UNDERSTANDING OF THERMAL DATA FOR IMPROVED MEDICAL DIAGNOSTICS

Antoni Nowakowski

Department of Biomedical Engineering
Gdansk University of Technology
Ul. Narutowicza 11/12, 80-952 Gdańsk, POLAND
antowak@biomed.eti.pg.gda.pl

1. Introduction
2. Diagnostic importance of thermal data
3. Active Dynamic Thermal Imaging
4. Medical applications of thermal diagnostics
   - skin burn diagnostics
   - monitoring of cardiosurgery interventions
   - thermal mammography
5. Conclusions

Illustrations based on research performed at the Department of Biomedical Engineering GUT in cooperation with the Department of Animal Physiology, University of Gdansk and several clinics of Gdansk Medical University

The aim of this talk is discussion of thermal tissue properties as diagnostic figures of merit allowing quantitative analysis in some of medical applications!

In general IR-TI (IR-Infra-Red Thermal Imaging; *Quantitative IR Thermography*) allows discrimination of internal structure of a tested object basing either on specific differences of temperature (IR static imaging - functional imaging) or determination of tissue thermal properties, based on analysis of dynamic processes following thermal excitation (Active Dynamic Thermography - structural imaging - ADT).

1. Knowledge of tissue thermal properties is limited. Use of thermal tissue properties (data given in literature or in a few existing databases) should be including specific conditions of data acquisition, what usually is impossible as this information is lacking.

2. Proper interpretation of thermal data requires construction of models but knowledge what boundary conditions should be assumed in thermal modelling of living organisms is not easy to be determined.

Therefore interpretation of thermal processes, based on analysis of dynamic processes following thermal excitation requires deep understanding of thermal flows in tested tissues.

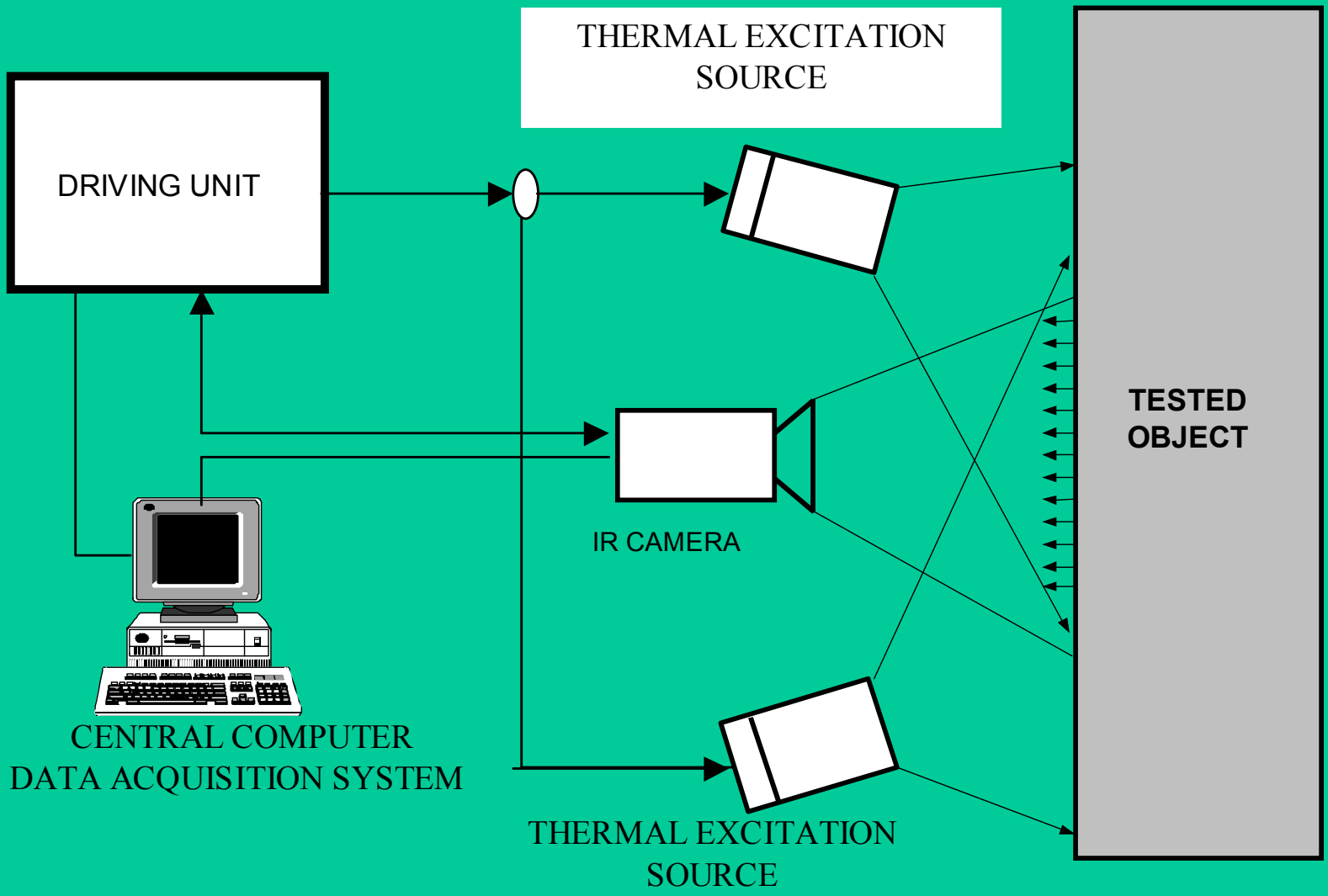
IR & ADT PROCEDURES

• Data acquisition of temperature distribution at the surface of a tested object and segmentation of images with specific value of temperature threshold - for years present in medical diagnostics.

• Different IR NDT (Lock-in; Pulsed Phase, Pulse & FFT).

• For medical diagnostics single pulse excitation and IR Imaging of thermal transients. In Active Dynamic Thermography visualization of synthetic data - time constants (in relation to equivalent tissue model!)

• Thermal Tomography - direct determination of internal structure of the thermal model which is strongly correlated to anatomy.



IR camera synchronised with an excitation source (in the experiment this was a set of halogen lamps) allows the surface temperature to be recorded at a speed of 30 frames/second. Changes in this temperature are caused by the external heating and are dependent on the internal structure of the object tested.

Excitation sources:

heating

• *optical, halogen and IR lamps + most frequent use due to handy & aseptic application!*

• lasers - difficult problem of surface excitation!

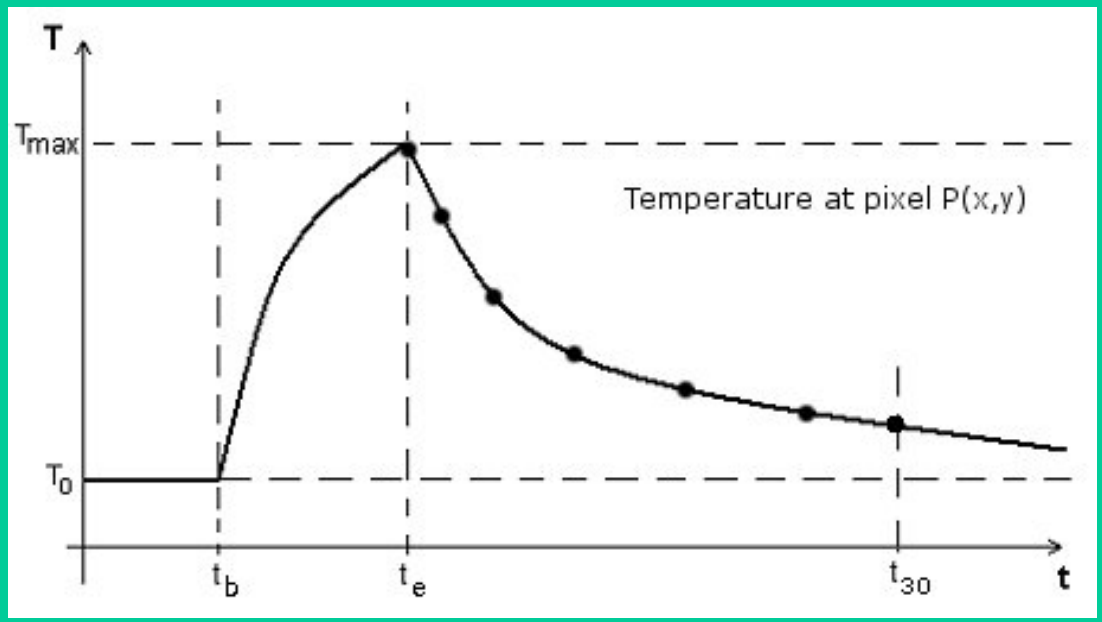
• microwave sources - difficult problem of energy distribution!

• air fan heating - control of temperature, speed and spatial distribution; only mechanical switching on & off!

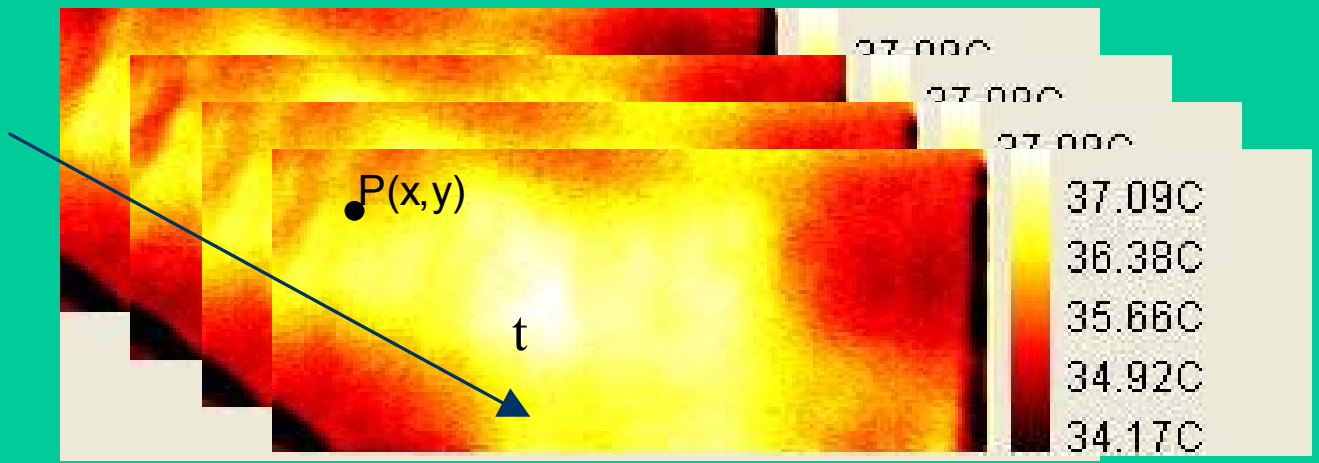
cooling

• *air fan cooling + very attractive for living organisms due to safe and relatively strong signal generation!*

• ice & water & thermal gels - very difficult quantitative control of energy exchange!

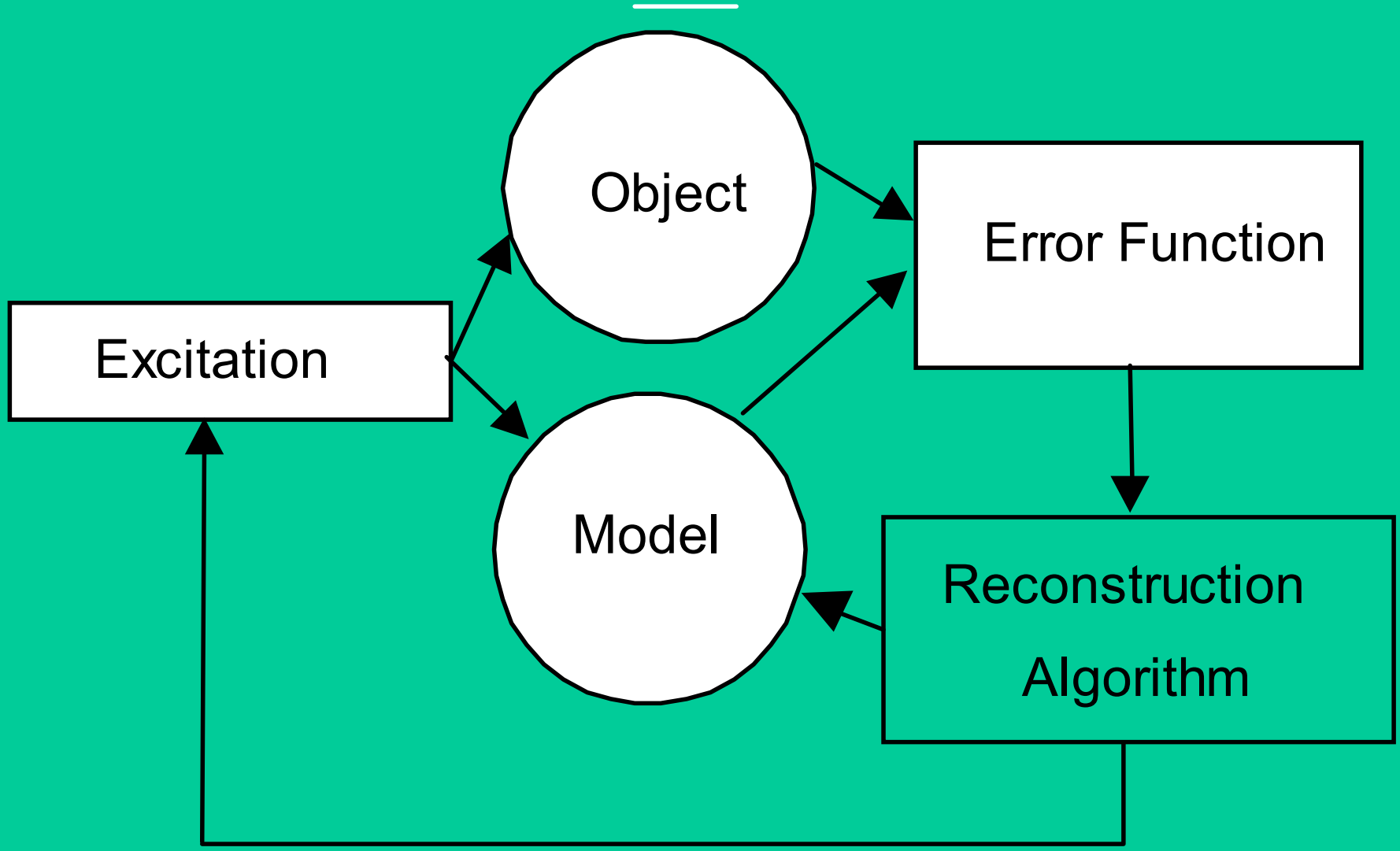


Optical heating & registration of thermal transients at the cooling period



Measurement procedure – **A)** course of temperature at the pixel *x,y* in time; $t_{b/e}$ – moments at which the heating source is switched *on* (beginning) and *off* (end) respectively, t_{30} – time of termination of the recording; **B)** thermogram showing temperature distribution at the surface;

Determination of model parameters, based on comparison of measurement and simulation data (T**hermal Tomography**)



Basic thermal Figures of Merit:

k – thermal conductivity - [$W \cdot m^{-1}K^{-1}$], it describes ability of a material (tissue) to conduct heat in the steady state conditions;

c_p – specific heat - [$J/(kg \cdot K)$], describes ability of a material to store the heat energy. It is described by the amount of heat energy necessary to rise the temperature of a unit mass by 1 K;

ρ - density of material – [kg/m^3];

$\rho\, c_p$ – volumetric specific heat - [$J/(m^3K)$];

α - thermal diffusivity - [m^2/s]; is defined by

$$\alpha = \frac{k}{\rho \cdot c_p}$$

Volumetric specific heat and thermal conductivity are responsible for thermal transients described by the equation

$$\frac{\partial T}{\partial t} = \alpha \cdot \nabla^2 T$$

For one directional heat flow (the case of uniform layer infinite plate structures) this may be rewritten as:

$$\frac{\partial T}{\partial t} = \frac{k}{\rho \cdot c_p} \cdot \frac{\partial^2 T}{\partial x^2} \quad .$$

Thermal diffusivity describes heat flow and is equivalent to the reciprocal of the time constant τ describing the electrical RC circuit:

$$\alpha = \frac{k}{\rho \cdot c_p} \quad \leftrightarrow \quad \frac{1}{\tau} = \frac{1}{RC} \quad .$$

Basing on this analogy materials are frequently described by equivalent thermal model composed of thermal resistivity R_{th} and thermal capacity C_{th}, which are responsible for the value of the thermal time constant, $\tau_{th,}$

$$\tau_{th} = R_{th} C_{th.}$$

Determination of τ_{th} is easy basing on measurements of thermal transients and using fitting procedures for determination of the applied model parameters.

