

# Perfusion Zones of the DIEP Flap revisited

Accepted for publication in the Plastic and Reconstructive Surgery Journal

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**Introduction:** Ever since the original description of the TRAM flap for breast reconstruction the Hartrampf perfusion zones are generally accepted. They form the basis for decision-making when creating the breast mound, as zone IV and eventually zone III are preferentially resected. Originally, these perfusion zones were based on the clinical impression of the perfusion in an uni-pedicled TRAM flap. Nowadays, however, the inferior epigastric pedicle has replaced the superior one, and the free perforator flap has replaced the pedicled TRAM flap as gold standard for autologous breast reconstruction. Even though clinical experience suggests that the blood supply to the DIEP flap is significantly different from that of a standard TRAM flap, the vascular supply and the perfusion zones of the DIEP flap have not yet been scientifically evaluated.

**Study objective:** To establish and quantify the perfusion zones of the DIEP flap

**Design:** Clinical, prospective, study.

**Patients:** Fifteen consecutive patients undergoing breast reconstruction with the free deep inferior epigastric perforator flap (DIEP).

**Measurements:** Evaluation of tissue perfusion was performed using the method of laser-induced fluorescence of indocyanine green. Fluorescence angiography was performed intraoperatively, immediately after the abdominal panniculus had been isolated on one or two perforator vessels.

**Results:** Perfusion of zone I occurred a median of 25 seconds after dye injection and the perfusion index amounted median 76% of normal tissue. Perfusion of zone II and III appeared 41 respectively 32 seconds after injection with perfusion index values of 25 respectively 47% (median values). Perfusion of zone IV was completely absent in 5 patients (33%); in the remaining patients it was dramatically decreased (median 5%) and occurred with a delay of 67 seconds after injection.

**Conclusion:** Blood supply of the abdominal skin, when based on one or two perforator arteries, occurs as a step-wise progression of perfusion across the skin paddle, originating from the perforator arteries on the ipsilateral side. The perfusion of the ipsilateral zone I and III of the DIEP flap is very reliable. Perfusion of the contralateral side is most variable, and the blood supply to zone IV is most frequently substantially compromised. Based on the results of this study, the classical Hartrampf zones should be rearranged, switching zone II and III. Zone IV of the DIEP flap should

always be discarded, unusually large perforators are present or unless an additional anastomosis on the contralateral side is performed.

**Key words:** *DIEP flap, perfusion zones, angiosome, laser, indocyanine green*

**Introduction:**

Due to its volume, colour and texture, the tissue of the lower abdomen has become the work horse in autologous breast reconstruction. Extensive studies exist on the supply and drainage of this most versatile panniculus of tissue. To the reconstructive surgeon, the information with the greatest matter of importance concerns the quality of the vascular supply, as this sets the limits for the amount of tissue available for breast mound creation. Basically, not all of the abdominal tissue can be used, and the tissue with the poorest vascularity is routinely discarded.

The algorithm for selection of the flap tissue to be resected is based on the Hartrampf perfusion zones (fig. 1). These zones divide the abdominal ellipse in 4 equal parts with different perfusion. The quality of vascularity is regarded poorer as the zone number increases. As a consequence, higher zones are resected first, and lower zones are left for reconstruction.

Familiarity with the Hartrampf perfusion zones belongs to basic knowledge of every plastic surgery resident. Only few plastic surgeons, however, are familiar with the establishment of these zones and the evidence, on which they are actually based:

Zoning of the abdominal panniculus was first described in the literature by Scheflan and Dinner in their papers on the unipedicled TRAM flap <sup>(1,2)</sup>. Scheflan divided the abdominal flap in four equal parts and numbered them according to his clinical impression of perfusion in the first 16 patients, who underwent the procedure <sup>(1,2)</sup>. The numbering of the perfusion zones was based on the tenet that perfusion zones immediately adjacent to the territory of the vascular pedicle have a better perfusion than zones which are farther away. The adjacent perfusion zone on the contralateral side (zone II) was considered to

have a better perfusion than the bordering perfusion zone on the ipsilateral side (zone III) (fig. 1).

Despite this significant work of Scheflan and Dinner, their perfusion zones should become better known after the second author to publish the TRAM flap, Dr. Carl Hartrampf <sup>(3)</sup>. Thus, the Hartrampf perfusion zones, with which we are all familiar today, are actually based on Scheflan and Dinners original description.

