Abstract
Free flap tissue transfer has allowed coverage of defects in many places of the body where appropriate local flaps are impossible to find. As many different forms of flaps have been added to the available armamentarium, their bulkiness has remained one of the potential problems. This is especially true for a defect that necessitates a very thin flap, for instance, on the hand or the dorsum of the foot, or almost routinely when harvesting a flap from an obese patient. As a consequence, microsurgeons have been obliged to devise some method for flap thinning. Our intent is to discuss this history of flap thinning, describe the anatomy of perforators to the dermis, and then present strategies to achieve ultra-thinning of the flap so that they become like a vascularized skin graft.

Keywords: Flap thinning, pure skin perforator, pure skin perforator flap, superficial circumflex iliac artery skin perforator flap

10.1 INTRODUCTION

The microsurgical transfer of vascularized tissues as a free flap has allowed coverage of defects anywhere in the body, particularly where local flaps prove difficult to reach. As many flap donor sites have been added to our repertoire, the bulkiness of most options has remained one of the problems. This is especially true for any defect necessitating a very thin cutaneous flap, like the hand where a skin graft alone can result in a contracture limiting function, or the dorsum of the foot where use of shoewear cannot be impeded. Almost always this will be difficult whenever harvesting a flap from an obese patient. As a consequence, microsurgeons have been obliged to devise some method for flap thinning. We intend to discuss the evolution of the history of flap thinning, the importance of the anatomy of perforators to the dermis, how preoperative imaging modalities can enable flap thinning, and ultimately provide strategies for achieving ultra-thinning of flaps.

10.2 HISTORY OF THE THIN FLAP

The concept of thin flaps was initially established by Colson in 1967, and developed by Thomas in 1980.[1,2] Abdominal and groin flaps were then used as pedicled distant flaps for coverage of the hands, fingers, and neck. At that time, thinning of these flaps was defined as the removal of adipose layers while keeping the subdermal region intact. A more precise surgical thinning technique developed as perforator anatomy was better delineated. In 2009, Kimura et al reported their elevation method using microdissection, and a "worm-eating" technique.[3] However, there still remained a clear distinction

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Fig. 10.1 Imanishi proposed the "subdermal plexus" should be called the "deep dermal plexus" (*yellow arrows*) because the "subdermal plexus" was actually found either in the subdermal plane or in the deep part of the dermis. (D, dermis; DA, deep adiposal layer; df, deep fascia; E, epidermis; M, muscle; SA, superficial adiposal layer; Sf, superficial fascia.) [Modified from Imanishi N, Nakajima H, Minabe T, Aiso S. Angiographic study of the subdermal plexus: a preliminary report. Scand J Plast Reconstr Surg Hand Surg 2000;34(2):113–116.]

between a thin flap and a skin graft as a flap always had an accompanying adipose layer including the subdermal plexus.

This overlooked the anatomical findings of Imanishi et al in 2000 who reported that the venous plexus in the subdermal plexus could be found either in the subdermal plane or in the deep part of the dermis.[4] So Imanishi et al[4] proposed that this plexus should not be called the "subdermal plexus" but instead the "deep dermal plexus" (▶ Fig. 10.1).

According to the concept of the deep dermal plexus, a skin flap without any subdermal adipose tissue should be possible. Moreover, by preserving a perforator branch that has penetrated the dermis, a free skin perforator flap like a skin graft could be elevated. Narushima et al reported this superthin flap as a "pure skin perforator (PSP) flap" that was nourished by a PSP that indeed was a perforator branch that had penetrated the dermis[5] (▶ Fig. 10.2). The existence of this dermal plexus was later confirmed and visualized for the first time using ultrasonography.[6] We have since postulated that the PSP flap survives due to the very existence of the dermal plexus. Three venous plexuses around the dermis layer have been identified: a subdermal plexus, a dermal plexus, and a subpapillary plexus from the deep layer to the surface.[7] If the dermal plexus and corresponding pure skin perforator (PSP) are preserved, a PSP flap can be vascularized without any subdermal tissues.