Additionally one may define **thermal inertia** as

$$k \cdot \rho \cdot c_p$$

Most frequently this is represented as **thermal effusivity** β - the root-square of the thermal inertia given by - [J/(m^2·K·s$^{1/2}$)] or [W·s$^{1/2}$/(m^2·K)].

$$\beta^2 = k \cdot \rho \cdot c_p$$

Heat flow equation

$$div(k \cdot gradT) - c_p \rho \frac{\partial T}{\partial t} = -q(P,t),$$

Pennes equation

$$c_p \rho \frac{\partial T(x,y,z,t)}{\partial t} = k\nabla^2 T(x,y,z,t) + Q_b + Q_m + Q_z$$

Numerical solutions

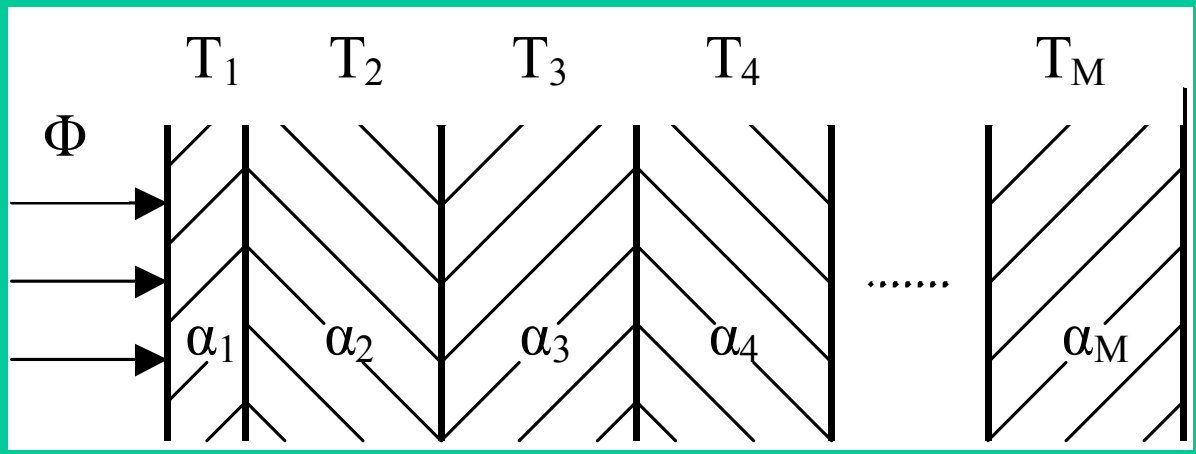
explicit forms

$$T_n^{k+1} = \frac{\Delta t}{\rho c_p V_n}\left[\sum_m G_{nm} T_m^k + \left(\frac{\rho c_w V_n}{\Delta t} - \sum_m G_{nm} T_m^k\right) + q_n V_n\right]$$

implicit

$$T_n^{k+1} - T_n^k = \frac{\Delta t}{\rho c_p V_n}\left[\sum_m G_{nm}\left(T_m^{k+1} - T_n^k\right) + q_n V_n\right],$$

parameter	density	Thermal conductivity	specific heat	volum. spec.heat.	dyfusivity	effusivity
unit of measure	[kg/m^3]	[W/(m·K)]	[J/(kg·K)]	[J/(m^{3}K)]	[m^2/s]	[J/(m^{2}K·s$^{1/2}$)]
Symbol	ρ	k	c	ρ·c	α	β
SOFT TISSUES						
heart muscle	1060	0,49-0,56	3720	3,94·10^6	1,24-1,42·10^{-7}	1390-1490
skeletal muscle	1045	0,45-0,55	3750	3,92·10^6	1,15-1,4·10^{-7}	1330-1470
brain	1035	0,50-0,58	3650	3,78·10^6	1,32-1,54·10^{-7}	1375-1480
kidney	1050	0,51	3700	3,89·10^6	1,31·10^{-7}	1410
liver	1060	0,53	3500	3,71·10^6	1,27-1,43·10^{-7}	1320-1400
lung	1050	0,30-0,55	3100	3,26·10^6	0,92-1,69·10^{-7}	990-1340
eye	1020	0,59	4200	4,28·10^6	1,38·10^{-7}	1590
skin superficial layer	1150	0,27	3600	4,14·10^6	0,65·10^{-7}	1060
fat under skin	920	0,22	2600	2,39·10^6	0,92·10^{-7}	725
HARD TISSUES						
tuth - enamel	3000	0,9	720	2,16·10^6	4,17·10^{-7}	1400
tuth - dentine	2200	0,45	1300	2,86·10^6	1,57·10^{-7}	1130
cancellous bone	1990	0,4	1330	2,65·10^6	1,4-1,89·10^{-7}	990-1150
trabecular bone	1920	0,3	2100	4,03·10^6	0,92-1,26·10^{-7}	1220-1430
marrow	1000	0,22	2700	2,70·10^6	0,82·10^{-7}	770
FLUIDS						
blood; 44% HCT	1060	0,49	3600	3,82·10^6	1,28·10^{-7}	1370
plasma	1027	0,58	3900	4,01·10^6	1,45·10^{-7}	1520



Discrete model structure

$$\left.\begin{array}{c} T_0(x) \\ \alpha(x) \\ \Phi_{exc} \ or \ T_{exc} \\ k(0) \end{array}\right\} \Rightarrow T(x,t) \ or \ \Phi(x,t)$$

$$\left.\begin{array}{l} T_0(x) \\ \Phi_{exc} \\ T(0,t) \end{array}\right\} \Rightarrow k(x), \rho c(x)$$

General case of the reverse problem

$$\left.\begin{array}{c} T_0(x) \\ \Phi_{exc} \\ T(0,t) \\ [k(x), \rho c(x)]\big|_{x \le d} = [k_{rub}, \rho c_{rub}] \\ [k(x), \rho c(x)]\big|_{x > d} = [k_{air}, \rho c_{air}] \end{array}\right\} \Rightarrow d$$

Determination of geometry

$$F(D) = \sum_{p=1}^{P} (T_{dir}^{p}(D) - T_{meas}^{p})^2 \xrightarrow{D} \min$$

Goal function

$$\left.\begin{array}{c} T_m^1,\ m = 1..M \\ \Phi_{exc} \\ T_1^p,\ p = 1..P \\ [k_m, \rho c_m] = [k_{rub}, \rho c_{rub}], gdy\ I_m = 1 \\ [k_m, \rho c_m] = [k_{air}, \rho c_{air}], gdy\ I_m = 2 \end{array}\right\} \Rightarrow I_m, m = 1..M, I_m \in <1,2>$$

Reconstruction of two-layer structure

$$F([I_1..I_M]) = \sum_{p=1}^{P} (T_{dir}^p([I_1..I_M]) - T_{meas}^p)^2 \xrightarrow{D} \min$$

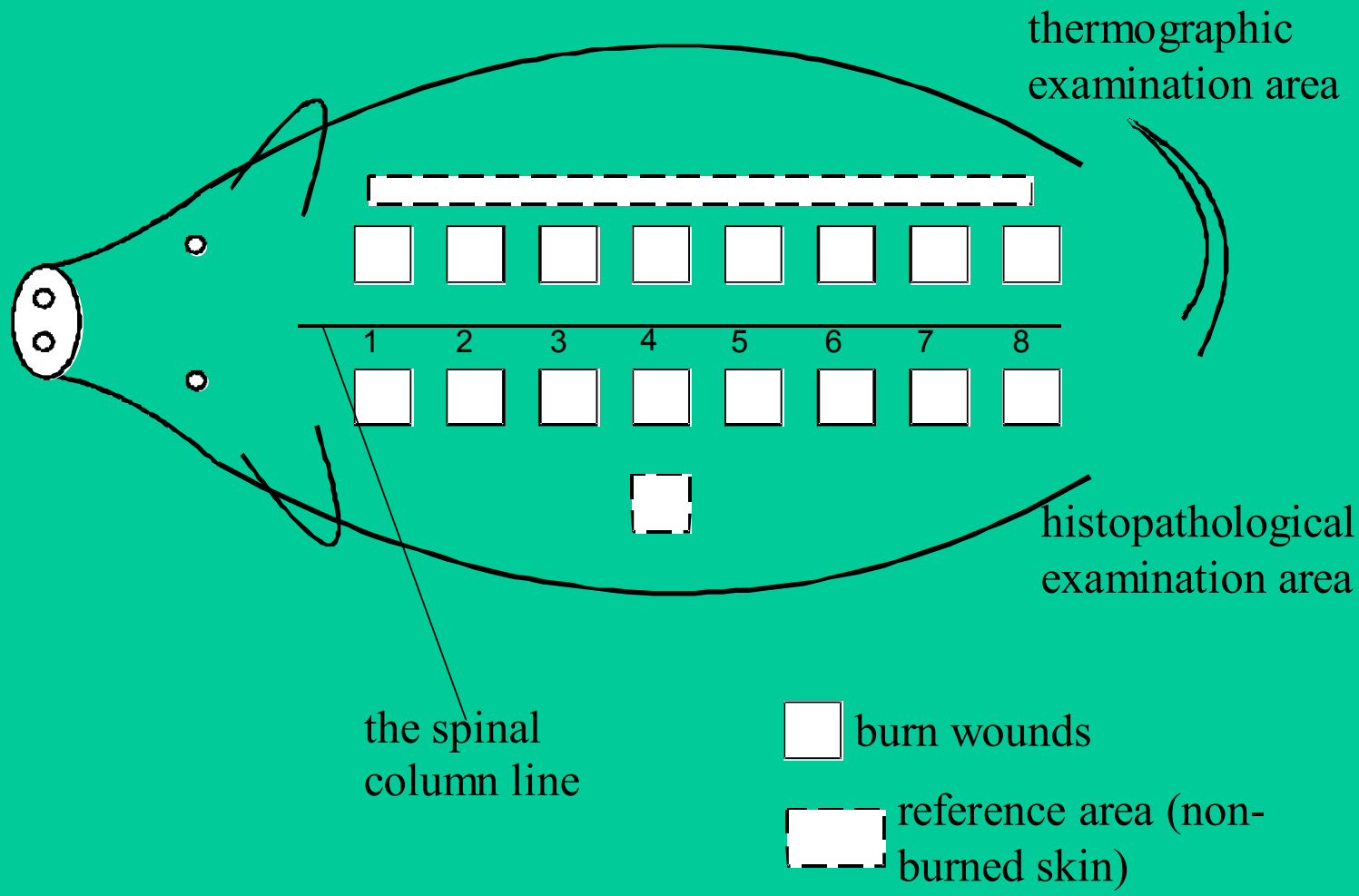
Goal function

QUANTITATIVE THERMAL METHODS IN BURN DEPTH EVALUATION STATIC IR-IMAGING AND ADT

Surgeons treating burns are of the opinion that conservative treatment should be applied to burn wounds that heal within three weeks of their occurrence, while surgery ought to be used for wounds that will not heal during this period.

Clinical estimation of burn wound depth, visual classification into 3 classes I^o, II^oa & b, III^o, is subject to numerous errors. A complementary, and perhaps objective, diagnostic method could therefore be of a great importance. Of the methods currently used in this field, the following are worth mentioning:

1. Thermography,
2. Laser Doppler imaging (LDI),
3. Indocyanine green (ICG) fluorescence,
4. Ultrasonography (USG),
5. Spectrophotometry,
6. Histopathologic examination of burn wound biopsies [the reference method!].



Positioning of the burned areas on the back of a pig. Symmetrical wounds for reference histopathologic examination and for thermographic observation are indicated.

Material and methods

The plan of the research was approved by the Local Ethics Commission for Experimentation on Animals at the Medical University of Gdansk, Poland. The experiments were conducted on 11 young domestic pigs, each weighing approximately 20 kg. The selection of the pig as an experimental animal was made in view of the high degree of functional similarity of the structure of pig skin to human skin.

The animals were subjected to burns while under anaesthesia and analgesia obtained by the administration of ketamine at a dose of 20 mg/kg of body weight intramuscularly, pentobarbital at a dose of 30-50 mg /kg and fentanyl at a dose of 0.05 – 0.1 mg/kg given intravenously. The animals were given fentanyl at the dose as above following the the infliction of burns and the securing of specimens for histopathologic examination. In the subsequent follow-up period of a few days there was no need to keep the animals on this agent. The general condition of the animals was good, they were fed in a natural way, and their daily gain in body weight was up to 0.5 kg.

Burn wound depth was assessed by determining the depth of damage to the following skin elements: hair follicle (epithelial cells), connective tissue collagen (a change in collagen staining), nerves and smooth muscles (mesenchymal cells) and blood vessels (endothelial cells). The depth was measured in millimetres starting from the epithelium basal layer.

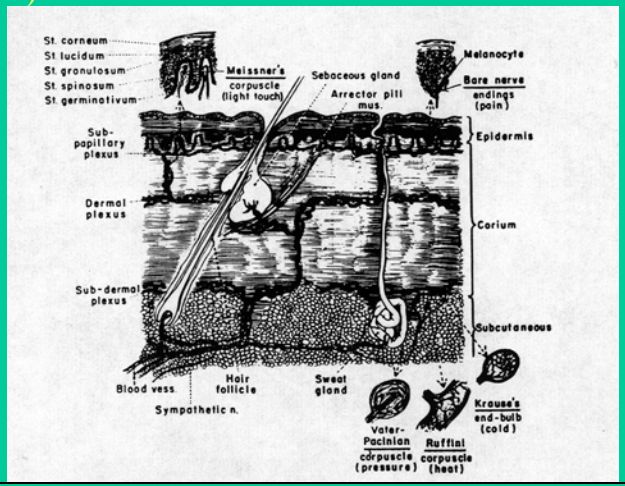
The results obtained were given as relative thickness, a percentage of the *dermis thickness at the measurement site* (*dtms*), and were subsequently used to calculate average values for all the elements undergoing assessment.

The epithelium was almost totally destroyed and therefore all the wounds were equally devoid of the insulation layer, which might have been responsible for the differences in *evaporation_water loss (ewl)* reported by Anselmo and Zawacki and therefore of some influence upon the surface temperature of the wound. No agents in the form of either jellies or protective membrane were used to prevent evaporation from the wound.

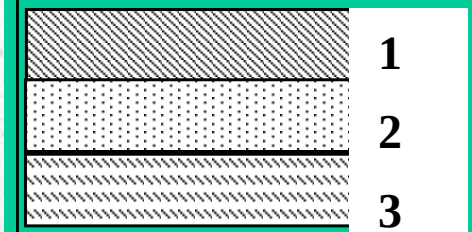
Structural model of the skin - each layer corresponds to the anatomy structure

a) Anatomy of the skin, b) three layer structural model, c) equivalent thermo-electric model

a)



b)

