Perhaps one of the most attractive features of "perforator flaps" is that instead of endless descriptions that focus on the tissue components of the flap or the geometry of various surgical gymnastics to raise them, often focused on the same vascular network, we are now revisiting, at last, the most important factor that determines flap survival, the anatomy of its blood supply and venous drainage.

By definition, a cutaneous perforator is any vessel that perforates the outer layer of the deep fascia to supply the overlying subcutaneous fat and the skin. These cutaneous perforators, whether arterial or venous, large or small, are derived ultimately from, or return to, underlying source or segmental vessels that usually course parallel to the bony skeleton. The pathway of these cutaneous perforators between the outer layer of the deep fascia and the source vessels has given rise to some discussion and different classifications of the blood supply of the skin. These cutaneous vessels branch from the source artery and pass either: (1) between the deep tissues to perforate the outer layer of the deep fascia as fasciocutaneous (septocutaneous) vessels; or (2) through the deep tissues, usually as musculocutaneous perforators, but also arising from vessels that supply other deep tissues, such as salivary glands, periosteum, and nerves (Fig. 1).

When we described the angiosome concept [1], we noted that the source (segmental or distributing) vessels supplied all tissues between skin and bone as composite blocks that were linked together by anastomotic arteries. We focused on the origin of the branches that supplied the various tissues from the "trunk to the leaves." The surgeons who introduced the concept of perforator flaps [2–4] examined the same network but in the reverse way, tracing it from the "foliage to the roots."

Before progressing further, it is important to review the anatomy of the connective tissue framework of the body; the vessels that ultimately supply the skin, follow this framework, from the aorta to the dermis. The connective tissue network is a honeycomb of fibers. It is loose in some areas and condensed into sheets and septa in others, and surrounds and penetrates the specialized tissues, whether skin, fat, muscle, tendon or bone, down to the cellular level. Gray [5] referred to the connective tissues as "what is left over from the mesoderm during development after the specialized tissues have differentiated." The connective tissue is subdivided into two compartments (Fig. 2).

The superficial fascia

The superficial fascia is a loose connective tissue honeycomb that connects the dermis to the outer layer of the deep fascia and houses the subcutaneous fat, the breast, and remnants of the panniculus carnosis, where it still exists (eg, the muscles of facial expression in the head, the platysma in the neck, the palmaris brevis in the hand, and the dartos muscle in the scrotum) (see Fig. 2). In some areas, the skin is fixed firmly to the deep fascia, such as the palms of the hands and the soles of the feet, by thick perpendicular connective tissue bands. Here, the cutaneous perforating vessels similarly are short and perpendicular. In other areas, the skin and subcutaneous fat is mobile over the outer layer of the deep fascia (eg, in the iliac fossa and over the loins). The vessels are
often large as they perforate the deep fascia at fixed skin sites and course for long distances oblique or parallel to the skin surface (see Figs. 1, 2).

The deep fascia

The deep fascia is also a honeycomb of connective tissue. It has a tough outer layer that surrounds and sometimes provides origin to the muscles, and is linked by radiating intermuscular septa to the underlying bony skeleton, where it becomes continuous with the periosteum. It is continued into the muscles as intramuscular septa. Once again the vessels follow this connective tissue framework from the source vessels (which themselves are usually housed in longitudinal conduits of connective tissue) to pass either between, or into, the muscles and other deep tissues (see Fig. 2).

In our dissection and lead oxide injection studies of fresh cadavers, which led to the angiosome concept, we identified an average of 374 cutaneous perforators of 0.5 mm or greater (Figs. 3, 4). These vessels emerged from the deep fascia from fixed skin sites where they appeared especially:

- In longitudinal rows overlying the intermuscular septa, especially in the limbs
- In relation to the fixed attachments of muscles where the vessels emerged from, or near, intramuscular septa, especially on the torso
- In relation to the fixed attachments of the scalp and face around the skull base, the parotid gland, orbits, nose, and lower border of the mandible

Thus, the dominant supply to the skin emerges from the outer layer of the deep fascia after passing either between the deep tissues as fasciocutaneous (septocutaneous) vessels, or through the deep tissues, usually as musculocutaneous perforators.

