Thermography in Plastic Surgery

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1. INTRODUCTION

Plastic surgery and tissue transfer

One of the main goals in plastic surgery is the correction and restoration of form and function. The realm of plastic surgery is large ranging from well-known cosmetic surgery to less well known sub-specialties such as reconstructive surgery, burn, craniofacial surgery, hand and micro-surgery. Reconstructive surgery deals with the closure of defects and restoration of form and function after trauma, pressure sore treatment, infection, cancer treatment and the treatment of congenital deformities. The use of tissue transfer or so-called flaps in the same patient is an important instrument in reconstructive surgery. Such a flap may consist of skin and subcutaneous tissue, muscle or bone or a combination of these tissues. Tissue transfer can be performed with so-called pedicled flaps and free flaps. In pedicled flaps the blood supply to the tissue is left attached to the area the flap has been harvested from, the donor site, and tissue is simply transposed to a new location, the recipient site. Blood supply of the flap is maintained via a pedicle which consists of an artery and vein or veins. In free flaps, the blood supply is detached from the donor site and the tissue is transferred to the recipient site to cover a defect and to restore form and, if possible, function. A free flap procedure involves disconnecting the blood supply via the pedicle of the flap and then reestablishing the blood supply again at the site of the defect.

Here the blood supply is reestablished by suturing the blood vessels of the pedicle, to blood vessels at the recipient site. Since the diameter of the blood vessels can be as small as 1 to 2 millimeters in diameter, skillful microsurgical techniques are required. Both pedicled and free flaps rely for their survival on adequate tissue perfusion. Inadequate tissue perfusion will lead to partial or total flap failure. Successful flap surgery requires a thorough knowledge of vascular anatomy and how the flap is perfused as well as microsurgical skills.

Tissue flaps

In earlier days, the use of myocutaneous flaps was the gold standard in reconstructive surgery. Such a flap consists of skin, subcutaneous tissue (fat) and the underlying muscle with its fascia. The muscle was included as a carrier of the blood supply to the overlying skin and subcutaneous tissue. The blood supply to the skin originates from a deeper lying main vessel under the muscle. Branches from this main vessel pass through the muscle, perforate the overlying fascia and continue their way through the subcutaneous tissue up to the skin. Since they perforate the fascia these branches are called perforators. During the earlier days surgeons included the muscle to guarantee the inclusion of many perforators so that adequate perfusion to the overlying skin of the flap was provided. A breakthrough in flap surgery came when Koshima & Soeda (12) discovered that the overlying skin and subcutaneous tissue could actually survive on a single perforator without including the underlying muscle. A perforator consists of a perforating artery and its concomitant vein. A flap that relies for its perfusion on a perforator is called a perforator flap. The main advantage of perforator flaps is that no muscle is included and therefore there is no loss of muscle function at the donor site. These perforator flaps are now the gold standard in reconstructive surgery. Preoperatively the most suitable perforator has to be selected to guarantee adequate perfusion to the flap. The use of perforator flaps requires microsurgical skill as the perforator is easily damaged intra-operatively. In free perforator flaps, the reestablishing of the blood supply to the flap after transfer is crucial for survival of the flap. In the direct postoperative phase, occlusion of the pedicle that supplies the flap due to a blood clot or due to torsion or kinking of the pedicle may lead to flap loss.

First use of thermography in perforator flap surgery

Theuvenet et al. (21) were one of the first to use thermography in the pre-operative planning of flap surgery, they called the technique thermographic assessment of perforating arteries in their myocutaneous flaps. They realized that warm blood

transported by perforators caused a hot spot on the skin surface. These hot spots became clearly visible during the rewarming phase following a cold challenge where a plastic bag filled with ice water was shortly brought in contact with the skin surface. Publications from Salmi et al. (17) and Zettermann et al. (25) from Finland have confirmed the usefulness of thermography in reconstructive surgery with myocutaneous flaps. Itoh and Arai (10, 11) described for the first time the use of thermography in the selection of a suitable perforator in free perforator flap surgery. Pre-operatively they employed the same cold challenge as Theuvenet et al. (21). The usefulness of thermography in pedicled perforator flap surgery was described by Chijiwa et al (4) from Japan.
At our department we have since 2000 successfully used dynamic infrared thermography (DIRT) as a technique to assist the plastic surgeon in the pre-operative, intra-operative and post-operative phase of perforator flap surgery (15). DIRT is used to help to more clearly identify vascular patterns in the skin (22). In DIRT the area of interest is exposed to a thermal challenge (cold or warm) and the thermal recovery towards equilibrium is registered. We have been using DIRT in perforator flap surgery for reconstruction after trauma surgery, cancer surgery and treatment of pressure sores. In order to illustrate the use of thermography in the pre, intra- and post-operative phases of plastic surgery we shall use breast reconstruction with the deep inferior epigastric perforator flap (DIEP flap) which is one of the most popular free perforator flaps as a main example. The usefulness of thermography in reconstructive surgery after trauma will be illustrated with some cases presentations.