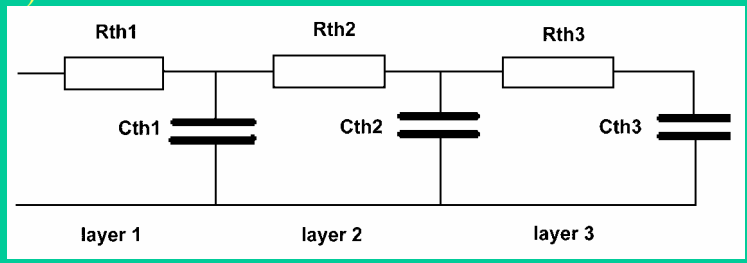


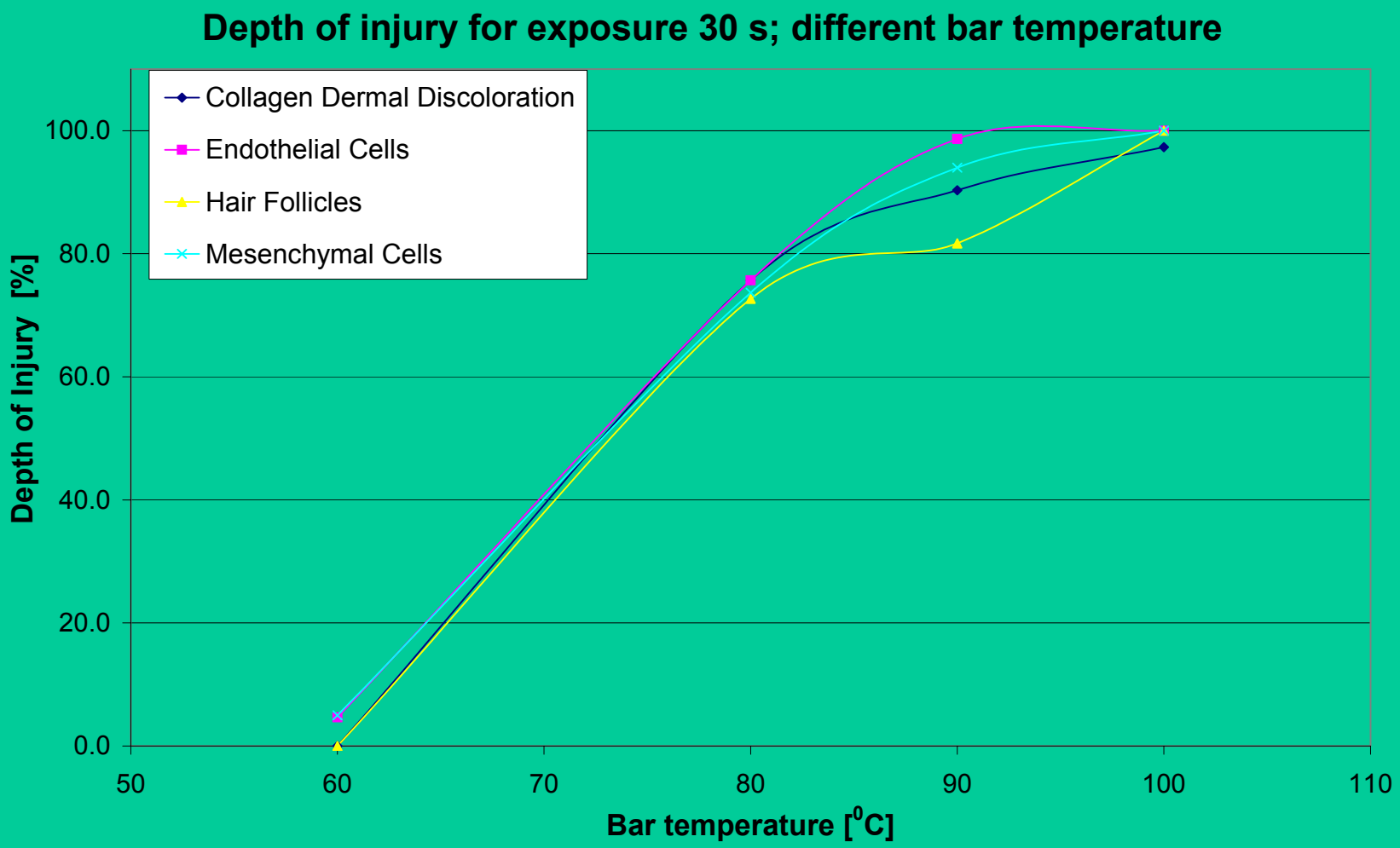
1 - Epidermis

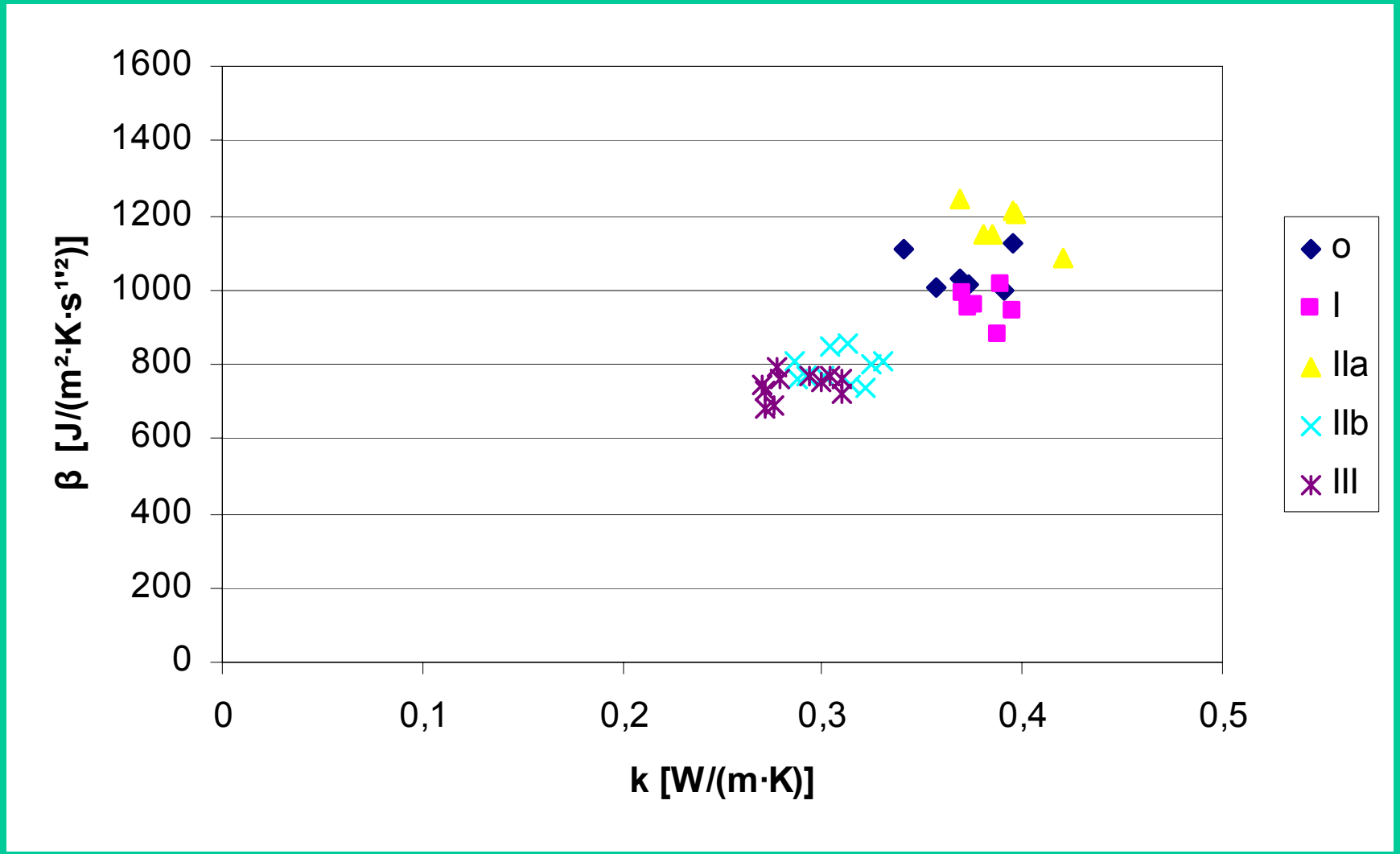
2 - Corium

3 - Subcutaneous

c)




Depth of injury for exposure 30 s; different bar temperature
Collagen Dermal Discoloration
Endothelial Cells
Hair Follicles
Mesenchymal Cells
Depth of Injury [%]
100.0
80.0
60.0
40.0
20.0
0.0
50
60
70
80
90
100
110
Bar temperature [0C]

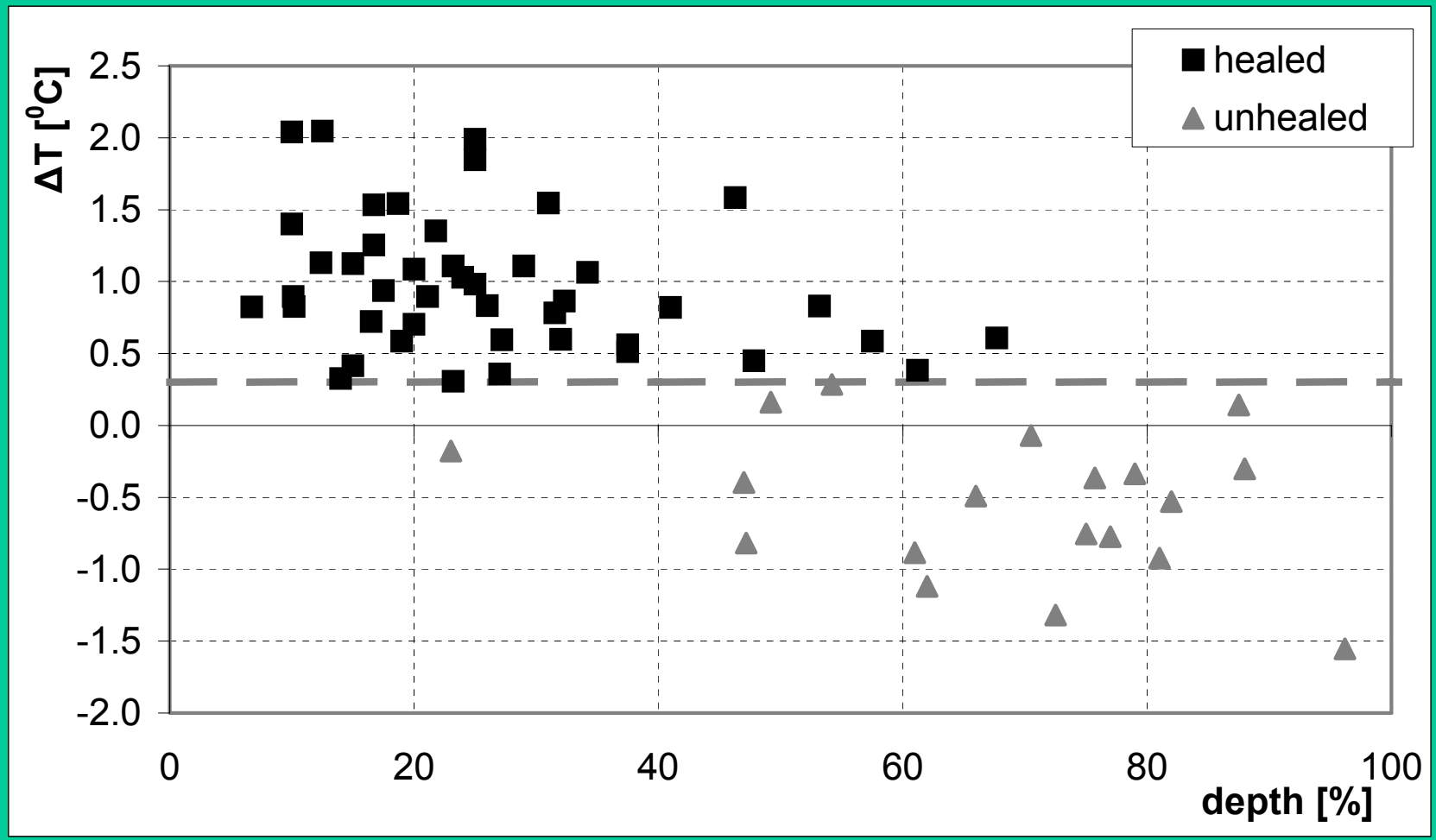


Thermal properties - conductivity and effusivity - of burned tissue

The ΔT was measured subsequently on days 1, 2, and 3 following wound infliction. The results obtained were subjected to statistical analysis by means of the ANOVA variance analysis method and by comparing the average *post-hoc* values with Turkey's RIR test to determine the *accuracy*, *sensitivity*, and *specificity* of the methods employed in the study. These quality parameters are defined as:

- *Accuracy* - the ratio of the sum of the cases with true positive and true negative results to the total number of cases;
- *Sensitivity* - the ratio of the number of cases with true positive results to the number of true positive results plus the number of true negative results;
- *Specificity* - the ratio of the number of true negative results to the number of true negative results plus the number of false positive results.

t



Distribution of values of average temperature differences ΔT of the healed and unhealed wounds classified according to histopathologic assessment.

In the light of the results it was proposed that the value of ΔT that marked off the "healed" from the "unhealed" burn wounds be taken as a criterion for choosing the mode of treatment. The value Δ T=0.3˚C was assumed as the classification threshold. Table summarises the parameters for the classification of the 64 burn wounds examined according to the clinical method, histopathologic assessment and the static thermography parameter ΔT for the healed and unhealed burn wounds.

Estimation of burn wound depth

	Clinical method	**Histopathology**	**Thermography**
Accuracy	62.5%	89.0%	93.75%
Sensitivity	44.19%	97.7%	97.67%
Specificity	100%	93.7%	85.79%

1. Correlation of the figure of merit ΔT with the classification according to the clinical method does not allow for a satisfactory choice of burn wound treatment!

2. Good correlation of the figure of merit ΔT with histopathologic assessment does confirm its reliability as a quantitative criterion when classifying the depth of burns, which groups burn wounds into healed and unhealed and allows a proper mode of treatment to be selected. The invasive reference method may be replaced by a wholly non-invasive thermal investigation!

3. Burn treatment centres using static thermography should work out quantitative values for burn classification based on the ΔT parameter in order to group burn wounds into those healed within three weeks and those not healed. No standards are determined!

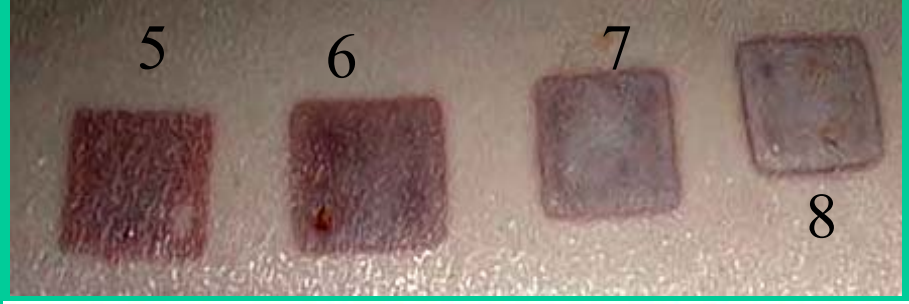
4. A multi-modal approach by the application of additional methods such as ADT, LDI, USG or ICG fluorescence, may still increase the credibility of diagnostic decisions.

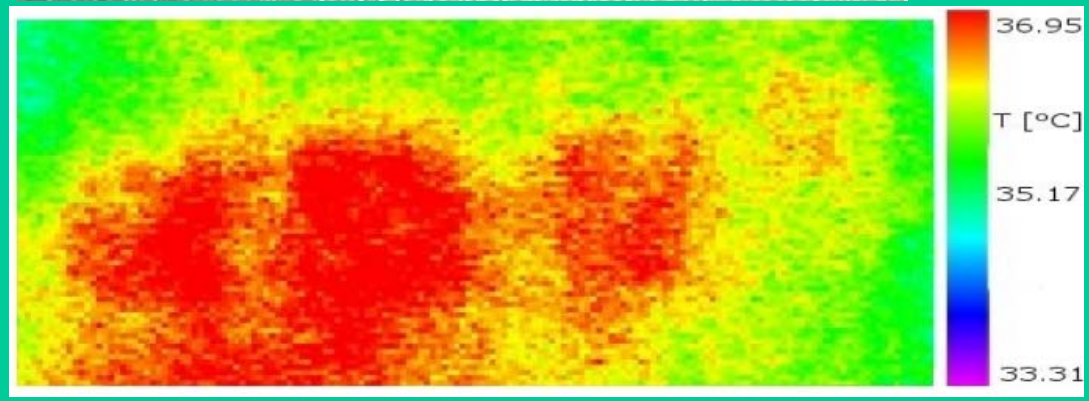
Active Dynamic Thermography

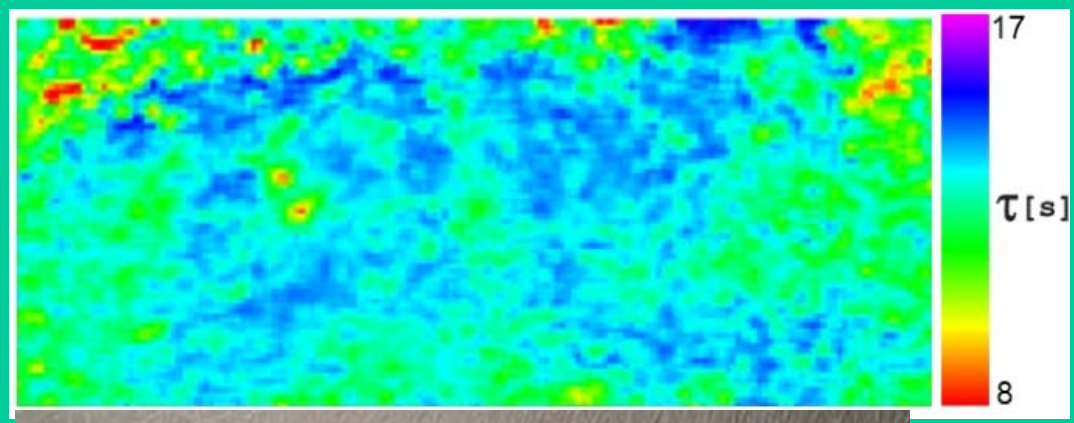
We propose a diagnostic modality which is new in medical applications – *Active Dynamic Thermography (ADT)*. This is a method based on infrared detection which uses the cameras already applied in static thermography, but which shows thermal tissue properties instead of changes in temperature distribution. Such an approach eliminates several of the drawbacks of traditional thermography while preserving the positive features and allowing for the quantitative objective assessment of burns.

The results presented here concern *in vivo* animal experiments as well as two clinical cases.

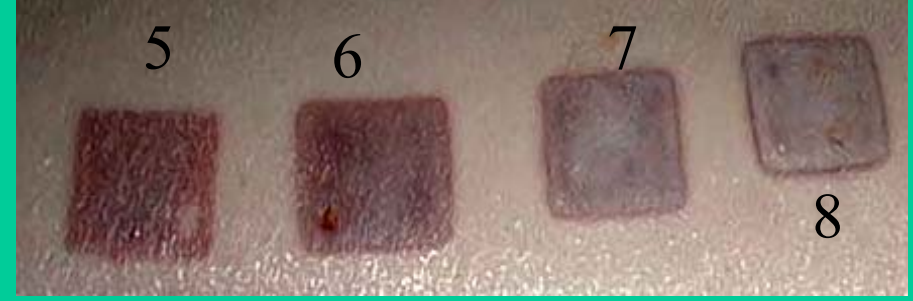
Post-burn day 2 - photographic and corresponding thermographic images of experimental burn wounds:
nº5 - *II˚a*, dermis thickness at the measurement site /dtms/ - 10.1%, prognosis: *will be healed*, result: *healed*;
nº6.- *II˚b*, dtms - 24%, prognosis: *will not be healed*, result: *healed*;
nº7 - *II˚b*, dtms - 41%, prognosis: *will not be healed*, result: *healed*;
nº8 - *II˚b*, dtms - 54.2%, prognosis: *will not be healed*, result: *healed*. .
Clinical assessment suggests no healing of the wounds nº6, nº7 and nº8 within 3 weeks; the treatment decision would be surgery.
Comparison of this clinical prognosis with the healing result (3 false negative cases and only 1 true positive) indicates the low diagnostic value of the clinical method in cases evaluated as *deep dermal*.

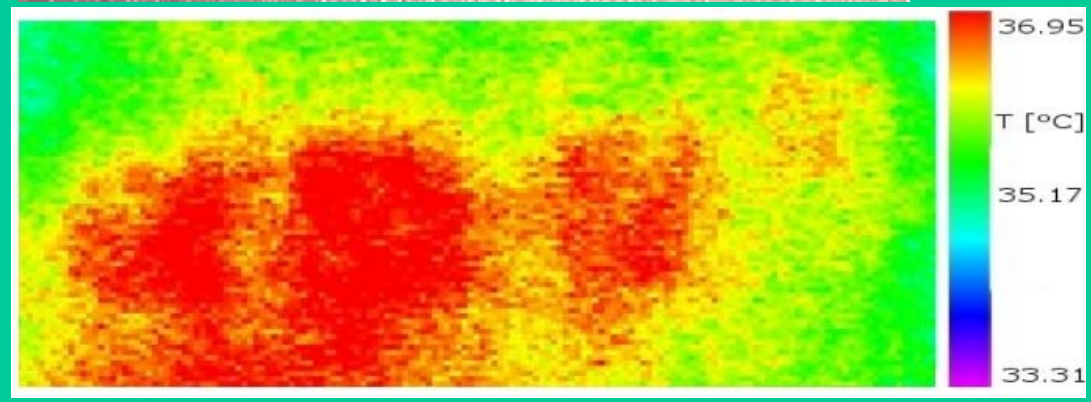


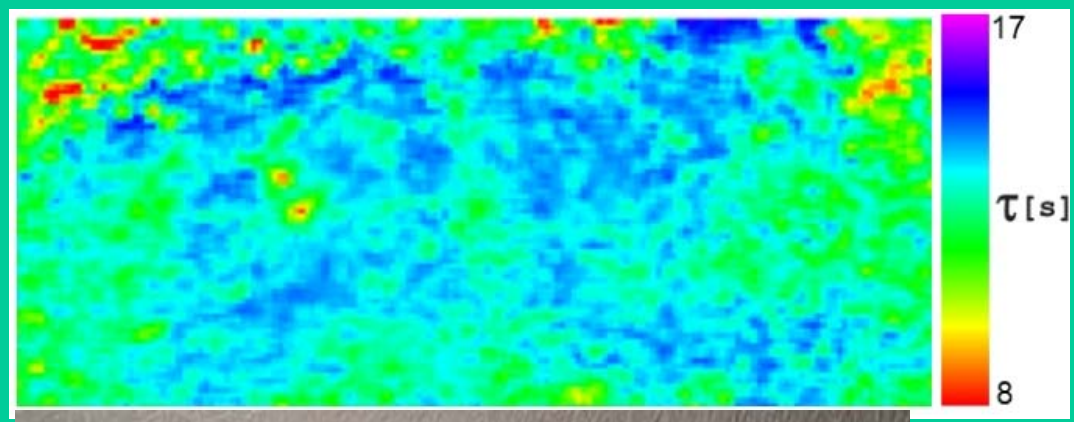




B) Static thermography (*ST*) image on post-burn day 2. *ΔT* of wounds nº5, nº6 and nº7 was greater than the threshold value *ΔT*=0.3˚C. The prognosis based on *ST* would be - *will be healed within 3 weeks of burn*. *ΔT* of the burn wound nº8 was 0.02˚C (smaller than the threshold value) and the prognosis would be - *will not be healed* (false-negative case). Thus static thermography would help in 3 out of 4 cases falsely evaluated by the *clinical method*.

