Deep and superficial inferior epigastric artery perforator flaps

Gagnon, A. R.*, Blondeell, P. N.**

Introduction

Since the dawn of Plastic Surgery, the lower abdominal region has always been a loyal provider of abundant well-perfused tissue. After being first used in pedicled and tubed flaps for distant transfers, the lower abdomen skin and fat was discovered to be an ideal material for breast reconstruction. That specific use of the rectus abdominis musculocutaneous flap was pioneered by Drever in 1977 (1) and a few years later Hartrampf showed that the skin island could be harvested transversally across the lower abdomen(2). The transverse rectus abdominis muscle (TRAM) flap was born and it eventually became the gold standard in autogenous breast reconstruction. Interestingly, the free TRAM was performed first in 1979 by Holmström but was not recognized for several years (3). The free TRAM eventually demonstrated better vascularity over its pedicled counterpart due to the vigorous blood supply brought in by the deep inferior epigastric system.

In the mid-1980's, following Taylor's landmark work on the vascular territory of the deep inferior epigastric artery (4), it became apparent that the lower abdominal flap could probably be perfused solely by a large periumbilical perforating vessel. That assumption was confirmed in 1989 when Koshima published two cases of "inferior epigastric skin flaps without rectus abdominis muscle" (5). Allen and Blondeel expanded the use of the deep inferior epigastric artery perforator (DIEAP) flap to breast reconstruction and raised the operation to a high level of technical refinement (6,7). The DIEAP flap quickly gained popularity as it allowed the same advantageous reconstructive results as a TRAM flap but without the added morbidity of sacrificing an important muscle.

In the meantime, other surgeons transferred the same lower abdomen anatomical unit but instead used the superficial inferior epigastric vessels to vascularize the flap. Back in 1971, this was the basis for the first free flap ever reported in the literature. In 1976, Boeckx published his experience with six superficial inferior epigastric artery (SIEA) free flaps, most of them for facial reconstruction (8). Hester et al demonstrated successful polyvalent use of the flap in 1984 (9) and Grotting was the first to use the free abdominoplasty flap for breast reconstruction in 1991 (10). The superficial inferior epigastric artery (SIEA) flap can provide ample skin and subcutaneous fat with minimal donor site morbidity as the abdominal musculature is not breached.

In this time of rapidly evolving Science, perforator flaps constitute the latest milestones in the never ending quest towards the best possible result with the least cost to the patient. The DIEAP and SIEA flaps can provide excellent quality autogenous reconstruction with minimum morbidity and should be considered by the contemporary surgeon.

REGIONAL ANATOMY

Arterial anatomy of the region

The vascular anatomy of the abdomen is a complex integrated ensemble of interlinked components (11). Different sources give rise to multiple vessels feeding the abdominal muscles and the overlying integument. The blood supply of the anterior trunk is founded on the presence of two epigastric arcades, each linking the external iliac artery and the subclavian artery through the rectus abdominis muscle. Caudally, the deep inferior epigastric artery (DIEA) originates from the external iliac artery just proximal to the inguinal ligament. It runs superomedially in the extraperitoneal tissue, pierces the transversalis fascia and gives off two or three small peritoneal branches. It then enters the rectus sheath by passing anterior to the arcuate line. After penetrating the muscle, the DIEA generally divides into two major branches. The lateral branch is dominant in 50% of the cases and the medial branch in 7%. There is equal caliber of both branches in 15% and one central axis with multiple side branches in 28% (12). The cephalad portion of the epigastric arcade is made of the internal mammary artery which arises from the subclavian artery. The internal mammary artery continues in the abdomen as the superior epigastric artery (SEA) to finally coalesce into a watershed area midway between the xiphoid process and the umbilicus. In this region, multiple anastomotic channels exist between the superior and the inferior epigastric systems. Laterally, the epigastric arcade anastomoses with the terminal branches of the lower six intercostal arteries as well as with the ascending branch of the deep circumflex iliac artery.

Through the seminal work of Ian Taylor, a clearer comprehension of the abdominal wall perfusion emerged. The concept of angiosome and choke vessels facilitated the task of delineating the safe clinical territory of flaps (4). In the case of the abdominal wall blood supply, it is evident that the DIEA is relatively more important than the SEA. First, the DIEA is larger with an external diameter of 3.4 mm at its point of origin as compared to 1.6 mm for the SEA. But second and most importantly, the vast majority of cutaneous perforators are located in the periumbilical region, inferior to the watershed anastomotic zone, therefore in the DIEA territory. There are muscular branches to the rectus abdominis, myocutaneous perforators with major contribution to the muscle and minor supply to the skin and conversely, perforators that are mainly directed at the skin. Obviously, the last ones constitute the target vessels to vascularize a DIEAP flap. Occasionally, one can see perforators going around the edge of the rectus abdominis and not through the muscle itself. These pararectal fasciocutaneous perforators either pass medially just next to the linea alba or laterally from the lateral segmental vessels through the external oblique aponeurosis. Overall, although small caliber perforators are numerous, there is an average of 5 perforators with a diameter > 0.5 mm originating from each DIEA (4,13,14). Sometimes, perforators as large as 1.5 mm can be encountered. Box 1 presents key points on the typical location of perforators.

