REVIEW

Development of Skin Flaps for Reconstructive Surgery : Random Pattern Flap to Perforator Flap

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Abstract : Flap transplantation has been an important procedure in plastic and reconstructive surgery to cover and fill various defects. Flap necrosis due to blood circulation failure leads to severe complications, especially in a patient undergoing reconstruction concerning the body cavity after tumor ablation. Surgical procedures for flap transplantation have been further improved and developed. We have reviewed from the random pattern flap to the newest procedure, the perforator flap. Perforator vessels were investigated in the process of development of the fasciocutaneous flap and have become important for blood supply of the skin flap. Blood circulation of the flap has become more stable and reliable than ever with the development and findings of the perforator vessels. Further development of a skin flap will be based on the perforasome concept, which involves the study of the territory and linking of perforator vessels. J. Med. Invest. 63 : 159-162, August, 2016

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INTRODUCTION

Free skin grafting is a procedure to cover skin defects such as burn ulcers or traumatic skin ulcers. However, a skin graft does not have blood circulation and cannot survive on bone surface without periosteum and on artificial material. Skin grafting cannot be performed until the deep ulcer is covered with granulation tissue. A skin flap having blood circulation can survive on any defect or ulcer without granulation tissue. Before mid-1960's, random pattern skin flaps had been used in reconstructive procedures. Random pattern flaps were elevated without any regard to any known blood supply other than the subdermal plexus. Because flap survival, especially of distal portion, was not stable and reliable, flaps were restricted to rigid length-to-width ratios to ensure their viability (1).

1. THE FIRST AXIAL FLAP

The following are the different types of reconstructive flaps that have been used : the deltopectoral flap was reported in 1965 (2). This flap is thought to be the first axial flap that has vascular supply from the internal thoracic artery. The flap base is placed on the lateral side of the sternum, where vessels from the internal thoracic artery to the flap can be found, and the flap is positioned toward the shoulder joint. Concept of an axial pattern flap was established after individual and large subcutaneous vessels with a predictable orientation were discovered in 1971 (3).

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2. MUSCULOCUTANEOUS TO FASCIOCUTANEOUS FLAP

Blood supply and vascular pedicle of the muscle had been known and muscle flaps were used to fill the thoracic cavity in the 1940s (4). In the 1970s, investigation started on the muscle as a carrier of the overlying skin to create larger musculocutaneous flaps (5). Many kinds of musculocutaneous flaps were developed and reported to fill defects of the leg, perineal region, and breast (6-8).

The axial and musculocutaneous flaps revealed that the viability of a skin flap depended on its vascularization but not on the length-to-width ratios (Figure 1). Major sources of blood supply related with the muscles for skin flaps were detected on the whole body. Eventually, in the 1980s, a concept of fasciocutaneous flap was recognized (9, 10). Cormack and Lamberty advocated three kinds of skin flaps ; direct cutaneous, musculocutaneous, and fasciocutaneous flaps (11, 12). They defined the fasciocutaneous flap as follows : "the fasciocutaneous flap specifically is supplied by arteries, which pass along intermuscular and intercompartmental fascial septa to reach the overlying deep fascia and in turn the superficial fascia and skin." (13).

3. SKIN PERFORATOR

Cormack and Lamberty divided the fasciocutaneous flaps into three types (11). Their early study did not show details of blood supply to the skin flap from deep vessels. Thereafter, Nakajima *et al.* advocated more precise types of six different patterns of vascular supply from deep vessels through deep fascia to skin flaps (14). Mathes and Nahai tried to combine Nakajima's patterns into three simple types : type A flaps with a direct cutaneous pedicle, type B with a septocutaneous pedicle, and type C with a musculocutaneous pedicle. These three types became important models for developing the perforator flap theory (Figure 2). The fasciocutaneous flap shed light on the vascular supply from the deep fascia