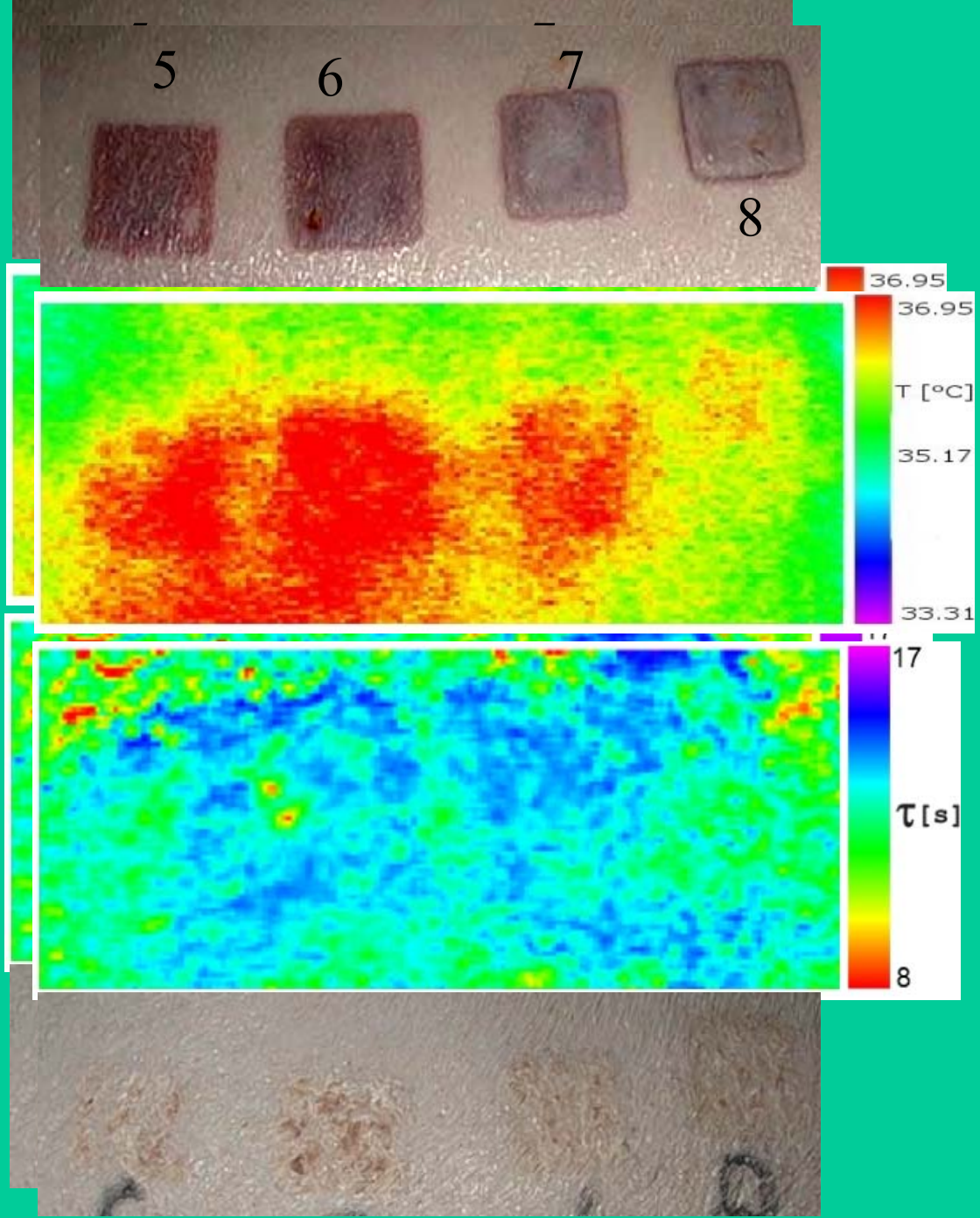


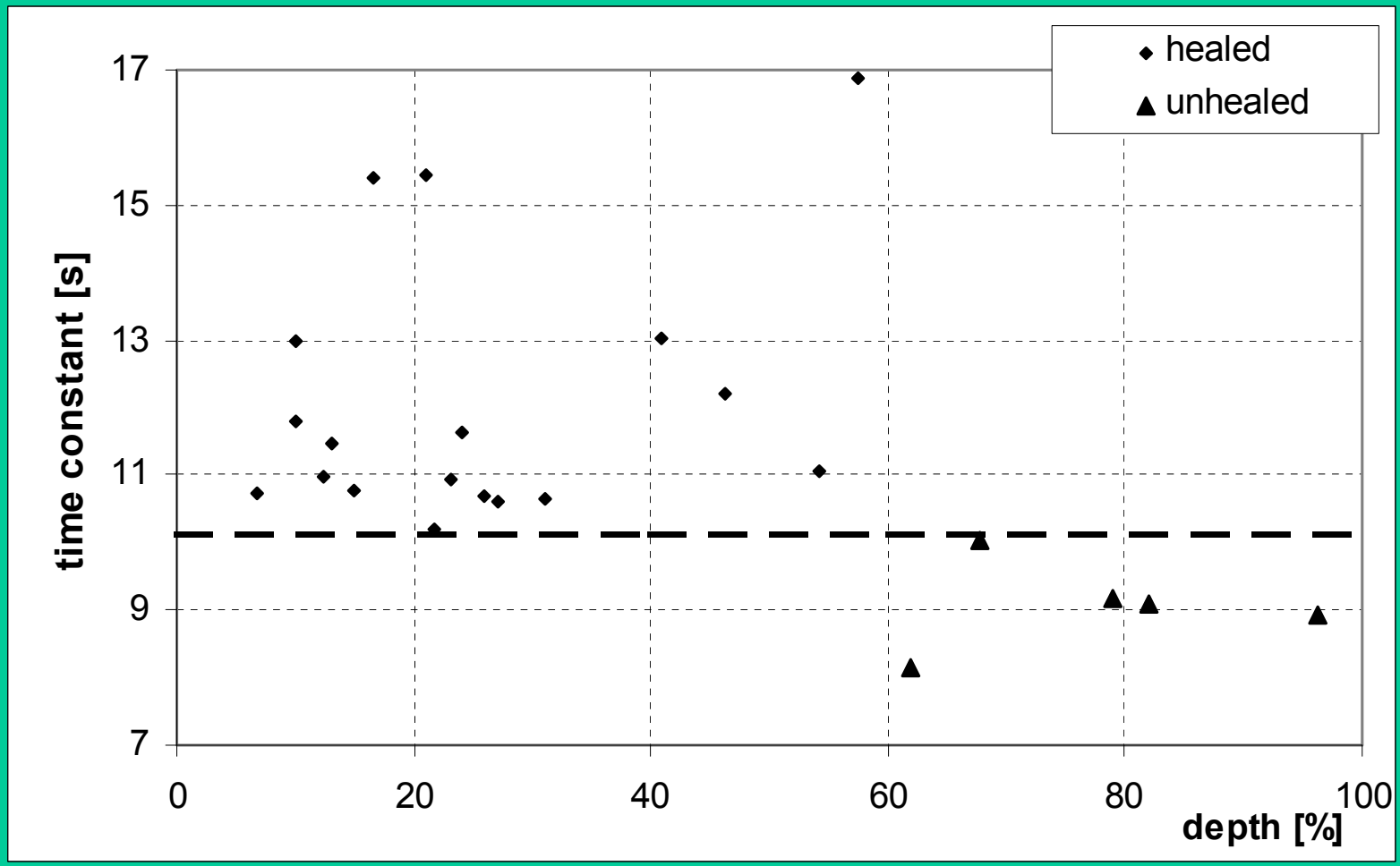




C) Parametric image τ is relatively uniform and burn wound borders are almost indistinguishable. However, τ values of all wounds are larger (longer) than the threshold value τ=10.125 s and, according to this threshold value of τ, the decision based on *ADT* investigation would be *to maintain a conservative treatment of all wounds as all should heal* (and in fact they did heal). This confirms the extremely high diagnostic value of *ADT*.

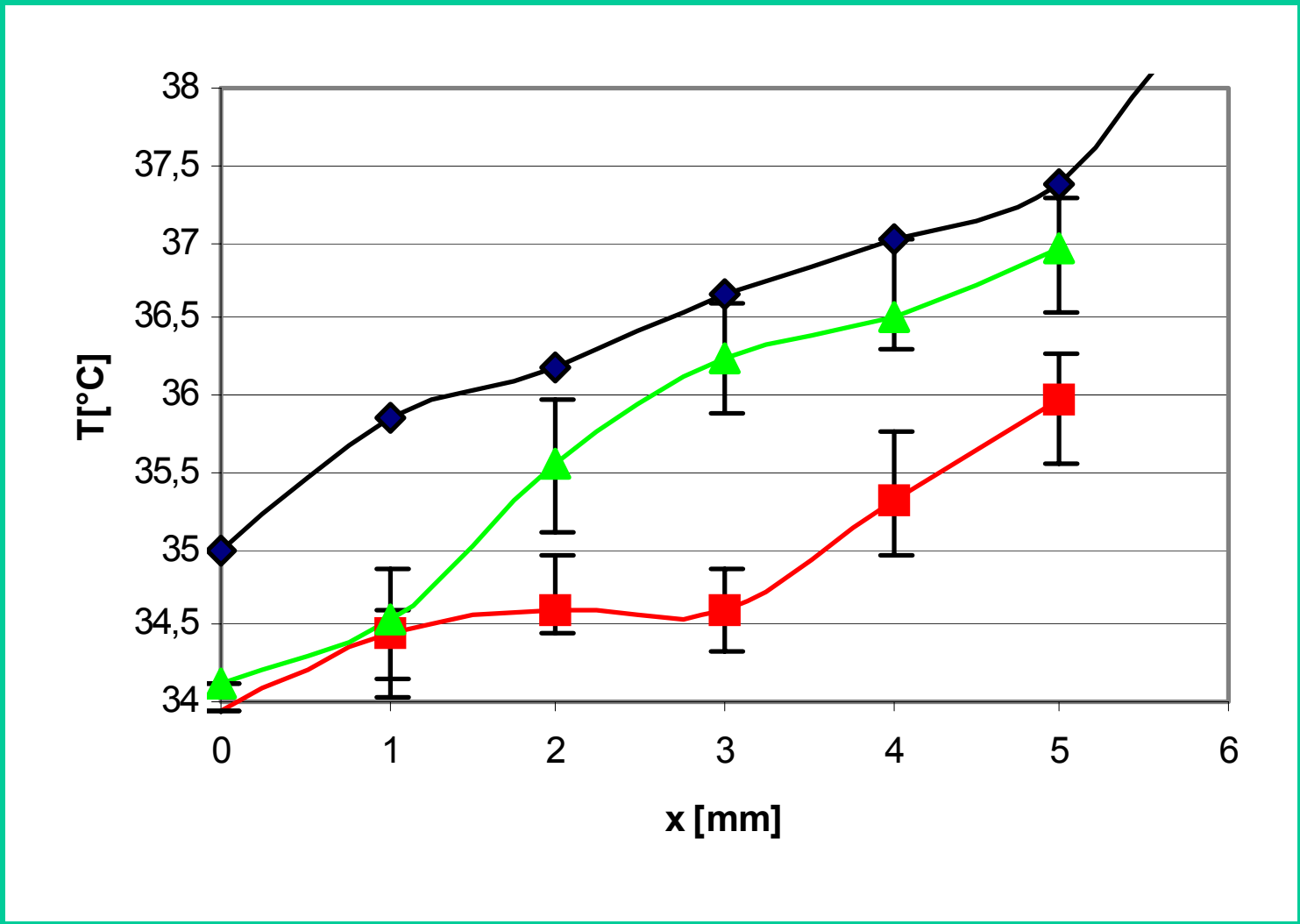
D) Photograph taken on post-burn day 21. All burns have healed.



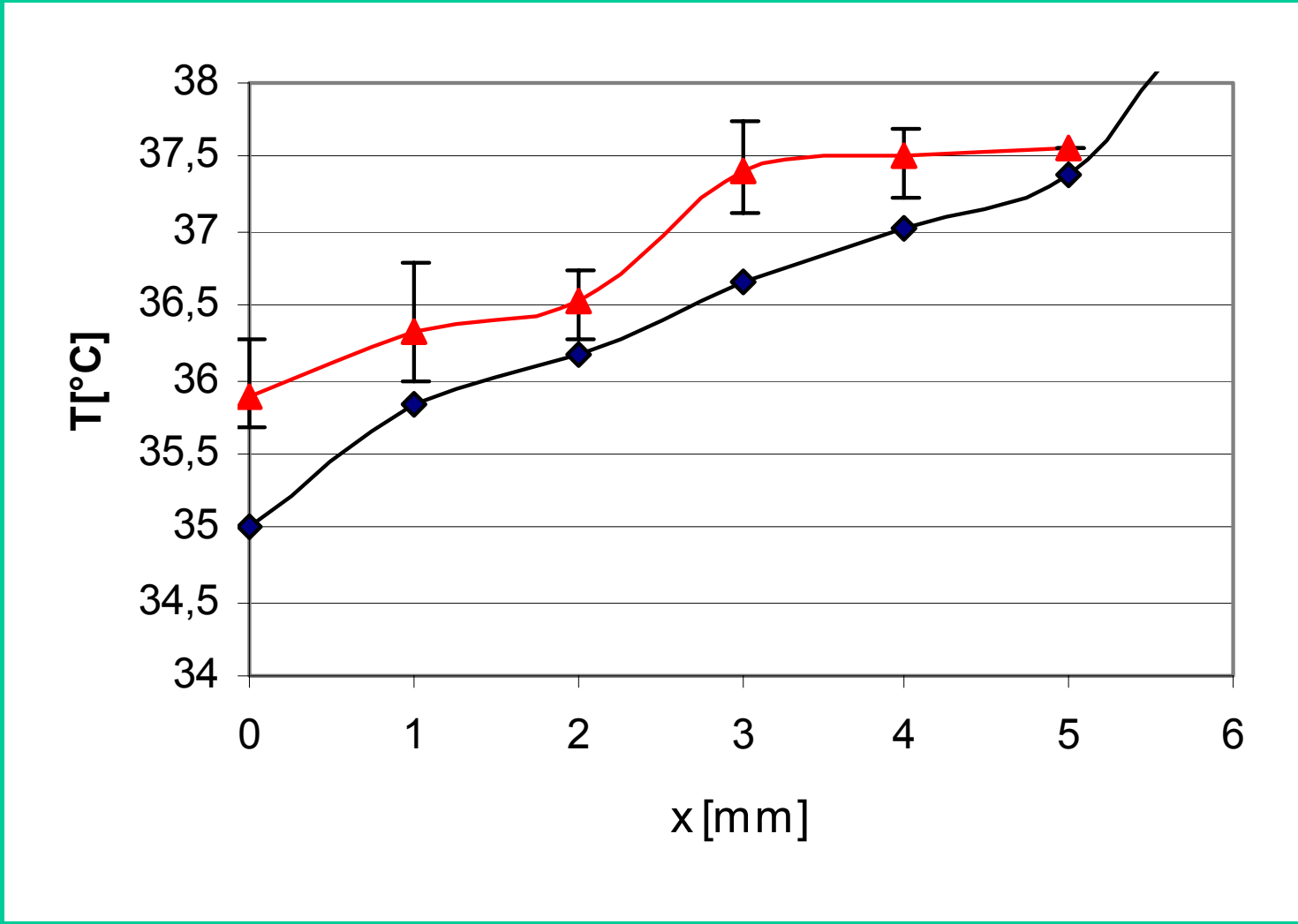


Thermal time constants τ of burn wounds classified by histopathologic examination as "*healed*" and "*non- healed*" within 3 weeks.

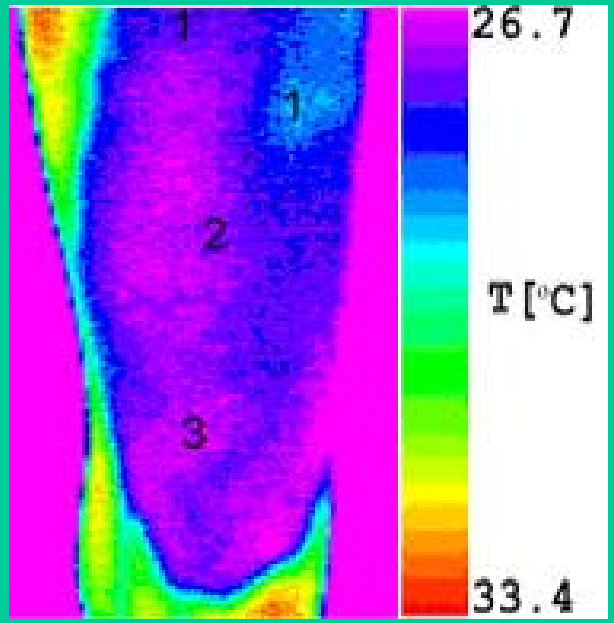
Results are surprising, as based on classical assumptions one could expect just reversed results of thermal time constant values for normal and affected by burn structures of the skin.

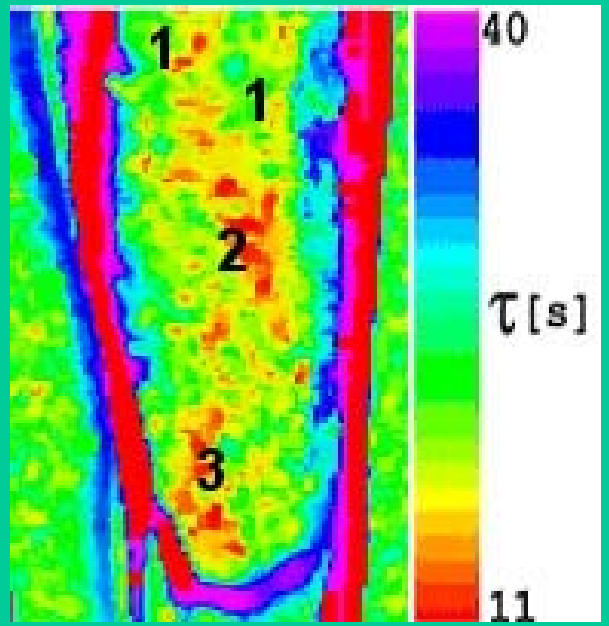


Fragment of averaged temperature profiles along pig skin depth for healthy (black) and deep burn wounds that not healed within 3 weeks (red 24h, green 72h after burn).