After piercing the anterior rectus sheath, the different perforators take on a variable course through the subcutaneous fat. Some ascend vertically to the overlying skin whereas others will have a more horizontal trajectory. Perforators usually arborize in a fractal manner until joining the subdermal plexus to supply it. The subdermal plexus effectively constitutes an intricate network of microvessels spanning the entire abdominal skin and allowing innumerable redundant connections. Through the subdermal plexus, we find the second level of anastomotic channels between the source arteries. This is where perforators from the DIEA will meet cutaneous branches of the SEA, lower intercostal arteries, deep and superficial circumflex iliac arteries, superficial inferior epigastric artery, superficial external pudendal artery and contralateral DIEA perforators. The subdermal plexus is the supporting vascular framework of lower abdominal skin flaps and the reason why the same skin/fat island can be perfused either by the deep or the superficial inferior epigastric system. In fact, the subdermal plexus can be conceptualized as an interface between the relatively scarce vessels originating from the deep fascia and the dense network of terminal dermal microvessels. It may act as a random equilibrating system that distributes blood evenly across surrounding cutaneous areas. If all vessels feeding into the subdermal plexus are ligated except for one perforator, the area of irrigated

skin would be determined by the capacity of the perforator to provide pressure into the subdermal system. Therefore, the diameter and branching pattern of the perforator become key elements in defining the clinical territory of perforator flaps. Of course, further anatomical and physiological studies are warranted to compare this theory to the angiosome and choke vessel concept in order to help elucidate the intricacies of skin perfusion.

The superficial inferior epigastric artery (SIEA) is the second important blood supply provider to the lower abdominal skin. The SIEA is a direct cutaneous vessel originating from the common femoral artery 2-3 cm below the inguinal ligament in 17 % of cases or from a common trunk with the superficial circumflex iliac artery in 48% of patients (15). The artery is absent or hypoplastic in 35% of specimens in which case it is often substituted by a large ascending branch from the superficial circumflex iliac artery. The SIEA passes superiorly and laterally in the femoral triangle, crossing the inguinal ligament at its midpoint and lying deep to Scarpa's fascia. The vessel continues on superomedially towards the umbilicus, penetrating Scarpa's fascia well above the inguinal ligament to lie in the superficial subcutaneous tissue. The SIEA often anastomoses with large periumbilical perforating arteries (4).

Venous anatomy of the region

The venous anatomy of the lower abdominal area is similar to the arterial anatomy in that the different venae comitantes closely follow their paired arteries to the proximal vessels. Indeed, the small veins perforating the anterior rectus sheath drain into the deep inferior epigastric veins (DIEVs) and then on to the external iliac vein. Likewise, the SIEA possesses two venae comitantes closely related to it which drain into the common femoral vein or occasionally into the saphenous bulb. However, these veins are often small and can even be absent. On the other hand, there is a constant and often large superficial inferior epigastric vein (SIEV) located medial to the SIEA and more superficial. The SIEV is not accompanied by an artery and is a tributary of the greater saphenous vein close to the fossa ovale. It actually drains an extensive polygonal network of subcutaneous veins in the anterior abdominal wall. There exist anastomotic connections between this superficial system and perforating veins from the deep inferior epigastric vein (16). The SIEV is considered by certain authors as the preferential drainage path of the abdominal panniculus in the normal, non-surgical condition (17).

Nerves in the region

The motor and sensory innervation to the abdominal wall is provided mainly by the intercostal nerves 7 to 12 with some contribution from the iliohypogastric and the ilioinguinal nerves. The lateral muscles are supplied by all eight nerves whereas the more medial rectus abdominis and pyramidalis are innervated solely by the intercostals. The sensory innervation to the abdominal skin is derived from the lateral and anterior cutaneous branches of the intercostal nerves giving rise to segmental dermatomes. A small skin area immediately superior to the pubis is supplied by the anterior cutaneous branch of the iliohypogastric nerve.

FLAP ANATOMY

Arterial supply of the flap

Dominant

The lower abdominal flap can be vascularized either by the deep or the superficial inferior epigastric artery. By definition, the DIEAP flap is perfused only via one or more perforator of the DIEA. When the pedicle is dissected up to the lower lateral rectus border, a typical pedicle length of 10 to 14 cm is obtained, depending of the position of the perforator. This can be increased by 4 cm if the pedicle is dissected up to its origin. At this point, the diameter of the artery is 3 to 3.5 mm. In the case of a SIEA flap, a recent anatomical study showed that the SIEA was identified in 72% of specimens, with an average diameter of 1.6 mm (0.75 to 3.5 mm) at the level of the inguinal ligament (18). In 58% of cases, the artery was present bilaterally. The length of the pedicle ranged from 4 to 7 cm.

Box 1. Topographic distribution of musculocutaneous perforators from the DIEA

- More than 90% of the major perforators are located within a 6 cm radius lateral and inferior to the umbilicus.
- There is a higher concentration of perforators in the middle and medial thirds of the muscle.
- The largest periumbilical perforators take origin from the terminal branches of the DIEA and are often located within the lowest tendinous intersection of the rectus abdominis.
- The lowest fifth of the muscle contains only sparse perforators and the veins are rarely of adequate size.
- Medial and lateral pararectal fasciocutaneous perforators are often of small caliber.
- The distribution of perforators on both sides of the abdomen is rarely symmetrical.