From the outer layer of the deep fascia the cutaneous perforators follow the connective tissue framework of the superficial fascia toward the skin with branches that were oriented along a particular axis (e.g., the superficial inferior epigastric artery, perforators of the internal thoracic stem, or the occipital vessels), or they radiated in all directions like the spokes of a wheel (e.g., the cutaneous perforators of the arm, forearm, thigh, and leg). In every case, the perforators connected with their neighbors, usually by reduced caliber choke arteries, to form a continuous vascular network, especially in the subdermal plexus beneath the skin. The size, length, direction, and connections of these cutaneous perforators provide the basis for the viable length of various skin flap designs, because at least one adjacent anatomical cutaneous vascular territory can be captured with safety when based on a particular cutaneous perforator [6–9]. In general, the cutaneous vessels on the torso, head, neck, arms, and thighs are large and spaced well apart. As this pattern of supply is traced to the extremities of the hands and the feet,
the skin vessels become smaller, more numerous, and closer together (Fig. 5).

When the cutaneous perforators were traced into the deep tissues toward their source vessels, they coursed either between the muscles and tendons, following the intermuscular septa, or penetrated the muscle to follow the intramuscular septa. In the former case, the perforators coursed between the deep tissues, either in loose areola connective tissue (e.g., the cutaneous branches of the radial artery), or they traveled adjacent to well-defined intermuscular septa (e.g., the cutaneous perforators of the profunda brachii artery which follow the lateral intermuscular septum of the arm).

In cases where the perforator emerged from the muscle by way of an intermuscular septum, it was traced either straight through the muscle to the underlying source artery [e.g., the cutaneous perforators of the internal thoracic (mammary) artery], or followed an indirect course parallel to the muscle fibers, where it was derived from one of the muscle branches of the source artery (e.g., those derived from the superior gluteal, thoracodorsal, or deep inferior epigastric arteries).

We subdivided the body anatomically into 40 composite tissue angiosome territories that are supplied by the various source arteries [1,10]. These angiosomes can be subdivided, in some cases, into smaller territories. To simplify the concept, we described only one all-embracing intercostal territory on each side of the torso (see Fig. 4). Obviously, each of these can be subdivided into the 12 individual intercostal territories. The same applies to each lumbar angiosome.
An overview of the angiosomes, their source arteries, the sites of origin of the cutaneous perforators and their points of emergence from the outer layer of the deep fascia are shown (see Figs. 3, 4). To provide for a better understanding of these angiosomes and their importance in various perforator flap designs, the territories of the anterior torso are shown in greater detail (Figs. 6–8). Let us examine each of these in turn.

The internal thoracic (mammary) angiosome

This artery provides the dominant supply to the skin on the chest with large musculocutaneous perforators that are derived from the main artery and from its anterior intercostal branches, especially those in relation to the fifth and sixth ribs. To reach the skin large musculocutaneous perforators pass through the pectoralis major muscle at its fixed attachment to the costal cartilages and the ribs. The perforators that arise from the anterior intercostal arteries in the fourth and fifth intercostal spaces are the main supply to the inferior pedicled breast reduction operation.

The internal thoracic artery passes behind the costal cartilages to enter the anterior abdominal wall, where it becomes the deep superior epigastric artery (DSEA). It then enters the back of the rectus abdominis muscle, before reaching the tendonous inter-
section in the muscle that is situated midway between the costal margin and the umbilicus. The artery subdivides into two or three main branches that subdivide further to form choke connections below, with branches of the deep inferior epigastric artery (DIEA) and laterally, with intercostal arteries (see Figs. 6–8).

The cutaneous perforators in the abdomen arise from the branches of the DSEA, usually just below the costal margin and in the vicinity of the aforementioned tendinous intersection. To reach the skin, they pierce the rectus muscle or sometimes pierce the rectus sheath beside the lateral border of the muscle. One of these perforators, situated just below the umbilicus, gives rise to the perforator flap, which is commonly used in aesthetic and reconstructive surgery.
costal margin, is often quite large and is named the superficial superior epigastric artery.

Surgical implications
If a perforator flap is to be dissected to reach the internal thoracic-deep superior epigastric source vessels, then in each case the perforator must be traced through either the pectoralis major muscle and intercostal muscles in the chest or through the rectus sheath and muscle in the abdomen.

The lateral thoracic angiosome

This artery (see Figs. 6, 7, 8C) may arise from the axillary artery or its subscapular-thoracodorsal branch. It is a direct fasciocutaneous vessel that passes obliquely downward and medially to supply the skin of the upper lateral chest wall. In 90% of cases, it supplies branches to the pectoralis major and minor muscles and is the dominant supply to the lateral half of the female breast.

Surgical implications
The lateral thoracic artery has been used as a free skin flap [11] and as a free skin and breast tissue flap [12] and is the basis of the lateral pedicled breast reduction technique of Skoog. [13] The Doppler probe may help trace the vessel, especially in the thin patient.