10.3 VARIOUS TYPES OF PSP FLAPS

Many conventional perforator flaps including the superficial circumflex iliac artery perforator (SCIP) flap, the anterolateral thigh (ALT) flap, and the thoracodorsal artery perforator (TAP) flap can be converted into a PSP flap.[5,8] Theoretically, in a similar fashion a PSP flap can be elevated from all parts of the body; but the SCIP flap donor

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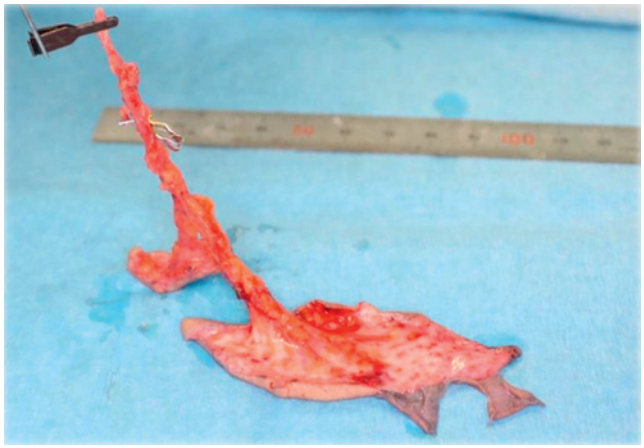

Fig. 10.2 Double pure skin perforator flaps in series based on perforator branches of the superficial circumflex iliac artery pedicle.

	Region	Epi + Der (um)		Region	Epi + Der (um)
1	Eyelid	521.2 ± 115.8	10	Front of forearm	1133.1 ± 214.7
2	Penis	546.0 ± 141.9	11	Cheek	1141.1 ± 292.3
3	Inguinal r.	625.9 ± 273.4	12	Back of arm	1171.8 ± 379.3
4	Postauricular r.	712.9 ± 231.1	13	Abdomen	1331.6 ± 254.2
5	Supraclavicular r.	770.0 ± 220.5	14	Neck (anterior)	1408.0 ± 362.1
6	Chin	857.1 ± 247.8	15	Chest	1438.5 ± 319.7
7	Forehead	865.9 ± 136.8	16	Buttock	1721.4 ± 555.1
8	Axilla	1011.1 ± 178.1	17	Back	1976.9 ± 395.1
9	Front of arm	1012.6 ± 233.3			

Fig. 10.3 Skin thickness of each region of the human body. (Der, dermis; Epi, epidermis; r., region; μm, micrometer.) (Modified from Lee Y, Hwang K. Skin thickness of Korean adults. Surg Radiol Anat 2002;24(3–4):183–189.)

site is preferred because the inguinal region has the third thinnest skin thickness (dermis + epidermis: 625.9 + 273.4 μm), following the eyelid (521.2 ± 115.8 μm) and the preputium of the penis (546.0 ± 141.9 μm) (▶ Fig. 10.3), and is more expendable than the latter two. The ALT–PSP flap or superficial circumflex iliac artery (SCIA)–PSP flap can also include vascularized nerve. The posterior auricular artery perforator (PAAP) flap can be considered as the fourth thinnest PSP flap (712.9 ± 213.1 mm). The PAAP flap has an excellent color and texture match for facial reconstruction, and thus is useful for facial coverage and for the back wall in microtia ear reconstruction.[9]

10.4 ANATOMY OF SCIA-BASED PURE SKIN PERFORATORS

While harvesting 40 SCIA-based PSP flaps, we identified 70 different locations of PSPs.[10] The locations of these PSPs entering the dermis are shown in ▶ Fig. 10.4. The PSPs were found to be clustered around the anterior superior iliac spine (ASIS). PSPs were isolated

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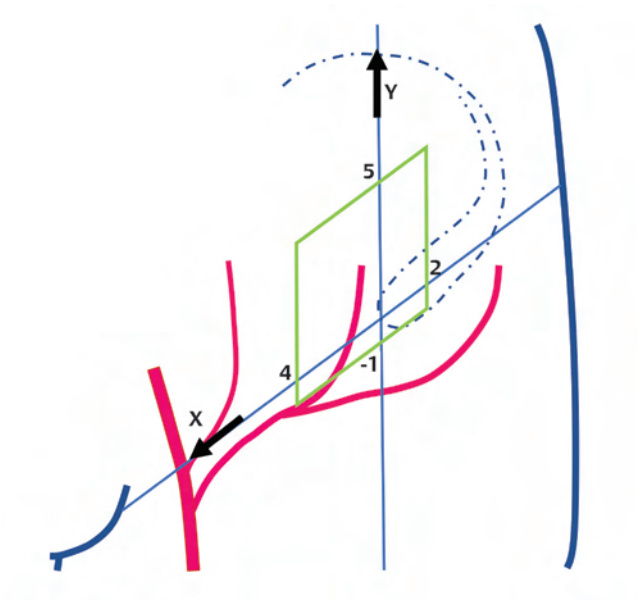

