EFFECTS OF FLAP DESIGN ON DISTAL TISSUE PERFUSION IN PERFORATOR FLAPS

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Running title: Dividing the skin base increases peripheral tissue perfusion in islanded perforator flaps

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Abstract

Background and objectives: Perforator flaps, both pedicled and free flaps, are increasingly used in reconstructive surgery. However, the microvascular perfusion pattern within these flaps still remains essentially unknown.

It is well known that in random-pattern flaps, flap length correlates directly with the width of the flap base. In perforator flaps, the importance of preserving a skin base is still an object of debate. We hypothesized that by dividing the skin base peripheral tissue perfusion in islanded perforator flaps increases. The abdominal panniculus in patients submitted to elective abdominoplasty was used to test and compare perforator flaps (intact skin bridge at the flap base in addition to a single perforator) and islanded perforator flaps (a single perforator located at the base of the flap only).

Methods: Flap perfusion was measured using dynamic laser induced fluorescence videoangiography (IC-VIEW, PULSION medical systems AG, Munich, Germany). The abdominoplasty flap was used to create the intended flaps and the fluorescent dye indocyanine green (ICG) was injected intravenously. Special software (IC-CALC) was used for quantitative analysis. The fluorescence intensity was compared after 2 minutes of registration. The results are presented as mean $\pm$ SEM, and considered statistical significant when $P < 0.05$.

Results: An increase in mean pixel intensity represents an increase in tissue perfusion. After surgical release of the skin base in the perforator flaps, the ICG fluorescence

increased in zone I (the most distal zone) in the islanded perforator flaps ($n=24$, $P<0.05$ both compared to control and the flaps with skin base intact)

Conclusions: Conversion of a perforator flap with skin base intact into an islanded perforator flap by dividing the skin base increases distal tissue perfusion. This finding could potentially enhance flap mobility and length- two major concerns in flap design.

Introduction

Perforator flaps, both pedicled and free flaps, are increasingly used in reconstructive surgery. They have low donorsite morbidity and superior aesthetic result (1). Holmstrom (2) introduced the concept that the deep inferior epigastric artery perforator (DIEP) flap could be adequately perfused by a single medial perforator already in 1979 and Koshima and Soeda (3) in 1989 demonstrated that a large adominal adipocutaneous segment could receive its vascular supply from a single vascular pedicle. Adequate microvascular perfusion is essential for integration and survival of a perforator flap. However, the microvascular perfusion pattern within these flaps still remains essentially unknown.

It is well known that in random-pattern flaps, flap length correlates directly with the width of the flap base. The importance of preserving a skin base in perforator flaps is still an object of debate. Recent studies indicate that blood velocity in perforator arteries is higher than that in the corresponding source vessel (5, 6). Schaverian et al (7) demonstrated consistent perfusion in the ipsilateral territory and the zone contralateral to the midline in abdominal flaps, consistent with large vessels across the midline. These findings may indicate that releasing the skin base in abdominal perforator flaps prevents an anatomical steal and increases distal perfusion.

We hypothesized that by dividing the skin base peripheral tissue perfusion in islanded perforator flaps increases. If this hypothesis should be proven correct it would be a physiological basis for enhanced flap mobility and length, two major concerns in flap design. To test the hypothesis we used the abdominal panniculus in patients submitted to elective abdominoplasty and compared perforator flaps (intact skin bridge at the flap base in addition to a single perforator) and islanded perforator flaps (a single perforator

located at the base of the flap only). Microvascular perfusion in the distal part of the flaps were evaluated by indocyanin green (ICG) fluorescence angiography.

Materials and methods

The study was approved by the regional committee for medical and health research + ClinTrials.gov Identifier: NCT01204554. Written informed consent was obtained from 12 patients submitted to elective abdominoplasty (Sept.-Nov. 2008). Exclusion criteria were body mass index >30 kg/m^2, diabetes, cardiovascular diseases, smoking, age <18 years, anti-coagulant therapy, pregnancy, lactation, hepatic failure or previous allergic reactions to ICG and iodide. Women of fertile age needed a negative pregnancy test to be included. The study included 10 women and 2 menn, 7 were classified ASA 1 (The American Society of Anesthesiologist) and 5 ASA 2. Mean age was 35.4 ± 2.9 (SEM) years, weight 76.7 ± 3.5 (SEM) kg, and height 168 ± 2.4 (SEM) cm.