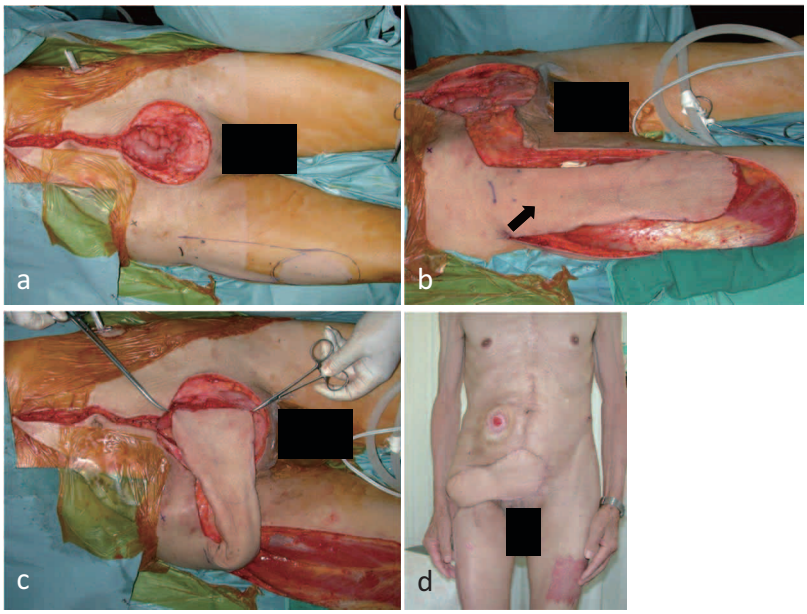

Figure 1. Tensor fascia lata musculocutaneous flap for abdominal wall reconstruction. (a) A malignant tumor spreading to the abdominal wall is resected. Note the colon observed through the defect of the abdominal wall. (b) A long skin flap is elevated on the base of vascular supply from the tensor fascia lata muscle. A arrow indicates location of the muscle under the skin. (c) The skin flap is rotated to the defect with connection to the muscle. Note that the skin color of the distal edge of the flap shows good blood circulation. (d) Five months after operation at standing position. The flap having fascia lata completely survives and is strong enough to avoid abdominal wall hernia.

to the skin and this led to the recognition of the skin perforator vessels. Because of this recognition, a concept of perforator flap was introduced by Kroll and Rosenfield (15) and Koshima *et al.* (16) during late 1980s. They revealed that skin flaps could survive with blood supply from the perforator vessels containing small arteries and veins without a 'carrier' such as the muscle or deep fascia. Search for the perforator vessels was extended to the whole body including the latissimus dorsi muscle (17), gluteus maximus muscle (18), and radial artery region (19).

4. PERFORATOR FLAP

The definition of a perforator vessel or a perforator flap has been ambiguous from the beginning. Wei *et al.* (20) argued that the only true perforator is a cutaneous vessel that first penetrates a muscle and then pierces the deep fascia to reach the skin. This means that flaps having direct cutaneous pedicle and septocutaneous pedicle do not belong to the category of perforator flaps (Figure 2). However, through a consensus meeting, the concept of a perforator flap included those having a direct cutaneous pedicle and a septocutaneous pedicle (21).

A perforator flap has few disadvantages including the necessity of a technique for dissecting the thin perforator vessels and possibility of blood circulation failure caused by pressure to or distortion of the perforator vessels, but has many following advantages. Perforator flap does not need a carrier muscle (Figure 3). Surgical removal of fatty tissue in the flap and volume adjustment of a muscle flap is easy and safe because the vascular pedicle from the deep fascia to fatty tissue and muscle is visible and can be preserved (Figure 4). A pedicle perforator flap can be moved, rotated, or advanced to a defect more easily than a conventional flap connected with the deep fascia or muscle.

Anterolateral thigh flap (ALT flap) was reported originally as a flap nourished by the septocutaneous artery (22). After overcoming an anatomical variation of its perforator vessels (23), the ALT flap is broadly accepted as a versatile and ideal perforator flap (24-26). Especially, a free ALT flap combined with a vastus lateralis muscle flap is very useful for head and neck reconstruction (Figure 3). This flap can be elevated from the thigh at the same time as tumor ablation in the head and neck region and is time saving during long reconstructive surgeries. Tissue defects in the head and neck are often complex, and the free ALT flap combined with the vastus lateralis muscle flap can be placed on the three-dimensional defect (26).

