Direct and Indirect Perforator Flaps: The History and the Controversy

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Learning Objectives: After studying this article, the participant should be able to: 1. Recognize the major role of the vascular supply to a cutaneous flap. 2. Predict its reliability. 3. Understand basic schemes for classification. 4. Realize that the evolution of these concepts is an ongoing dynamic process.

Currently, the vascular supply to the fascial plexus is considered the factor of greatest importance in ensuring the reliability of any skin-bearing flap. The multiplicity of origins of the deep fascial perforators to this plexus has led to a bewildering array of terminology intended to encompass all possible flap options. A brief review of the history of the evolution of cutaneous flaps provides insight essential in understanding a simple proposal for their classification. Because all fascial perforators course either directly from a source vessel or indirectly first through some other tissue to ultimately reach the suprafascial layer, the corresponding flaps based on any such perforators could most simply be termed either direct perforator flaps or indirect perforator flaps, respectively. (Plast. Reconstr. Surg. 111: 855, 2003.)

During the first half of the last century, the repertoire of skin flaps was limited to random flaps, which were raised without regard to any known blood supply other than the subdermal plexus and were thus restricted to rigid length-to-width ratios to ensure viability. These flaps were differentiated according to how they were constructed, including the method of movement (e.g., advancement or rotation), conformation (e.g., direct or tubed), and destination (e.g., local or distant). This situation changed forever when McGregor and Morgan discovered discrete, large, subcutaneous vessels with a predictable orientation that could completely nourish huge cutaneous or “axial” flaps (Fig. 1, above). Ger and others soon thereafter were instrumental in proselytizing the use of muscle, not only as a soft-tissue flap itself but also as a carrier of the overlying skin to create even larger musculocutaneous flaps (Fig. 1, below).

Both the concepts of axial and musculocutaneous flaps corroborated Milton’s assertion that the vitality of a skin flap depended entirely on its means of vascularization and had nothing whatsoever to do with numeric length-to-width ratios. By the same reasoning, if these flaps are constructed as distally based cutaneous flaps, their reliability, even in comparison with supposedly safer proximally based flaps, depends not on the orientation of the flap pedicle per se but, more importantly, on the nature of the included vascular supply. The concept of flap length-to-width ratios has now been relegated to our historical archives, and as a corollary, the stigma against distally based flaps, even in critical situations, today has been lifted when appropriate.

As this development of cutaneous flaps evolved over the past century, knowledge of their intrinsic blood supply was eventually recognized as the most important determinant for ensuring success. Despite this intuitively obvious fact and an omnipresent zeal in investigating every nook and cranny of the body for new axial or muscle flaps, a major source of blood supply to the integument was completely overlooked. Ponten recognized this fact when
he reintroduced the principle of fasciocutaneous flaps. His lower-limb "superflaps," which included the deep fascia, had a longer survival than could be predicted for random flaps of comparable size, although no anatomical explanation at that time was given. Thus, modern anatomists overlooked what the medical student Manchot knew in 1889, more than 100 years ago: "larger cutaneous arteries . . . appear from the fissure between . . . muscles. Directly above the fascia, they divide into terminal branches . . . and interconnect . . . ." Salmon expanded these same observations using radiopaque injection techniques, but both contributions were largely unavailable to the English-speaking world.15

**THE EMERGENCE OF THE FASCIOCUTANEOUS FLAP**

Further investigations for anatomical explanations of the robustness of Ponten’s flaps led Cormack and Lamberty16,17 to state that there was a tripartite system of direct cutaneous, musclecutaneous, and fasciocutaneous flaps that would include all known skin flaps. They stipulated that “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.”11 Others used the term septocutaneous flap interchangeably with fasciocutaneous flap,18 but Cormack and Lamberty19 and Satoh20 were quick to point out how this could cause confusion, because true septocutaneous vessels traverse the compartmental septa alone, whereas those traversing intermuscular septa are intermuscular cutaneous vessels and their flaps should then instead be called intermuscular cutaneous flaps.