Fragment of averaged temperature profiles along the pig skin depth for healthy (black) and shallow burn I-st grade (red 24h after burn; after 72 h it was almost the same as for healthy tissue).





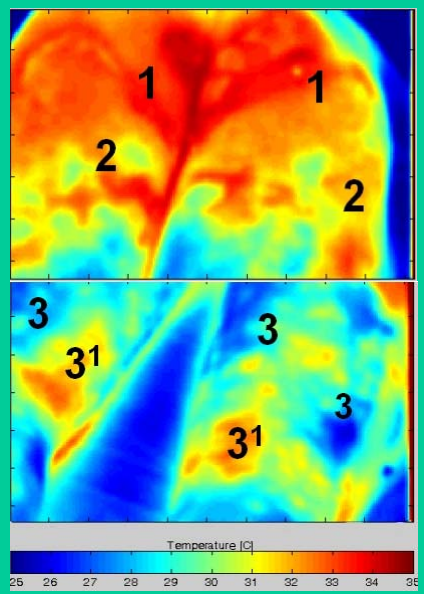
A) **B)** **C)**

Photographic and corresponding thermographic images of a burn wound to the posterior surface of the right thigh of a 49-year-old patient: **A)** Clinical burn depth evaluation of the area marked:
1 - *II˚a - superficial dermal*,
2 - *II˚a - superficial dermal* and, more centrally, *II˚b - deep dermal*
3 - *II˚b - deep dermal* and, in the lower part, *III˚ - full thickness*
B) Static thermography (the extremity is slightly medially rotated in comparison to the photograph). Areas **2** and **3** are the coldest and are without marked internal differentiation.
C) Active Dynamic Thermography parametric image (rotation of the extremity as above). The areas with short thermal time constants $\boldsymbol{\tau}$ and which qualified for surgery are well defined. These areas are markedly smaller when compared with areas **2** and **3** in the photograph and in the static thermogram.

A burn wound to the buttocks and posterior thighs of an 18-year-old patient (due to different fields of view of the photo-camera and the thermograph one photography is represented by two thermal pictures). post burn Day 2.

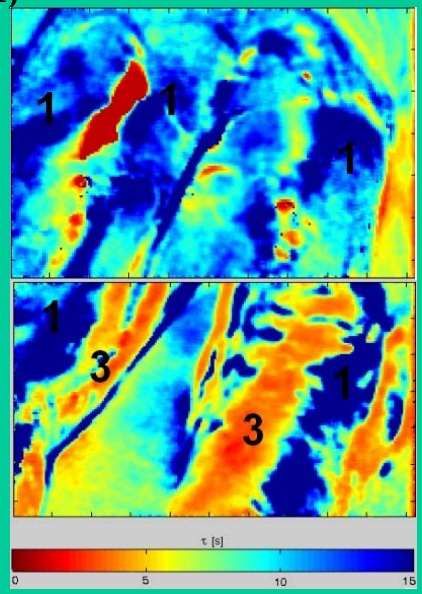
A1)

A1 Photograph - clinical evaluation within 3 weeks of the burn were:
1 - *II˚a, will be healed*,
2 - *II˚a/II˚b, no decision*, indeterminate burn,
3 - *II˚b/III˚, will not be healed* .



temperature *T*

A2)



thermal time constant τ

A3)

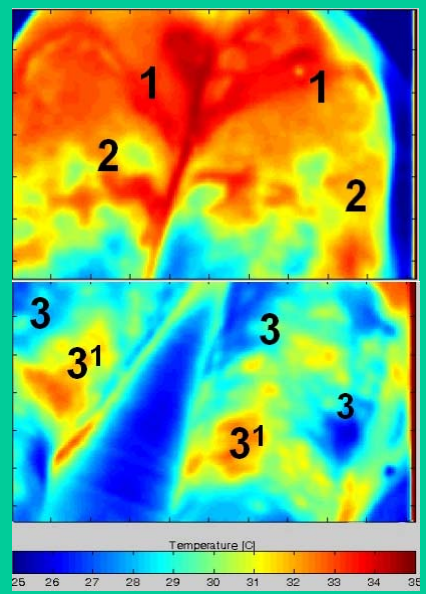
A2 static thermographic images (upper – buttocks and lower - thighs). Prognoses:
1 – areas of a greater than discriminating value *ΔT, will be healed*,
2 – similar but cooler than **1,** *will be healed*.
3 –areas of *ΔT* smaller than discriminating value, *will not be healed*,
3¹ warm areas – "islands" are difficult to interpret. They are localised like the areas of short τ on the *ADT* picture.

B)

A3) corresponding to **A1)** *ADT* parametric images (upper – buttocks and lower - thighs). Prognoses based on *ADT* were:
1 – well defined areas of long τ, *will be healed* within 3 weeks.
3 - areas of short τ, *will not be healed*.

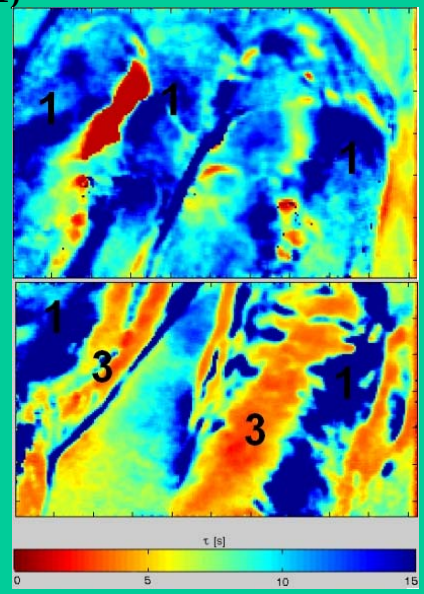
B) the healing result – photograph taken on post burn day 18
1 – healed areas,
2 –mainly healed area,
3 – not healed parts of the wound before skin grafting.

A1)



temperature *T*

A2)



thermal time constant τ

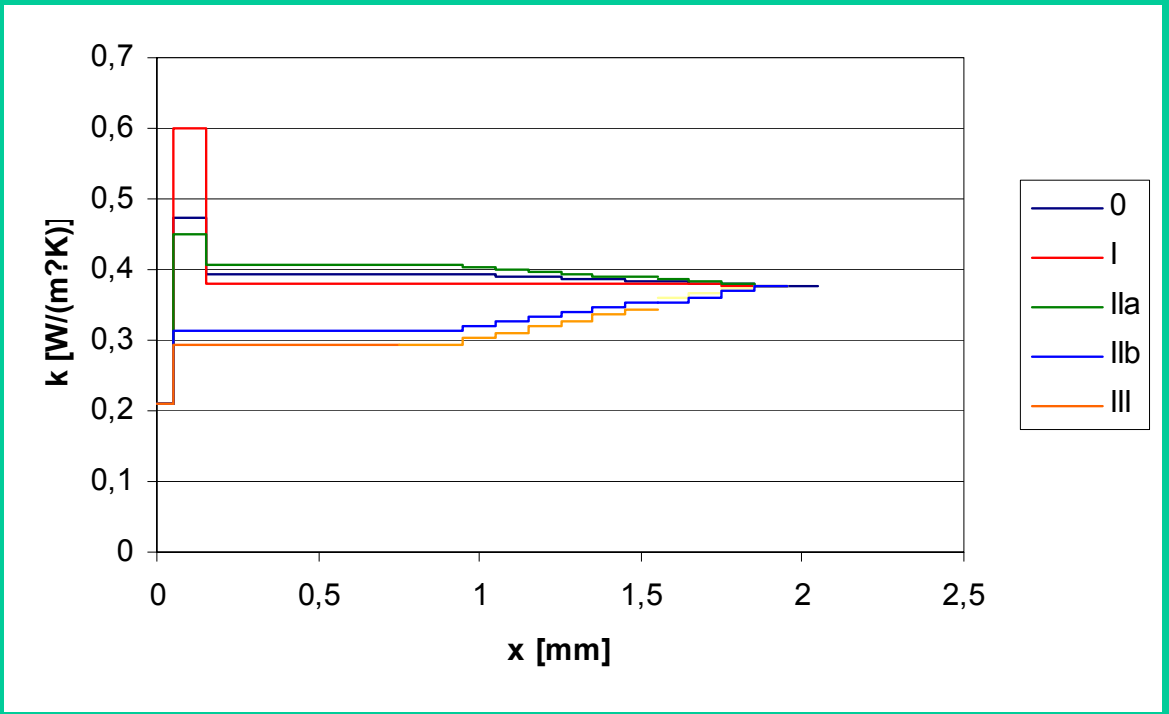
A3)

B)

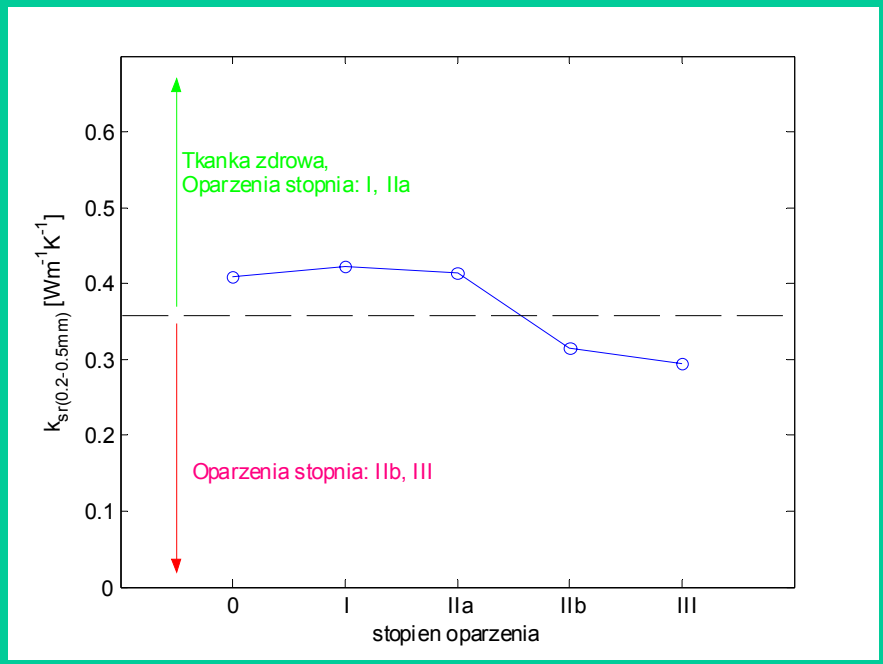
Static thermography has already been in practical use in burn diagnostics for many years. However, the disadvantages of this method, limit its popularity. In our studies the quality parameters: *accuracy* - 91.3%, *sensitivity* - 94.4%, and *specificity* - 80%, show its usefulness as an adjunct method in burn wound depth assessment and confirm the conclusions drawn from clinical tests.

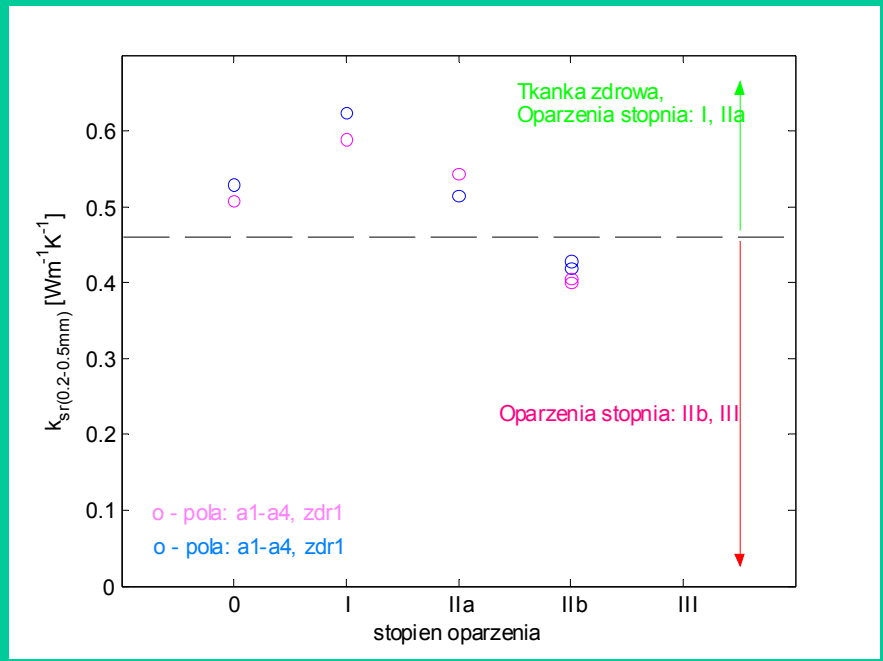
The results obtained for the *ADT* method (thermal time constants) show that **this may be declared a new effective method for burn wound discrimination**, recommended for early burn treatment planning. The results of the *ADT* and *histopathologic evaluations* are fully in agreement. In the *histopathologic assessment* of burns the *accuracy, sensitivity and specificity* of the method in our experiment was 100% giving its position as the reference method. However, its invasive character, the necessity of multiple burn wound biopsies and a delay of several days while waiting for the result markedly restricts the usefulness of this method in everyday hospital practice.

Thermal models of healthy and burned tissue



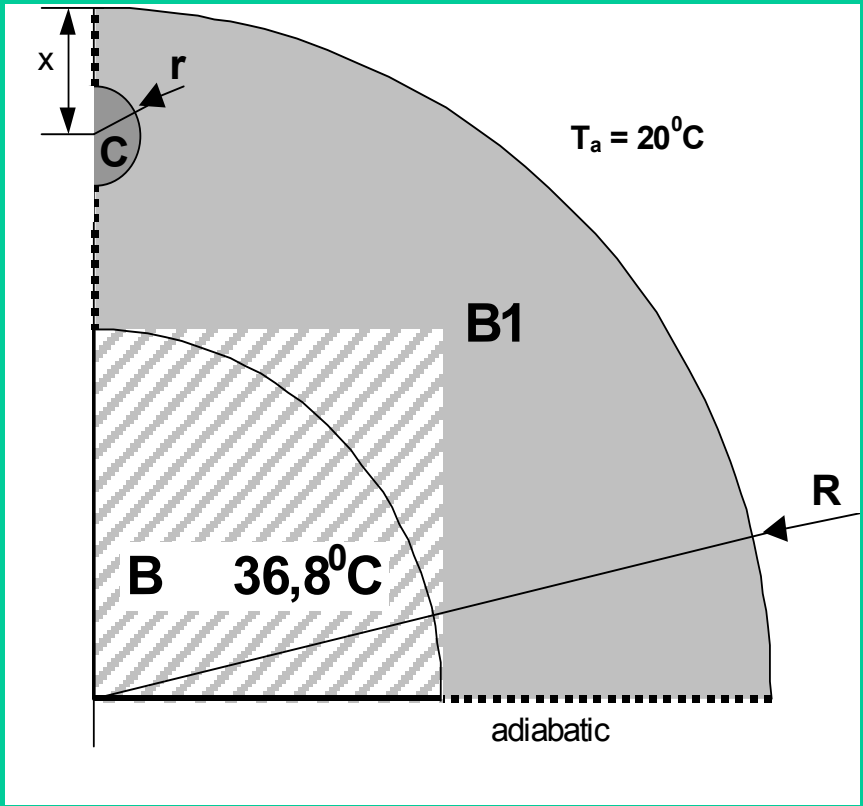
Classification criterion for burns diagnostics - mean value of thermal conductivity (0,2-0,5 mm).