The posterior intercostal angiosomes

These intercostal vessels (see. Figs. 6, 7, 8D) course parallel to the ribs where they groove the bone, and lie deep to the internal intercostal muscles. In the chest, they anastomose, often without change in caliber, with the anterior intercostal branches of the internal thoracic artery. In the abdomen, they leave the rib cage and enter the anterior abdominal wall between the transversus abdominis and internal oblique muscles where they anastomose with lateral branches of the DSEA and the DIEA. Their musculocutaneous branches pass through the fixed attachments of muscles. In the mid-axillary line they emerge from the outer layer of the deep fascia as a vertical strip of vessels. This occurs where the external oblique muscle interdigitates with the serratus anterior in the chest and where it interlocks with the latissimus dorsi in the lower lateral abdominal wall. Further anteriorly, some cutaneous vessels pierce the internal oblique and the external oblique muscles to reach the skin.

Surgical implications
These musculocutaneous perforators may be quite large; if a perforator skin flap is to be designed, dissection must proceed through several muscles before reaching the intercostal source vessels. The Doppler probe is a useful aid to locate these perforators on the skin surface, especially in a thin, well-muscled individual.

The deep inferior epigastric angiosome

Currently, this source vessel (see Figs. 6, 7, 8E) provides the most popular musculocutaneous perforator flap. It has been described in detail elsewhere [14–17]. The DIEA arises from the terminal portion of the external iliac artery, just above the inguinal ligament. It ascends upward and medially, passing behind the rectus muscle where it travels on its deep surface for a variable distance before
Fig. 6. Radiographic lead oxide study of the anterior torso without skin showing the source vessels and their branches. One side is color-coded to match the angiosomes in Fig. 4. Lines have been drawn through the choke anastomotic vessels that define the boundaries of the adjacent angiosomes. From top to bottom they are acromiothoracic, lateral thoracic, internal thoracic, posterior intercostal, lumbar, deep circumflex iliac, deep inferior epigastric, and common femoral. The umbilicus is highlighted as an ellipse and lead beads (shown on the left side) show the site of origin of the cutaneous perforators from the source vessels. (See also Color Plate 4).
Fig. 7. Radiographic lead oxide study of the skin of the anterior torso in the same subject that is shown in Fig. 6, including the shoulders and proximal thighs. The cutaneous perforators are color-coded to match the angiosomes in Fig. 6 with the emergence of large perforators that are highlighted as dots on the left side. In addition to Fig 6, portions of the angiosomes of the transverse cervical and inferior thyroid have been included at the top of the figure. Note the choke anastomotic connections that link adjacent cutaneous perforators. (See also Color Plate 5).
entering the muscle. The DIEA provides a recurrent branch that returns toward the pubis (see Fig. 6) and may ascend as: (1) a single vessel with “herringbone” branches (29%); (2) two main branches, medial and lateral, (57%); or, (3) multiple branches (14%) [14]. Regardless of the pattern, these branches anastomose, usually by reduced caliber vessels, with branches of the DSEA within the rectus muscle above the umbilicus. Branches also radiate laterally and pierce the rectus sheath to lie in company with the incoming intercostal nerves between the internal oblique and transversus abdominis aponeuroses and anastomose with the posterior intercostal arteries.

Two types of vessels are provided to the overlying skin. Medially, musculocutaneous perforators

Fig. 8. Schematic diagram of the source vessels and dominant cutaneous perforators of the (A) anterior torso, (B) internal thoracic, (C) lateral thoracic, (D) posterior intercostals, (E) deep inferior epigastric, and (F) deep circumflex iliac angiosomes that are color-coded to match Figs. 3, 4, 6, and 7. (See also Color Plate 6).
pierce the anterior rectus sheath over the muscle in line with the main branches of the DIEA or its subdivisions. Laterally, fasciocutaneous perforators pierce the aponeuroses of the internal and external oblique muscles to emerge along the lateral border of the rectus muscle. A large fasciocutaneous perforator is seen on each side of the abdomen (see Fig. 6). The largest number of sizeable perforators are clustered within 3 cm of the umbilicus [14].

**Surgical implications**

Many designs of vertical, transverse, or oblique skin flaps are available that may incorporate one or several perforators. In most cases, one or two musculocutaneous perforators are included along the axis of the DIEA branches. Care must be taken to preserve as many intercostal nerves as possible, however, because they pass anteriorly (superficial) to the DIEA branches.

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**Fig. 9.** Arterial injection radiographic study of the latissimus dorsi muscle with thoracodorsal, posterior intercostal, and lumbar angiosome territories defined. The sites of large musculocutaneous perforators are highlighted. A large arrow identifies one perforator that arises from the posterior intercostal artery but which could also be traced by way of it large anastomotic branch to the thoraco-dorsal system (small arrows). (See also Color Plate 7).

