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R E V I E W   P A P E R S

THE USE OF THE DIEP FLAP IN THE MODERN RECONSTRUCTIVE SURGERY

ŁUKASZ ULATOWSKI, ANNA KANIEWSKA

Department of Plastic Surgery, Medical Centre for Postgraduate Education in Warsaw
Kierownik: dr hab. *B. Noszczyk*

Perforator-based flaps

Studies of skin vascularisation have become the basis of the modern knowledge of reconstructive surgery utilising skin flaps. The earliest studies of skin vascularisation were performed in the 17th (by Harvey) and 19th centuries (by Thomas and Spalteholz). In the 19th century, Carl Manchot distinguished areas of skin vascularisation covering the entire surface of the human body. In the beginning of the 20th century, Salmon observed a system of vessels reaching the skin through deeper structures. Eventually, in 1987, Taylor and Palmer combined the observations of the previous researches with their own and presented a detailed model of skin vascularisation. They also created the so-called angiosome concept (1). An angiosome is a three-dimensional anatomical area supplied by an artery and accompanying veins. This observation is of great clinical importance, since tissues contained in an angiosome may be transferred as a flap comprised of various tissue types. The existing connections between vessels of the subcutaneous plexuses in the adjacent angiosomes make it possible to incorporate the tissues of the adjacent angiosomes into the flap.

The vessels supplying the skin, so-called skin perforators, branch away from the source arteries (direct perforators) or their muscular branches (indirect perforators). The knowledge of the route of a perforator is of crucial importance while preparing the flap, as it enables establishing the plane in which it should be visualised. The nomenclature and definitions of terms pertaining to perforator flaps were precisely established and narrowed in the so-called Gent consensus: a perforator flap comprises skin and/or subcutaneous tissue and is based on an isolated perforator, running through and/or between deeper tissues (mainly muscles) (2). In practice, only flaps based on muscular perforators (a vessel running through a muscle) or septal perforators (a vessel running through a septum between muscles) are considered perforator flaps (2).

It needs to be emphasised that the main advantage of perforator flaps is lower morbidity of the donor site. The blood supply of such a flap is independent of the underlying muscle. The source of blood supply of previously used, classic flaps was the underlying muscle, and elevation of the flap made it necessary to utilise the muscle (3).

For nearly 30 years after the publication of Taylor and Palmer's anatomical research, the anatomy of perforators was studied in detail for specific flaps in various areas of the body.

The flaps of greatest clinical use were called "work-horses" of reconstructive surgery, and the described DIEP flap is considered one of them.

The discovery of the DIEP flap

Flaps from the abdominal wall were used for the first time in breast reconstruction in the 1970s by Holmstrom and Robbins as free flaps and by Hartrampf as pedunculated flaps (4, 5, 6). An important fact regarding the Hartampf's method was that it enabled creating a transverse skin island within the abdominal wall (6). It needs to be noted that the initially used pedunculated and free flaps contained the transverse rectus abdominis muscle (TRAM).

The donor site for the DIEP flap is the skin and subcutaneous tissue of the lower abdomen. The name of the flap comes from the perforator deep inferior epigastric artery. The first clinical use of a cutaneous-adipose flap from the lower abdomen with complete sparing the transverse rectus abdominis muscle was presented in 1989 by Koshima and Soeda (7). That paper was, above all, the first report of perforator flaps, and it presented the ground-breaking discovery that "a large flap without muscle can survive on a single muscular perforator". Since 1994, Allen and Blondeel have extensively studied and propagated the use of this flap in clinical practice for breast reconstruction (8, 9).

The anatomy of the DIEP flap

The DIEP flap extends in the lower abdominal area between the navel, the anterior superior iliac spines and the pubic symphysis (fig. 1). The possibility of using such a large area stems from the already mentioned fact of connections between vessels of adjacent angiosomes. Clinically relevant perforators are localised preoperatively, and their route is taken into account after while planning the flap. This will be discussed in detail in the remaining part of the paper.

The DIEP flap can reach significant sizes, which makes it a good material for reconstructions requiring a large amount of tissue. The average dimensions of the cutaneous-adipose island are as follows: height – 13 cm (maximum up to 18 cm), width – 34 cm (maximum up to 60 cm) (10).

