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Thermal sequences database of the skin flaps in breast reconstruction and burns

Abstract

This paper presents a database of Active Dynamic Thermography (ADT) thermal sequences gathered throughout 6 year study on ADT application in skin flap blood perfusion monitoring and burn wounds diagnosis. For skin flap monitoring the database comprises of data collected during three different breast reconstruction procedures. The patients were monitored pre, intra and post surgically within 90 days period. The sequences were used in skin flap parametric imaging aimed at reducing complications and improving flap perfusion. For burns investigation patients were monitored following an accident, at the 3-rd day and 21 days after.

Keywords: thermography, active dynamic thermography, burns, breast reconstruction, image database.

1. Introduction

A transverse rectus abdominis muscle (TRAM) flap is a type of breast reconstruction in which blood vessels remain connected to the skin and fat tissue of the skin flap. The flap is removed from the lower abdomen and transferred to the chest to reconstruct a breast being still connected to the abdomen muscle. It is a common technique among women who underwent mastectomy. To guarantee a successful reconstruction a surgeon must carefully select the area of the flap that will be transferred to the chest making sure to keep the best perfused part. Otherwise patient is very likely to develop post-surgery necrosis [1, 2, 3, 4].

In TRAM flap breast reconstruction there are no objective and non-invasive methods that would help the surgeon in selecting proper flap area for the procedure. Some guidelines were defined by Hartrampf [5] where the flap area is divided into four zones. The central zones I and II are considered to be the best for reconstruction, while zones III and IV are more likely to develop post-surgery necrosis (flap zones are shown in Fig 1.) Unfortunately the clinical practice often differs from theory and often it is very difficult to determine which area of the flap has the best blood perfusion [6, 7].

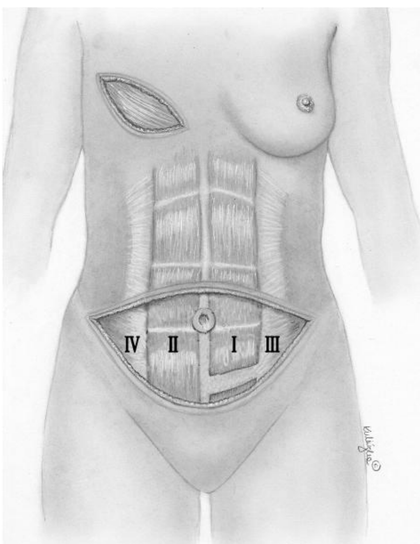


Fig. 1. Classical DIEP flap partition into four zones (I, II,III and IV) according to Hartrampf in IPSI reconstruction [1, 6]

Among methods that are used in skin flap perfusion monitoring there are: indocyane green dye, angio CT and others [8, 9, 10]. Unfortunately they do not meet the requirement for non-invasiveness. The only exception is Laser Doppler Imaging unfortunately is not commonly available due to its costs [11]. In our opinion Active Dynamic Thermography (ADT) could fill that gap as it provides the possibility of monitoring thermal processes that are induced by metabolic activity and blood perfusion. High rates of metabolic and blood perfusion activity determine the perfect donor area of the flap.

ADT utilizes cold or hot stress which forces energy exchange within the volume of the tissue [12]. It originates from different modalities of dynamic thermography, especially pulse thermography [13, 14]. The diagnostic information is usually extracted form raw ADT data via parametric imaging which transforms the time series of surface temperature measurements usually into a set of two to five parametric images, examples of which are shown in Figure 2 - Simplified Magnitude-Temporal Parametrization (SMTP). Such technique was examined in burn wound imaging [15, 16, 17], cardiosurgery wound healing [18] or in skin flap blood perfusion monitoring [6, 10, 19, 20] and others [21, 22, 23].