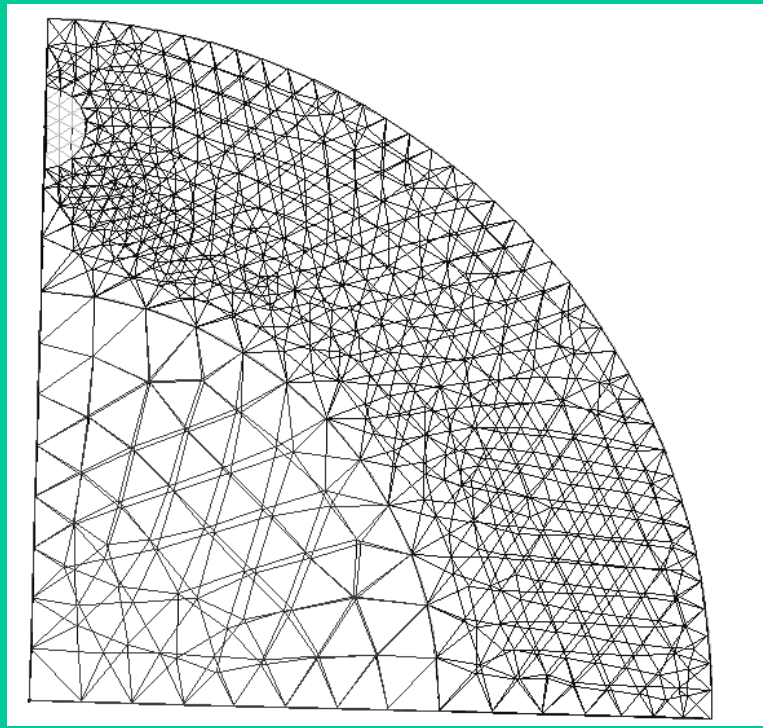


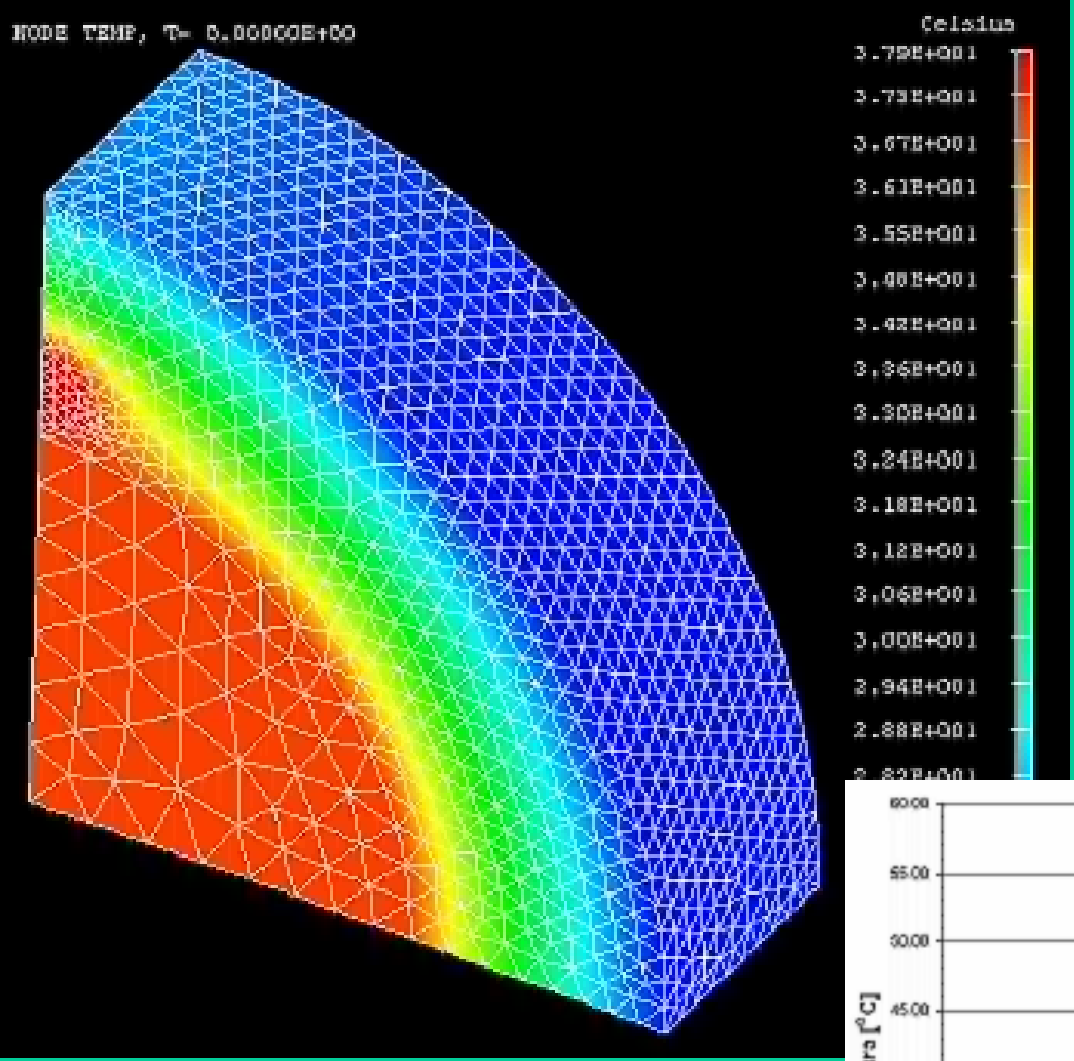


Breast cancer

Thermal model of a breast



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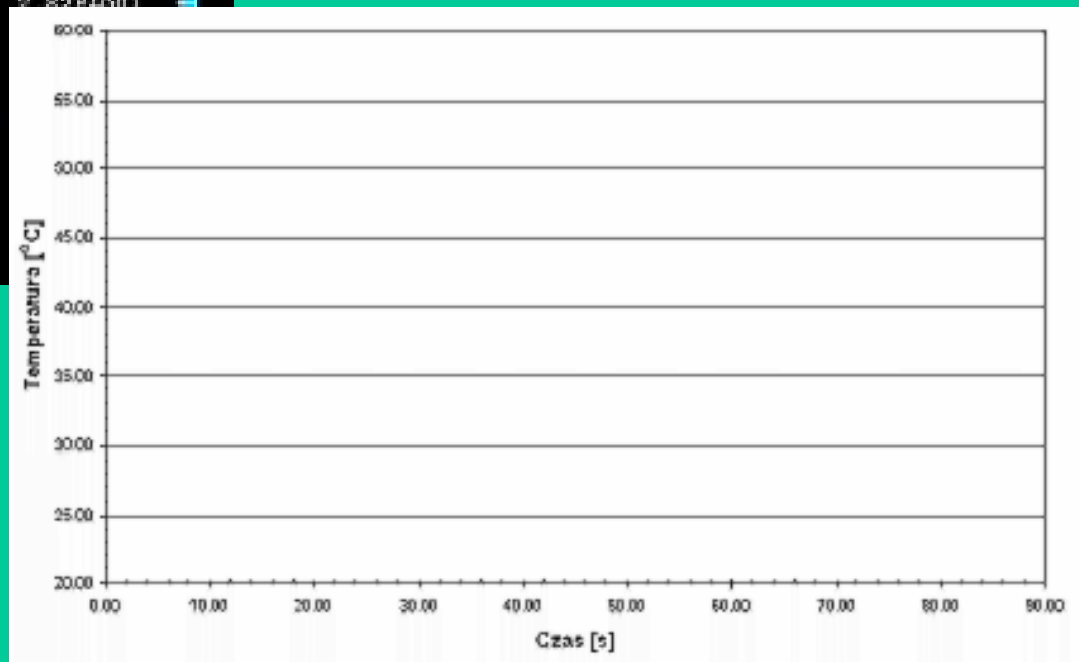
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Clinics:

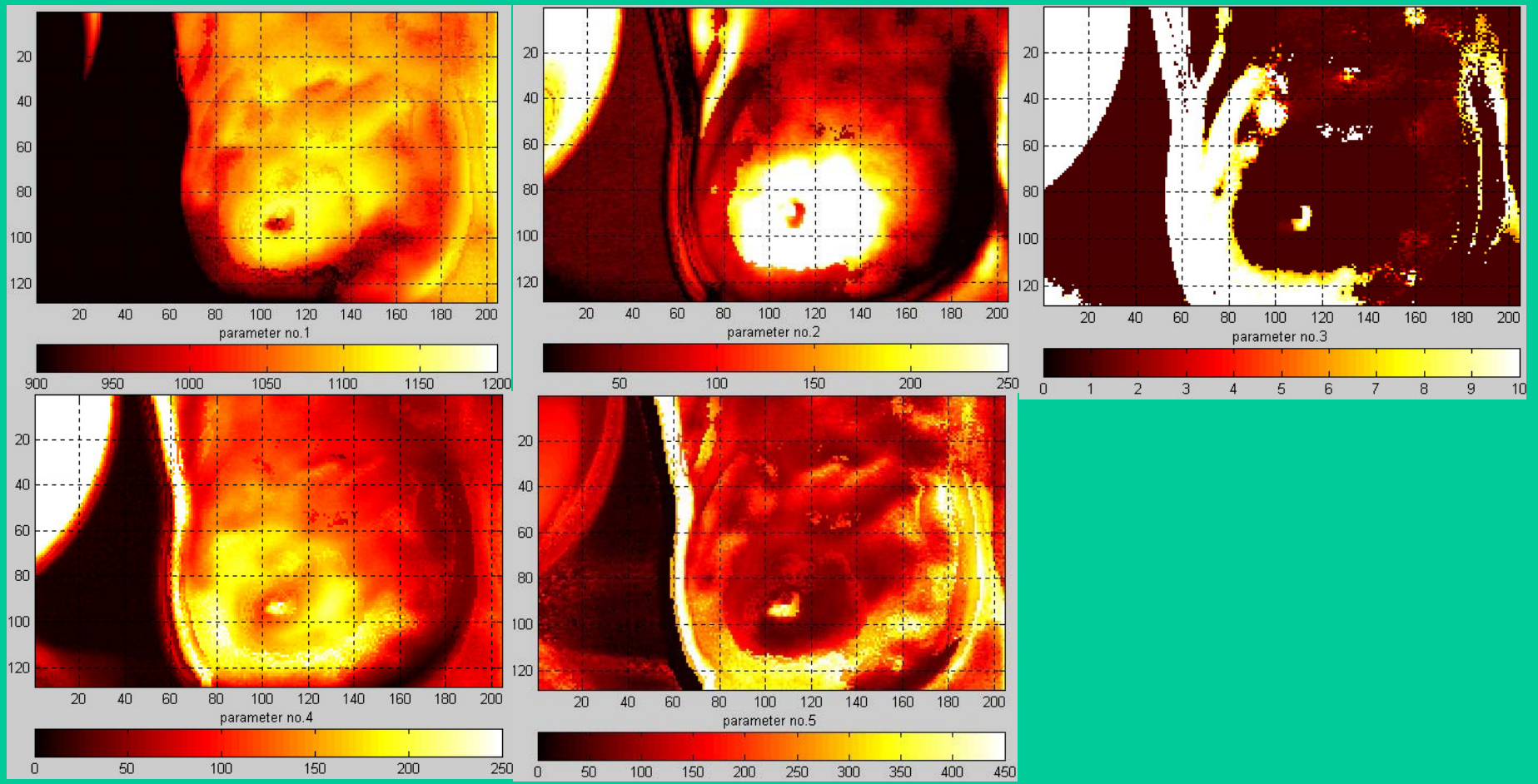
Patients from the Oncology Surgery Clinic Gdansk Medical University. All with well recognized cancer using other modalities.

The case discussed - patient S.W. with the diagnosis:

- diagnosed cancer of the left breast, diameter 2,5cm;
- the scale RB3;
- 3 mammary glands already affected by the cancer;

Methodology: thermographic registration of the recovery phase after using pulse heat excitation of halogen lamps - 1000W, from the distance 50 cm; heating time t=30 s.

Synthetic pictures: a) T_{eq}, b) ΔT_1, c) τ_1, d) ΔT_2, e) τ_2

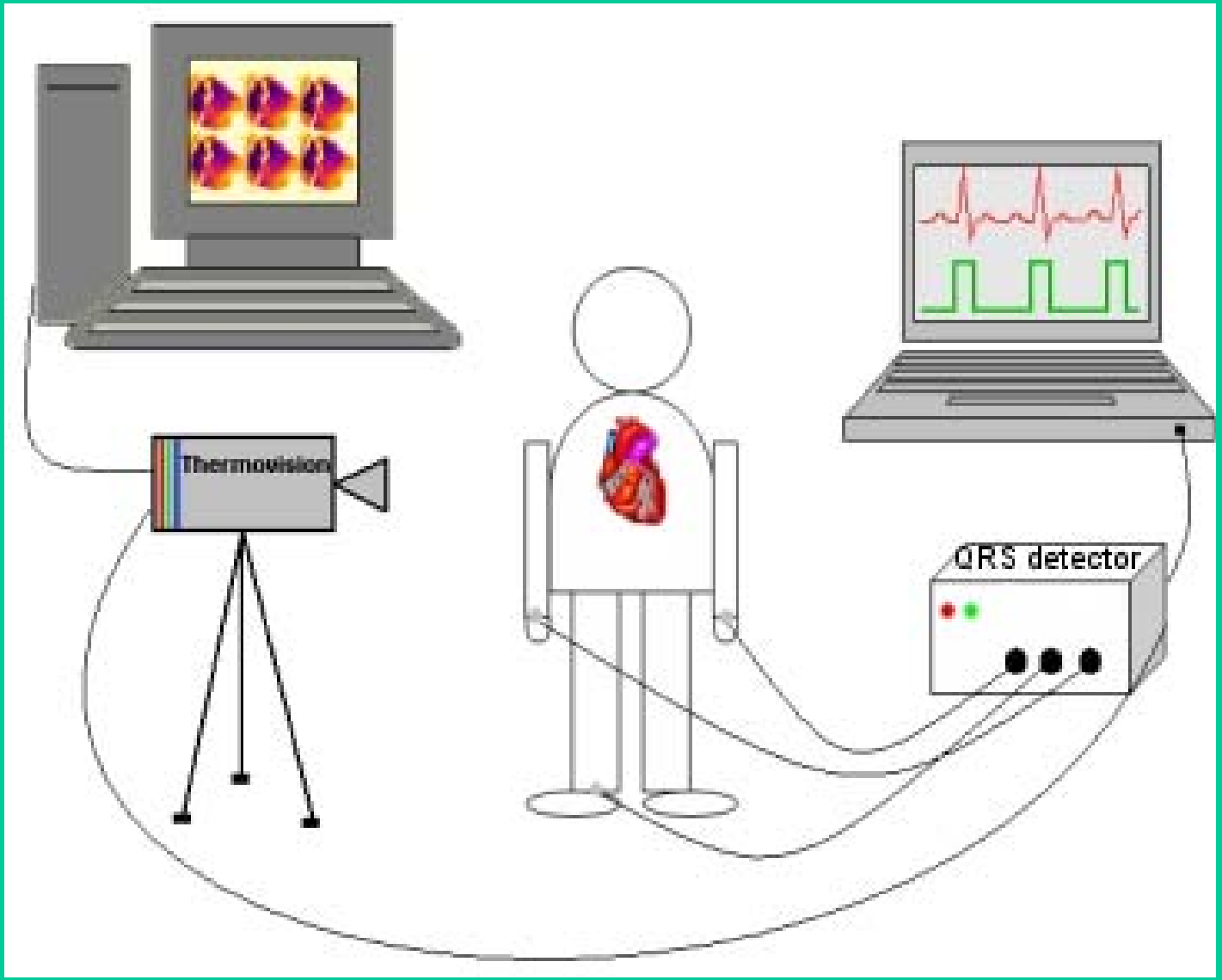


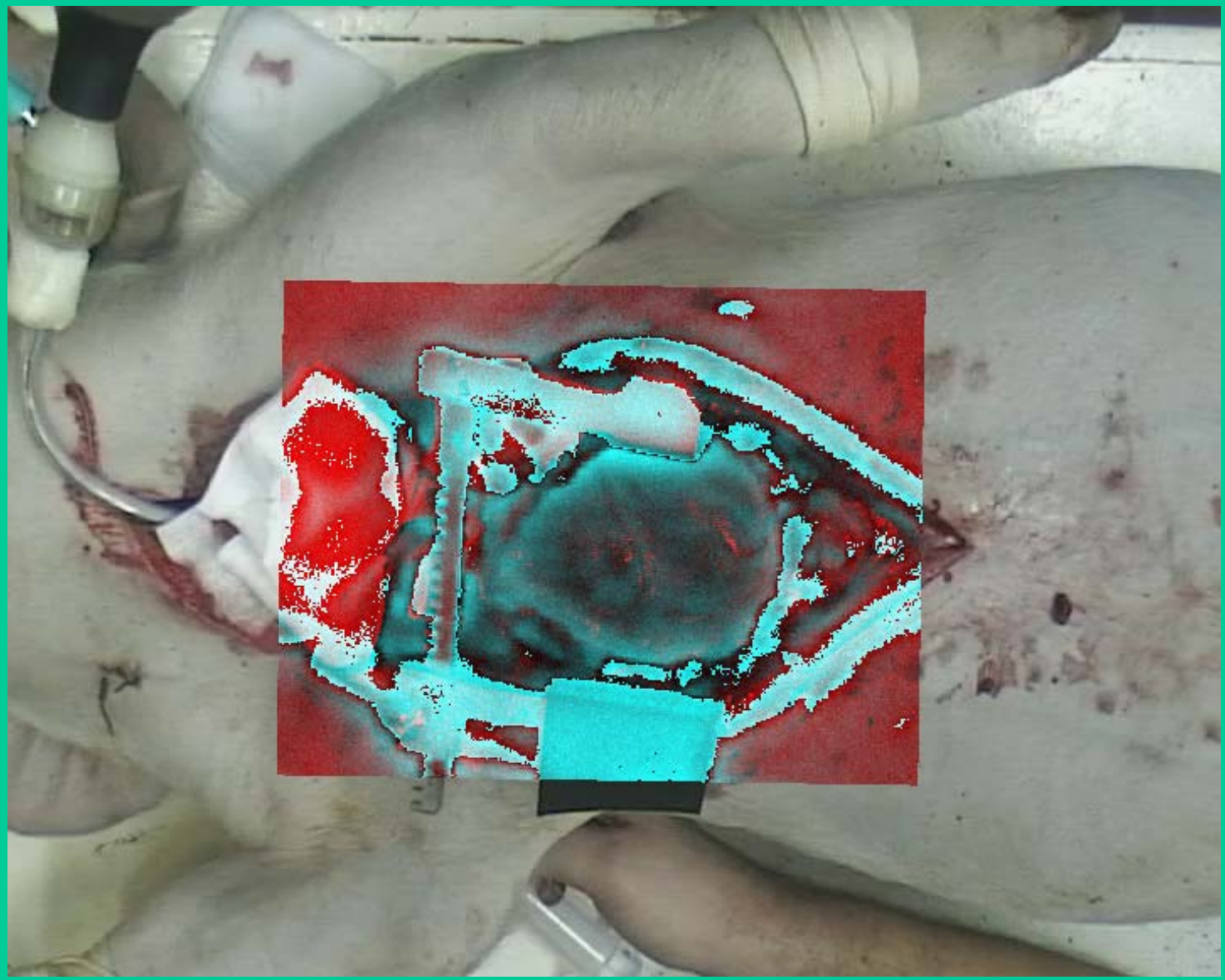
Discussion:

Calculated values of the equivalent thermal model parameters underline tissue changes at the right upper quadrant of the breast, showing clearly the location of cancer, what was later confirmed during the surgical treatment!

