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DIEP flap perforator mapping by infrared thermography: state of the art and research progression.

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Abstract

Dynamic infrared thermography (DIRT) has been used to locate perforating vessels and to assist in reconstructive breast surgery. Qualitative information on the perforating vessels is obtained by analyzing the rate and pattern of rewarming of hot spots which are easily registered with an infrared camera. Thermal measurements are made before and during surgery and are compared with the CT images available before operation. The thermal images can provide the individual influence of each perforator on the flap, as well as the dimensions of the perfused area. It will be investigated if the thermal image sequence locating the different dominant perforators will prove to be a useful tool for reconstructive DIEP-flap surgery.

1. Introduction

Breast cancer treatment still involves the removal of the breast in a number of cases. Reconstruction after breast amputation, preferable with autologous tissue, should always be discussed with the patient as part of the treatment. The reconstruction itself is a delicate operation because of the fragile blood supply. In some cases, the surgeon selects tissue for transplantation that does not fulfil the requirement concerning sufficient blood supply. This can result in flap failure and necrosis of the transplanted tissue. With the use of infrared thermography, the blood vessel distribution of the abdominal wall and its vascularization can be visualized. Based on the information of the pre-operative CT scan and the information of the thermography, a possible better selection of the perforators of the free flap can be performed, and also the design of the flap can be optimized based on the visualization of the vascularization of the perforators. The aim of this research is to check and visualize the blood flow in the flap by means of infrared thermography. The thermal images will help to decide which parts of the flap can or cannot be used for the DIEP flap reconstruction. Currently, the assessment of the perfusion of the flap is clinical. The necrosis is only identified visually in the post-operative phase, causing additional surgery to be performed. By making use of dynamic infrared thermography in the pre-operative phase but also during the reconstructive operation, it is our goal to identify the cause of necrosis and diminish all negative side-effects [1].

2. Measurements on DIEP flaps: Method

The camera used for the thermal measurements (Fig. 1) is a Xenics Gobi 640 microbolometer 640x480, NETD 30 mK, 50 Hz with 7.5-14 μm spectral range. This is an uncooled, long-wavelength microbolometer camera and is chosen because of its compact size, high image resolution, and precision at relatively low temperature-measurements [1]. The performed measurements during breast reconstruction with the used thermal camera deliver an image sequence (3D-matrix) with a frames measured at 6.25 Hz [1]. A frame rate of 6.25 Hz is used to clearly visualize the emerging hot spots. The format of the data set is a three-dimensional matrix $[m \times n \times o]$ with m pixels width, n pixels height and o frames. The measuring unit is Celsius. No absolute temperatures are measured, only temperature differences are displayed so calibration of the thermal camera is not necessary.

The measurements are divided into 3 sections: pre-, intra- and postoperative. Each section of a measurement has a different purpose, as shown in the list below [2].

- Preoperative : Pinpoint the exact location of the dominant perforators.
- Peroperative : Mapping the specific influence of each perforator on the abdominal flap regarding blood supply. As well as defining the perfused area of the flap after transplantation. Monitoring of perfusion after anastomosis and flap inset.
- Postoperative : Examining whether or not thermal images can give an early warning of vascularisation problems in order to avoid partial or complete necrosis (thrombosis).

Fig. 1. *Measurement setup to perform IR-thermography measurements on DIEP-flap.*

Preoperative Measurements: External cooling

The purpose of the preoperative measurement is to accurately determine the location of the dominant perforators. Therefore, an ideal thermal image for this section would be one with few but obvious hot spots. The reduction of the so-called 'fake hot spots' is critical for the accuracy of this method. 'Fake hot spots' are small areas where superficial blood vessels give the impression of an underlying perforator [1]. To obtain this ideal image, cooling was applied to make the hot spots narrower and to reduce the so-called 'fake hot spots'[3]. Further research has to be done to reduce the number of 'fake hot spots'.

The following criteria are involved when determining the most suitable perforators:

- Perforator has a well-developed branching pattern right after passing through the abdominal muscles and the fascia [4]. This usually ensures that the perforator perfuses enough tissue of the abdominal flap.
- The diameter of the perforator must be large enough. This ensures a sufficient flow of blood to perfuse a large enough area of the abdominal flap.