Nowadays, however, the deep inferior epigastric perforator flap has definitely replaced the unipedicled TRAM flap as gold standard for autologous breast reconstruction. This flap depends on only one or two perforator vessels as opposed to the conventional TRAM flap, which has a very large number of perforators. Even though one can infer that the blood supply to the DIEP flap must be significantly different from that of a standard TRAM flap, the perfusion pattern and the perfusion zones of the DIEP flap have not yet been evaluated.

Therefore, the purpose of this prospective study was to delineate and quantitatively assess the perfusion of the deep inferior epigastric perforator flap, when based on only one or two perforators. In particular, we wanted to verify the continuous validity of the Hartrampf perfusion zones in a time, where perforator flaps have replaced the pedicled mucocutaneous flaps for autologous breast reconstruction.

## **MATERIALS AND METHODS:**

### **Patients and Operative Technique:**

Fifteen consecutive patients undergoing autologous breast reconstruction with the DIEP flap during the period from November 2003 to August 2004 were included in the study. Morbidly obese and overweight patients were excluded from the study as were patients significant comorbidity or diabetes.

In the operating room the patient was placed in the supine position. Two teams operated simultaneously, so that one team was harvesting the flap from the abdomen, while the second

team prepared the internal mammary recipient vessels. The flap was harvested in the standard way, as it has been previously described <sup>(4)</sup>.

One or two perforators were dissected, depending on their calibre. Once a perforator vessel was found, the anterior rectus sheath was opened and the vessel was dissected from the rectus muscle fibres through a longitudinal direction split. The rectus abdominis motor nerves were spared when possible to avoid muscular denervation of the abdominal wall. When the deep venous system provided insufficient venous drainage, the superficial epigastric vein was dissected to enhance the venous drainage of the flap.

After transferral of the flap to the thorax, it was placed in the mastectomy region and sutured to the anterior chest wall. A conventional end-to-end anastomosis was performed with 9-0 interrupted nylon sutures under surgical microscope enlargement. The internal mammary vessels were preferentially chosen as recipient vessels.

The Medical Ethics Committee of our hospital approved the study.

#### **Evaluation of abdominal flap perfusion:**

Perfusion measurements were performed intraoperatively, using the technique of dynamic laser-fluorescence-videoangiography (IC-VIEW, PULSION Medical Systems AG, Munich, Germany). After isolating the abdominal flap on the perforator vessels, the Hartrampf perfusion zones were marked on the abdominal skin ellipse with ink. Then, a single dose of 0,5mg/kg indocyanine green (ICG-PULSION, PULSION Medical Systems AG, Munich, Germany) was injected intravenously, using a peripheral or central venous catheter. Under illumination with a laser (energy  $P_i=0.16$  W, wavelength  $\lambda=780$  nm) the resulting fluorescence was recorded with a digital video camera using an infrared filter.

A special software (IC-CALC, PULSION Medical Systems AG, Munich, Germany) was used for quantitative analysis of the recorded video sequences, where the fluorescence intensity served as a function of tissue perfusion. In the 4 Hartrampf zones of the abdominal skin, the increment of fluorescence (the slope of the intensity curve during inflow of the ICG) was recorded and compared with the intensity curve of normal tissue, which was not involved in surgery (thoracic wall). The slope of the intensity curve of this region was set to 100%. This allowed a percental

comparison with normally, well perfused tissue. The results were presented graphically as the percentage of pixel intensity increment compared to the reference region.

Furthermore, the interval time (seconds after injection) until dye filling of the region of interest occurred was recorded and graphically displayed for each of the 4 perfusion zones.

### **Results:**

Fifteen consecutive patients undergoing DIEP flap surgery were included in the study. The indications included 13 cases of unilateral and two cases of bilateral breast reconstruction following mastectomy. All reconstructions were done as a delayed procedure.

Fifteen intraoperative ICG perfusion measurements were performed by the same investigator. A mean of 18.5 ml (15-22) of indocyanine green was intravenously injected. In 12 cases a central venous, in 3 cases a peripheral venous line was used. No adverse reactions to the injection were noted.

The results of the ICG videoangiography were stored as video and captured images (fig. 2). A quantitative evaluation of the video sequences was performed using the ICCalc software. The results of the quantitative assessment are graphically displayed in fig. 3 and 4.