5. PERFORATOR FLAP IN THE PERINEAL REGION

In the perineal region, reconstruction with fasciocutaneous and musculocutaneous flap achieved better results than that with a random pattern flap. However, the vascular pedicles of fasciocutaneous and musculocutaneous flaps for perineal reconstruction exist on the thigh and are far from the perineal region (27, 28). Therefore, the vascularization of the distal edge of these flaps is not reliable and distal necrosis is sometimes observed. In the 1990s, the internal pudendal artery, which is very close to the perineal region was investigated. Small sized skin flaps designed to have vascularization from the internal pudendal artery were reported and used mainly for vaginal reconstruction (29). These flaps were designed based on the famous angiography study by Salmon (30). Because this significant study showed the skin surface in two-dimension, the internal pudendal artery and its skin perforators are not clearly demonstrated and not obvious. After studying the details of the skin perforators and internal pudendal artery in cadavers (31, 32), the gluteal fold flap nourished by these perforators is widely used for perineal reconstruction (33, 34) because this flap has a stable blood circulation under a stable surgical procedure. A new concept about the perforator flap is a free style flap idea where any shape of the flap can be designed on the skin perforators. We have advocated a free style pedicle flap, internal pudendal artery perforator flap (ipap flap) that contains the ipap gluteal fold

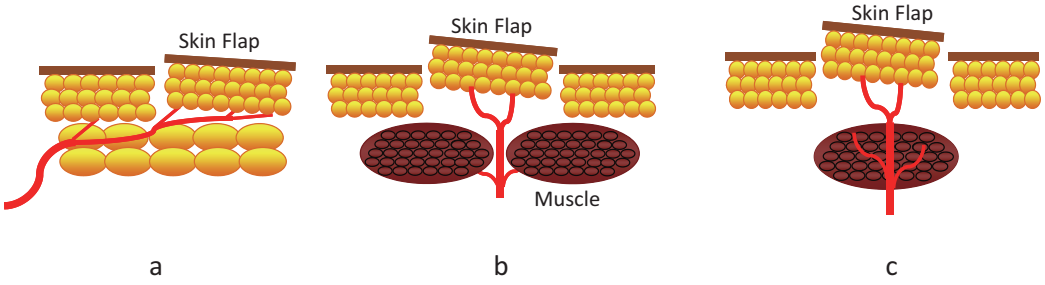

Figure 2. Simple classification of fasciocutaneous flap to perforator flap concept
(a) direct cutaneous pedicle, (b) septocutaneous pedicle, (c) musculocutaneous pedicle.

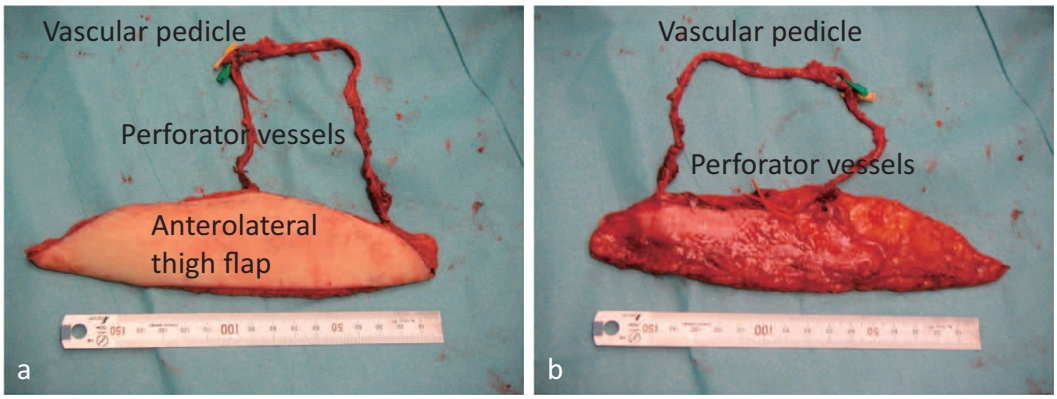

Figure 3. Anterolateral thigh flap (a) Skin flap, two perforator vessels, and vascular pedicle. (b) The skin flap is connected with the perforators but without the muscle component.

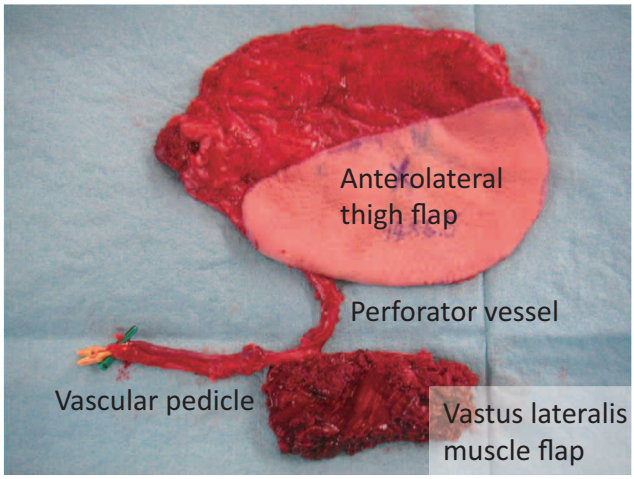

Figure 4. Anterolateral thigh flap and vastus lateralis muscle flap. Note that the muscle and skin flaps have individual vascular pedicle and the muscle flap is not a carrier for vascular pedicle of the skin flap.