Fig. 10.4 The location of pure skin perforators (PSPs) in the groin area around the anterior superior iliac spine (ASIS) (*dotted blue* area)—X axis (abscissa): parallel to the inguinal ligament, Y axis (ordinate): parallel to the midline of trunk. The *green rhomboid* represents the concentrated region (51/70 [72.9%]) of PSPs. In 93.1% (27/29) of the patients, PSPs were found in this area between 1 cm below and 5 cm above the inguinal ligament, and between 4 cm medial and 2 cm lateral to the ASIS.

from 51 out of 70 (72.9%) in the area between 1 cm below and 5 cm above the inguinal ligament, and between 4 cm medial and 2 cm lateral to the ASIS (▶ Fig. 10.4). From our experience, PSPs can be found in this region in 93.1% of the patients. The diameter of the PSP at the position of dermal entrance was usually 0.2 mm or less. A PSP with a diameter exceeding 0.1 mm can be reliably chosen as the perfusing pedicle of a PSP flap. The mean location of the PSP from the ASIS was X = 0.99 ± 2.68 cm and Y = 1.48 ± 1.97 cm, as explained in ▶ Fig. 10.4.

10.5 FLAP DESIGN AND DIMENSION EXPECTATIONS

Whether identified preoperatively using ultrasonography, or intraoperatively by surgical dissection under microscope, the location of the PSP, or an arterial branch entering the dermis, plays a critical role in the planned flap dissection. Ideally, the PSP should be placed in the center of the skin paddle, as in other perforator flaps. However, from our experience, no differences could be seen in the flap survival rate and the potential flap size when the PSP was placed centrally or peripherally. The maximum dimensions of a PSP flap remain unknown, but from our experience, up to 10 cm from the entry site of a PSP should be perfused by a single PSP. Again, in our experience, flap size based on a single PSP varied from 3 to 60 cm^2. Flap size based on two PSPs varied from 16 to 90 cm^2. Flap size based on three PSPs varied from 22.75 to 90 cm^2. To observe postoperative malperfusion of a PSP flap, indocyanine green (ICG) angiography, which has been reported to detect flap congestion as well as ischemia, can be performed.[11]

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10.6 PREOPERATIVE IMAGING OF PURE SKIN PERFORATORS

Computed tomography angiography (CTA) for many is the current gold standard modality for planning an elevation of a perforator flap. However, because its resolution limitation is around 0.5 mm in diameter, it is extremely difficult to precisely visualize PSPs using CTA. Color duplex ultrasonography often can be more useful for elevation of perforator flaps.[12,13] The terminal branches of the SCIA, which run in the region most suitable for procuring ultrathin flaps, can be observed using a color duplex ultrasound device. The resolution of ultrasonography images decreases, however, when the color duplex mode is used, which makes it impossible to visualize the PSPs precisely. To visualize and identify the correct location of the PSPs, an ultrasound device with an ultra-high frequency, up to 70 MHz, is required.[6] Using 70 MHz ultrasonography, observation of small arteries entering the dermis layer will be possible. Small veins entering the dermis can also be identified and visualized using 70 MHz ultrasonography (▶ Fig. 10.5). The arteries can be distinguished from the veins by applying pressure to the skin: the veins collapse, whereas the arteries retain their shape, as in conventional ultrasonography. There are several tips for finding PSPs using the ultra-high frequency ultrasonography. First, the distal portion of the SCIA should be identified around the ASIS using a probe with lower frequency. This is because the SCIA runs toward the superficial layer as it travels distally, and thus it can be identified superficially in the proximity of the ASIS. After identification of the SCIA, it should be traced down distally using an ultra-high frequency probe, looking for small branches entering the dermis.