Additional controversy arose because Tolhurst,22 like Ponten,13 was far less restrictive in his definitions; he claimed “when a flap contains skin, fat, and deep fascia that are in continuity with the same three layers of the flap’s...
pedicle, it deserves no other name than a fasciocutaneous flap.”21 A more reasonable compromise suggested by Nahai22 was that “any skin flap made more reliable by the inclusion of the underlying fascia during elevation to preserve its nutritive inflow via this ‘fascial plexus’ should be called a ‘fasciocutaneous flap.’”

Just what this “fascial plexus” was became the key element for deciphering the nomenclature for fasciocutaneous flaps that was to arise. The fascial plexus encompasses all component parts, including the subfascial, intrafascial, and suprafascial vascularplexuses and the dermal, subdermal, superficial adipofascial (above Scarpa’s fascia), and deep adipofascial layers, which all in some way then form an array of interconnected vessels.23–25 Cormack and Lamberty11 emphasized that their term fasciocutaneous implied this anatomical system of vascularization and did not refer to any specific tissue constituents per se. They realized, for example, that the skin and/or deep fascia portions could then be excluded, but any such flap dependent on this fascial plexus would still be a fasciocutaneous flap.11 Thus, a fasciocutaneous flap could be interpreted to be any flap with a defined blood supply (servicing the fascial plexus of the flap) that was composed of any or all component layers found between the skin and deep fascia.26

THE CLASSIFICATION OF FASCIOCUTANEOUS FLAPS

Mathes and Nahai27 proposed a system for classifying muscle flaps on the basis of their vascularization to simplify surgical dissection; for the same reason, several schemes have been suggested for fasciocutaneous flaps. The first system by Cormack and Lamberty16 was subdivided into three major subtypes (Fig. 2). Their type A fasciocutaneous flap (e.g., Ponten’s flap) depended on multiple fascial perforators (never requiring specific identification) that entered the fascial plexus and then the pedicle at the base of the flap. Type B flaps had inflow through a solitary, identifiable perforator. The “ladder type” or type C flap had multiple small fascial perforators from a single subfascial source vessel, which must also always be contained within the flap (Table I).

Nakajima et al.,23 in what could be considered a classic but underappreciated treatise on this subject, were far more precise in their identification of six different types of deep fascial perforators (Fig. 3) and their correspond-
the fasciocutaneous flap. Two completely new types of fascial perforators and their potential flaps were also proposed. In essence, these were cutaneous twigs that arose as branches from the pedicle to a muscle and differed only in whether or not they actually traversed the substance of that muscle.

Nahai\textsuperscript{28} tried to coalesce Nakajima’s\textsuperscript{25} schema into fewer but similar subtypes; for example, all flaps in which the perforators passed through muscle should be musculocutaneous in origin and all those with perforators coursing between or around muscles were septocutaneous. This thereby briefly explained the rationale for Mathes and Nahai’s\textsuperscript{29} later classification of fasciocutaneous flaps (Fig. 5). Nakajima et al.’s\textsuperscript{25} most recent rebuttal against accepting this contraction as valid used computer graphics imaging to develop a three-dimensional view of the fascial plexus of the dermis, subdermis, and superficial and deep adipofascial layers. When based on axiality, vessel size, and the layer of predominant course of the arteries so analyzed, there was even greater evidence to justify their original system of six distinct fascial perforators. For example, in their types A through D only (Fig. 3), the predominant course and arborization of perforator branches was within the deep adipofascial layer.

This observation has further demonstrated the importance of clarification of the basic anatomy, even of perforators, to define the surgical approach and reveals a previous limitation of our knowledge. If these flaps, as cutaneous flaps, were split above Scarpa’s fascia, their vascular supply would be excluded and their viability compromised, in contradistinction to an adipofascial flap retaining the deep adipose layer. This also confirms the validity of the prior admonition by Nahai\textsuperscript{22} to preserve the deep fascia with a fasciocutaneous flap, which in most cases will indeed protect the necessary nutritive inflow to the fascial plexus if nothing else.
FURTHER SIMPLIFICATION OF CUTANEOUS FLAP NOMENCLATURE