The perfusion index in zone I amounted median 76% of reference (mean 75.43%, +/- 21.9%) and ranged from 35-89%. Dye filling occurred a median of 25 seconds (mean 24.1, +/- 7.3 sec.) after injection. Perfusion of Zone II amounted median 25% (mean 33.4, +/- 20.3%) and ranged from 8 to 71%. Dye inflow to this zone appeared median 41 seconds post injection (mean 44.5 sec +/- 17.2 sec.) (range 22- 80). Perfusion index in zone III was median 47 % (mean +52.1 +/- 22.6) and ranged from 18 to 114. Dye inflow was seen median 32 seconds (mean 30.7 +/- 9.8) post injection, ranging from 15 to 52%. Perfusion of zone IV was completely absent in 5 patients (33%); in the remaining patients it was very variable (2-55%). In most patients it was dramatically decreased (median 5%)

(mean 11.1 +/- 14.7). In these patients who did show perfusion, dye inflow occurred with a delay of 67 seconds after injection (mean 69.4).

### **Discussion:**

Indocyanine green absorbs light in the near-infrared spectral range with a maximum at 805 nm and emits fluorescence with a maximum at 835 nm. Thus, laser-induced fluorescence of ICG is based on the same objectives as the fluorescence technique using fluorescein, but indocyanine green has helped overcome the physiological shortcomings of this substance. These include a long half-life, diffusion into the interstitium, and an excitation maximum in the ultraviolet spectrum, allowing penetration into the superficial dermis only. The absorption and emission values of ICG lie in the “optical window” of the skin, where the absorption of intrinsic chromophores such as haemoglobin and water is low. Penetrating deeper into the skin, the excitation light induces fluorescence from blood vessels within the deep dermal plexus and subcutaneous fat.

To the reconstructive plastic surgeon working with free and pedicle tissue transfer, laser induced fluorescence of ICG has shown to provide the currently most accurate information on dermal and subdermal circulation <sup>(5)</sup>. In previous clinical studies we were able to demonstrate the sensitivity of this technique for evaluation of skin perfusion of pedicled flaps <sup>(6)</sup>, free flaps <sup>(7)</sup>, and most recently, for quantitative assessment of the consequences of conventional abdominoplasty on the perfusion of the abdominal wall <sup>(8)</sup>. Common to these studies was the ability to demonstrate the *dynamics* of flap circulation. Thus, the videoangiography was able visualize the *inflow* of blood through the feeding vessel(s) (the arterial phase), the *spreading* of blood across the flap (the perfusion phase) and the final *distribution* of blood within the flap. The significant correlation between dye filling defects in the distribution phase and clinical outcome indicated a significant correlation between dye filling and the nutritive blood flow to the skin <sup>(6)</sup>.

The idea to delineate the DIEP flap using dynamic indocyanine green angiography was born, after mapping of the vascular territory of the superficial inferior epigastric artery had been performed using this technique (paper in processing).

We decided to perform the angiography *before* dividing the deep inferior epigastric vessels to leave the measurement independent of patency of the microvascular anastomosis. Thus, the angiography was supposed to reflect the *physiological* territory of the inferior epigastric pedicle on the lower abdominal wall. Incited by previous findings in axial pattern skin flaps, the dynamic imaging provided by ICView was supposed to demonstrate the spread of indocyanine green across the abdominal ellipse as it occurs in-vivo, as opposed to previous non-physiological anatomic injection studies in cadaver specimen.

Using a *dynamic* technique of perfusion evaluation, the results of this actual study provide significant additional information on the flow-physiology of free perforator flaps. The quantitative assessment of skin perfusion in different areas enables a first evidence based approach to zoning of the deep inferior epigastric perforator flap.

First and foremost, the results of the videoangiographies convincingly showed that the four empiric zones of Schefflan and Dinner are actually based on the angiosomes of the superficial and deep arterial epigastric system on the lower abdominal wall. As revealed by previous imaging of the angiosome of the superficial inferior epigastric artery (fig. 5), Hartrampfs zone III is obviously identical with vascular territory of the ipsilateral superficial inferior epigastric artery and zone IV with the territory of the contralateral superficial inferior epigastric artery (fig. 5). Zone I meets with the territory of the ipsilateral deep inferior epigastric artery (the vascular pedicle) and zone II correlates with the territory of the contralateral deep inferior epigastric artery<sup>(9, 10)</sup>.