2. AUTOLOGOUS BREAST RECONSTRUCTION

The deep inferior epigastric perforator flap (DIEP) in breast reconstruction.
Breast reconstruction using tissue from the patient's lower abdomen has become an increasingly popular method after surgical treatment of breast cancer with removal of the breast, a so-called mastectomy (2). The lower abdomen can provide a large amount of skin and subcutaneous tissue that allows for the reconstruction of a natural looking breast with a soft consistency and adequate volume. The deep inferior epigastric artery and vein are the main blood source to the lower abdomen. Perforators arising from the deep inferior epigastric system traverse through the overlying rectus abdominis muscle, perforate the overlying muscle fascia and connect with the subdermal plexus. The perforators provide the blood supply to the skin and subcutaneous tissue. Each deep inferior epigastric system has often 4-7 of these perforators. Normally, the area between the umbilicus and symphysis and between both anterior iliac spines is harvested as a flap. In a DIEP (deep inferior epigastric perforator) flap the blood supply to the flap is provided by a perforator of the deep inferior epigastric vessels. After transfer to the thoracic wall, where the blood supply to the flap is reestablished by connecting the perforator to the internal mammary vessels, a breast is reconstructed (Fig.1). With a DIEP flap, the abdominal wall muscles are left intact and patients can after recovery do sit-ups as normal.

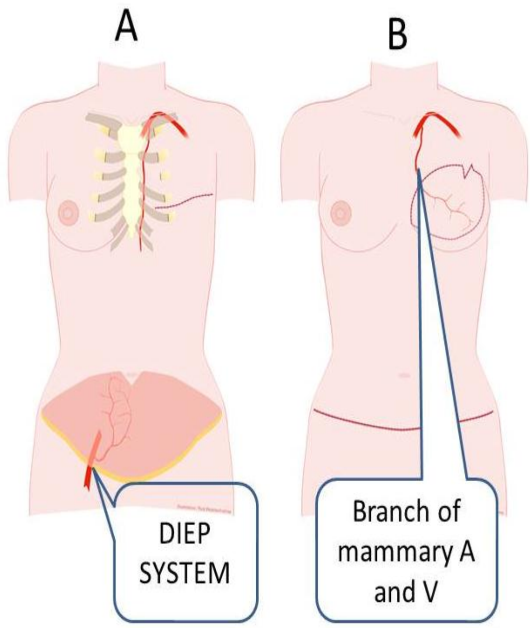

Fig. 1 - Principle of autologous breast re-construction. (A) Abdominal skin flap with blood supply from deep inferior epigastric artery and vein DIEP system (B) Transplanted abdominal skin flap anastomosed to branch of mammary artery and vein.

The wound at the abdomen is closed as in a tummy tuck which is by many patients considered a bonus of this technique.The psychological, cosmetic and sexual benefits of post-mastectomy breast reconstruction have been well documented. As with any operation complications may occur. One of the most serious complications in breast reconstruction is flap loss due to inadequate perfusion. Flap loss is a devastating experience for a patient. In addition, it causes an economic burden on the hospital health budget as re-operations are necessary. To prevent flap loss it is important to guarantee adequate blood supply to the flap. Breast reconstruction with DIEP flap can be divided into a pre-operative phase, an intra-operative phase and a post-operative phase. Below we present our experiences with the use of DIRT in each phase.

2.1 The pre-operative phase

In the preoperative phase the surgeon has to plan the breast reconstruction. An estimate has to be made of the size of skin area and subcutaneous fat volume that is required to reconstruct the new breast. The dimensions of the flap will be marked on the skin surface. To guarantee adequate perfusion of the DIEP flap the surgeon has to select a suitable perforator to perfuse the flap. Although one could select such a perforator intra-operatively, the large variability in the numbers and locations of perforators makes this time consuming. Perforator selection is preferably done pre-operatively as this reduces operation time and minimizes the risk of damaging the perforator due to inadvertent traction. The use of the multi-detector row computer tomography (MDCT) scan is today considered the gold standard in pre-operative imaging of perforators. The location, caliber and branching pattern of the perforator can be visualized nicely with the MDCT scan (1, 3, 13). The disadvantage of MDCT is the exposure of the patient to ionizing radiation and intravenous contrast medium. With over 10 years of experience we have been able to demonstrate that DIRT provides an excellent non-contact, non-ionizing, real-time imaging technique for the pre-operative selection of suitable perforators (7, 8).