On the basis of its vascular anatomy, the body is composed of some 40 blocks of composite tissue, most with a unique cutaneous territory; all in turn are supplied directly by a discrete and named source vessel. Taylor and Palmer, on the basis of this “angiosome” concept, have tried to overcome the obfuscation and mayhem wrought by the terms random, reticular, segmental, axial, adipofascial, septocutaneous, musculocutaneous, fasciocutaneous, and so on that are used for what are just variations of cutaneous flaps. According to Taylor et al. and Timmons, Spalteholz had postulated as early as 1893 that all arteries to the skin could quite simply be considered either direct or indirect branches from an underlying source vessel. Taylor and others suggested that the direct vessels are the primary cutaneous supply, regardless of whether they first pierce intermuscular or intramuscular septa, because their main destination is always the skin.

These direct vessels can (1) arise from source arteries that may course just beneath the deep fascia, (2) continue as their terminal continuation, (3) follow the septa from deeply situated named vessels or branches of muscle pedicles, or (4) proceed from the source artery of a muscle as it courses on the latter’s undersurface. In contrast, indirect vessels are a secondary means of cutaneous supply. They emerge through the deep fascia as terminal, spent branches whose main purpose is to supply the deeper tissues, especially muscles. Thus, all deep fascial perforators could also be considered either “direct” or “indirect” (Fig. 6), and with only a slight modification for further simplification, all the corresponding cutaneous flaps could most simply be subdivided as either direct or indirect perforator flaps.

If any classification schema for stratifying cu-

taneous flaps is to be all inclusive and straightforward, it must allow all presently described and any potential new genres of flaps to be readily assimilated. For example, where would perforator flaps or neurocutaneous flaps fall into this system? This first requires some additional reconciliation regarding the term “perforator" itself, which is a term entrenched and ubiquitous in some form throughout the flap literature. Manchot named perforators “shoots.” Tolhurst preferred the term “conductor” to describe any vessel coursing from the source vessel of a given angiosome to the fascial plexus of its corresponding cutaneous territory. Niranjan et al. call them “fascial feeders” for self-explanatory reasons. However, it makes intuitive sense that any vessel that enters the suprafascial plane through a defined fenestration in the deep fascia, regardless of origin, must have perforated the fascia and can reasonably be considered a perforator.

Perforator Flaps

In contradistinction to the preceding definition of a “perforator,” Wei et al. argue that the only true perforator is a cutaneous vessel that first penetrates a muscle and then pierces the deep fascia to reach the skin. As a corollary, a true perforator flap must always be supplied by fascial perforators that have required an

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**Fig. 4.** Types of fasciocutaneous flaps named after the origin of the perforator to its fascial plexus, according to the schema of Nakajima et al. (*Above, left*) Type I, direct cutaneous flap. (*Above, right*) Type II, direct septocutaneous flap. (*Center, left*) Type III, direct cutaneous branch of muscular vessel flap. (*Center, right*) Type IV, perforating cutaneous branch of muscular vessel flap. (*Below, left*) Type V, septocutaneous perforator flap. (*Below, right*) Type VI, musculocutaneous perforator flap. Modified with permission from Nakajima, H., Fujino, T., and 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, 1986.
intramuscular dissection during elevation of the flap. What makes this flap subtype uniquely valuable is that morbidity is minimized at the donor site by preserving the previously passive muscle carrier, its motor nerve and function, and the deep fascia to maintain the donor site contour and appearance. The consensus at the Gent Perforator Conference in 2001 was to label such flaps as “muscle” perforator flaps and to name them according to the pedicle of the underlying muscle (for example, the deep inferior epigastric flap, which requires an intramuscular dissection through the rectus abdominis muscle).

The intent of restricting the terminology in this way was to enhance an understanding of the necessary surgical approach to the given flap. Yet one must agree, however reluctantly, that this is a somewhat radical departure from the prior conventional and more liberal use of the term perforator. Note that Nakajima et al. previously recognized these perforators as a “perforating cutaneous branch of muscular vessel” (Fig. 3) and the corresponding flap as a type D fasciocutaneous flap (Fig. 4 and Table I). Mathes and Nahai would consider them type C musculocutaneous pedicle fasciocutaneous flaps (Fig. 5).