Vascularisation of the flap

The deep inferior epigastric artery (DIEA; average diameter: 3.5 mm) branches off the external iliac artery, running cephalically in the extraperitoneal, pierces through the transverse fascia (fig. 2) and entering the rectus sheath. Within the rectus abdominis, it divides into two main branches giving off muscular branches and muscular-cutaneous branches, i.e. perforators. Numerous perforators branching off the DIEA are observed. Clinically relevant perforating vessels are those running towards the skin and characterised by a diameter above 1 mm (10). Perforators are arranged in two rows in relation to the rectus abdominis: the medial row and the lateral row (fig. 3).

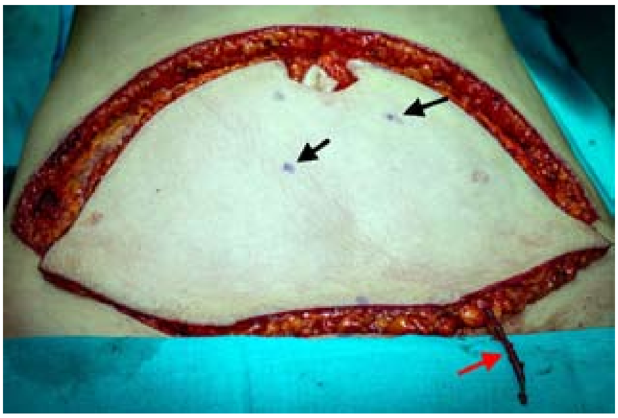

Fig. 1. The extent of DIEP flap preparation – the previously marked perforators (black arrows) and superficial inferior epigastric vein (SIEV) (red arrow)

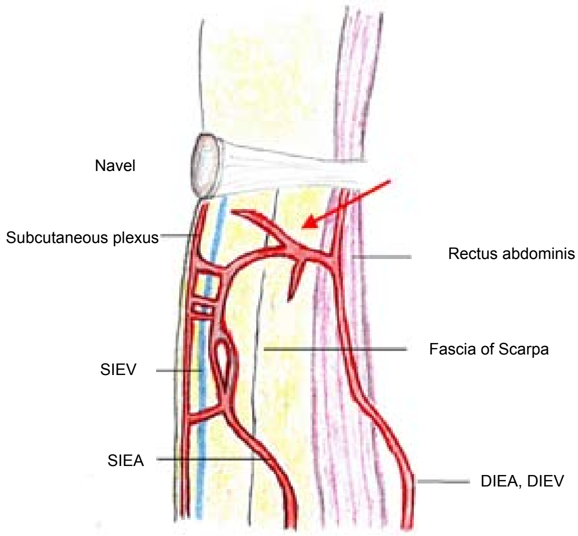

Fig. 2. Overview of vascularisation of the lower abdominal wall in the sagittal plane. SIEA – superficial inferior epigastric artery; DIEA – deep inferior epigastric artery; the red arrow indicates a perforator

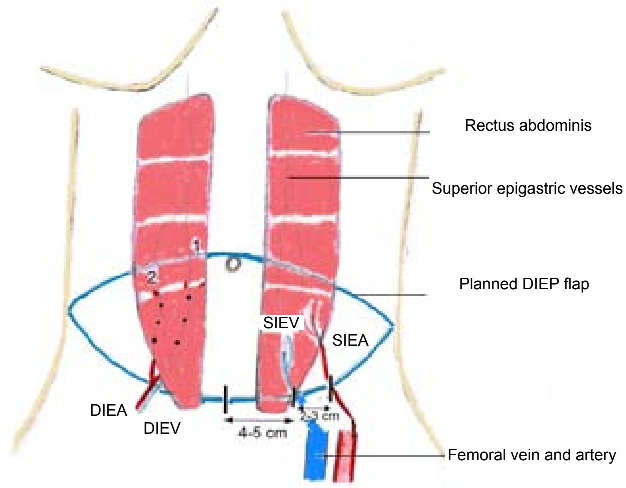

Fig. 3. Overview of the DIEP flap anatomy. DIEA – deep inferior epigastric artery; DIEV – deep inferior epigastric vein; SIEV – superficial inferior epigastric vein; SIEA – superficial inferior epigastric artery. Perforators branching off the deep inferior epigastric vessels: 1 – medial row, 2 – lateral row

The anatomy of deep inferior epigastric artery perforators

Based on imaging and intraoperative examinations, the distribution of perforators within the abdominal wall has been established. The anatomy of clinically relevant perforators is as follows:

- more than 90% of perforators are located within a 6 cm radius laterally and below the navel;
- the highest concentration is observed in the medial and central part of the one third of the rectus abdominis;
- vessels of the highest diameter come off the branches of the terminal deep inferior epigastric vessels;
- the distribution is not symmetric on both sides of the abdomen (10).