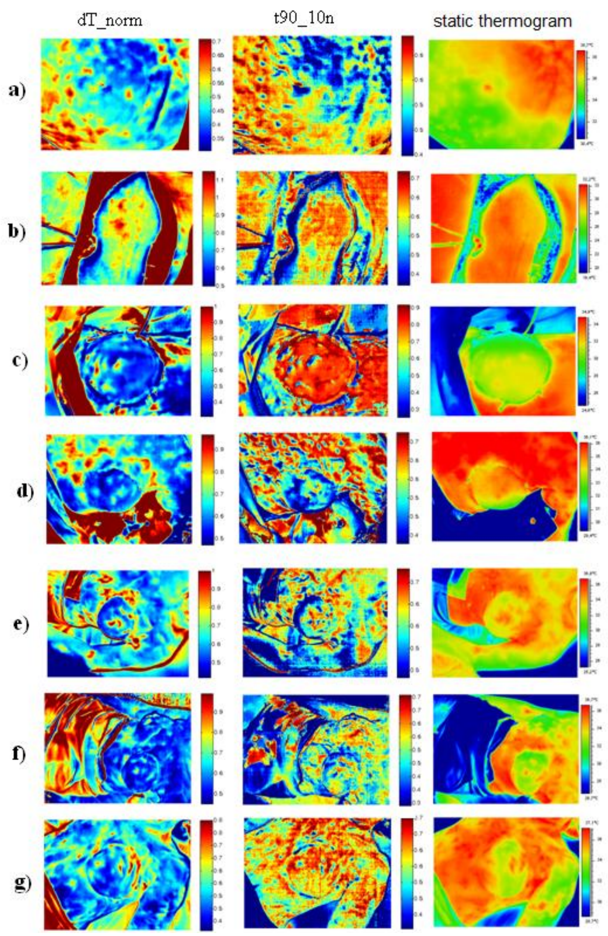


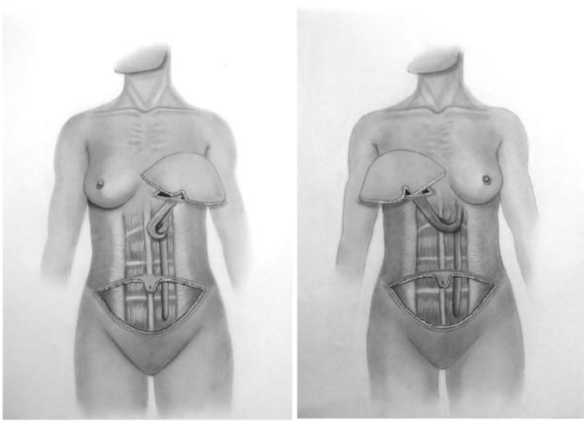
Fig. 2. An example of ADT parametric imaging using SMTP parametrization [19, 20]

Throughout years, in response to feedback from scientists all over the world asking to share the results of our ADT experiments we decided to create database consisting of thermal sequences we collected during our research. We believe that sharing the results could help to invent other thermal transient analysis methods that would potentially helpful not only in monitoring blood perfusion of skin flaps but also other applications of ADT functional imaging.

2. Breast reconstruction methods

To describe the issue of application of ADT in skin flap monitoring there are three important things that need to be addressed:
- the surgical plastic reconstruction of the breast using three different techniques: IPSI, CONTRA and microsurgery,
- the procedure of ADT experiment concerning stimulating examined tissue with cold or hot stimulus,
- the post processing of the collected temporal data and its parametrization.

At first the database is divided according to the three different breast reconstruction techniques utilizing the DIEP flap (Deep Inferior Epigastric Perforators). That is: IPSI, CONTRA and microsurgery technique [6]:
- IPSI is the technique where the flap with its rectus abdominis muscle which blood vessels supply the flap in blood are located on the same side of the body as the reconstructed breast. It is shown in the left section of Figure 3.
- CONTRA involves the rectus abdominis muscle that is located on the contralateral side of the body to its destination (shown in the right section of Fig. 3).
- Microsurgery utilizes additional blood vessel coupling using microsurgery techniques: the flap is connected to blood vessels that run in patient chest. Such operation improves flap reperfusion and reduces risk of developing partial necrosis.



a) b)

Fig. 3. Illustration the idea of IPSI (a) and Contra (b) flap replacement [6]

3. Image acquisition and processing

Image acquisition of the skin flaps in breast reconstruction

In our experiments, we were using FLIR A320 thermal cameras to record the flap temperature change [24]. The frame rate was set to 1 frame per second. Thermal processes inside tissues are relatively slow, and a frequency of 1 Hz is sufficient to analyze this type of physiological phenomenon, such as heat transport through blood. The distance between the thermal camera and the body region of interest (ROI) was 1 meter. A standard FLIR sequence file format (*.seq) was used.

Thermal excitation was performed either by modified Titan Cool TC 21 air conditioner device in the case of flap cooling or by the set of 1000 W halogen lamps in the case of flap heating [6, 19]. In the particular experiments we used 60 s of tissue cooling/heating time and 180 s of temperature natural return phase. In Fig. 4 typical temperature transients in ADT cooling and ADT heating procedure are presented.