10.7 ELEVATION OF A SCIA-BASED PSP FLAP

10.7.1 Pedicle Dissection and PSP Identification

In almost all patients (93.1%), PSPs can be found in an area between 1 cm below and 5 cm above the inguinal ligament, and between 4 cm medial and 2 cm lateral to the

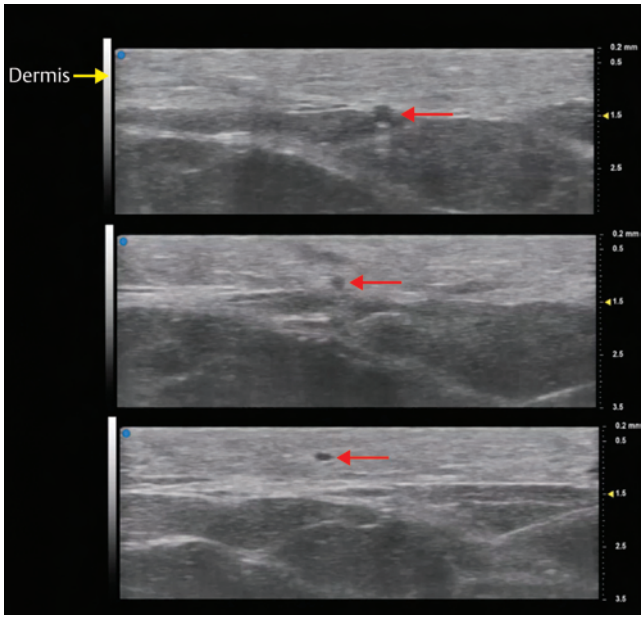

Fig. 10.5 The pure skin perforator (PSP) (*red arrow*) can be visualized entering the dermis using an ultra-high frequency ultrasonography.

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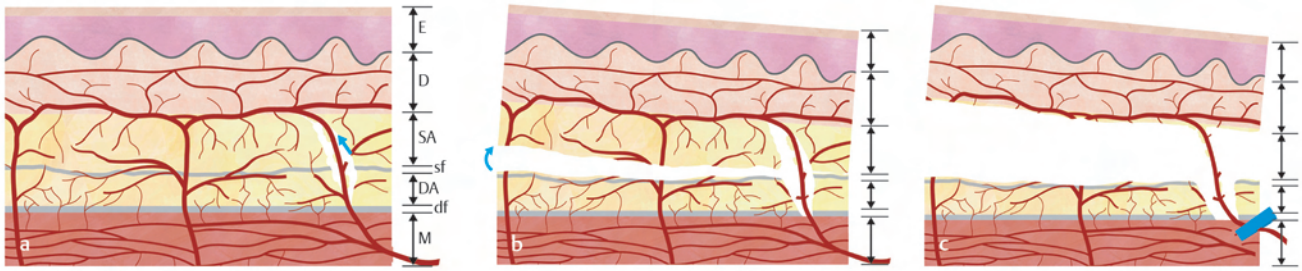

Fig. 10.6 (a) Schematic demonstrating plane of microdissection for following the pure skin perforator (PSP) (*blue arrow*) under the microscope. **(b)** Primary thinning of the superficial subcutaneous layer (*curved blue area*). **(c)** Temporary clamping of the source pedicle (*blue microclamp*) for subsequent extensive defatting to dermis without bleeding.

ASIS (the "hot zone")[10] (▶ Fig. 10.4). Begin with an incision made parallel and at least 1 cm caudal to the inguinal ligament. The SCIA is dissected through this incision and is traced back proximally until the required pedicle length is achieved. The SCIA is then traced distally into the hot zone until a PSP, a branch penetrating the deep dermal layer, is found (▶ Fig. 10.6a). When this procedure is performed using monopolar cautery, the power of the device should be reduced to one half or one-third of its usual strength used for flap elevation. Distinction between a PSP and a subdermal vein can be made by looking at the two following points: pulsation is seen under microscope only with the PSP, and the PSP usually runs with a vena comitans. If there are several PSPs, a PSP with the strongest pulsation seen under the microscope and the one which has a diameter larger than 0.2 mm before entering the dermis should be chosen.