Peroperative Measurements

The peroperative measurements for mapping the influence of a specific perforator will determine which areas of the abdominal flap will be perfused by which dominant perforator (Fig. 4). This information can influence the choice of considered perforators. This, of course, in a situation where there are multiple perforators. The best-suited perforators can appear to have similar properties on the CTA, yet their heated areas of the abdominal flap will have a different surface area. The perforator that perfuses the largest part of the abdominal flap is most likely to be chosen for transplantation. Currently, the choice of what area of the abdominal flap is used for transplantation is a clinical evaluation based on the CTA images and the experience of the surgeon. As described by Hembd et al. up to 14,4 percent of the patients develops flap fat necrosis [5, 6]. Thus there is room for optimization in determining which part of the flap is well perfused through the selected perforator and which part of the flap is safe to use. The surgeons do not exactly and with certainty know the maximum surface area perfused by the chosen perforators when examining the CTA images [2]. Before transplantation, the best-suited perforator which perfuses most likely the largest part of the abdominal flap is chosen to be anastomosed. After anastomosis, the blood flow in the DIEP flap can be checked with DIRT to verify if the flap is properly vascularized to reduce the chance of necrosis.

Postoperative Measurements

One to two days after the surgery a dynamic measurement of the reconstructed breast after the introduction of a cold challenge are taken as can be seen in Figure 2. With those two measurements there is a possibility that the IR-camera can visualize potential necrotic area(s), due to arterial or venous thrombosis, before clinical observation [7]. Further research has to be done in the postoperative phase and is not further discussed in this article.

Post-processing

The peroperative measurements take place during several phases of the surgery. The surgeon needs instant feedback on the measurements of the DIEP flaps without obstructing the time window of the surgery. No real-time post-processing

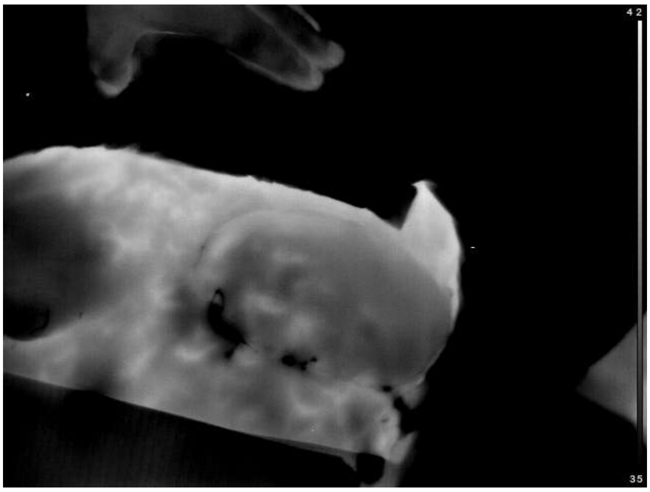


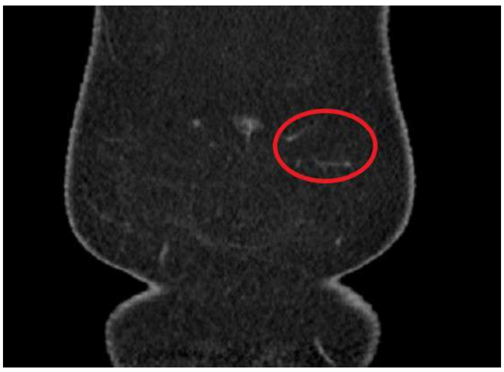
Fig. 2. *Postoperative image of the reconstructed breast one day after surgery. The IR-camera can visualize potential necrosis.*

for determining hot spots and perforators has been tested yet as discussed further in this article. The realtime acquired image sequence is visualized with the "Xeneth64" software delivered by the manufacturer of the IR-camera Xenics Gobi 640 microbolometer 640x480. The chosen color profile is "16-bit grayscale", the temperature scale as well as the range to histogram thresholds has been adjusted to fit the measured temperatures and data.