Venous drainage from the flap occurs through the deep and superficial inferior epigastric veins (DIEV, SIEV) (fig. 3).

The perforating veins run along the corresponding perforating arteries as so-called accompanying veins. After running through the anterior lamella of the rectus sheath, they join forming two deep inferior epigastric veins (DIEV), which accompany the homonymous arteries (DIEA) and enter the exterior iliac veins.

The superficial inferior epigastric vein (SIEV) does not accompany the homonymous superficial epigastric artery (SIEA), but instead it runs 2–3 cm medially and more superficially than the SIEA, 4–5 cm laterally to the midline (10) (fig. 3).

The main venous drainage utilised in the DIEP flap are two veins accompanying the artery (fig. 4). It is important to spare a 4–6-cm section of the superficial epigastric veins during the preparation of the flap, so that they can be used in case of disturbed drainage from the flap (11, 12) (fig. 1).

The SIEA flap

Here, we also need to mention flaps based on the superficial epigastric vessels (SIEA and DIEA). The skin island is planned in a similar way to that in the DIEP flap. The veins supplying it run in the subcutaneous tissue above the rectus sheath, and it is not necessary to open the sheath to elevate the flap, which reduces the donor site morbidity (fig. 2). Unfortunately, high interpersonal variation is observed, and an artery of good flow and a diameter which enable its utilisation (min. 1.5 mm) is present in fewer than 20% of the population (13-17).

Preoperative identification of perforators

Preparation of the flap based only on intraoperative identification of vessels is possible,

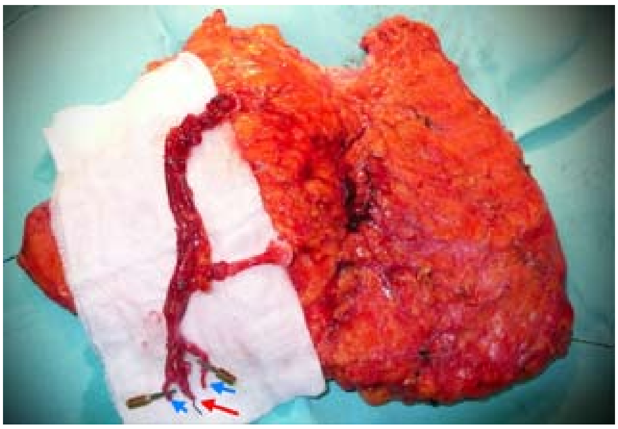

Fig. 4. An inverted DIEP flap with the vascular peduncle. The red arrow indicates the artery; the accompanying veins are marked with blue arrows

but time-consuming and can be burdensome for the operator.

According to the current reports, preoperative identification (perforator mapping) has become the standard procedure. It allows for better planning of the procedure and reduction of the preparation time. The mapping may be performed using blind pencil Doppler, colour Doppler, angio-CT or angio-MRI (the assessment of the location, diameter and route of vessels) (fig. 5) (18-22).

The choice of an adequate perforator

It has been determined that one perforator of a diameter > 1 mm is sufficient to provide accurate blood supply of the tissues of a cutaneous-adipose flap taken from the lower abdomen (10). As has been mentioned above, the preliminary choice of a perforator is based on imaging examinations. Vessels located in the central part of the flap are preferred. This stems from the fact that perfusion in the most distant area from the perforator in the ½ of the abdominal cavity opposite its location may be significantly decreased (23). More detailed perfusion studies revealed that the area of blood supply provided by perforators of the medial row extends beyond the midline, while the lateral row perforators in most cases fail to provide blood supply on the opposite side of the midline (24, 25). According to other authors, perforator located laterally may be used provided that their branches are directed mainly towards the flap centre (which may be determined based on a CT scan) (fig. 5) (10).