10.7.2 Flap Elevation: Supra-Superficial Fascia Elevation

After identifying the location of the PSP, the path from the proximal portion of the pedicle to the location of that PSP is marked both on the skin surface and the subcutaneous side to avoid inadvertent damage. The skin paddle is designed, and the flap is elevated from the lateral side to the medial side immediately above the superficial fascia using monopolar cautery, as described by Hong et al.[14,15] The superficial fascia can be seen as a thin, white film layer between the deep and the superficial fat layers (▶ Fig. 10.6b). A large subcutaneous vein in the fat layer should also be elevated and included for better venous drainage of the flap. A sensate flap can be achieved by including an intercostal nerve. However, our result reveals that there is no difference in sensation between a PSP flap with or without nerve coaptation.

10.7.3 Flap Thinning: Temporary Clamping and Microdissection

After flap elevation above the superficial fascia layer, the main trunk of the pedicle vessels is temporarily clamped with a microvascular clamp (▶ Fig. 10.6c). Temporary clamping is performed during the flap thinning procedure to maintain a bloodless surgical field, thereby preventing inadvertent damage to the PSP and the dermal venous network. Next must be microdissection, as described by Kimura et al (see ▶ Video 10.1 for microdissection technique).[3] Under a microscope, the flap vessels are again identified, and the adipose tissues are removed using scissors, regardless of the presence of

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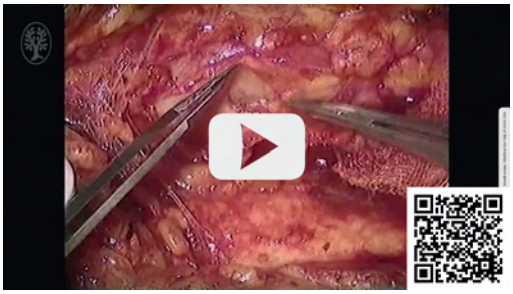

Video 10.1 Microdissection technique.

the subdermal plexus. We can freely perform three-dimensional defatting until the PSP flap is thin, similar to a skin graft (▶ Fig. 10.2). The clamps are removed after the required flap thickness is achieved. The perfusion of the PSP flap is confirmed by observing bleeding from the dermis.

For more precise evaluation of flap perfusion, the following ICG angiography can be performed. ICG is diluted to 2.5 mg/mL with normal saline when administered intravenously: 1 to 2 mL of this diluted ICG is administered via a peripheral intravenous bolus followed by 10 mL of normal saline. Even more precise evaluation requires ICG to be injected into the femoral artery just above the SCIA origin, in which case the ICG should be diluted to 0.25 mg/mL. After sufficient perfusion is confirmed, the pedicle is transected for transplantation. The elevation of a PSP flap can be performed directly, without this time-consuming thinning process once the surgeon is facile with the abovementioned techniques.[16]

For safety concerns, a postoperative vasodilator such as an intravenous drip containing alprostadil alfadex (40 mg; Prostaglandin E1: Ono Japan) is administered over 2 hours in the morning and evening for 1 week. For patients with arteriovenous malformations (AVMs), heparin (10,000 units/day) was added for 1 week as a postoperative anticoagulant.

10.8 PSP FLAP CASE EXAMPLE

10.8.1 Thumb Arteriovenous Malformation

A 74-year-old female with an AVM of her left thumb was referred to our department for a second opinion after she was told that amputation was the only curative method (▶ Fig. 10.7a). The patient had severe pain and atrophy of the thumb, so was classified as third grade in the Schöbinger classification. Resection of the AVM and preservation of the remaining thumb using a SCIA-based partial PSP flap was planned as an ultrathin flap would be required. The AVM was located distal to the snuff box of the radial artery (▶ Fig. 10.7b). The AVM and soft tissues of the thumb were removed completely except for the tendons and the nail bed (▶ Fig. 10.7c). The deep branch of the SCIA was identified in the right inguinal region. The SCIA was dissected proximally to the femoral artery and then distally to find the PSP. After identifying the PSP entering the dermis, a 25 × 6 cm flap was elevated (▶ Fig. 10.7d). The two main PSP vessels were confirmed, and the surrounding adipose tissue was resected to reconstruct the ventral side of the thumb (▶ Fig. 10.7c). The SCIA was anastomosed to the arch of the deep palmar artery in an end-to-side fashion. The superficial circumflex iliac vein (SCIV) and the vena comitans of the