The tenet that the watershed between these zones is made up by the choke anastomosis between the vascular territories is consistent with the dynamics of blood distribution between the four territories, seen in the ICG-angiography <sup>(11)</sup>. Thus, a step-wise progression of perfusion across the abdominal skin paddle was seen, originating from the perforator arteries on the ipsilateral side (fig. 2 a, b,c,d). The poor perfusion of zone four (fig. 2d) is probably in accordance with the distance of this region from the perforator arteries, as this most distal part of the flap is the only region where the blood supply has to pass *two* watersheds (or choke anastomoses). Perfusion of zone III, however, occurred consistently faster and with a higher intensity than in zone II (fig. 2b,c), even though these zones are placed in an equal distance from the territory of the vascular pedicle (zone I). Thus, the choke anastomoses between the vascular territories on the ipsilateral side of the flap appeared consistently stronger than the choke anastomosis connecting the angiosomes across the midline (fig. 3,4).

This finding of a poor cross linking of the two halves of the deep epigastric perforator flap actually confirms previous observations. In 2000, Blondeel et al performed an anatomical study of 15 fresh cadavers and four abdominoplasty specimen to explain the variability of the circulation in the DIEP flap zone IV <sup>(12)</sup>. By injecting the venous system with acrylic polymer, multiple branches were seen draining the subdermal plexus of the outer parts of the flap. Medial branches crossing the midline, however, were much less frequent and of a smaller calibre. Large side branches, providing a direct connection between the subdermal plexus of the two halves of the flap could be found in only 18% and patients, and in 36% of patient's medial cross linking of the venous system was completely lacking <sup>(12)</sup>.

These findings that the ipsilateral half of the abdominal flap is anatomically and physiologically better perfused than the zones on the contralateral half are in obvious contradiction with the conventional Hartrampf perfusion zones. So why were these zones taken for granted for so many years?

When reading the literature very carefully a switch of zone II and III was actually already proposed. Thus, already a year after the original description of Schefflan and Dinner, Dinner's further clinical observations persuaded the authors to change their minds about the arrangement of zone II and III <sup>(13)</sup>. Despite that, the zones continued to be numbered according to their original description until today.

As scientific evidence now becomes available for the true perfusion pattern of the abdominal panniculus, we believe that the time has come to number the abdominal skin correctly. Even though most experienced microsurgeons surely are aware of this already, a correct classification will allow a teaching of young plastic surgeons, which is in accordance with the available anatomical and physiological facts (fig. 6). Basing this new zoning on the perfusion of the deep inferior epigastric perforator flap agrees with current standards for autologous breast reconstruction <sup>(14,15)</sup>.

Another significant finding of this actual study regards the perfusion of zone four in the DIEP flap. Even though clinical experience suggests that the blood supply to at least some DIEP flaps may be significantly less robust than that of a standard TRAM flap, <sup>(16)</sup> the results of the quantitative assessment were alarming. Thus, we found a mean reduction of skin perfusion in zone four of median 95%, when compared with the perfusion of the surrounding skin, which was not involved in surgery (fig 3). In 33% of patients a total lack of perfusion of zone IV was noted. This substantial compromise of the circulation probably reflects the distance from the perforators. Probably, the one or two small calibre perforators provide such low perfusion pressures in the subdermal plexus vessels of zone one, that a traversal of two watersheds, one of them including the less developed choke vessels across the midline, is not warranted. This may explain the better perfusion of zone IV in the TRAM flap, where the arterial inflow occurs through a large number of perforators, which are even left surgically non-dissected.

Altogether, our results add scientific evidence to the subjective opinion that one of the precautions that must be taken to avoid a significantly increased incidence of flap loss and fat necrosis in a DIEP flap is to discard zone IV completely <sup>(12, 16)</sup>. Based on the perfusion indices in zone four, survival of the skin and the subcutaneous fat in this region seems improbable and most unsteady. Also, we agree with previous authors that the DIEP flap should be avoided in patients who need more than 70% of the usual TRAM flap skin paddle to make an adequately sized breast mound, unless unusually large perforators are present or unless an additional anastomosis on the contralateral side is made <sup>(12, 16)</sup>.

Blondeel used the absence of crossing venous branches in the majority of patients to explain the variability and unpredictability of the survival of zone IV in the DIEP flap. Based on these findings and his clinical experience, he claimed, that the limiting factor in survival of zone IV was not the arterial outflow but a failure of venous outflow <sup>(12)</sup>.

The dynamic mapping of the arterial supply of the DIEP flap provided by this study does not support this assumption. Thus, it seems that the arterial inflow to zone IV is as unpredictable as the venous outflow.