Box 2. General thoughts on choosing the right perforator

- Preoperative investigation with a color duplex scan or with a multidetector spiral CT is a key element in surgical planning. Information such as vessel position, diameter and branching patterns can be obtained. This is used as a road map to ease dissection and decision-making.
- The largest perforating vessels from the deep inferior epigastric artery are virtually all located within a six cm radius lateral and inferior to the umbilicus.
- Usually only one perforator of adequate diameter (> 1mm) is sufficient to vascularize the entire lower abdominal skin. Inflow is rarely a problem when the perforator shows good pulsatility.
- One of the most important factors in selecting a perforator is the size of the accompanying vein. In order to minimize the chances of outflow insufficiency, the largest diameter vein should be selected if the paired perforating artery is suitable.
- When only small to moderate caliber vessels are present, the flap can be harvested based on two or three perforators in the same vertical row. In this case, intervening motor nerves between perforators must be cut and resutured after flap harvest.
- If possible, the perforator should be located close to the center of the flap. A marginal perforator can also be satisfactory if the branching pattern seen peroperatively or in the preoperative study appears to be directed mainly into the flap.
- Perforators from the lateral row have a shorter intramuscular course and are easier to dissect. Further, the lateral branch of the DIEA is dominant in the majority of cases.
- Perforators in the medial row are more centrally located in the flap. Use of a medial row perforator may result in better perfusion of zone IV because it is anatomically closer to the distal contralateral side. This can be an important factor in cases where as much volume as possible is required. However, the intramuscular course of a medial row perforator can be longer.
- A large medial pararectal perforator constitutes an ideal choice because of its central location in the flap and because the dissection is much less tedious, being completely extramuscular.
- The lowest tendinous inscription of the rectus is situated at the level of the umbilicus or slightly below. It constitutes a common point of emergence for fairly large lateral perforators. Although the dissection can be somewhat tedious because of fibrous attachments, the intramuscular course is usually quite short. The vessels typically traverse the muscle directly and then run on top of the posterior fascia. This can result in a decreased harvest time.

Minor

Secondary arterial inputs to the lower abdominal flap come from the SEA, lower intercostal arteries, superficial and deep circumflex iliac arteries and superficial external pudendal artery. Since the DIEAP and SIEA flaps are elevated as skin islands isolated on their respective dominant pedicle, the minor contributors are ligated during harvesting of the flap. If indicated however, a minor pedicle can be dissected and anastomosed in addition to the dominant pedicle to extend the territory of the flap.

Venous drainage of the flap

Primary

The lower abdominal skin has two primary outflow pathways: the deep and the superficial inferior epigastric veins. In most cases, the DIEAP flap is primarily drained via the DIEVs. These veins have an average diameter of 3.5 to 4.5 mm close to their junction with the external iliac vein. However, there exists an inverse size relationship between veins from the deep system and the superficial veins. The SIEV network might actually be dominant in some cases. When the SIEV is important in diameter, it should be preserved because the selected perforating vein(s) from the DIEV could be insufficient (19). At the opposite, if the superficial veins have been interrupted by a previous Pfannenstiel incision, a delay-type phenomenon can occur resulting in enlargement of the deep system veins. Of course, in the case of a SIEA flap, the SIEV constitutes the primary venous drainage system. Its diameter ranges from 2 to 4 mm.

Secondary

The secondary venous drainage of the flap is composed of the venae comitantes of the SIEA, SIEA, circumflex iliac arteries and lower intercostals. If the venae comitantes of the SIEA are large, they can be used to drain the flap. However, they are often less than 1 mm in diameter or even nonexistent.

Flap innervation

Sensory

The DIEAP flap can be innervated using one of the sensory intercostal branches entering the panniculus on its way to the skin, usually in company of a perforator from the DIEA (20). After traveling in the plane between the internal oblique and the transversus abdominis muscles along with their respective intercostal arteries and veins, the mixed intercostal nerves T7-T12 pierce the lateral edge of the rectus sheath and then run on the posterior surface of the muscle. They enter the rectus abdominis usually at the junction of the middle and the lateral thirds (21,22). At that point, they arborize into muscular motor branches to the medial and lateral muscle and a pure sensory branch that perforates the anterior rectus sheath to supply the overlying skin. The SIEA flap is not used as an innervated flap because harvesting a sensory nerve entails an intramuscular dissection.

Motor

No muscle is included with these flaps therefore there is no motor innervation.

Flap Components

The DIEAP and SIEA flaps consist solely of skin and fat from the lower abdomen. No muscle or fascia is harvested.

ADVANTAGES

The DIEAP/SIEA flap combines essentially all the advantages of the TRAM flap without most of its disadvantages. It provides generous amounts of well perfused soft tissue and its complication rate is similar to other free tissue transfers. The first and foremost advantage of the DIEAP/SIEA over the TRAM is its markedly decreased donor site morbidity (23,24). Since no muscle is sacrificed, the incidence of late hernias and abdominal bulges is minimized. The problem of abdominal and umbilical asymmetry seen with the TRAM flap is also eliminated. Postoperative pain is minimal and the hospitalization time is reduced therefore resulting into lower health care costs (25,27). Furthermore, patients can return more quickly to work and physical activities. Because of the intramuscular dissection, the pedicle length obtained with a DIEAP flap is longer by several centimeters, translating into superior flexibility in the way the flap can be positioned at the recipient site. In addition to these advantages, the patients undergoing a DIEAP/SIEA flap reconstruction also benefit from an abdominal contour improving procedure with a well concealed scar.

DISADVANTAGES

The DIEAP flap has a few points that can be seen as disadvantages. As other perforator flaps, the operation has a steep learning curve and demands delicate dissection. The operation duration can be marginally longer than a comparable free TRAM flap, especially if the surgeon is not familiar with the technique. On rare occasion, a state of venous congestion can occur after flap harvest. However, this situation is usually successfully treated with an extra venous anastomosis (19). With a SIEA flap, the volume of tissue safely perfused is slightly inferior to that of a DIEAP or TRAM flap. Further, the SIEA pedicle is rather short, making the insetting and shaping of the flap more difficult. The SIEA is anatomically inconstant and can be absent in up to a third of the cases. Due to the pedicle dissection in the area of inguinal nodes, the SIEA flap has a higher rate of donor site seroma than the DIEAP or TRAM flaps (28).