The sequences were recorded in seven different time moments during five different days in the reconstruction period: before, during and after the plastic breast reconstruction procedure:
- three experiments during the day of breast reconstructions (D0 folder):
  - before the procedure,
  - during the procedure of the elevated skin flap,
  - immediately after the flap transplant,

and consequently:
  - 24 h after the procedure (D1),
  - 7 days (D7),
  - 30 days after the procedure (D30),
  - 90 days after the procedure (D90).

Image acquisition of the skin burns

Data in form of static thermography (TS), the active dynamic thermography (ADT) and visible light photo are collected for each patient for assessing the depth of burn.

All static thermography sequences (ST, without external stimulus) were recorded with 60 Hz frame frequency and lasting 15 seconds. The ADT sequences lasting 240 seconds are divided for forced cooling phase (60 seconds, during external stimulus by cryogenic device) and natural heating phase (180 seconds), recorded with 30 Hz frame frequency.

Thermal processes inside the tissues are relatively slow and we don't need such high acquisition frequencies (60 or 30 Hz). But it allows for an advanced image processing and developing algorithms for super resolution images reconstruction, etc.

For quantitative evaluation, the natural recovery phase is analyzed and data are fitted to two exponential model. It is possible to calculate the values of all four parameters: ΔT_1, ΔT_2, τ_1 and τ_2 and form the four parametric pictures. The fifth parameter is taken from ST recordings. Normally, time constants are about 5 to even 60 seconds.

Static temperatures and calculated time constants τ_i obtained for normal tissue differ significantly between the control group of patients according to differences in their metabolism, blood circulation, fat tissue thickness etc. To remove this unwanted variability and obtain uniform data for comparison, a new parameter was introduced: - the normalized time constant τ_{i_n} which is described by equation $\tau_{i\_n} = \frac{\tau_i - \tau_{ref}}{\tau_i + \tau_{ref}}$, where: τ_i – is the time constant for *i*-th pixel in the parametric image, τ_{ref} – is the averaged time constant for healthy (not burned) tissue chosen in a reference region.

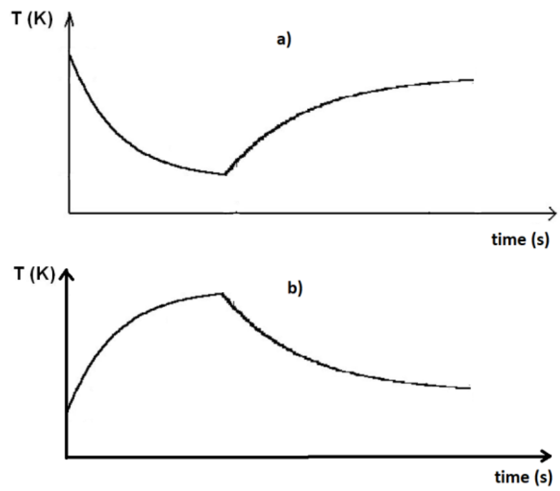


Fig. 4. a) Temperature transient in ADT with cooling, b) with heating stimulus

So, the normalized time constant τ_{i_n} range from <–1; 1> and is dimensionless.

4. Data base structure

Database of the skin flaps in breast reconstruction

The resulting folder structure of the database is presented for all types of reconstruction in Figure 5. In total 42 patients were examined: 11 Contra, 11 IPSI and 20 microsurgery patients. Considering seven observation periods and two types of thermal excitation used gives in total 588 thermal sequences.

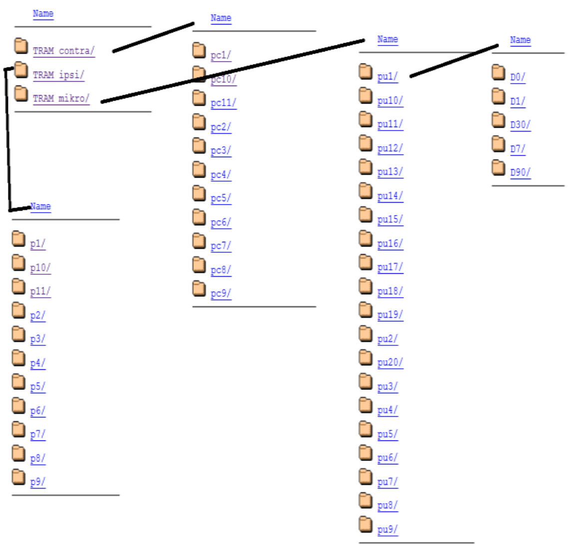


Fig. 5. Folder structure of database and its contents; TRAM contra – contra patients, TRAM ipsi – ipsi patients and TRAM micro – microsurgery patients

Burns investigation database

We have also the thermographic sequences from burn wound diagnostics projects [15, 16, 17] collected and structured as a database. The nature of heat flow in tissues is similar to this described in previous sections. The natural heating process is as presented in Fig 4a, and could be fitted into two exponential thermal model characterized by time constants parameters. An example of burn investigation is presented in Fig. 6: Data are collected at the day zero (accident day, burn start), then at third day following the accident and the last after 21 days of treatment.