### **Summary:**

This study provided a dynamic investigation of the perfusion of the deep inferior epigastric perforator flap, as it occurs on the operating table. In in-vivo angiographies of the subdermal plexus it was shown that the blood supply of the abdominal perforator flap occurs as a step-wise progression of perfusion across the skin paddle, originating from the perforators on the ipsilateral side. Arterial cross-linking of the two flap-halves seemed to be poorer than previously believed; meaning that perfusion of the vascular territories across the midline was always delayed and less intensive than of the territories on the ipsilateral side.

Further studies are warranted to evaluate the new vascular axes, which are enabled due to continuous progress in microsurgical techniques. The dynamism of this new investigation technique may help to recognize and elucidate the complexity of the vascular system of the lower abdominal wall and its multiple interrelated territories.

**Literature:**

1. Schefflan M, Dinner MI. The transverse abdominal island flap: part I. Indications, contraindications, results, and complications. *Ann Plast Surg* 1983; 10: 24-35.
2. Schefflan M, Dinner MI. The transverse abdominal island flap: part II. Surgical technique. *Ann Plast Surg* 1983; 10: 120-9.
3. Hartrampf CR, Schefflan M, Black PW. Breast reconstruction with a transverse abdominal island flap. *Plast Reconstr Surg* 1982; 69: 216-25.
4. Blondeel PN. One hundred free DIEP flap breast reconstructions: A personal experience. *Br J Plast Surg* 1999; 52: 104.
5. Holm C., Mayr M., Tegeler J., Becker A., Pfeiffer U. J., Mühlbauer W. Laser-induced fluorescence of indocyanine green: Plastic surgical applications. *Eur. J. Plast. Surg.* 26: 19-25, 2003.

6. Holm C., Mayr M., Höfter E., Becker A., Pfeiffer U. J., Mühlbauer W. Intraoperative evaluation of skin-flap viability using laser-induced fluorescence of indocyanine green. *Br. J. Plast. Surg.* 55: 635-44, 2002.
7. Holm C, Tegeler J, Mayr M, Becker A, Pfeiffer UJ, Mühlbauer W. Monitoring free flaps using laser-induced fluorescence of Indocyanine green. A preliminary experience. *Microsurgery* 2002; 22(7): 278-87.
8. Mayr M, Holm C, Höfter E, Becker A, Pfeiffer UJ, Mühlbauer W. Effects of abdominoplasty on abdominal wall perfusion: A quantitative evaluation. *Plast Reconstr Surg* 2004; in press.
9. Taylor GI, Palmer JH. The vascular territories (angiosomes) of the body: experimental study and clinical applications. *Br J Plast Surg* 1987; 40: 113-41.
10. Rickard R. TRAM and DIEP flap zones. *Br J Plast Surg* 2001; 54: 272-80 (short correspondence).
11. Moon HK, Taylor GI. The vascular territory of rectus abdominis musculocutaneous flaps based on the deep superior epigastric system. *Plast Reconstr Surg* 1988; 82: 815-32.
12. Blondeel PN, Arnstein M, Verstraete K, Depuydt K, Van Landuyt KH, Monstrey SJ, Kroll S. Venous congestion and blood flow in free transverse rectus abdominis and deep inferior epigastric perforator flaps. *Plast Reconstr Surg* 2000; 106: 1295-99.
13. Dinner MI, Dowden RV, Schefflan M. Refinements in the use of the transverse abdominal island for post mastectomy reconstruction. *Ann Plast Surg* 1983; 11: 362-72.
14. Gill PS, Hunt JP, Guerra AB, Dellacroce FJ, Sullivan SK, Boraski J, Metzinger SE, Dupin CL, Allen RJ. A 10 year retrospective review of 758 DIEP flaps for breast reconstruction. *Plast Reconstr Surg* 2004; 113: 1153-60.

15. Craigie JE, Allen RJ, Dellacroce FJ, Sullivan SK. Autogenous breast reconstruction with the deep inferior epigastric perforator flap. Clin Plast Surg 2003; 30: 359-69.
16. Kroll SS. Fat necrosis in free transverse rectus abdominis myocutaneous and deep inferior epigastric perforator flaps. Plast Reconstr Surg 2000; 106: 576-83.

**Legend to figures and tables:**

**Figure 1:** The conventional Hartrampf perfusion zones

**Figure 2a:** The lower abdominal flap after isolation on two perforator arteries from the left deep inferior epigastric artery. The conventional Hartrampf perfusion zones are marked on the skin with ink.

**Figure 2b:** ICG-angiography 25 seconds after injection showing filling of the vascular network in zone I and III. The midline has not yet been crossed.