Cardiosurgery

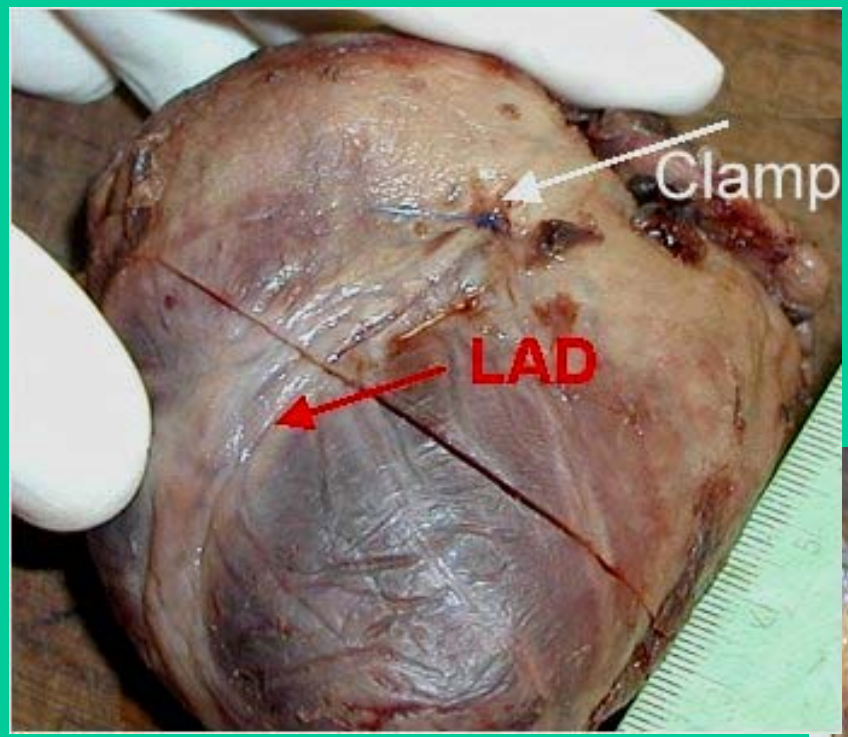
EXPERIMENT SETUP

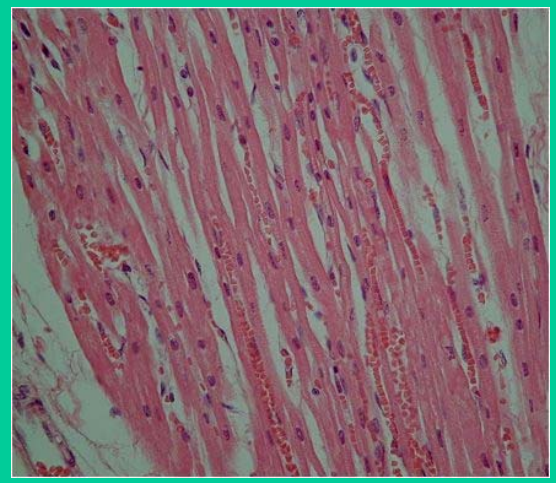




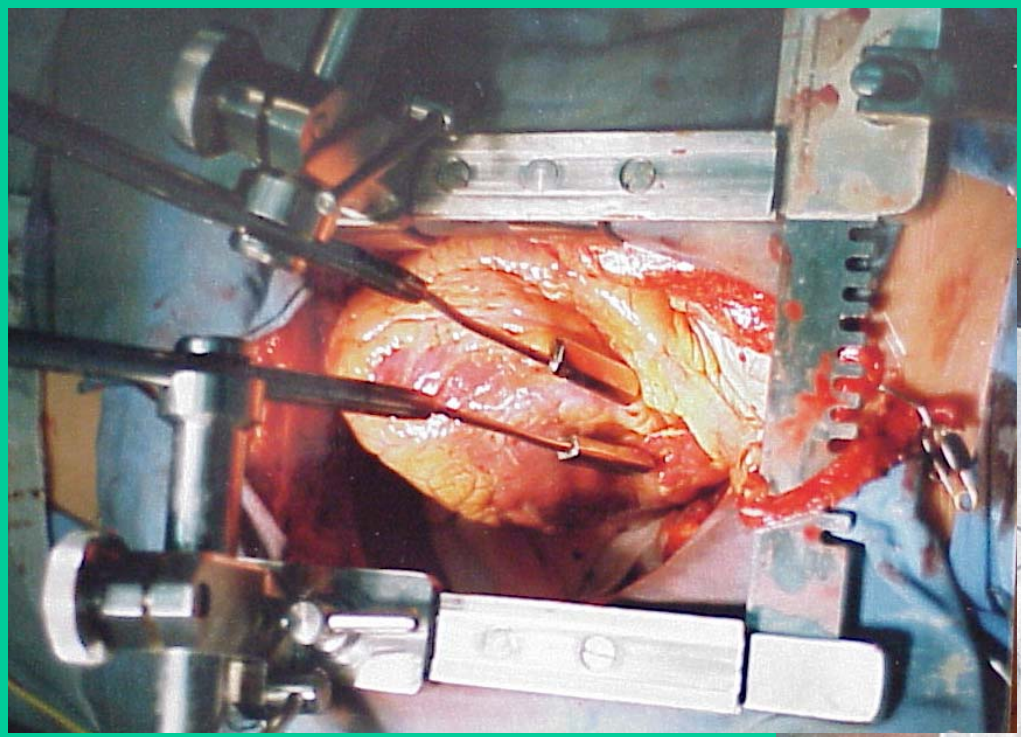
Fused image (data of the Thermogram in the red and green Channel)

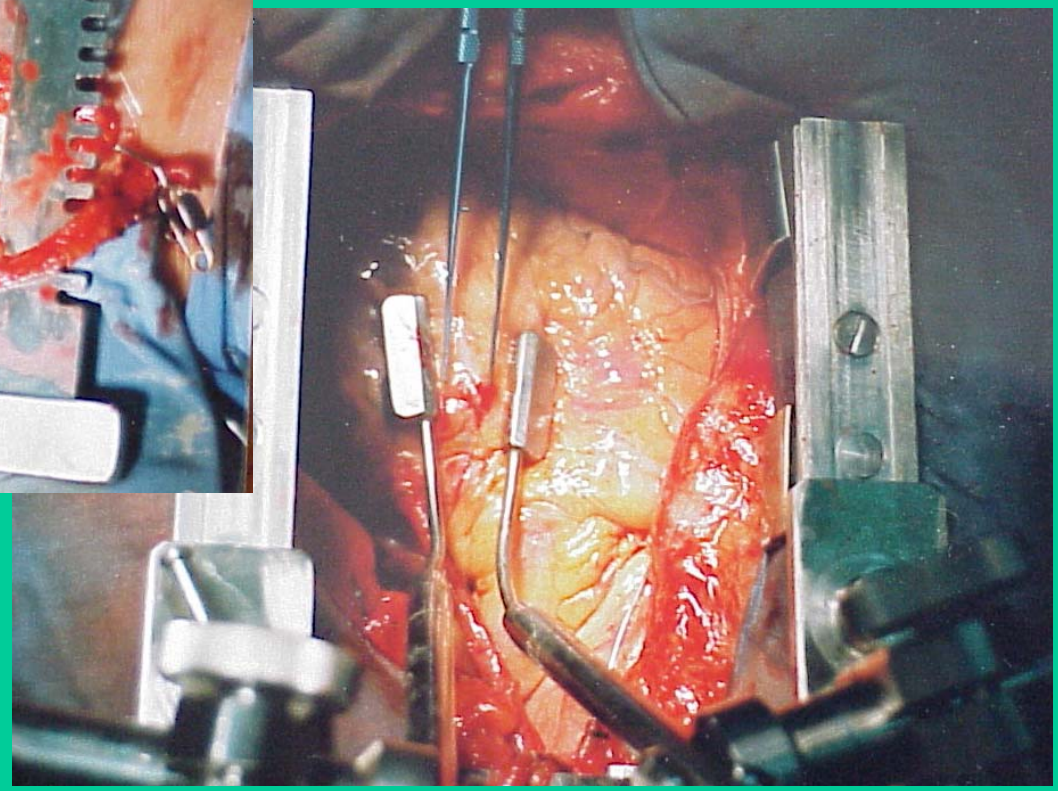
In vivo experiments on domestic swine for study of surgery procedures



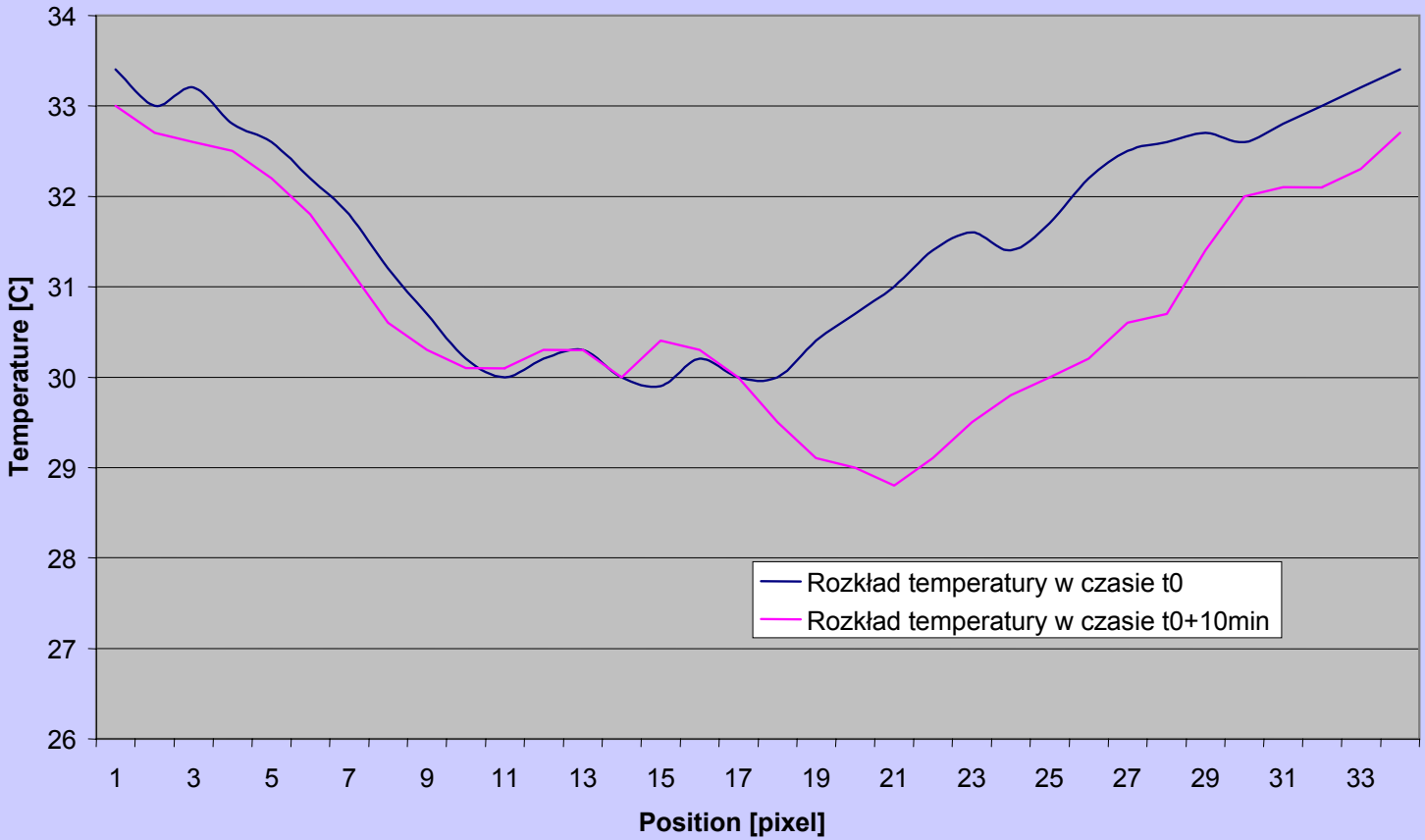


OPCABG - „GDAŃSK” stabilizer

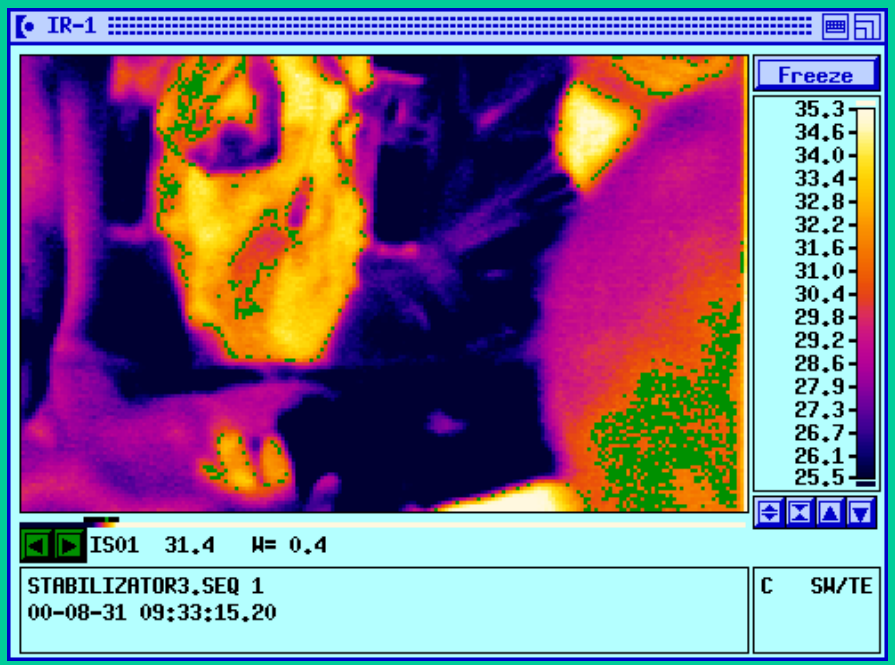


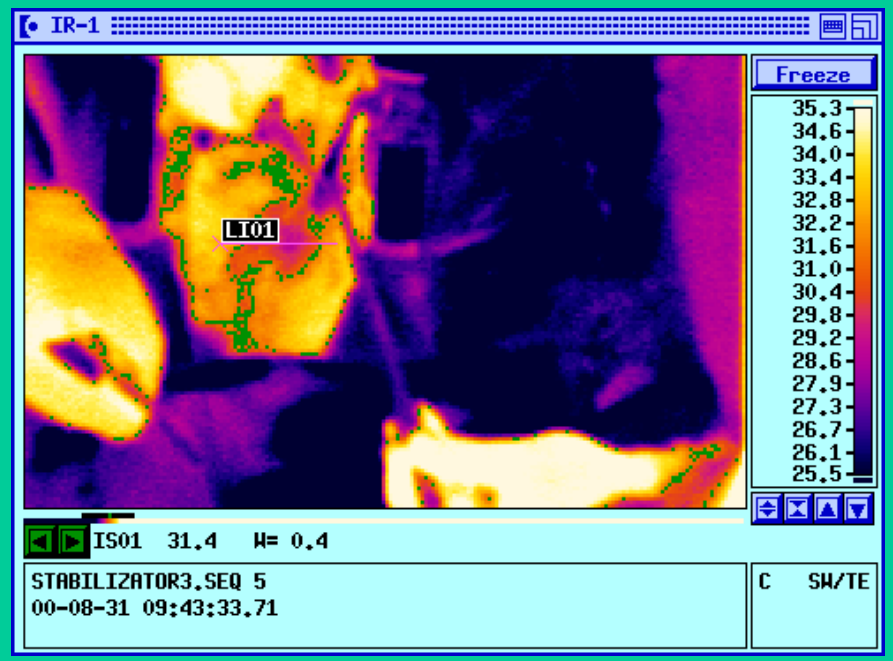


Influence of the stabilizer on vascularisation of the heart muscle

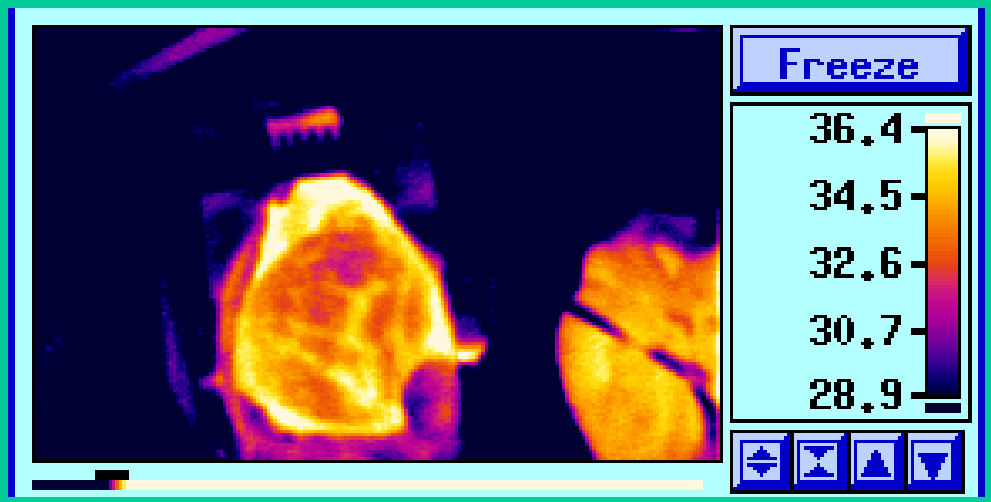


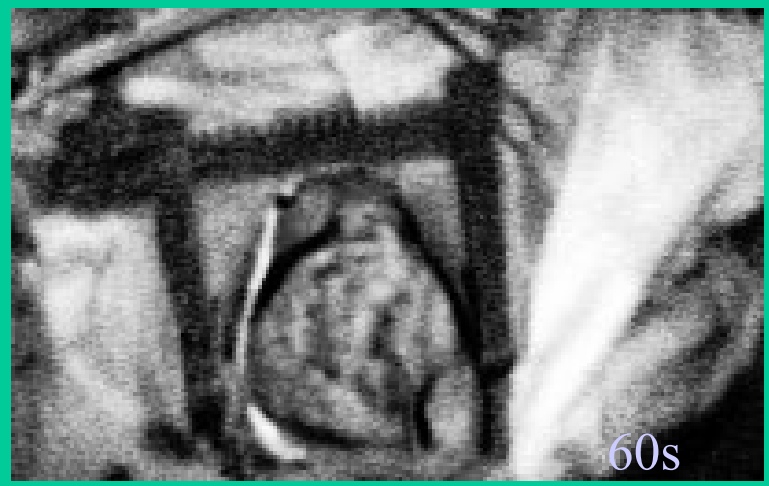
Influence of the stabilizer on vascularisation of the heart muscle