PREOPERATIVE PREPARATION

When contemplating elective microsurgical reconstruction with perforator flaps, adequate patient selection is foremost in order to insure a satisfactory outcome. During the patient's first visit, a complete history and physical examination is performed. Comorbid conditions and abdominal scars are noted. A previous abdominoplasty or abdominal lipectomy is an absolute contraindication for a DIEAP or SIEA flap. A past history of abdominal liposuction is a relative contraindication but if a DIEAP/SIEA flap is considered nonetheless, an attentive preoperative duplex or CT-scan investigation of the cutaneous vessels will be absolutely required. So as to withstand the prolonged anesthesia associated with free tissue transfer, the patient should be in a good general state of health. Age is usually not an important factor but we prefer to offer autogenous microsurgical reconstruction to patients under the age of 80. Although perforator flap surgery is not contraindicated in obese patients, those are advised to loose weight before the operation to limit the incidence of postoperative complications. Smokers are asked to refrain from smoking for at least three months before surgery. Use of aspirin, non steroidal anti-inflammatory drugs and herbal medications should be avoided for three weeks before surgery.

During the initial consultation, selected patients also receive thorough explanations on the procedure including possible complications, both at the donor and recipient sites. The usual course of reconstruction is discussed and typical expected outcomes are presented with the use of photographs. All questions are answered and the patient's motivation is carefully assessed. Patients who are unsure about the procedure are given time for reflection or are offered an alternative option.

The preoperative investigation should include a study of the abdominal wall vascular anatomy. Although it is possible to harvest a DIEAP flap without knowledge of the exact position and size of the perforators, we believe it is much safer and faster to do so with a map of the perforators on hand. Therefore, color duplex imaging is routinely used in our department in the planning of DIEAP flaps (29). This allows the creation of a three-dimensional map of the perforating vessels with coordinates centered on the umbilicus. Not only the location and diameter of the vessels are evaluated but also the blood flow and arborization patterns. This provides the surgeon with invaluable information to help with the safe planning of a DIEAP flap in different individuals. The status of the internal mammary vessels is also assessed at the same time as they are our preferred recipient vessels in breast reconstruction. Alternatively, the perforator mapping

can be done using a handheld Doppler flowmeter but one should be aware that, although more accessible and less costly, this device generates more false positive and false negative signals and provides less detailed anatomical and functional vessel information. Recently, high resolution multi-detector spiral CT scan has been used and appears to be a promising new modality in preoperative investigation of perforating vessels (Fig. 1). Although the venous side of the flap circulation cannot be assessed and no flow information is obtained, it allows excellent tridimensional understanding of the arterial perforator morphology and the intramuscular course of the DIEA.

FLAP DESIGN

Anatomic landmarks

The major anatomic landmarks are the umbilicus, both anterior superior iliac spines and the pubic symphysis.

General thoughts about flap design

As studies of skin perfusion showed, perforating vessels can safely irrigate skin islands of their own angiosome as well as skin from immediately adjacent angiosomes (30). This is related to the presence of interconnections in the subdermal plexus between angiosomes. Therefore, DIEAP flaps can have custom-designed skin paddles located over any reasonably sized perforator. First, the desired perforator is localized on the abdomen and then the flap is designed over it. The extension of the flap can confidently encompass skin from adjacent angiosomes (intercostal vessels and contralateral deep inferior epigastric vessels). We routinely harvest DIEAP flaps using a conventional abdominoplasty design. This affords an esthetic closure and the benefits of abdominal recontouring. Additionally, the extra tissue harvested provides us with more flexibility in how the flap is inset and shaped at the recipient site.

Special considerations

Particular attention needs to be directed towards abdominal scars. Although it can constitute a contraindication for a SIEA flap, the presence of a low transverse scar (i.e. Pfannenstiel) is usually not an issue in DIEAP flaps because the lower incision can be placed in the same location. However, large caliber musculocutaneous perforators from the recti muscles may or may not still be present, depending on the extent of upper flap undermining performed at the initial operation. Therefore, a preoperative duplex or CT-scan study is mandatory in this case. Small abdominal scars, for example appendectomy scars, can also be ignored because their presence does not affect significantly the vascularization of the flap. Midline scars are more problematic because they will result in insufficient blood flow to the contralateral side of the flap. If the whole flap is necessary for the reconstruction, then dissection of a bipedicled flap with an extra pair of microanastomoses will result in excellent vascularization to both halves.

Difference in design, if any, when performing the flap as pedicled or free

The DIEAP/SIEA free flap is most often used in breast reconstruction and it is harvested routinely using the abdominoplasty pattern. On the other hand, pedicled flaps are used for local defects and should be tailored to adequately fill them while allowing primary closure of the donor site if possible.

Flap dimensions

The average size of the abdominal skin fat paddle harvested in a DIEAP flap is 34x14 cm but can range as high as 50x20 cm depending on the patient's body habitus and tissue requirements. Most often, zone IV is not needed and is discarded. In a SIEA flap, the perfusion can be unreliable passed the midline. However, the same elliptic design as a DIEAP flap is used to facilitate donor site closure but usually only the ipsilateral half of the flap is used in the reconstruction.

Flap markings

The patient is in the supine position. First, the position of the major perforators is marked on the skin according to the findings of the preoperative duplex or CT-scan study. A system of coordinates centered on the umbilicus is used to accurately localize the perforators. A handheld Doppler can be used to locate and mark the position of the superficial inferior epigastric arteries and veins. Next, the flap is designed over the main perforator. Total skin resection is typically elliptical and extends from one anterior superior iliac spine to the other (Fig.2). If necessary, the flap design can be expanded laterally in the flanks along the iliac crest. It is important to note that the position or shape of the skin paddle should be adapted to guarantee the safe capture of the most interesting perforator. The lower incision is positioned in the suprapubic crease whereas the superior incision runs just above the umbilicus. The tissue laxity is then examined using the "pinch test" to insure that wound closure will be possible without excessive tension. Alternatively, the abdominal flap can be harvested using an infraumbilical upper incision. In that case however, the large caliber periumbilical perforators would be excluded from the flap. Further, basing the flap on a more caudal perforator will result in a shorter pedicle.