**Figure 2c:** ICG-angiography 34 seconds after injection showing also filling of zone II on the contralateral side.

**Figure 2d:** ICG-angiography 42 seconds after injection showing diffuse filling of the entire flap. Perfusion defects of the most distant part of zone IV are seen.

**Figure 3:** Median perfusion index of the 4 Hartrampf perfusion zones (in percent of reference).

**Figure 4:** Median time in seconds to dye inflow in each of the 4 Hartrampf perfusion zones.

**Figure 5a:** Isolation of the lower abdominal flap on the left superficial inferior epigastric artery (SIEA).

**Figure 5b:** Angiosome of the left superficial inferior artery shown by dye filling area of the skin after indocyanine green injection.

**Figure 6:** Correct numbering of the perfusion zones of the DIEP flap.

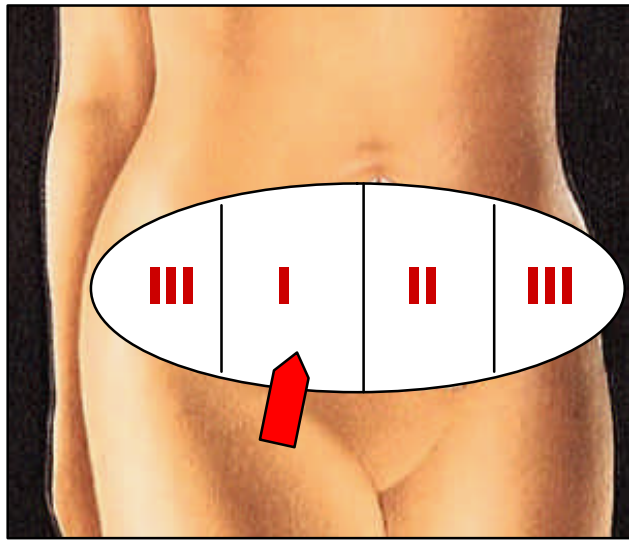


Fig. 1

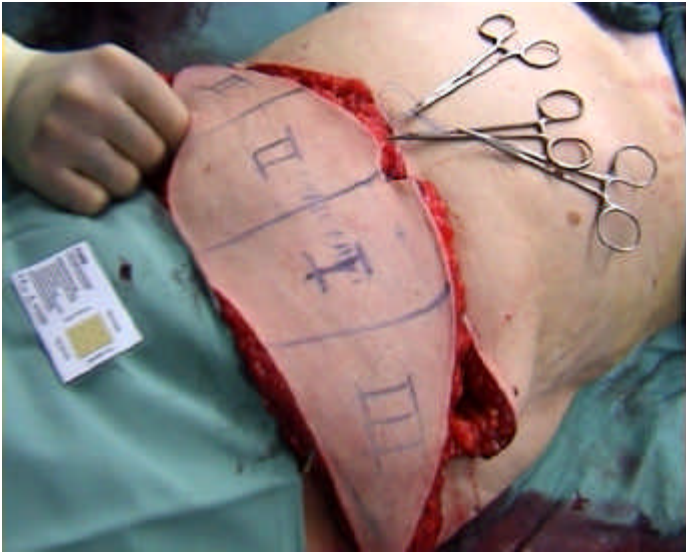


Fig. 2a.



Fig. 2b

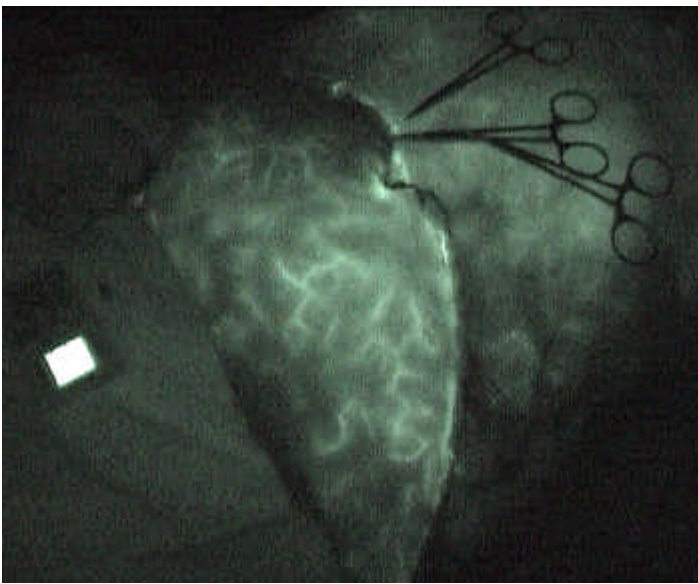


Fig. 2c.