Because Wei et al. have shown in their unparalleled voluminous experience with anterolateral thigh flaps that even the tiniest musculocutaneous perforator can be consistently and thus reliably dissected back to the source vessel, it becomes unclear with this advanced technology if any musculocutaneous perforator is an indirect vessel using Taylor and Palmer’s terminology. In addition, Manchot noted from his knowledge of the embryological development of the circulatory system that at first “primitive vessels form a net in the area vasculosa, from which shoots [sic. perforators] grow into the embryo . . . . Their direction of advance [sic. to the source vessel] is determined by the least resistance.” It can therefore be surmised that only by chance alone does a muscle perforating branch or a direct cutaneous branch of a muscular vessel develop, so again both may really be direct or primary cutaneous vessels. However, to distinguish and appreciate the difference in the surgical approach, as emphasized by the Gent consensus, the former, which requires an intramuscular dissection, would better be considered an indirect perforator to what would then be termed an indirect perforator flap, whereas the latter, with less controversy, would nourish a direct perforator flap (Fig. 6).

Neurocutaneous Flaps

Ponten’s “superflaps,” by serendipity, may in fact have been neurocutaneous flaps. The axially of these flaps may be derived from their reliance on the intrinsic and extrinsic neurocutaneous or venocutaneous vascular supply.
that accompanies the peripheral cutaneous nerves\textsuperscript{9,35,40,41}. Often, the extrinsic vascular supply courses as a true artery with the nerve, and depending on the nerve, both structures can simultaneously pierce the deep fascia before proceeding within the subcutaneous tissues.\textsuperscript{9,34,35,41} The major purpose of these vascular systems is to provide circulation to the accompanying nerve, and only secondarily are cutaneous branches spun off. Therefore, neurocutaneous flaps, because only indirectly supplied by terminal cutaneous branches of these perforating vessels as an afterthought, must also be considered indirect perforator flaps.

Niranjan et al.\textsuperscript{36} suggest that fascial feeders or perforators, in addition to those accompanying nerves, can also arise from fascioperiosseal or larger tendon sheath branches, confirming this same observation by Timmons,\textsuperscript{15} although indirect muscle perforators throughout the body are far more common. These additional examples of indirect or secondary terminal branches of fascial perforators can also potentially supply an indirect perforator flap. Just as with neurocutaneous flaps, each would require a unique approach for safely raising the corresponding flap, reminiscent of Wei et al.’s\textsuperscript{33} argument that a muscle perforator flap is different because elevation requires a special dissection through the muscle. Thus, indirect perforator flaps deserve to be distinguished from all other cutaneous flaps with direct perforators, because more than just dissection of the requisite vascular supply is always required. If a distinct subcategorization is still needed, as suggested by the Gent consensus,\textsuperscript{37} these could be further subdivided into indirect “muscle” perforator flaps, indirect “periosteal” perforator flaps, indirect “nerve” perforator flaps, and so on as needed.

**The Future Stratification of Cutaneous Flaps**

All past and present skin-bearing flaps can now most simply be stratified according to the distinct origin of their vascular supply as either direct or indirect perforator flaps. This schema is based on what many inarguably consider the most important factor in flap selection, i.e., its circulation.\textsuperscript{10,11} However, we must not neglect the fact that there are other important, albeit secondary, characteristics for prioritizing the choice of any donor site. This decision must incorporate the six “C’s” of flap design per Cormack and Lamberty\textsuperscript{19}: in addition to the

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**Fig. 6.** Modification of Nakajima et al.’s pattern of deep fascia perforators (Fig. 4), with a slight variation of Taylor and Palmer’s simplification of these as being either direct or indirect vessels, which in turn would nourish direct or indirect perforator flaps, respectively. Modified with permission from Nakajima, H., Fujino, T., and 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, 1986.
circulation, one must consider the flap constituents (e.g., type of tissue composition), construction (e.g., type of pedicle), conformation (geometry), contiguity (location in relation to the defect), and any conditioning (e.g., delay). Tolhurst\textsuperscript{21,42} called this the “atomic” classification system, in which for a complete description of each flap (Fig. 7), the “nucleus”
was determined by the flap composition or tissue type and the “electron shells” described the other requisite characteristics. In an updated version of this more complete and comprehensive schema for cutaneous flaps for the purist, the circulation component, now based on its dual source of perforators, more appropriately occupies the nucleus (Fig. 8).