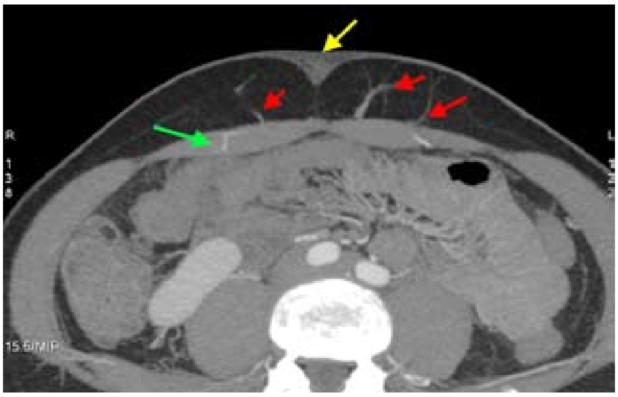

Fig. 5. Angio-CT image. The image shows the perforators (red arrows), rectus abdominis (green arrow) and navel (yellow arrow)

The authors of the present paper use preoperative angio-CT mapping according to a special protocol (26) as well as flow examination utilising colour Doppler, performed by the operator (ŁU). A perforator of adequate diameter and flow is selected, one that is located in the central part of the flap and has the shortest possible intramuscular route. Intraoperatively, the choice of a given perforator is based on its diameter and palpable pulsation.

Surgical technique

The surgery may be performed by two teams, in two surgical fields at the same time. In the case of DIEP flap breast reconstruction, the abdomen and chest may be prepared simultaneously. This reduces the surgery time. A transverse cutaneous-adipose flap of a spindly shape is planned in the line connecting the pubic symphysis with the anterior superior iliac spines up to the navel level. Marks are modified depending on the location of perforators. Preparation should be done in surgical loupes. The flap is incised on its lower edge. At this stage, the superficial epigastric artery is evaluated, if it has been found in an angio-CT examination. After clinical evaluation, a decision can be made to elevate the SIEA flap. Four to six centimetre long sections of the superficial veins are prepared and spared, since they can prove useful as additional venous drainage in the case of disturbed drainage from the flap (fig. 1). The preparation is performed above the rectus sheath.

If a decision is made to use the DIEP flap, the operator should aim at finding a perforator used for the elevation of the flap. Preparation is performed using coagulation. Precise closure of unused perforators is important to prevent haematoma formation and ensure a dry surgical field. After reaching the area of a previously mapped perforator, it is carefully prepared using preparation scissors and microsurgical instruments. Then the anterior lamella of the rectus abdominis is dissected, leaving a small fragment around the perforator, and the rectus abdominis is exposed. The perforator is prepared intramuscularly towards the groin. At this stage, it is important to carefully clip or ligate branches to the muscle (fig. 6). Frequently, there is more than one perforator meeting the clinical criteria of

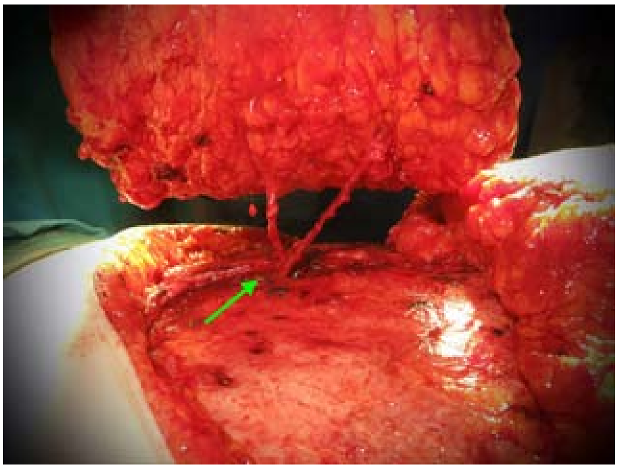

Fig. 6. The DIEP flap separated from the rectus sheath on two perforators with the inferior epigastric artery. The green arrow indicates where the rectus sheath was dissected

the supplying vessel. In such situations, one can choose the most favourable perforator by testing the blood supply of the flap after clipping the other perforator, or prepare both perforators. It is important to spare the branches of motor nerves leading to the rectus abdominis. Preparation is performed until achieving a peduncle of a sufficient length and vessels of an adequate diameter. Usually, the peduncle is 8–12 cm long with vessel diameters of 2–3 mm (fig. 4).

Subsequently, the navel is cut out and left on the peduncle, as during the abdominoplasty procedure. The flap is elevated with blood supply provided by the perforator. The circulation in the flap stabilises, which may be observed through evaluation of the group of vessels on its entire area. Peristalsis of vessels should be fast on the entire flap area. Excessive hyperaemia of the flap may suggest venous stasis. Some authors have described the procedure of using indocyanine dye administered intravenously and assessed its distribution in the flap with a special camera, after exposure to laser light of proper wavelength. This was especially useful in the assessment of the range of flap perfusion provided by the superficial epigastric artery (27). The loss of skin and subcutaneous tissue after removal of the flap is supplemented with a prepared cutaneous-subcutaneous flap from the abdominal wall, as in the abdominoplasty procedure. Preparation is performed high up to the ensiform process and costal arches. Next the flap is moved down towards the pubic symphysis, performing layered primary closure, possibly without tissue tension and with two Redon drains left in place. A hole is made in the flap for the navel which was previously left on the peduncle. The navel is sutured in a new place of the abdominal wall after making a V-shaped incision. According to the most recent literature, a technique may be used involving placement of additional sutures to quilt the flap to the fascia. This enables faster removal of the drains and significant reduction of complications in the donor site (28).