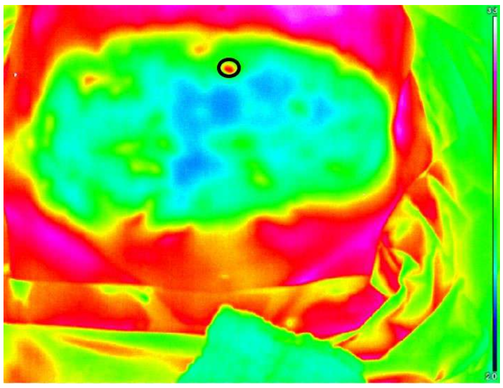
3. Results and Discussion

Preoperative Measurements

Perforators A1 and A2 on the left (anatomical right) side in Figure 3 originate from the same pedicle and could potentially be used together when sacrificing the muscle. Both emerge from the deep inferior epigastric artery and vein. They can be used together to vascularize the DIEP flap but means that the surgeon has to sacrifice a part of the muscle. These two perforators can be correlated with 2 hot spots in Figure 3. Namely, the upper hot spot just above the umbilicus and the lowest hot spot. Perforator B on the right side swiftly splits into 2 branches and curves sharply to the anatomical left side as seen in Figure 3. This matches with the thermal image after 4 minutes of rewarming, Figure 3(b). Eventually, perforator B was chosen for its well-developed branching pattern and therefore its large perfused area.



(a) *Visualization of perforator B on CTA image*



(b) *Perforator B after 4 minutes of rewarming.*

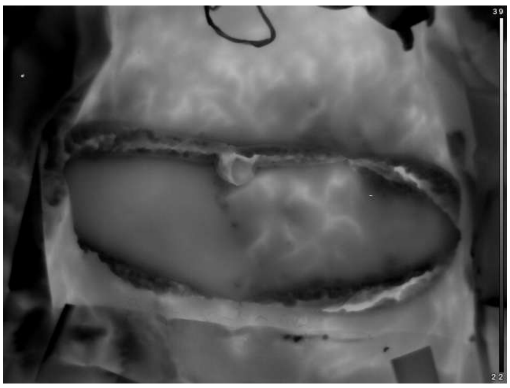
Fig. 3. *Preoperative measurement. The cooling was done with a plastic bag filled with ice and water.*

Peroperative Measurements with Hemostatic Clamps

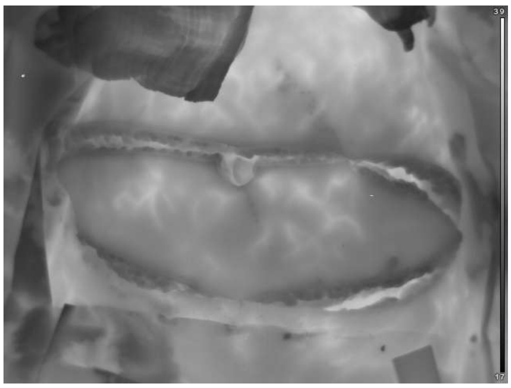
After dissection of the DIEP flap with the perforators still connected, blood flow can be controlled in the different parts of the flap by closing and opening perforators with the help of hemostatic clamps. In Figure 4 the region vascularized by A is clearly noticeable. At time stamp zero, perforator A is opened and the evolution is tracked for 5 minutes. It can be noticed that the bottom part of the flap cools down, the top and middle part of the flap is vascularized by perforator A and the temperature increased and stabilized.

Fig. 4. *Thermal measurements with left flap in rest and perforator A open*

In a different case, Figure 5b, when the clamps on perforator A and B are removed and steady-state conditions are achieved after 4 minutes, it can be seen that both perforators together vascularize the flap well. When perforator B is opened while keeping perforator A closed, one can notice the region that is perfused by perforator B. The effect of opening a perforator can clearly be visualized by looking at the thermal measurement at different moments in time. It becomes possible to distinguish the colder from the warmer areas on the abdominal flap. The warmer areas indicate blood perfusion and thus a minimal chance of necrosis after transplantation. It now becomes possible to paste red lines onto the steady-state images which will mark the separation line between the warmer and the colder areas caused by the chosen connected perforator. However, defining the well-perfused area has to be done by analysing the reheating process over the ca. 5 minutes following the clamp removal after the anastomosis has been completed. This will ensure that the visualised temperature difference on the thermal images is solely produced by the reintroduction of warm blood. Only a steady-state image will be able to indicate the different surface areas. This is because of the conductive heating of the flap by perfusion. These thermal images could help the surgeon to decide which parts of the abdominal flap to use for the actual reconstruction of the breast.