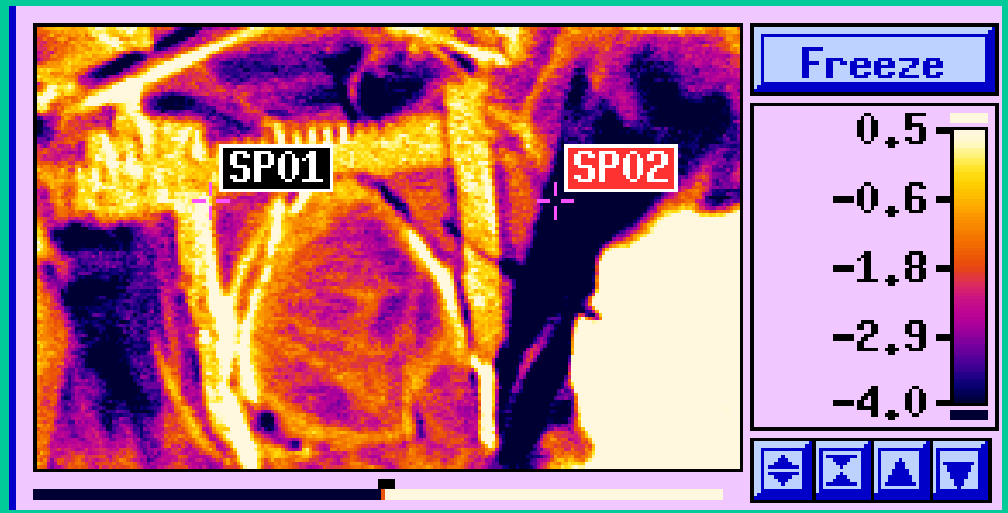


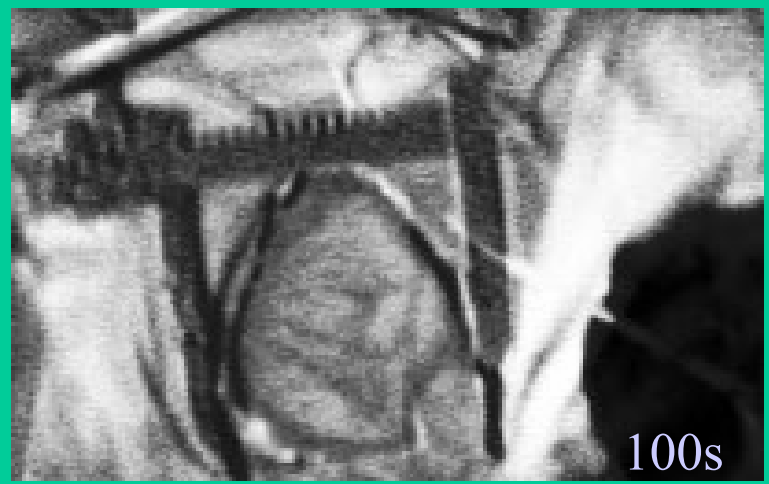


NDE-DT thermograms of clinical intervention – after the CABG



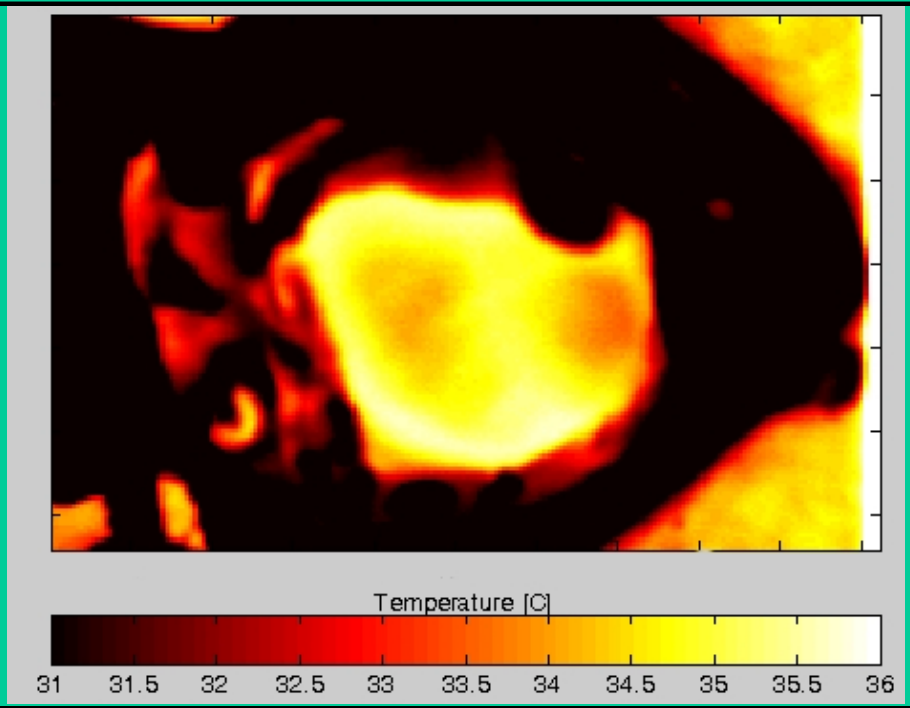


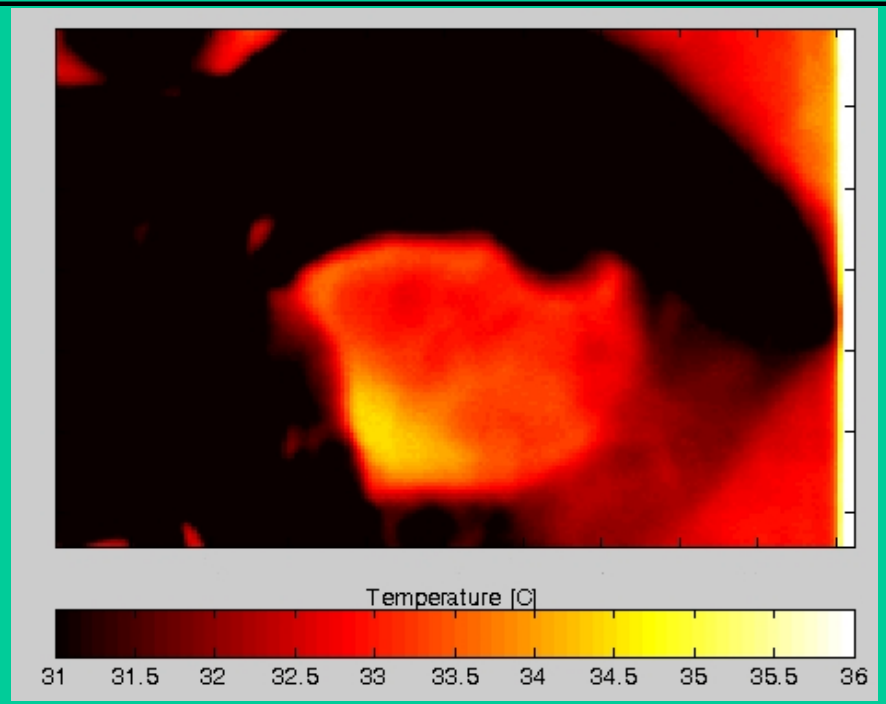




Before blood arrest by clamping LAD	30 minutes after the blood arrest

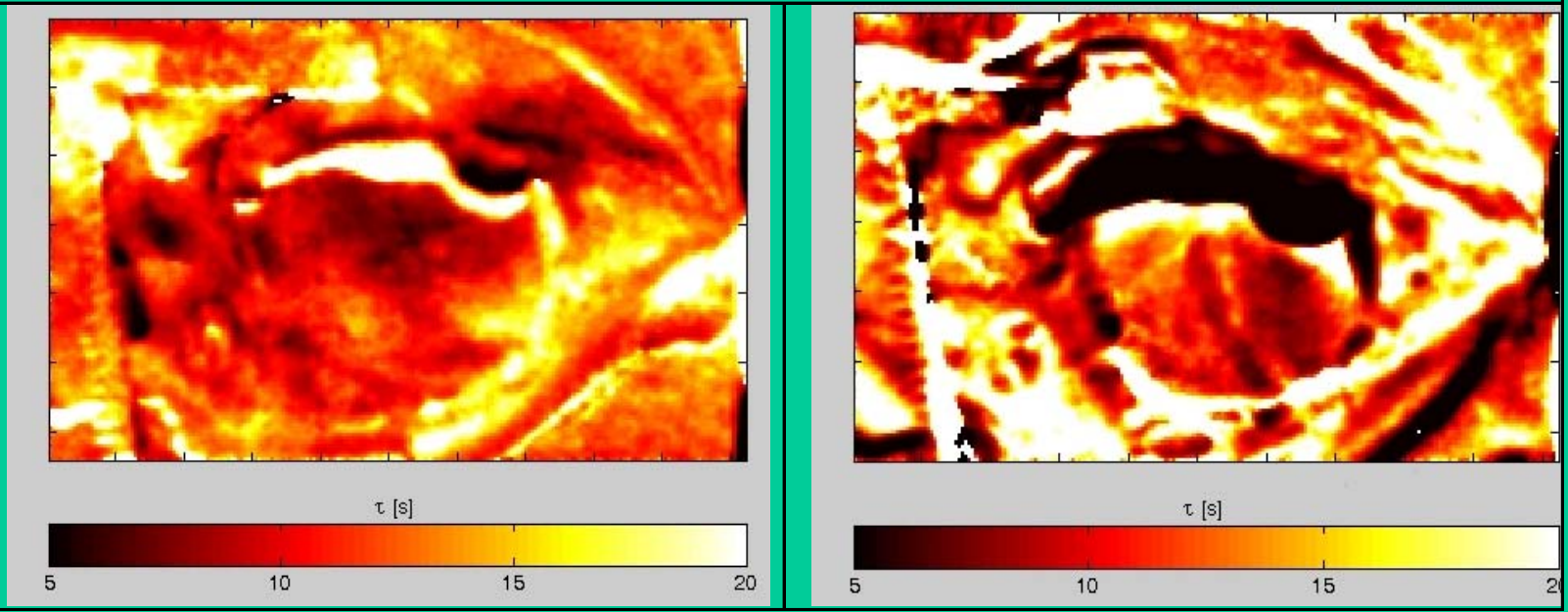
IR-thermal imaging – classical thermography



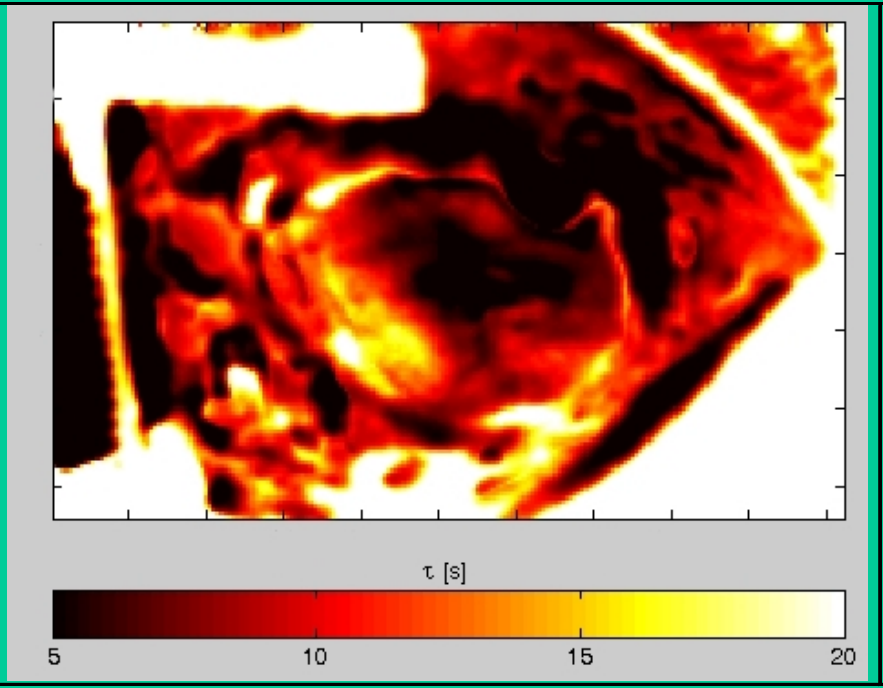


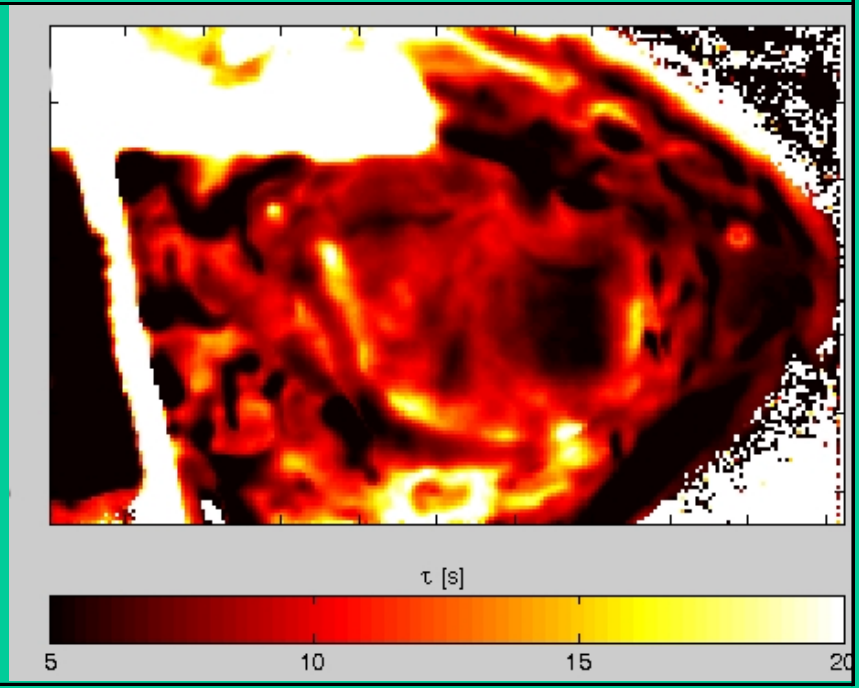
ADT experiments – parametric images of τ –thermal time constant of the heart muscle tissue

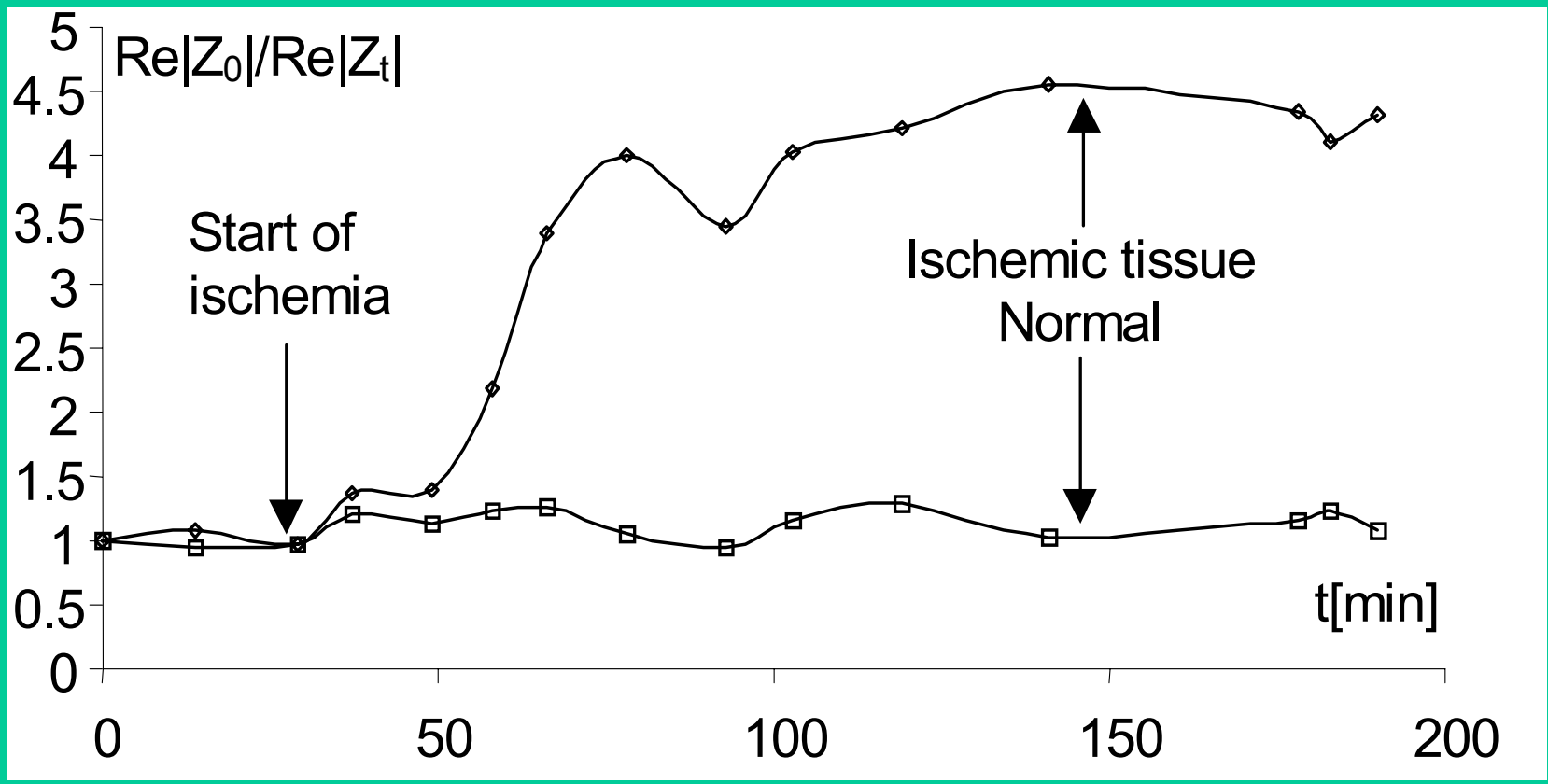
Optical – halogen pulse excitation (heating) lasting 15 seconds and followed by 60 second registration of the phase of natural cooling



Cooling 30 seconds by forced air flow of the temperature 5^0 C; registration during 90 seconds at the phase of natural recovery (self-heating)







Changes of impedance modulus (related to its initial value measured before clamping of LAD) during the time of experiment; reference data obtained for normal tissue are also presented

Conclusions

The analysis performed shows that the information taken from thermography and active thermography is giving in each case data of different nature but always of a great importance in terms of the evaluation of burn wounds, breast cancer, the open heart during cardiosurgery, and other.

Active thermography is giving information of the state of inspected tissue. After application of tomographic procedures it also allows 3D presentation of superficial layers of a tested organ. Necrosis may be easy discriminated.

CONCLUSIONS

The main condition for medical diagnostic is to apply a non-invasive method, safe and aseptic, but also easy to use and reliable. Boundary conditions always have to be taken into account as play crucial role on heat flows.

Cooling is safer than heating, but not easy in terms of finding a source of cooling of controlled excitation energy and uniformity. Here a cooling air fan might be a solution, but the control of energy level and uniformity is limited. Also condition of fully aseptic interaction is difficult. Another advantage of cooling is the acceptable amplitude of excitation. The change of the skin temperature by 20^{o}C or even more is acceptable, safe and still comfortable for a patient.

ACKNOWLEDGMENT

The author thanks all of his co-workers and Ph. D. students, who actively participated in the research devoted to the development of active dynamic thermography and thermal tomography in medicine and who produced the data presented in this paper.
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Department of Biomedical Engineering

CEMET - Centre of Biomedical Technologies

Faculty of Electronics, Telecommunication, Informatics

Technical University of Gdansk
ul. G. Narutowicza 11/12, 80-952 Gdansk, Poland

http://www-med.eti.pg.gda.pl