If the flap is used for breast reconstruction, another team simultaneously operates the chest. They cut out the mastectomy scar. While preparing the wound edges, a skin envelope is made for the flap tissues. In the 2nd or 3rd intercostal space, they reach the internal thoracic artery and the accompanying veins. Currently, these are the recipient vessels of choice.

After the vessels are prepared, the peduncle of the flap is ligated. The flap is transferred onto the chest and anastomosis is performed of the DIEA and DIEV to the internal thoracic artery and the accompanying vein. These can be both end-to-end and end-to-side anastomoses. The anastomoses are performed under magnification (operating microscope), using microsurgical instruments and 9/0 or 10/0 sutures. The patency of the anastomoses and peristalsis of vessels in the flap are evaluated. If the flap is properly perfused, it is placed in the skin envelope after partial deepithelisation, and the newly formed breast is modelled.

Complications

Early complications occur up to the third day after the surgery. The most frequently reported ones include disturbances in the flap perfusion caused by venous thrombosis, arterial thrombosis, peduncle folding or compression of the peduncle by a haematoma (29, 30). Longer-lasting ischaemia, if no revision is performed, may lead to complete loss of the flap. This happens rarely, in fewer than 1% of cases. The flap can also undergo partial necrosis of different degrees. The rate of microsurgical anastomosis revision reaches 4%. Later after the surgery (1–4 months), adipose tissue necrosis of various degrees may develop (6%) (10, 29, 31, 32).

Donor site morbidity

The most common donor site complications include wound healing disturbances (up to 10%, mainly in tobacco smokers) and accumulation of serous fluid/lymph (3%) (10). To reduce the risk of fluid accumulation, it is recommended to possibly limit preparation of the cutaneous-subcutaneous flap of the upper abdomen, clip larger lymphatic vessels and, if needed, use a compression band. Very rarely observed sequelae of DIEP flap removal include bulging of the lower abdomen (1%). They should be differentiated from cases of hernia, which – as reported by centres with extensive experience – are not observed in this type of surgery (10). The risk of bulging in the case of the DIEP flap is lower by a half compared to the free TRAM flap (33, 34). These clinical observations indicate the advantage of the perforator flap.

Utilisation of the DIEP flap in breast reconstruction

In recent years, breast reconstruction has become an element of comprehensive treatment of breast cancer patients. There has been a search for methods of reconstruction with native tissues that would make it possible to form a breast protrusion whose appearance and structure would most closely resemble a natural breast, at the same time reducing the donor site morbidity. The simultaneous development of the microsurgical reconstructive technique and discovery of perforator-based flaps made it possible to meet these criteria. This method allows for reconstruction of a naturally looking breast with a low level of ptosis, which reduces the need for subsequent symmetrisation of the other breast (fig. 7). Utilisation of native tissues makes it possible to avoid the use of implants and all associated complications. According to the FDA report of 2009, the revision rate after breast reconstruction with implants can be as high as 50% after 7 years. Thus, in some cases, this method may ultimately prove cheaper and less burdening for the patient. Reconstruction with native tissues is especially recommended in patients after radiation therapy, since it allows for replacement of tissues damaged by irradiation with healthy ones.

Recipient vessels used in breast reconstruction

The recipient vessels are most commonly the internal thoracic artery and accompanying veins (35, 36). Choosing these vessels makes it possible to place the flap medially and thus fill the medial and upper pole of the reconstructed breast. The disadvantages of using these vessels as recipient vessels that have been described in the literature include the necessity to remove a rib fragment and their possible unsuitability to be used in coronary bypassing (37, 38). According to reports and the author's experience, removal of a rib fragment is not always necessary, and there are situations where it can be spared. Performing vascular anastomosis to the side of the internal thoracic artery does not rule out its later use. Alternative recipient vessels are the thoracodorsal vessels (36, 39). However, if mastectomy was accompanied by axillary lymphadenectomy, these vessels could have been damaged and rendered unusable (39).