PATIENT POSITIONING

The patient should be in supine position with the upper extremities adducted and immobilized next to the trunk. For breast reconstruction, the installation should be planned in order to allow sitting up the patient as this position is useful to adequately inset the flap and verify symmetry. To facilitate donor site closure, it is also usually necessary to elevate the lower extremities. The resultant hip flexion decreases tension on the lower abdominal skin.

ANESTHETIC CONSIDERATIONS

The flap is harvested under general anesthesia. It is crucial that the patient be fully paralyzed during the intramuscular dissection of the perforators to facilitate surgical manipulation and to avoid undue damage to the flap pedicle by muscular contraction. Because the operation can take place over a prolonged period, IV fluid replacement should be controlled meticulously throughout surgery in order to avoid hyper- or hypovolemia. Fluid overload can result in deleterious flap edema whereas hypoperfusion will lead to sluggish microvascular flow and increased risk of thrombosis. Appropriate measures of thromboprophylaxis should also be taken in the peri- and postoperative period. We use antiembolic stockings and low molecular weight heparin during surgery and until discharge from the hospital.

TECHNIQUE OF FLAP HARVEST

Since the DIEAP/SIEA flap is virtually always used as a microvascular tissue transfer, the standard technique of a DIEAP/SIEA free flap harvest is described here. Other variations and further modifications are presented in the next sections.

After induction of general anesthesia, the patient is prepped and draped in a sterile fashion. The incision lines are infiltrated with an epinephrine-containing local anesthetic except for the region of the superficial inferior epigastric vessels. The lower abdominal incision is made first. A bloodless dissection of the subcutaneous fat is performed with the electrocautery needle. The SIEV is identified on both sides in the superficial subcutaneous tissue at a point about 4-5 cm lateral to the midline. The diameter of these vessels is noted as it gives an important clue on the relative importance of the superficial drainage system versus the deep inferior epigastric pathway. Unless it is very small and insignificant, the SIEV is always dissected for a few centimeters by careful ligation of all side branches. Of course, in the case of a SIEA flap, the SIEV constitutes the flap's main drainage path and should be dissected down to its origin. A large SIEV should be preserved during a DIEAP flap dissection as it can potentially be used to supercharge the flap in the advent of venous outflow insufficiency of the deep system.

The dissection then proceeds laterally to identify the SIEA. It is usually located at the midpoint of the inguinal ligament, 2-3 cm lateral to the SIEV and deep to Scarpa's fascia (Fig.3). If the diameter of the SIEA is larger than 1 mm, the abdominal flap can be safely harvested based on the superficial vessels. If not, the contralateral SIEA should be explored or the flap converted to a DIEAP.

If the decision is taken to base the flap on the SIEA, the artery and its two venae comitantes are dissected down to their points of origin. The periumbilical and superior abdominal incisions are made and deepened down to the muscular fascia. The flap is harvested by dissection in the plane immediately superficial to the deep fascia, quite in the same way as a classical abdominoplasty resection. The SIEA can reliably irrigate the flap up to the midline, sometimes with some extension over the medial half of the contralateral rectus muscle. Therefore, the rest of the flap usually needs to be resected.

In the case of a DIEAP flap harvest, following dissection of the superficial inferior epigastric veins, the operation proceeds with the identification and skeletonization of one or more suitable musculocutaneous perforator from either rectus abdominis muscle. The dissection is first done on one side of the abdomen while leaving the other side intact and keeping it as a lifeboat. The periumbilical and superior incisions are made according to preoperative markings. The superior aspect of the flap is dissected through fat with slight cephalic beveling until the deep fascia is visualized. This allows inclusion of more volume in the flap and avoids damage to marginal perforators. The flap is then detached from the deep fascia in a lateral to medial direction (Fig.4). Dissection proceeds rapidly up to the semilunar line, at which point a meticulous exploration for musculocutaneous perforators starts. Using the preoperative duplex markings, the largest perforating vessels are isolated sequentially, taking care not to sacrifice a perforator before a more suitable one is found. Probably the most crucial part of the operation is choosing which perforator(s) to use. To help with this decision, refer to box 2 where we have compiled general guidelines derived from our experience.

Once the best perforator is selected, it is freed circumferentially above the level of the fascia. The anterior sheath of the rectus muscle is then opened longitudinally in direction of the pubis, starting at the point of emergence of the vessel. There is usually an open slit in the fascia around the perforating vessels which facilitates inserting the tips of the microscissors. Caution should however be used because the pedicle sometimes follows a subfascial course and can easily be damaged by a careless move. The fascia should also be opened for 2-3 cm on the cephalic side of the perforator to ease exposure. Following the fasciotomy, the most delicate phase of the flap harvest begins. The intramuscular dissection demands constant attention and meticulous handling of tissues both by the surgeon and the assistants. It is also mandatory to have the patient in a completely paralyzed state so as to avoid muscle jerking movements and ensuing avulsion damage to the pedicle.