Surgical technique

All procedures were performed in general anaesthesia. General anesthesia was induced with sodium pentobarbital (250-400 mg) and fentanyl (0.1-0.4 mg) and maintained with remifentanyl and desflurane. Tracheal intubation was facilitated by cisatricurium. Dobutamine (2-10 microgram/kg/min) was used to maintain MAP >70 mmHg throughout surgery. Preoperative CT angiography was performed to select the most suitable perforators, depending on the arterial diameter (1.5-2.5 mm for all patients). The abdominalplasty flap was harvested in a similar fashion as the conventional DIEP flap (Fig. 1) (8). During dissection, two perforator flaps with intact skin bases were designed on the same side of the abdomen in each patient (n=24) (Fig. 2A). After the first set of measurements the skin base was surgically released and converting to two islanded flaps with a singel vascular pedicle at the base of each (Fig. 2B). The rectus fascia was not

opened. After the perfusion measurements were completed, the abdominoplasty tissue was discarded and the abdominalplasty procedure continued.

Evaluation of the flap perfusion

Perfusion was assessed by dynamic laser-induced-fluorescence-videoangiography (IC-VIEW, PULSION Medical Systems AG, Munich, Germany). ICG is a water-soluble, tricarbocyanine dye that binds to plasma proteins and remains in the intravascular space after iv injection (9). It absorbs light in the near-infrared spectral range with a maximum at 805 nm and emits fluorescence at 835 nm. Illumination with laser (energy p00.16 W, wavelenght ≥780 nm) light induces fluorescence from blood vessels within the deep dermal plexus and subcutaneous fat. ICG has a normal plasma halflife of 3-4 min, allowing for sequential monitoring of skin perfusion with short intervals between injections. The energy in the laser used in the present study lies well below the damage threshold of the skin, and represents no potential for local tissue damage.

At each time of measurement 0.5 mg/kg ICG dissolved in 5 % dextrose (2 mg/ml) in a total volume of 10 ml and administrated through a peripheral intravenous (iv) line as an injection. The videoangiography started immediately thereafter. No adverse reactions were noted.

Image-processing and quantification software (IC-CALC, Pulsion Medical systems, AG, Munich, Germany) was used to analyse the recorded video sequence. Vessel perfusion was measured as the fluorescence of ICG. The method is a semi-quantitative measurement of perfusion. Data are given either as mean pixel intensity or perfusion index. The slope of the intensity curve at the different zones in the flap were recorded and

compared with the slope of the intensity curve of normal tissue on the abdomen, allowing a comparison between flap perfusion and normal tissue perfusion (table 1). Mean pixel intensity in an area represents tissue perfusion 2 min after ICG injection. The results were stored as video and captured images and analysed postoperatively.

Experimental setup

The abdominal panniculus on each patient was used to design two perforator flaps with the vascular pedicle positioned on the base of the flap (Fig. 1 and 2). The flaps were isolated using sterile gauze and draping to prevent fluorescence from underlying structures. In each patient data were obtained from both flaps. In the first set of measurements mean pixel intensity was evaluated in the two most distal zones (zone I and II) in perforator flaps with the skin base intact (Fig. 3a) immediately after dissection of the vascular pedicle. 30 min thereafter, in the second set of measurements, mean pixel intensity was registered in the two most distal zones after surgical release of the skin base (Fig. 3A). Mean pixel intensity in the two most distal zones was compared to the control zone and between the two types of flaps. The surgical procedure and perfusion measurements were performed by the same investigators, and data analysed by an independent unbiased person.

Peroperative conditions were monitored and kept as stable as possible (table 2). Temperature was kept at 36-38°, systemic arterial blod pressure at 120-140 mmHg and heart rate at 70-80 beats/min during all measurements.