Fig. 7. State after right breast reconstruction with the DIEP flap and secondary reconstruction of the nipple with a local flap

It is worth emphasising that the DIEP flap may be used for simultaneous reconstruction of both breasts (40). The flap is dissected in the sagittal plane. Two vascular peduncles are used, each containing an independent perforator and the deep inferior epigastric artery (fig. 8).

Examples of using the DIEP flap in bilateral reconstruction include: prophylactic bilateral mastectomy, therapeutic mastectomy with prophylactic removal of the other breast and cases of failed breast reconstruction with implants (41, 42).

Specific uses of the DIEP flap include unilateral underdevelopment of a breast and the thoracic wall (Poland syndrome) (43, 44). Cases have also been reported of thoracic wall reconstruction after resection of a breast cancer relapse (45).

To sum up the issue of breast reconstruction, it needs to be mentioned that patients who have undergone breast reconstruction experience a higher level of emotional and physical well-being (46). Data from England reveal that delayed reconstruction with native tissues using free flaps is, according to the patients, the most favourable of all breast reconstruction methods. Based on the 20-year-long experience of Robert Allan, the pioneer in breast reconstruction with native tissues (2,850 reconstructions), the DIEP flap has remained the method of first choice (47). The utilisation of perforator-based flaps in breast reconstruction is associated with the necessity to perform thorough microsurgical training and create a specialist centre and team, which is associated with significant costs (48).

Other uses of the DIEP flap

The DIEP flap is mostly used for breast reconstruction with native tissues, and it is the most frequently used from the available flaps. However, the literature contains reports of using the DIEP flap in reconstructive surgery of other body areas: in the case of extensive losses in the face and neck (caused by burns, neoplasms, total laryngectomy, glossectomy and Parry-Romberg syndrome) (49–56). The DIEP flap has been also used as a free and pedunculated flap to reconstruct tissues in the areas of the hip, pelvis, proximal part of the thigh and groin (57–61), as well as in vaginal reconstruction (62).

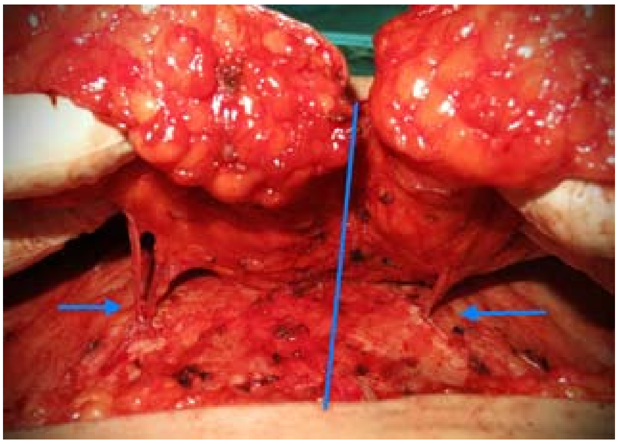

Fig. 8. The DIEP flap. The blue arrows indicate perforators. The blue line indicates the plane of possible division of the flap

Summary

Perforator flaps are one of the most complex currently known forms of tissue reconstruction. Their discovery base based on the knowledge of many generations of scientists. The DIEP flap is used in clinical situations where there is need to reconstruct a large tissue volume. Owing to the similarity of tissue structure and skin colour, it is a flap of choice in breast reconstruction with native tissues. It has large dimensions size and a considerable volume. Its peduncle is characterised by a large diameter and significant length of vessels. Anatomical variation is low and possible to assess preoperatively.

It is for these reasons that the DIEP flap is counted among the flaps of the highest clinical use. With careful planning, application of meticulous surgical technique and utilisation of the operating team's experience, the complication rate is relatively low.

The current reality of medical procedure pricing makes it impossible not to mention the costs. DIEP flap breast reconstruction is apparently expensive. Breast reconstruction with implants is associated with lower initial costs, but often requires additional procedures spread over time (e.g. implant replacement, plastic surgery of the other breast), which makes the costs difficult to estimate. Costs incurred by a facility performing DIEP flap reconstruction are currently not reflected in the pricing of this procedure by the Polish National Health Fund (NFZ), which is another factor affecting the number of such surgeries performed in Poland.

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Adress correspondence: 00-416 Warszawa, ul. Czerniakowska 231
e-mail: lukaszu@tlen.pl