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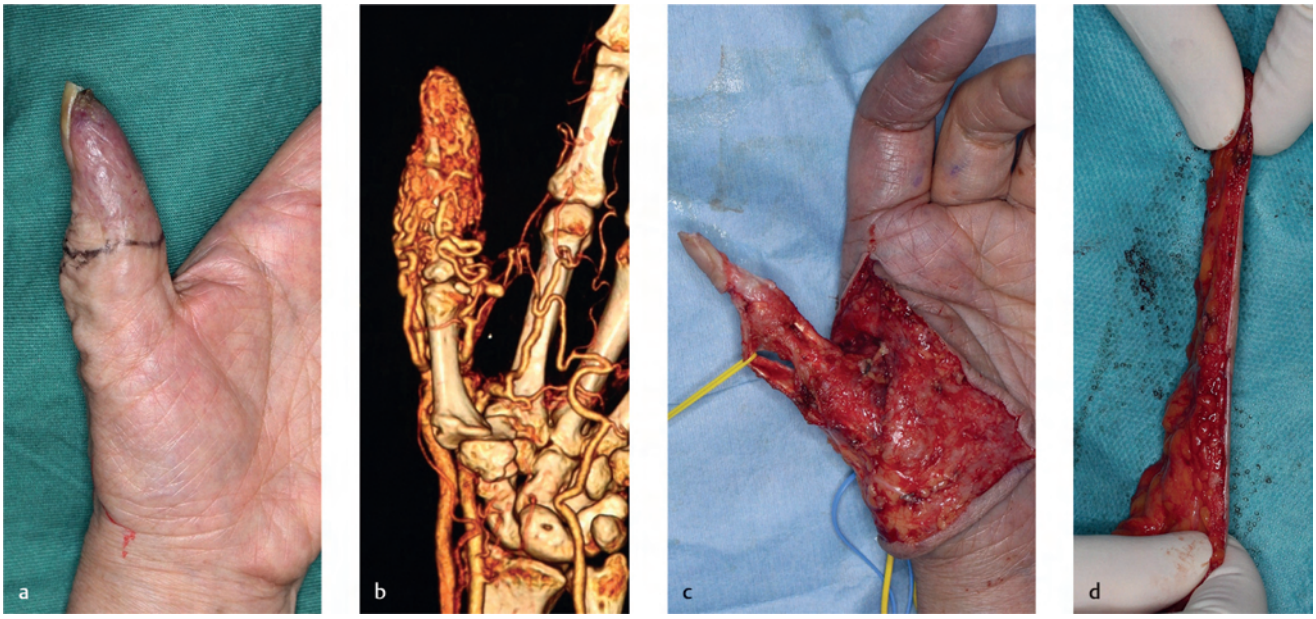

Fig. 10.7 A 74-year-old female with arteriovenous malformation (AVM) of the left thumb: **(a)** Preoperative left thumb appearance. **(b)** Preoperative computed tomography (CT) angiography demonstrating extent of AVM. **(c)** Following radical resection of the AVM leaving the nail plate and nail bed. **(d)** The ultra-thin distal extent of the free superficial circumflex iliac artery–pure skin perforator (SCIA–PSP) flap.

SCIA were anastomosed to dorsal cutaneous veins of the index finger. After 1 year of the operation, there was no recurrence of the AVM, and we were thus able to preserve her thumb without any complications (▶ Fig. 10.8). A distorted nail plate did regrow as well.

10.9 PEARLS AND PITFALLS

10.9.1 Steps for Safe PSP Flap Elevation

Three steps are important for safe PSP flap elevation:

- Supra-superficial fascia elevation.
- Temporary pedicle clamping during thinning.
- PSP microdissection.

Only by adopting these three steps, can the PSP flap be safely elevated. Once the thickness is adjusted according to the reconstructive needs, the flap can be folded, bent, and trimmed for insetting as required.

10.9.2 Back-Up Plan if PSP Flap Aborted

The greatest risk in raising the SCIA–PSP flap is the failure to find a PSP, which ends up in harvesting of a devascularized full-thickness skin graft. In such a case, the deep adipose tissue or areolar tissue above the deep fascia can be elevated with the deep branch of the SCIA. It is then transplanted to the recipient site and the inadvertently harvested skin graft can placed on the flap. The transplanted areolar tissue flap will also be thin and provide a vascularized bed for survival of the skin graft.