The mapping of the locations of perforators from the deep inferior epigastric system is simply based on the fact that perforators that transport blood to the skin surface become visible as hot spots on the skin surface on the infrared images (thermograms).The localization of the hot spots can be more clearly defined by observing the rewarming pattern following a cold challenge. We normally examine the patient in a special examination room (room temperature ca. 22-24°C) with the abdomen exposed. After an acclimatization period of 10 minutes air is blown over the skin surface for 2 minutes using a desk top fan. This form of mild skin cooling is well tolerated by patients and causes skin temperature changes well within the physiological range. The rate and pattern of rewarming is continuously monitored with the infrared camera. Analysis of the rate and pattern of rewarming of the hot spots makes the identification of the most powerful perfused perforator easy. A hot spot that shows a profound rewarming of the area surrounding the hot spot is of interest as such a hot spot is considered to be associated with a well-developed vascular network. An example of a cooling and recovery sequence on the abdomen is shown in fig 2.

Interestingly there is a large variability between the number and location of hot spots between the left and right side of the abdomen in an individual patient, in other word there is no clear left/ right symmetry in their distribution. Also, there is a large inter-individual variability in the number and position of hot spots between patients.

The hot spots revealed by the DIRT technique are the result of transport of warm blood from the body core through the perforators. This can easily be confirmed by the use of Doppler ultrasound flowmometry. We have shown that first appearing hot spots are always associated with an arterial Doppler sound. There is a positive relation between the brightness of the hot spot and the auditive Doppler volume. Very recently we have carried out further studies in which we have compared the results from DIRT, Doppler ultrasound flowmemetry and MDCT for preoperative perforator selection on the abdominal skin. These studies confirm that DIRT is, indeed, a reliable technique for identifying suitable perforators in the pre-operative planning phase for autologous free flap surgery. All first appearing hot spots could be related to clearly visible perforators on the MDCT scans (5, 7, 8, 23).

2.2 The intra-operative phase

During the intraoperative phase we have our infrared camera mounted on a special rig so that the camera is suspended above the patient on the operating table and above the heads of the operating team (Fig. 3). The thermal images can be viewed in real time on a large monitor. The camera is controlled by an operator using a lap-top computer located outside the sterile field. We use thermography to establish if the perforator is still working after it is prepared free but still connected to the lower abdomen (9).

Damage of the perforator can easily be verified using thermography. By applying a metal plate at room temperature to the skin surface overlying the perforator, the rate and pattern of rewarming after this cold challenge is analyzed. If the perforator has been damaged, there will be no or a slow rewarming. In such a case the surgeon may decide to use another perforator in order to avoid the use of a possible damaged perforator.

The main use of thermography during the intra-operative phase is to monitor the outcome of the microsurgical procedure where the blood supply to the flap is re-established after it has been transferred to the thoracic wall (6) (Fig 4). Suturing together blood vessels with diameters as little as 1 to 2 mm requires great skill in order to avoid damage to the vessels. Damaging the blood vessels may lead to a blood clot in the vessel lumen that will cause perfusion problems of the flap and finally flap loss.

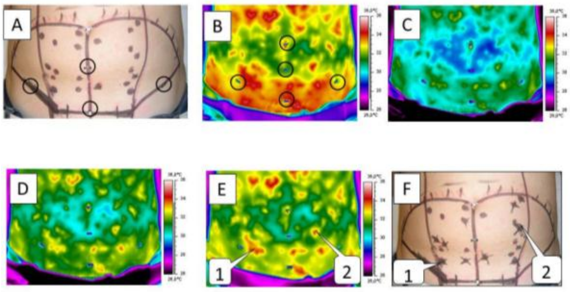

Fig. 2 - A: photograph of lower abdomen. The 4 black circles mark the location of small pieces of metal tape used as reference points in the IR images. B. IR thermal image prior to abdominal cooling. C: IR thermal image at end of 2 min cooling period. Following the abdominal cooling the skin temperature rapidly rewarms (D and E). The location of two strong hot spots are indicated in E. In panel F each black spot marked with an X indicated where a strong arterial sound can also be heard at the hot spot with a Doppler ultrasound instrument.

Fig. 3 - IR camera system used during surgery

After the blood vessels have been connected the clamps, that have temporarily occlude the vessels, are removed and the flap will become perfused with warm blood again. During the entire process we monitor the skin temperature of the flap with the infrared camera. Typically, a successful procedure is characterized by a rapid reappearance of hot spots on the flap and a general rewarming of the entire flap (Fig.4. top panel).