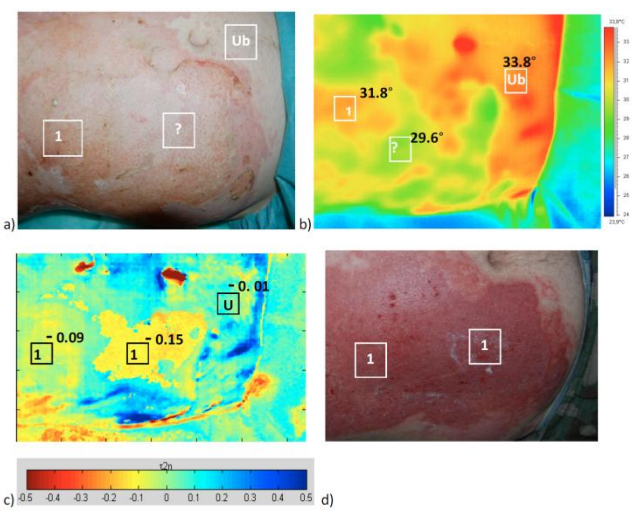


Fig. 6. The result of a clinical study of burns of 19 year old man hot oil on the second day after the burn; a) photo b) static thermogram, c) parametric image τ_{2n}, d) image after 3 weeks of conservative treatment

All cases are described post-treatment by physicians and many of them has the histopathological investigation; e.g. Fig. 6 case was 19 years old patient with abdomen burn injury. The histopathology of the biopsy specimen taken in the center of the undetermined burn area was 50.4% dtms. This result means that this part of the wound should heal within 3 weeks. Meaning the marks on the images: Ub – unburned skin, 1 = superficial burn which will heal within 3 weeks, ? = undetermined burn. On the corresponding ADT images: mean value of τ_{2n} in Ub area was -0.01. In the area diagnosed as superficial burn tau was –0.09. Mean value for the undetermined area was –0.15. The threshold was calculated as value equal 0.000113, thus, both the analyzed areas "1" and "?" value of τ_{2n} lie below the threshold value, therefore, belong to the class of wounds that will to heal within three weeks of conservative treatment. The last photo shows healing result - photograph taken 3 weeks after burn. The undetermined in visual inspection part of the wound was accurately diagnosed by means of ADT method. The whole abdomen area was healed in 3 weeks.

We collected over 20 clinical cases of burn wounds at different location: abdomen, legs, arms, hands. It is database with over 120 thermal sequences and thousands of thermal images of burn wound and reference healthy region around the wound.

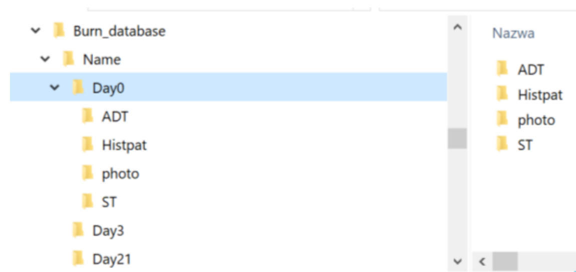


Fig. 7. Folder structure of database and its contents

5. Conclusions

We hope that the information we provide will result in developing new diagnostic methods based on ADT imaging. If you find the data contained in the database useful please consider referencing our work related to this topic that is enlisted in the reference list of this paper.

Anyone who is interested in accessing the thermal sequences is asked to send an inquiry at: matmod@biomed.eti.pg.gda.pl or mariusz.kaczmarek@eti.pg.edu.pl.

In future we plan to extend the database to other research projects: e.g. cardiosurgery wound healing [18] and oncological and scars thermograms. In cooperation with the Clinic of Cardiac Surgery, Medical University of Gdansk we proposed to use the techniques of infrared imaging for intraoperative monitoring in cardiac surgery mainly in by-pass procedures. To learn more details about the research that is contained in the discussed topic of plastic breast reconstruction please refer to our work [6, 19, 20]. Additional information in the field of ADT can be found in [12, 13, 14].

We also plan to make improvements on providing web browser interface enabling automatic user registration and providing access to the database.

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