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Fig. 10.8 (a) Palmar view of successful superficial circumflex iliac artery–pure skin perforator (SCIA–PSP) flap covering left thumb 1 year after operation. **(b)** Radial lateral view demonstrating retention of pinch capability, and deformed nail plate.

10.10 VASCULARIZED AREOLAR FLAP CASE EXAMPLE

10.10.1 Great Toe Donor Site Coverage

A 60-year-old female suffered a thumb injury in a heat press machine, resulting in total necrosis of the thumb. A partial right great toe-to-thumb transfer was planned for reconstruction of the thumb. A PSP flap was planned for thin coverage of the donor site (▶ Fig. 10.9). The PSP flap was elevated without finding any perforator branches, so this turned out to be only a full-thickness skin graft. A 12 × 5 cm areolar tissue flap was secondarily elevated above the deep fascia based on the deep branch of the SCIA. The areolar tissue flap was used to cover the exposed distal phalanx of the great toe (▶ Fig. 10.10a). The deep branch of the SCIA was anastomosed to the first dorsal metatarsal artery, and the venae comitantes of the SCIA were anastomosed to respective venae comitantes of the dorsal foot artery. The inadvertently harvested skin graft was placed on the transplanted areolar tissue flap (▶ Fig. 10.10b). The skin graft took completely, permitting an excellent salvage as seen 1 year after the operation (▶ Fig. 10.11).

10.11 CONCLUSION

The PSP flap is a cutaneous flap essentially devoid of adipose tissue and nourished by a perforator branch entering its dermal plexus. Whereas previously the bulkiness of a perforator flap in most cases has been a concern, now the immediate creation of even an ultrathin flap is possible using this strategy, albeit a microdissection of the flap and its vascular supply will for now be required. In its simplistic form, this could be

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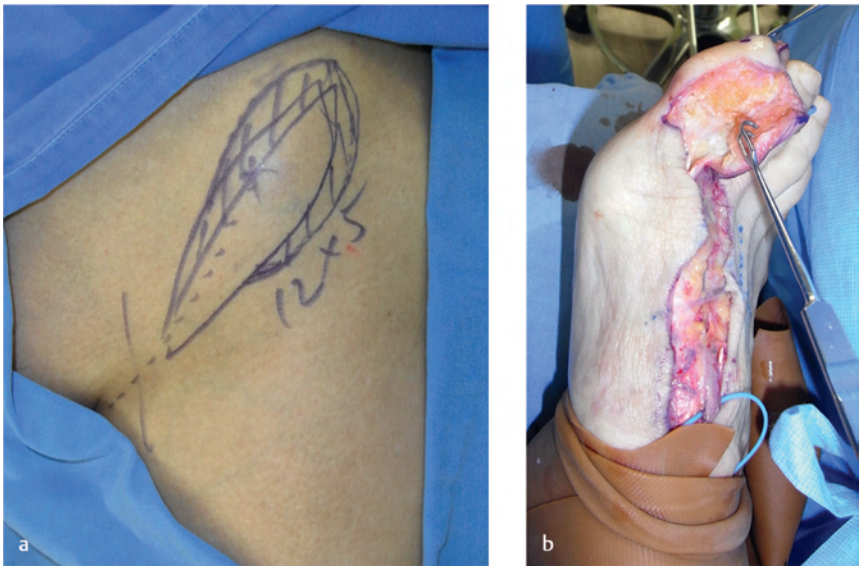

Fig. 10.9 (a) Design for superficial circumflex iliac artery perforator–pure skin perforator (SCIP–PSP) flap in left groin with axis paralleling inguinal ligament. **(b)** Defect after partial great toe flap harvest.

Fig. 10.10 (a) Inset vascularized deep branch superficial circumflex iliac artery perforator (SCIP) areolar flap. **(b)** Fenestrated, full-thickness skin graft on SCIP free flap.

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Fig. 10.11 **(a)** Frontal view of right great toe showing thin coverage achieved 1 year later. **(b)** Thin coverage of dorsum right foot that would not impede use of shoewear.

considered to be a vascularized full-thickness skin graft. Although it is possible to harvest pure perforator skin flaps anywhere a perforator branch can be found penetrating the dermis, most experience has been so far accomplished using the groin region as the donor site, since not only is the skin thickness here inherently thin compared to the rest of the body, but also any donor site residues are readily concealed by clothing.

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