The dissection proceeds by sagittal splitting of the muscle between its fibers thereby minimizing muscular damage. Undue transection of muscle fibers should be avoided. Using blunt dissection, the pedicle is gently teased off the surrounding perimysial areolar tissue. Side branches are carefully ligated and cut. Although there is great variability in the intrarectal course of the vessels, it is usually easier to dissect them in the most inferior portion because, at this point, the vessels have emerged on the posterior side of the rectus and lie in a fatty plane. During dissection of the pedicle, one or more segmental intercostal nerves will normally be encountered. Those mixed nerves enter the rectus sheath laterally, penetrate the muscle posteriorly and then split into a motor and a sensory branch. The sensory nerves usually accompany perforating vessels on their course towards the skin. They can be sacrificed or used to obtain a sensate flap. The motor branches travel horizontally across the muscle and usually are located anterior to the intramuscular vascular pedicle (Fig.5). These nerve branches should be preserved to avoid denervation of the muscle. When two or more perforators are used in the same vertical row, sometimes an intervening motor nerve has to be cut during harvest. In these cases, the nerve is reanastomosed before closure.

The deep inferior epigastric vessels are usually dissected until they reach the lower lateral border of the rectus muscle. At this level, exposure of the vessels is obtained easily by a separate short fascial incision in the lower semilunar line. After an adequate dissection of the pedicle, the contralateral side of the flap can then be detached from the deep fascia. Following flap dissection, adequate arterial inflow is most often present up to the most distal portion of the flap. Therefore, it can be used in its totality if needed. However, zone IV will often be resected because it is not needed or because it can occasionally suffer from venous congestion, similar to a free TRAM flap. If the whole flap is required for the reconstruction and zone IV is congested, the flap should be supercharged by anastomosing the contralateral SIEV thereby facilitating venous drainage of zone IV. After flap transfer to the recipient site, the anterior sheath of the rectus is repaired with a braided non-resorbable suture. Since no fascia has been resected, there is no tension on the repair and a mesh is never required. The epigastric skin is undermined up to the xiphoid process, the umbilicus is exteriorized at its new position, suction drains are inserted and the abdomen is closed in layers. Dermabond ® (Ethicon Inc., Somerville, NJ) is applied on all skin incisions.

FLAP MODIFICATION/FLAP HANDLING

The lower abdominal skin flap can be harvested as a Siamese flap by dissecting a vascular pedicle on each side. Because the two sides are independent, any combination of pedicle is possible: DIEAP/DIEAP, DIEAP/SIEA or SIEA/SIEA. This way, excellent vascularization of the whole flap can be obtained in patients with a median scar. The Siamese flap can also be converted into two separate flaps by dividing it in halves. This constitutes an ideal choice for bilateral simultaneous breast reconstruction (31,32). Lastly, another application of the double pedicle concept would be to extend the viable territory of the DIEAP flap. Indeed, a larger flap can be transferred when the contralateral superficial circumflex iliac vessels are used to supercharge it.

It is also possible to harvest the DIEAP flap as a sensate flap (20). The selected perforator will usually be accompanied on its way to the skin by a pure sensory nerve, which is the anterior cutaneous branch of one of the mixed segmental nerves supplying the rectus muscle. This sensory branch can be harvested by epineural splitting of the mixed nerve up to the lateral edge of the rectus sheath. This provides a length of 3 to 9 cm thus making it feasible to reanastomose the nerve at the recipient site. In breast reconstruction, the anterior ramus of the lateral cutaneous branch of the 4^{th} intercostal nerve is preferentially used as a recipient nerve resulting in good sensory restoration and even erogenous sensation return.

Koshima has described the use of thin paraumbilical perforator-based flaps (33). He effectively showed that it is possible to obtain a thin version of the DIEAP flap by resecting most of the pannicular fat. Only 5 mm of adipose tissue is left under the skin to protect the subdermal plexus. However, it is crucial that a 3 cm cuff of tissue be preserved around the perforator during the thinning process to avoid putting the blood supply of the flap into jeopardy. In the absence of precise knowledge of the perforator morphology, this thinning procedure remains nonetheless risky and should probably be undertaken only by experienced surgeons using careful microsurgical dissection around the perforator. We believe it is more advisable to proceed to flap debulking and sculpturing using liposuction at a later procedure.

Lastly, it is possible to design a DIEAP flap containing a piece of vascularized bone (34). Such a compound flap can be obtained by harvesting part of the superior pubic ramus which is supplied by pubic branches of the deep inferior epigastric vessels. It has been used in maxillofacial reconstruction with a thinned cutaneous paddle.

TECHNICAL TIPS TO OPTIMIZE OUTCOMES AND AVOID COMPLICATIONS

In spite of the fact that, at first sight, perforator flaps may look more challenging and more technically demanding than other flaps,

their dissection rapidly becomes routine with growing surgical experience. Several recommendations can help make the DIEAP flap a safe and reliable operation with complication rates not higher than other free flaps. First, two basic surgical principles need to be reemphasized: exposure and hemostasis. Good exposure is important to obtain during the intramuscular dissection of the perforator. Before even starting to ligate side branches, the muscle should be widely split along the length of its fibers to unveil the three-dimensional neurovascular structures. Perfect hemostasis should constantly be sought. Even a small amount of blood will stain the areolar planes of dissection thereby obscuring the path. Further, extraluminal hemoglobin acts as a vasoconstrictor, therefore blood should be quickly washed away with an irrigation syringe. Use of the bipolar electrocautery allows efficient bloodless dissection. The operator should take time to clearly understand the anatomy and its variants before progressing any further. Delicate tissue manipulation is mandatory and the flap harvest should be performed using loupe magnification.