flap, ipap V-Y flap, and ipap thigh flap (35, 36). It is demonstrated that these ipap flaps have reliable blood circulation and offer suitable flap volume for any defect in the perineal and ischial region (35, 36).

6. FURTHER STUDY ON FLAP CIRCULATION

Taylor and Palmer have shown important details on flap design and harvest, which contain direction and territory of vessels under the skin (37). In addition, the perforasome theory has recently revealed that one perforator has a wide vascular territory through linking vessels and communicating branches in the adipose layer (38). These two concepts will help in understanding the differences in blood supply and flap direction between trunk and limbs, and finally, to help develop a new perforator flap concept.

CONFLICT OF INTEREST

None of the authors has any conflicts of interest to declare.

REFERENCES

1. Julian CG, Callison J, Woodruff JD : Plastic management of extensive vulvar defects. Obstet Gynecol 38 : 193-198, 1971
2. Bakamjian VY : A two-stage method for pharyngoesophageal reconstruction with a primary pectoral skin flap. Plast Reconstr Surg 36 : 173-184, 1965
3. McGregor IA, Morgan G : Axial and random pattern flaps. Br J Plast Surg 26 : 202-213, 1973
4. Prioleau WH : Muscle flap closure of cavity resulting from lung abscess. Trans South Surg Assoc 57 : 195-203, 1946
5. Ger R : The technique of muscle transposition in the operative treatment of traumatic and ulcerative lesions of the leg. J