(a) *Thermal measurements with left flap in rest and perforator B open*



(b) *Perforator A and B ca. 4 minutes after the clamp was removed.*

Fig. 5. *Peroperative Measurements with hemostatic clamps*

4. Initial results and future application

From the presented results of this study based on 33 flaps [8], one can conclude that infrared thermography offers extra information on the location of the perforators and its vascularization pattern. In the future, DIRT can be a promising alternative to CTA for preoperative perforator mapping in DIEP flap breast reconstruction. In this pilot study, the enhanced preoperative measurement results are obtained using our standardized measurement setup [1] are in accordance with the published results by De Weerd et al. [9]. However, in this initial study, particular emphasis is placed on peroperative measurements with our improved and standardized measurement setup during surgery. The measurements are interesting and deliver promising results to assist the surgeon. A large clinical study is needed in order to reveal how far one can go with infrared thermography for identifying perforators in an accurate manner. Also, during surgery, IR thermography can identify which zone of the free flap is to be used for the reconstruction, depending on the level of bleed through the flap.

The correlation between the best-suited perforators and hot spots should be determined as well as the correlation between the hot spots on the thermal images and the perforator locations seen on the CTA images. Additionally, Infrared Thermography clearly visualizes the perforators which have the largest perfusion area. A large supply of blood is only one of the main criteria used when determining the best-suitable perforators for transplantation. Perforators which have an extremely well-developed branching pattern may be invisible right after the cooling is removed, however, they will start to re-appear in the moments following the removal of the cold challenge.

The applied techniques can be used to determine the location of the dominant perforators. A prominent hot spot does not always equal to a dominant perforator. Furthermore, it is impossible to pinpoint the exact location of where the perforator passes through the fascia. This is due to the anatomy of the perforators and the fact that thermal cameras only measure the superficial temperatures. There is an inseparable link between the depth of the perforator and its visibility on thermal images because these measurements are superficial. The deeper parts of the perforator, when the perforator doesn't go straight up, will have to warm up more abdominal tissue before they become visible on the thermal images.

It becomes obvious that the heat development of the hot spots over a certain time is a determining factor. As well as the expansion rate of the warmed-up surface area with the hot spot as the source. Therefore, the image right after the removal of cooling does not represent the entire result of the test. In most cases, a static comparison between the images, taken a certain time apart, will not be sufficient to determine the most dominant perforator(s). Consequently, a need for dynamic analysis of the series of images arises. Through post-processing, the visualization of the data can be optimized and compressed. This allows easy analysis and use of the measured thermal images by non-experts in the field of thermography.

The mapping of the influence of the different dominant perforators over a set time (5 minutes) has proven to be a useful tool. The thermal images provide the individual influence of each perforator on the flap, as well as the dimensions of the perfused area. This additional information is an asset when determining the best-suited perforator(s) for transplantation. The visual separation between the warmer, perfused area and the colder area can visualize the sections that will possibly develop necrosis just by analysing a 5-minute measurement. This easy, non-invasive technique can minimise the chances of partial necrosis. In conclusion, the non-invasive thermal measurements provide the surgeon with real-time visualization of the considered perforators and their influence on the flap. This additional information can definitely optimize the choices made regarding the selection of the best-suitable perforator and the determination of the maximal perfused area of the flap.

5. Conclusions

Dynamic infrared thermography (DIRT) has been used to locate perforating vessels and to assist in reconstructive breast surgery. Qualitative information on the perforating vessels is obtained by analyzing the rate and pattern of rewarming of hot spots which are easily registered with an infrared camera. The thermal images provide the individual influence of each perforator on the flap, as well as the dimensions of the perfused area. This additional information is an asset when determining the best-suited perforator(s) for transplantation. The thermal measurements provide the surgeon with real-time visualization of the considered perforators and their influence on the flap. This additional information can definitely optimize the choices made regarding the selection of the best-suitable perforator and the determination of the maximal perfused area of the flap. In the majority of the measured cases of unilateral reconstruction, the selected perforator had the largest perfused area of the two remaining perforators. The visual separation between the warmer, perfused area and the colder area can visualize the sections that will possibly develop necrosis just by analyzing the infrared imaging sequence.

Acknowledgments

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. Ethical approval has been obtained from ethics committee. Belgian registration: B300201941125

Disclosures

The authors declare no conflicts of interest.

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