Tissues should be periodically irrigated with normal saline to avoid dessication of the small vessels. As the pedicle becomes exposed and vulnerable to shearing and traction damage, the flap should always be stabilized on the patient either by an attentive assistant or by using staples. If more than one perforator seem suitable to vascularize the flap thus making the choice not straightforward, the surgeon can use microvascular clamps to selectively occlude perforating vessels and check for flap perfusion. After completion of the microanastomoses at the recipient site, the long and redundant flap pedicle should be checked to be in appropriate position without any twist or kink. Following flap reperfusion, the surgeon should exercise low-threshold tolerance for venous congestion and perform an additional venous anastomosis at the slightest doubt. We either use the SIEV or a second perforating vein. This will add little time to the whole procedure but will ensure proper flap healing and will minimize the risk of flap loss and steatonecrosis.

FLAP USAGE

In our practice, the DIEAP and SIEA flaps have completely replaced the use of the free TRAM flap and constitute our first choice for autologous breast reconstruction. Although sharing the same adipocutaneous component as the TRAM, the DIEAP and SIEA flaps have the additional benefit of significantly lower donor site morbidity. That reason makes these flaps more desirable considering the current medical trend towards less invasive procedures. We use the DIEAP/SIEA flap when there is a need for microsurgical transfer of a moderate to large amount of soft tissue. The lower abdomen is effectively the single largest donor site of vascularized skin and fat in the human body. A typical DIEAP flap will yield anywhere from 400 g to 2 kg or more of soft fatty tissue. A considerable area of skin is also provided by the flap as demonstrated by typical skin paddle dimensions of 34x14 cm. We feel the DIEAP/SIEA flap is very useful as a volume filler, especially when a soft and natural texture is required. It can also be used for coverage of large area defects, specifically in cases where additional bulk is necessary.

Typical indications for the use of this flap

The DIEAP/SIEA flap is most often used in post-oncological breast reconstruction because it provides an ideal tissue match (12, 35-37). We prefer to harvest the lower abdominal flap based on the side contralateral to the reconstructed breast. This allows the simultaneous unhindered presence of two surgical teams, one harvesting the flap and the other preparing the recipient site. Further, the insetting of a contralateral flap implies that the flap is rotated by 180° when it is put in place. This movement brings the SIEV cephalad and closer to the internal mammary vessels, our preferred recipients. Thus the SIEV can easily be mobilized and microanastomosed as the primary outflow vessel in a SIEA flap or as a secondary drainage pathway in the advent of venous congestion in a DIEAP flap. In the case of a bilateral breast reconstruction, the abdominal flap is harvested as a bipedicled flap. The flap is split in two and each half is microanastomosed to the contralateral chest. It is interesting to note that the lower abdominal flap provides virtually always sufficient soft tissue for a simultaneous bilateral breast reconstruction, even in thin women.

Although sharing the same indications as the DIEAP flap, the SIEA flap is more suited to clinical situations where only a moderate amount of tissue is required for unilateral or bilateral breast reconstruction (18, 38,39). This is because the perfusion to the contralateral side of the flap is less reliable than in a DIEAP flap. Obese patients often have a well developed superficial system and can be good candidates for a SIEA flap. Furthermore, in overweight patients, the ipsilateral side of a large abdominal panniculus may be more than enough for unilateral breast reconstruction. Bilateral breast reconstruction seems to be an ideal indication for the SIEA flap because it avoids any intramuscular dissection. Another good indication is in partial breast reconstruction where a limited volume of tissue is required to correct a secondary breast deformity following breast-conserving surgery.

A typical indications for the use of this flap

Still within the realm of breast surgery, the DIEAP/SIEA flap can be utilized to correct congenital asymmetry such as in Poland syndrome or to salvage a failed implant augmentation. The DIEAP and SIEA flaps have also been used with excellent results for esthetic autogenous breast augmentation (40). The long pedicle of the DIEAP flap allows the use of a single axillary incision to inset the flap behind the gland and perform microanastomoses to the thoracodorsal vessels. A highly natural and lasting result can thus be achieved with a minimal scar.

The DIEAP flap can be useful in head and neck reconstruction especially in cases requiring bulk, such as in total glossectomy(41,42). Its long pedicle easily reaches the cervical vessels and the flap can be harvested while the ablative surgery is being performed thereby reducing total operative time. Use of the DIEAP and SIEA flaps has also been described for facial contour deformities such as Romberg's disease (43,44). In addition, defects of the upper and lower extremities can sometimes be good indications for a DIEAP flap, specifically when bulk and extensive skin coverage need to be provided(45-47).

Lastly, a less common usage of the DIEAP flap is as a pedicled flap for reconstruction of locoregional defects (48,47). By dissecting the deep inferior epigastric vessels to their origin, a pedicled DIEAP flap will easily cover the perineum, the greater trochanter, the sacrum and even the middle third of the thigh. If a further reach is needed, zone IV can be extended and supercharged by anastomosing the contralateral superficial or deep inferior epigastric pedicle or even the superficial circumflex iliac system to the genicular vessels. The harvest of a pedicled DIEAP usually entails the division of one or more segmental motor nerves and those should be repaired before closure.

POST-OPRATIVE CARE

The patient is sent to the surgical ward where flap monitoring is performed clinically. Factors such as flap color, temperature and capillary refill are assessed regularly. Intravenous hydration is continued for 2 days to support adequate intravascular volume and optimize flap perfusion. On postoperative day 1, parenteral narcotics are replaced by oral analgesics and the patient is allowed to ambulate. All patients receive low molecular weight heparin and Nootropil® (Piracetam) 12 gram / 24 hours IV for 5 days and as a solution 20% orally 25 cc q.i.d for another 5 days. This drug increases the viability of the distal portion of the skin flap due to an increase in capillary blood flow. Patients are usually discharged on postoperative day 4 to 6.