Trauma 11 : 502-510, 1971
6. Orticochea M : The musculocutaneous flap method : an immediate and heroic substitute for the method of delay. Br J Plast Surg 25 : 106-110, 1972
7. McCraw JB, Massey FM, Shanklin KD, Horton CE : Vaginal reconstruction with gracilis musculocutaneous flaps. Plast Reconstr Surg 58 : 176-183, 1976
8. Schneider WJ, Hill HL Jr, Brown RG : Latissimus dorsi myocutaneous flap for breast reconstruction. Br J Plast Surg 30 : 277-281, 1977
9. Ponten B : The fasciocutaneous flap : its use in soft tissue defects of the lower leg. Br J Plast Surg 34 : 215-220, 1981
10. Donski PK, Fogdestam I : Distally based fasciocutaneous flap from the sural region. A preliminary report. Scand J Plast Reconstr Surg 17 : 191-196, 1983
11. Cormack GC, Lamberty BG : A classification of fascio-cutaneous flaps according to their patterns of vascularization. Br J Plast Surg 37 : 80-87, 1984
12. Cormack GC, Lamberty BG : Alternative flap nomenclature and classification. In : The Arterial Anatomy of Skin Flaps, 2nd ed. Churchill Livingstone, Edinburgh, 1994, pp.514-522
13. Cormack GC, Lamberty BG : The anatomical basis for fasciocutaneous flaps. In : Hallock GG, eds. Fasciocutaneous Flaps. Blackwell Scientific Publications, Cambridge Mass, 1992, pp.13-24
14. Nakajima H, Fujino T, Adachi S : A new concept of vascular supply to the skin and classification of skin flaps according to their vascularization. Ann Plast Surg 16 : 1-19, 1986
15. Kroll SS, Rosenfield L : Perforator-based flaps for low posterior midline defects. Plast Reconstr Surg 81 : 561-566, 1988
16. Koshima I, Soeda S : Inferior epigastric artery skin flaps without rectus abdominis muscle. Br J Plast Surg 42 : 645-648, 1989
17. Angrigiani C, Grilli D, Siebert J : Latissimus dorsi musculocutaneous flap without muscle. Plast Reconstr Surg 96 : 1608-1614, 1995
18. Allen RJ, Tucker C Jr : Superior gluteal artery perforator free flap for breast reconstruction. Plast Reconstr Surg 95 : 1207-1212, 1995
19. Koshima I, Moriguchi T, Etoh H, Tsuda K, Tanaka H : The radial artery perforator-based adipofascial flap for dorsal hand coverage. Ann Plast Surg 35 : 474-479, 1995
20. Wei F C, Jain V, Suominen S, Chen H C : Confusion among perforator flaps : What is a true perforator flap? Plast Reconstr Surg 107 : 874-876, 2001
21. Blondeel PN, Van Landuyt K, Hamdi M, Monstrey SJ : Perforator flap terminology : update 2002. Clin Plast Surg 30 : 343-346, 2003
22. Song YG, Chen GZ, Song YL : The free thigh flap : a new free flap concept based on the septocutaneous artery. Br J Plast Surg 37 : 149-159, 1984
23. Kimata Y, Uchiyama K, Ebihara S, Nakatsuka T, Harii K : Anatomic variations and technical problems of the anterolateral thigh flap : a report of 74 cases. Plast Reconstr Surg 102 : 1517-1523, 1998
24. Wei FC, Jain V, Celik N, Chen HC, Chuang DC, Lin CH : Have we found an ideal soft tissue flap? An experience with 672 anterolateral thigh flaps. Plast Reconstr Surg 109 : 2219-2226, 2002
25. Hashimoto I, Sedo H, Inatsugi K, Nakanishi H, Arase S : Severe radiation-induced injury after cardiac catheter ablation : a case requiring free anterolateral thigh flap and vastus lateralis muscle flap reconstruction on the upper arm. J Plast Reconstr Aesthet Surg 61 : 704-708, 2008
26. Hashimoto I, Nakanishi H, Yamano M, Abe Y : Usefulness in combined free anterolateral thigh and vastus lateralis muscle flaps. Eur J Plast Surg 35 : 867-872, 2012
27. McCraw JB, Massey FM, Shanklin KD, Horton CE : Vaginal reconstruction with gracilis myocutaneous flaps. Plast Reconstr Surg 58 : 176-183, 1976
28. Goldberg MI, Rothfleisch S : The tensor fascia lata myocutaneous flap in gynecologic oncology. Gynecol Oncol 12 : 41-50, 1981
29. Hagerty RC, Vaughn TR, Lutz MH : The perineal artery axial flap. Ann Plast Surg 31 : 28-31, 1993
30. Salmon M : The external genitalia and perineum. In : Taylor G, Tempest MN, eds. Arteries of the Skin. Churchill Livingstone, Edinburgh, 1988, pp.109-128
31. Hashimoto I, Nakanishi H, Nagae H, Harada H, Sedo H : The gluteal-fold flap for vulvar and buttock reconstruction : anatomic study and adjustment of flap volume. Plast Reconstr Surg 108 : 1998-2005, 2001
32. Hashimoto I, Murakami G, Nakanishi H, Sakata-Haga H, Seike T, Sato TJ, Fukui Y : First cutaneous branch of the first pudendal artery : An anatomical basis for the so-called gluteal fold flap. Okajimas Folia Anat Jpn 78 : 23-30, 2001
33. Salgarello M, Farallo E, Barone-Adesi L, Cervelli D, Scambia G, Salerno G, Margariti PA : Flap algorithm in vulvar reconstruction after radical, extensive vulvectomy. Ann Plast Surg 54 : 184-190, 2005
34. John HE, Jessop ZM, Di Candia M, Simcock J, Durrani AJ, Malata CM : An algorithmic approach to perineal reconstruction after cancer resection experience from two international centers. Ann Plast Surg 71 : 96-102, 2013
35. Hashimoto I, Abe Y, Nakanishi H : The internal pudendal artery perforator flap : free-style pedicle perforator flaps for vulva, vagina, and buttock reconstruction. Plast Reconstr Surg 133 : 924-933, 2014
36. Hashimoto I, Goishi K, Abe Y, Takaku M, Seike T, Harada H, Nakanishi H : The internal pudendal artery perforator thigh flap : a new free style pedicle flap for the ischial region. Plast Reconstr Surg Glob Open 2 : e142, 2014
37. Taylor GI, Palmer JH : The vascular territories (angiosomes) of the body : Experimental study and clinical applications. Br J Plast Surg 40 : 113-141, 1987.
38. Saint-Cyr M, Wong C, Schaverien M, Mojallal A, Rohrich RJ. The perforasome theory : Vascular anatomy and clinical implications. Plast Reconstr Surg 124 : 1529-1544, 2009