Statistical analysis

Data are given as mean ± SEM. Differences in perfusion between the two different flap types and between flap types and control tissue were tested with paired sampled t-tests with Bonferroni correction for multiple comparisons. P<0.05 was defined as statistical significant.

Results

ICG flourescens as measure of tissue perfusion

There was no significant difference in ICG fluorescence in the control zone between the two measurements.

After surgical release of the skin base in the perforator flaps, the ICG fluorescence increased in zone I (the most distal zone) in the islanded perforator flaps (n=24, P<0.05 both compared to control and the flaps with skin base intact) (Fig. 4)(Table 1).

In zone II releasing the surgical base also increased the ICG fluorescence in the islanded flap (n=24, P<0.05, compared to the flaps with skin base intact) (Fig. 4)(Table 1).

Perfusion index

After surgical release of the skin base in the perforator flaps, the perfusion index increased in zone I in the islanded perforator flaps (n=24, P<0.05 both compared to the flaps with skin base intact) (Fig. 4)(Table 1).

In zone II tended to increase the perfusion index, however failed to reach statistical significance.

Discussion

The present study demonstrates that conversion of a perforator flap with the skin base intact into an islanded flap by dividing the skin base increases distal tissue perfusion. This finding is in accordance with our hypothesis. The increased microvascular perfusion in the flap periphery was assessed by increased ICG fluorescence and perfusion index.

Perforator flaps represent a significant milestone in reconstructive surgery. Conceptually, perforator flaps are based on recognizing the vascular supply of a given skin zone, identifying and isolating the perforators responsible (1, 10). The vascular tree in a perforator flap represents only a part of a complete segment of systemic circulation. During the anatomic course of the vessel from its origin to the point of entrance in the skin, all branches have been sealed because of surgical dissection of the pedicle. The calibre of the vessel and the conduit decreases along its course.

The vascular supply of the lower abdominal flap has caused much debate. Hartramp et al (12) orginally proposed perfusion zones in the lower abdomen based on an centrally perfused skin ellipse with declining perfusion of the peripheral ends. Scheflan and Dinner (13-15) described the perfusion of the pedicled transverse rectus abdominis flap as a centrally perfused skin ellipse noting that ipsilateral perfusion was consistently stronger than that seen contralateral to the midline. Clinical experience indicates that dividing the skin base when designing islanded perforator flap increases distal perfusion as seen observed by increased vascularization and colour.

It is well known that in random-pattern flaps, the flap length correlates directly with the width of the flap base. However, the importance of preserving a skin base in perforator flaps is still an object of debate. In the present study the distal perfusion was

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more pronounced in the DIEP based perforator flaps without an intact skin base. Schaverian et al (7) have shown that perfusion of the lower abdomen through the DIEP occurs in a stereotype pattern. Branches of the DIEP medial row perforators are connected across the midline through large diameter vessels at the level of the subdermal plexus. In previous studies by Rubino et al (6) it has been demonstrated that blood velocity in perforator arteries is higher than in the corresponding source artery, possibly due to the decreasing diameter of the conduit in perforator flaps. Furthermore, in a single pipe conduit with rigid walls and continuous flow, such as the perforator flaps in our study, it is reasonable to assume that all the blood that enters will come out. Taken together, these data are in accordance with the findings in the present study. As far as we are aware of, this is the first study, in which it has been directly demonstrated that conversion of a perforator flap with the skin base intact into an islanded flap by dividing the skin base actually increases distal tissue perfusion.

The findings in the present study are in contrast to the theory that the skin base may provide supplemental perfusion. By dividing the skin base, blood flow from the perforator is redirected to the distal flap zone. Thereby an anatomical steal to the contralateral side is prevented. An important clinical consequence of our findings is that it offers the possibility to design flaps that are longer with better mobility than skin based flaps. However, one should be aware of the fact that only lower abdominal flaps based on perforators from the deep inferior epigastrica artery were used. It has previously been demonstrated that these perforators have branches connected to vessels that cross over the midline to the contralaterale side (7). Whether this effect also is present in other

perforator flaps remains uncertain. One should also be aware of the fact that our findings are obtained in cardiovascular healthy patients.

