some of the other techniques mentioned here are preferable in cases in which the ulnar artery is injured and when the aesthetic result of the donor area is of paramount importance.

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