Outcomes

Expected outcomes

Our experience with over 1400 DIEAP and SIEA free flaps in the last decade supports the claim that these flaps are safe and success-

ful in achieving superior esthetic results. When adequately planned and performed, these operations actually have a complication rate equal or inferior to comparable free TRAM flaps while still maintaining the high standard of autogenous reconstruction. Additionally, since donor site morbidity is minimal, a swifter rehabilitation is expected (Cases 1-3, Fig. 6-8).

Untoward outcomes

As free flaps, the DIEAP and SIEA are subject to known microvascular complications (49). Currently, we experience a re-exploration rate of 4% and a total flap loss rate of less than 1%. Partial flap necrosis was observed in 7% of our earlier cases but since we started discarding zone IV systematically, it rarely is a problem. Fat necrosis is seen in 6% of cases but that figure can be higher in smokers and patients with postreconstruction radiotherapy. Persistent nodules of fat necrosis are resected 6 months postoperatively at the time of nipple reconstruction.

Donor site complications can also happen. Wound healing problems occur in up to 10 % of cases and this complication is often associated with smokers. Seroma formation develops in about 3% of DIEAP flaps but it is much more common following SIEA flaps because of the more extensive dissection in the inguinal region. Clips should be used to ligate large lymphatic channels whenever they can be observed. A compression garment can also be used postoperatively. Lastly, lower abdominal bulging after DIEAP flap harvest is seen in less than 1% of cases. True incisional hernias have not been a problem in our practice. This constitutes a major improvement over the TRAM flap and is an eloquent demonstration of how donor site morbidity is minimized with perforator flaps.

Long-term outcomes

The use of the DIEAP or SIEA flap in breast reconstruction is expected to produce high quality and durable results. However, the final outcome is usually achieved after at least three steps:

1) 0 months: initial flap transfer

2) 6 months: volume and symmetry adjustments, surgery to contralateral breast, nipple reconstruction, scar revision

3) 9 months: tattooing of areola

As opposed to prosthetic reconstruction, the results of a DIEAP/SIEA tissue transfer are expected to improve with time, as the flap settles and maturates. It is interesting to note that the flap volume can fluctuate in time as the patient gains or loses weight. Following transfer of a sensate DIEAP flap, the outcome of sensory recovery is in general quite satisfactory, especially in reconstructions with a larger skin island. Thirty percent of the patients even recover erogenous sensation. Of course, factors such as age of the patient, smoking and radiotherapy will greatly influence the final level of sensory return.

Coclusions

The lower abdomen definitely constitutes an ideal donor site of abundant soft tissue and has become the first choice for autogenous breast reconstruction. The development of perforator flaps can be seen as the ultimate refinement of myocutaneous flaps as they allow harvesting the ideal tissue with the most minimal donor site sequelae. Nowadays, the DIEAP flap has become the gold standard in breast reconstruction and is paving the way to an exciting new chapter in the evolution of Plastic Surgery.

List of figures

Fig 1. Multidetector CT scan is very useful to evaluate the vascular anatomy of the abdomen. The position, size and morphology of musculocutaneous perforators can easily be assessed.

Fig 2. The position of perforators from the deep inferior epigastric arteries is marked onto the abdominal skin. The skin paddle can then be designed by basing it on the most appropriate perforator(s). In this case, the skin island is positioned slightly high to incorporate the most cranial perforators into the flap.

Fig 3. After proceeding with the lower skin incision, the superficial inferior epigastric vessels are explored. This photograph is from the left groin. The SIEV is located more medial and more superficial than the SIEA.
SIEV: superficial inferior epigastric vein
SIEA: superficial inferior epigastric artery
SCIA: superficial circumflex iliac artery

Fig 4. When the flap is dissected off the deep fascia, the deep inferior epigastric perforators (arrows) can be visualized as they pierce the rectus sheath to reach the skin.

Fig 5. During intramuscular dissection of the DIEP flap pedicle, segmental intercostal motor nerves are visible as they cross over the vessels. If possible, these nerves should be left intact to spare a maximum of function to the rectus muscle.

Fig. 6, Case1 - Delayed breast reconstruction
(a) This 47 year old woman presented with a request for breast reconstruction, following a right mastectomy and axillary lymph node dissection. She underwent radiotherapy and chemotherapy. A free SIEA flap, pedicled on the left superficial inferior epigastric artery and vein and anastomosis to the internal mammary artery and vein was used to perform a secondary autologous breast reconstruction. (b,c): show her result after nipple reconstruction and tattoo.

Fig. 7, Case 2 – Immediate bilateral breast reconstruction
(a) This 53 year old woman presented with mixed multi-focal invasive and in situ ductal carcinoma widely dispersed in both breasts. A bilateral skin sparing mastectomy was performed together with a bilateral axillary dissection. A reconstruction was performed by a bilateral DIEAP flap. Postoperatively she underwent adjuvant chemotherapy. Six months postoperatively she underwent a bilateral nipple reconstruction but no further corrections to the flaps.
(b-d): Another three months later, a bilateral nipple areola tattoo was performed

Fig. 8, Case 3– Correction of an amputation stump
(a, b) This 27 year old young man underwent an upper leg amputation after a severe motor vehicle accident. In an initial phase, to preserve the length of the amputation stump, the distal part of the stump was covered by split thickness skin grafts. Two years later this patient presented with an instable scar and ulceration at the point of maximum pressure of his prosthesis. He had no sensation in this area.
(c) In one operative procedure the skin grafts were removed and the ulcers debrided. At the same time a free DIEAP flap was used to provide sufficient padding and skin coverage. Sensory re-innervation of the flap provided protective sensation of the stump.