Laser-induced fluorescence of ICG is a newly developed method to visualize skin perfusion. It is similar to flourescein angiography, with improved physiological, pharmacokinetic and spectral properties to visualize dermal and subdermal plexa too small for visualization by conventional angiography (4). It has provided a valuable tool for accurate evalution of dermal and subdermal circulation in pedicled and free flaps in both experimental and clinical studies (11). The flap modell used in this study retains a vascular pedicle at its base. Although only semi-quantitative ICG laser induced florescence videoangiography seems sensitive enough to detect changes in flap perfusion associated with surgical manipulation.

In conclusion, conversion of a perforator flap with skin base intact into an islanded perforator flap by dividing the skin base increases distal tissue perfusion. This finding could potentially enhance flap mobility and length- two major concerns in flap design.

References

1.   Wei FC, Celik N. Perforator flap entity. Clin Plast Surg 2003;30(3):325-9.
2.   Holmstrom H. The free abdominoplasty flap and its use in breast reconstruction. An experimental study and clinical case report. Scand J Plast Reconstr Surg 1979;13(3):423-27.
3.   Koshima I, Soeda S. Inferior epigastric artery skin flaps without rectus abdominis muscle. Br J Plast Surg 1989;42(6):645-8.
4.   Holm C, Mayr M, Hofter E, Becker A, Pfeiffer UJ, Muhlbauer W. Intraoperative evaluation of skin-flap viability using laser-induced fluorescence of indocyanine green. Br J Plast Surg 2002;55(8):635-44.
5.   Figus A, Ramakrishnan V, Rubino C. Hemodynamic changes in the microcirculation of DIEP flaps. Ann Plast Surg 2008;60(6):644-8.
6.   Rubino C, Coscia V, Cavazzuti AM, Canu V. Haemodynamic enhancement in perforator flaps: the inversion phenomenon and its clinical significance. A study of the relation of blood velocity and flow between pedicle and perforator vessels in perforator flaps. J Plast Reconstr Aesthet Surg 2006;59(6):636-43.
7.   Schaverien M, Saint-Cyr M, Arbique G, Brown SA. Arterial and venous anatomies of the deep inferior epigastric perforator and superficial inferior epigastric artery flaps. Plast Reconstr Surg 2008;121(6):1909-19.
8.   Blondeel PN. One hundred free DIEP flap breast reconstructions: a personal experience. Br J Plast Surg 1999;52(2):104-11.
9.   Muckle TJ. Plasma proteins binding of indocyanine green. Biochem Med 1976;15(1):17-21.
10. Blondeel PN, Van Landuyt KH, Monstrey SJ, Hamdi M, Matton GE, Allen RJ, et al. The "Gent" consensus on perforator flap terminology: preliminary definitions. Plast Reconstr Surg 2003;112(5):1378-83; quiz 1383, 1516; discussion 1384-7.
11. Holm C, Mayr M, Hofter E, Ninkovic M. Perfusion zones of the DIEP flap revisited: a clinical study. Plast Reconstr Surg 2006;117(1):37-43.
12. Hartrampf CR, Scheflan M, Black PW. Breast reconstruction with a transverse abdominal island flap. Plast Reconstr Surg 1982;69(2):216-25.
13. Scheflan M, Dinner MI. The transverse abdominal island flap: part I. Indications, contraindications, results, and complications. Ann Plast Surg 1983;10(1):24-35.
14. Scheflan M, Dinner MI. The transverse abdominal island flap: Part II. Surgical technique. Ann Plast Surg 1983;10(2):120-9.
15. Dinner MI, Dowden RV, Scheflan M. Refinements in the use of the transverse abdominal island flap for postmastectomy reconstruction. Ann Plast Surg 1983;11(5):362-72.
16. Wong C, Saint-Cyr M, Mojallal A, Schaub T, Bailey SH, Myers S, et al. Perforasomes of the DIEP flap: vascular anatomy of the lateral versus medial row perforators and clinical implications. Plast Reconstr Surg;125(3):772-82.

Figure legends