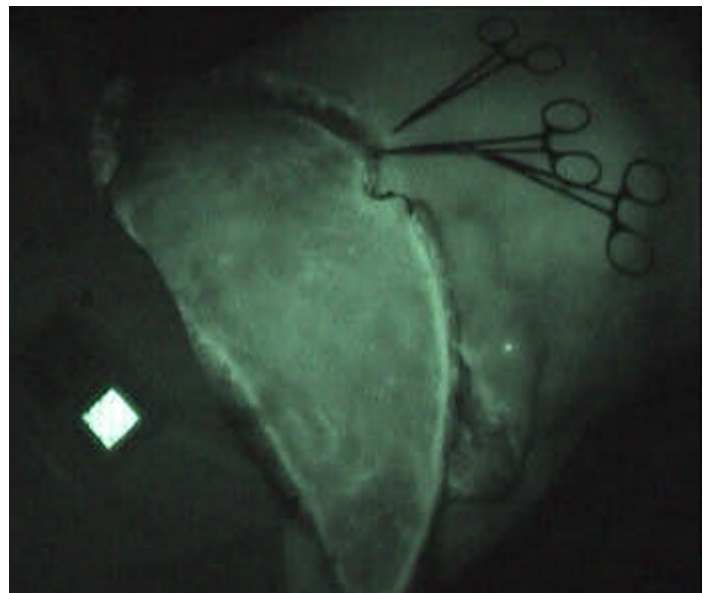


Fig. 2d

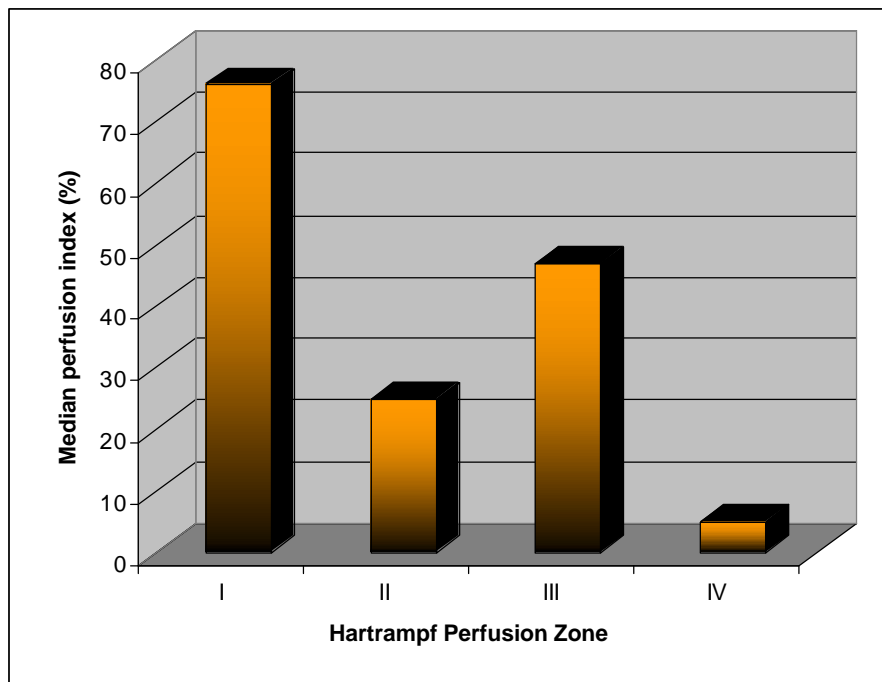


Fig. 3

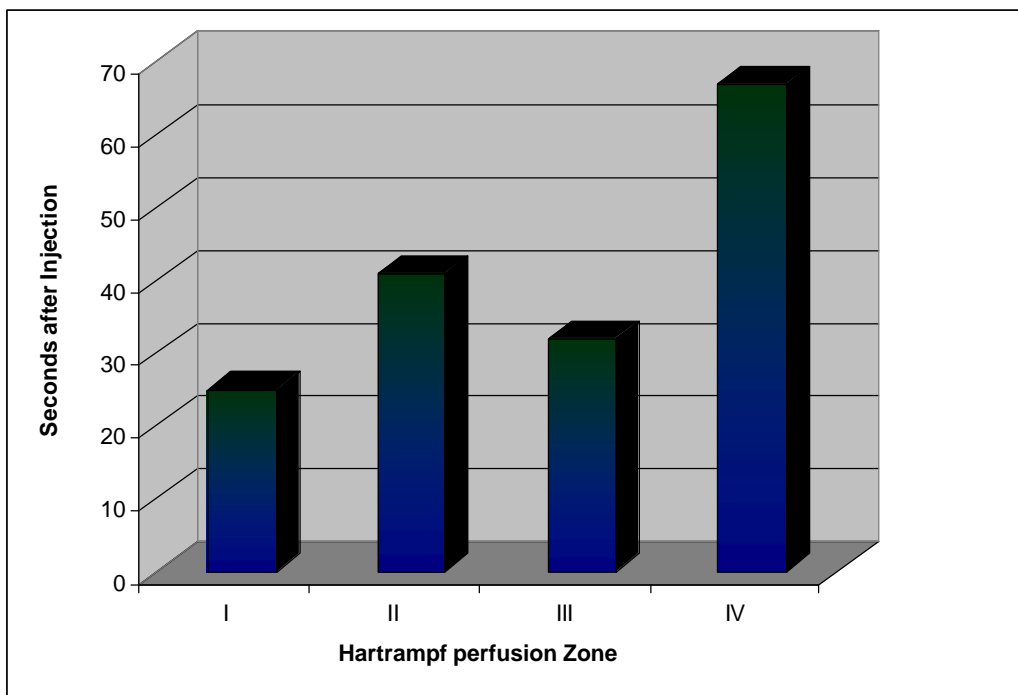