With the advent of supramicrosurgery and the expected universal improvement of technical capabilities, perforator-to-perforator free flaps and so-called freestyle free flaps may relegate the knowledge and importance of any flap source vessel as being totally irrelevant, as was the case with the dictum of length-to-width

ratios. At that time, only the suprafascial location of the more than 300 major perforators of the body, as mapped by Taylor and Palmer, would be of any significance. When that time comes, the simple categorization of cutaneous flaps into either direct or indirect perforator flaps becomes a moot point, because cutaneous flaps will then truly just all be suprafascial perforator flaps. At that point, our destiny will have come full circle, because any secondary flap characteristics would again assume paramount importance for differentiating the individual perforator territories, as reminiscent of the “random” flap era.

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REFERENCES


Self-Assessment Examination follows on the next page.
1. WHICH OF THE FOLLOWING BEST DESCRIBES THE CHRONOLOGICAL ORDER OF EVOLUTION OF CUTANEOUS FLAPS?
   A) Random, axial, perforator, musculocutaneous, fasciocutaneous
   B) Random, axial, fasciocutaneous, musculocutaneous, perforator
   C) Random, perforator, axial, musculocutaneous, fasciocutaneous
   D) Random, axial, musculocutaneous, fasciocutaneous, perforator
   E) Random, axial, musculocutaneous, perforator, fasciocutaneous

2. WHICH OF THE FOLLOWING BEST DESCRIBES THE ANATOMIC ORDER OF THE ARRAY OF BLOOD VESSELS SUPPLYING CIRCULATION TO THE “FASCIAL PLEXUS” THROUGH FASCIAL PERFORATORS FROM THE DEEP FASCIA TO THE INTEGUMENT?
   A) Subfascial, intrafascial, suprafascial, adipofascial, epidermal
   B) Subfascial, suprafascial, adipofascial, subdermal, epidermal
   C) Subfascial, intrafascial, suprafascial, adipofascial, subdermal
   D) Subfascial, suprafascial, intrafascial, adipofascial, subdermal
   E) Subfascial, suprafascial, adipofascial, subdermal, epidermal

3. WHICH OF THE FOLLOWING IS NOT CONSIDERED A FASCIOCUTANEOUS FLAP?
   A) Indirect perforator flap
   B) Direct perforator flap
   C) Adipofascial flap
   D) Fascia flap
   E) Musculocutaneous flap

4. WHICH OF THE FOLLOWING VESSELS IS LEAST LIKELY TO SUPPLY A DIRECT PERFORATOR FLAP?
   A) Septocutaneous vessel
   B) Direct cutaneous (axial) vessel
   C) Direct cutaneous branch of a muscular vessel
   D) Perforating branch of a muscular vessel
   E) Subdermal plexus

5. WHICH OF THE FOLLOWING IS THE MOST IMPORTANT FACTOR TO ENSURE VIABILITY OF THE CUTANEOUS FLAP?
   A) Conditioning
   B) Circulation
   C) Contiguity
   D) Composition
   E) Conformation

6. WHICH OF THE FOLLOWING IS THE MOST ACCURATE DEFINITION OF “SUPRAMICROSURGERY”?
   A) Performed only by “macho” microsurgeons
   B) Required for proper execution of exceedingly small microanastomoses
   C) Not a risk for perforator-to-perforator free flap transfer
   D) State-of-the-art microsurgery

To complete the examination for CME credit, turn to page 980 for instructions and the response form.