The thermal challenge in this form of DIRT is created by a reperfusion of the flap with warm blood. The information obtained from the infrared image proves the surgeon with real-time indirect information on the skin blood perfusion.

Thermography during surgery can also be used to register other causes that may lead perfusion problems. For example there may be partial or total restriction of arterial in flow. By observing the thermal images the surgeon is able to see immediately such a problem which is characterized by a slow or no rewarming of the flap. Sometime inadequate in flow (poor or absent rewarming) may be caused by a torsion or kinking of the vessels or by external compression of vessels. Such a problem can easily be corrected as soon as it is noticed.

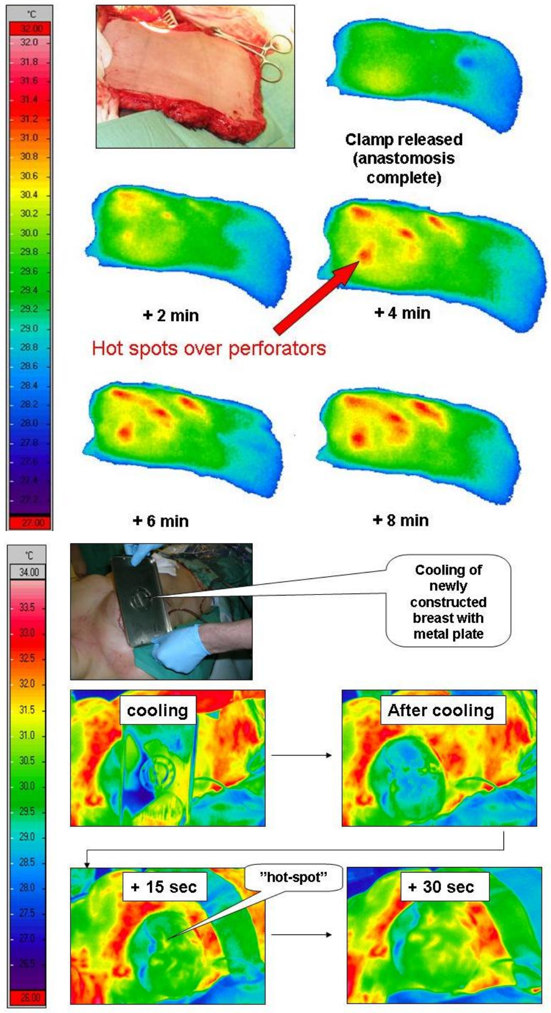

Fig. 4 - Top Panel: A series of IR thermal images illustrating rewarming of a free DIEP flap following the successful completion of the microsurgical anastomotic procedure. Note the rapid appearance of hot spots.

Bottom Panel: Final test at end of surgery. Cooling of the newly modeled breast with a metal plate at room temperature. Rapid return of warm spots indicates adequate perfusion.

However, if such a problem is not diagnosed, partial or total flap failure will occur. Inadequate venous outflow (venous congestion) is also easily diagnosed and is characterized by a diffuse rewarming without a clear appearance of hot spots on the thermal images. By anastomosing a second vein of the flap to a recipient vein such as the cephalic vein a super drainage of the flap will be created.

Opening of this second venous route showed that in case of venous congestion, the diffuse pattern disappears and a pattern of hot spots appears. After the flap perfusion has been successfully re-established the flap is molded into new breast. We continuously monitor the flap with thermography during this procedure. This is important since the remodeling procedure involves physical manipulation of the flap which may compromise its newly established blood supply due to torsion or external compression of the blood vessels. The advantage of intraoperative use of DIRT is that perfusion problems can be identified rapidly and that corrective measures can be taken immediately during the same operation (18).

At various stages during the surgery we routinely check blood flow status by applying small cold challenges to the flap (DIRT). This is normally done by applying a metal plate at room temperature for 5-10 seconds against the skin. A similar result can also be obtained by washing the skin with using physiological saline at room temperature. Immediately after the washing the skin is quickly dried with a surgical compress to remove excess liquid. Either way, the rate and pattern of rewarming after these mild thermal challenges give the surgeon a clear indication of the perfusion status of the flap (Fig. 4. Bottom panel). It has become our standard to perform such a cold challenge at the end of each operation. In an experimental situation it has also been shown that thermography can provide valuable information on the perfusion of other types of flaps (20, 24).