**Latissimus dorsi**

Fig. 9. Arterial injection radiographic study of the latissimus dorsi muscle with thoracodorsal, posterior intercostal, and lumbar angiosome territories defined. The sites of large musculocutaneous perforators are highlighted. A large arrow identifies one perforator that arises from the posterior intercostal artery but which could also be traced by way of it large anastomotic branch to the thoraco-dorsal system (small arrows). (See also Color Plate 7).
The deep circumflex iliac angiosome

Arising from the external iliac artery, this vessel (see Figs. 6, 7, 8F) courses laterally, parallel to the inguinal ligament and deep to all muscles of the abdominal wall, to reach the inner surface of the wing of the ileum in the groove between the transversus abdominis and the iliacus muscles. It provides a large ascending branch that pierces the transversus muscle medial to the anterior superior iliac spine (ASIS) after which it ascends the abdominal wall between the transversus abdominis and internal oblique muscles. The deep circumflex iliac artery (DCIA) provides a significant cutaneous perforator in only 10% of cases [18]. The main DCIA trunk, however, pierces all three muscles of the lateral abdominal wall, approximately 6 cm to 8 cm beyond the ASIS, to provide a sizeable musculocutaneous perforator.

Surgical implications

DCIA has been used to provide a musculocutaneous flap for lower limb reconstruction [19] and as the so-called “Ruben’s flap” [20] for breast reconstruction. In each case, however, a segment of muscle was included to incorporate several musculocutaneous perforators, although, in theory, a pure musculocutaneous perforator flap could have been raised (but not without some technical difficulty).

The superficial inferior epigastric angiosome

This direct fasciocutaneous perforator, the superficial inferior epigastric artery (SIEA) (see Figs. 7, 8A), provided the basis for the first reported free flap [21, 22]. It arises from the common femoral artery either alone, or in combination with, the superficial circumflex iliac artery [23], pierces the deep fascia below the inguinal ligament, and ascends the abdominal wall for a variable distance. In some cases, it may reach as high as the level of the umbilicus. The SIEA anastomoses with branches of the superficial circumflex iliac artery (SCIA), intercostal perforators, DIEA perforators, and its fellow of the opposite side.

Surgical implications

The SIEA can be identified and traced for a considerable distance with the Doppler probe in a thin individual. Its territory is quite large and it has been used extensively as a pedicled flap for hand reconstruction [24]. The SIEA also has been used as a fasciocutaneous perforator free flap for breast reconstruction with the skin paddle designed transversely in the lower abdomen [25, 26].

The latissimus dorsi muscle

Many large cutaneous vessels emerge as musculocutaneous perforators from the superficial surface of the latissimus dorsi muscle. There are a few traps for the unwary, however. Close inspection of Fig. 9 reveals that the muscle traverses three angiosomes, an upper thoracodorsal, middle intercostal, and lower lumbar. In the last two territories, the muscle is fixed to the rib cage and the lumbar arteries and perforate the latissimus muscle vertically to reach the skin.

In the thoracodorsal territory, however, where the muscle is mobile, the musculocutaneous perforators arise from branches of the thoracodorsal artery as they course parallel to the muscle fibers and the skin surface.

In some sites, the cutaneous perforator can be traced in either of two directions, vertically to reach the underlying intercostal stem, or horizontally along the muscle fibers by way of the anastomotic connection (which is usually a true anastomosis) with a branch of the thoracodorsal artery to provide a lone pedicle (see arrows in Fig. 9).

Discussion

It is apparent from the above examples that, with some exceptions, most perforator flaps on the torso will involve an intramuscular dissection to reach the underlying source vessel of the angiosome. In the limbs, the reverse usually is the case. A cross-section of the thigh where the dominant supply to the skin passes between the muscles in most cases is shown (see Fig. 2). Nevertheless, a large musculocutaneous perforator is seen arising from the lateral circumflex femoral artery in this study.

Any attempt to classify either the blood supply to the skin or the various types of “perforator flaps” was intentionally avoided because this issue is still in a state of flux. Whatever the outcome, it is important to make the distinction as simple as possible. From the practical point of view, it is important to know which source vessel is giving origin to the perforator and whether the perforator will be isolated with its skin paddle by a dissection either between tissues (usually muscle, but they could be tendon or bone) or through the tissues (usually muscle). Thus, most perforator flaps would ultimately be supplied by either fasciocutaneous (septocutaneous) or musculocutaneous vessels. In some cases, usually in the first group, the skin perforator will be accompanied by a cutaneous nerve.
It is pleasing that perforator flaps have refocused our attention on the fundamental basis of all good surgery, the applied anatomy of the region.

References