Fig. 4



Fig. 5a

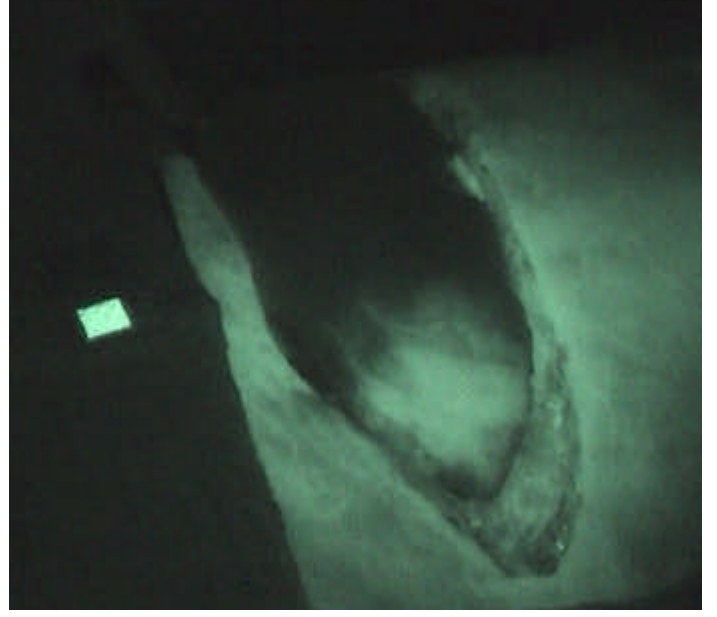


Fig. 5b

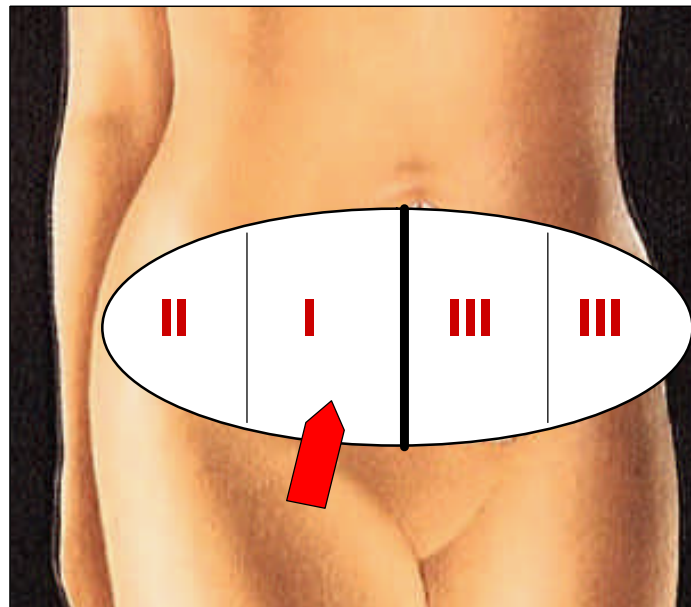


Fig. 6