The post-operative phase

Although post-operative complications are rare they may occur and DIRT is a very convenient way to monitor flap perfusion in the post-operative phase. Again simple cooling and recovery protocols, such as fan cooling can easily be used. In addition to carrying out such procedures to detect possible complications, post-operative monitoring has revealed some interesting facts on perfusion dynamics of DIEP flaps during the first week after the operation (7, 8). The thermal images show an improvement in perfusion during this period. Characteristically the number of the hot spots on the thermal images increases with time. In the first day we see hot spots confined to the skin area associated with the location of the selected perforator. During the following days hot spots appear in the neighbouring skin areas. Interestingly, there is initially a state of hyperaemia, which is most pronounced in the area of the hot spot related to the selected perforator. During the following days this hyperaemia disappears. Our results have shown that the perfusion of the DIEP flap during the first postoperative week is a dynamic process. This phenomenon can be explained by the angiosome concept (19). Initially the vascular territory belonging to the deep inferior epigastric system is optimally perfused through the selected perforator. During the following days neighbouring vascular territories become perfused after the interconnections, the so-called choke vessels, between these territories have opened. The perforators in the neighbouring vascular territories become now perfused and their associated hot spots become visible on the thermal images. With the increased perfusion of the neighbouring vascular territories, a redistribution of blood starts which may explain the disappearance of the hyperaemia. After about 6 days the entire flap is normally adequately perfused. Thermography can also help to optimize flap design as it has shown that it may identify areas that are inadequately perfused. These areas can then be removed before they cause complications (14, 20).

3. THE USE OF DIRT IN RECONSTRUCTIVE SURGERY FOLLOWING TRAUMA

Introduction

As mentioned before reconstructive plastic surgery also deals with the closure of defects and restoration of form and function after trauma. One of the challenges in reconstructive surgery after trauma is that there is often extensive tissue damage surrounding the defect. Such tissue damage may include damage to the blood vessels. It can be difficult to detect the extent of vessel damage and sometimes this can only be done intra-operatively. Thus a reconstructive procedure with either a pedicle flap or free flap for closure of a traumatic defect can be quite a challenge as the pedicled perforator flap and free perforator flap rely for their blood supply on the quality of the blood vessels surrounding the defect. The use of perforator flaps, either pedicled or free, is associated with a higher risk of flap failure compared to situations where the anatomy of the tissue surrounding the defect is intact.

The reverse sural artery (RSA) island flap

A typical example of where DIRT can be useful in trauma surgery is the treatment of soft tissue defects of the lower part of the tibia and dorsum of the foot. The reverse sural artery (RSA) island flap is commonly used to close such defects. The RSA flap is based on the vascular network that accompanies the sural nerve and is therefore classified as a neurovascular flap. The RSA flap is harvested from the posterior side of the leg with its base approximately 5 cm above the lateral malleolus and its axis along the sural nerve. This distally based flap receives its blood supply from a perforator that arises from the peroneal artery at the lateral distal third of the leg and that communicates with the vascular network accompanying the sural nerve. What is interesting here is that the direction of the blood flow in the flap is the reverse of normal. The flap relies entirely for it blood supply on the perforator of the peroneal artery after the flap has been transposed to the defect. It takes about 3 weeks for the vessels at the defect to make contact with the vessels of the flap. For cosmetic reasons it may be necessary to resect the skin bridge that connects the flap with the perforator. However, this can only take place after vessels at the defect have grown into the flap and contribute to the flaps' blood supply.

Hand and elbow traumas

In as similar way we have also used DIRT to treat traumatic defects of the hand and elbow where open wounds had to be covered with a free flap in the case of the hand injury and a pedicled flap in the case of the elbow injury. As the preferred recipient vessels were damaged by the trauma another recipient vessel had to be selected. DIRT provided important pre-surgical information on the quality of these other recipient vessels as well as providing the surgeon with important intra- and post-operative information on tissue perfusion.

4. CONCLUSION

In this short article we have shown that infrared thermography and specifically DIRT has a clear place in the battery of imaging technologies available in the 3 main phases of perforator flap surgery, namely the pre-operative, intra-operative and post-operative phases. Even though the technique only measures changes in skin surface temperature these simple thermal signals combined with a thorough knowledge of physiology and vascular anatomy provide plastic surgeons with a relative simple, non-invasive tool for real time indirect monitoring of skin blood perfusion. In our experience this technology can not only help in pre-surgery planning but also can help to reduce surgical time and post-operative complications by quickly detecting problems in skin blood perfusion, thereby allowing the surgeon to take appropriate corrective measures. Medical thermography has for many years been a recognized medical imaging technique (16) suitable for many areas of medicine and as these authors point out and as we have described in this article, it has a valuable place in plastic surgery.

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