FACTORS DETERMINING SKIN TEMPERATURE CONTRAST AND THE CONCEPTION OF *NATURAL* NORMAL VALUES[1]

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SUMMARY

Some essential causes of restrained acceptance of thermographic methods in medical diagnosis are discussed: First, the rather unclear understanding of mechanisms of skin temperature contrast formation are considered: (1) Heat convection and conductance; (2) Humoral-hormonal-enzymatic factors; (3) Nervous reflexes. The evidence is gathered that heat convection and conductance can play important role in thermography only in case of greater (>20 mm) non-deeply situated foci with extremely high caloric effect (60-70 mW/cm^3). Heat convection and conductance are bound to attenuate the original peri-focal contrast while propagation towards the surface. The skin vascular reactions seem to be much more important for thermography. They are elicited by: (A). The focal temperature shift changing the enzyme reaction rate (e.g. acetylcholine-cholinesterase) and subsequently the nervous conduction; (B) The non-thermal, bio-physico-chemical changes in and about the focus, on the neuro-humoro-hormonal way; (C) Axon and viscero-cutaneous reflexes. The literature review shows that mechanisms other that heat convection and conductance have hitherto drawn none or very little attention. On the other hand quite an obstacle is the ambiguous conception of what result should to be considered as *normal.* Thus a *natural local norm* conception is proposed, and some examples of establishing it using data sets counting about thousand of minimal temperature values and temperature restoration rate after chilling indexes. Some features of the program conceived for peripheral blood supply diagnosis are presented. The essential trick consists on transforming an ordinary thermal image into a

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diagnostic level classified map of pixels, classified only in three or four categories: *excessive, good, not to bad* and *poor* blood supply, metabolism or thermoregulatory blood vessels activity. Thus for instance a 10-colored plain thermogram is transformed to the 3-colour map of pixel groups with temperature classified in three mentioned above diagnostical classes. The resulting simplification of diagnostic information and decisions are discussed.

Key words

Thermography; computer program; diagnosis; blood circulation; skin temperature; blood heat convection; tissue heat conductance; vascular reactivity; thermoregulation; nervous reflexes; enzyme-substratum affinity; tissue hormones; tumors; inflammation; normal values.

After a rather enthusiastic period of thermal mapping methods in medical diagnosis during sixties and seventies decades, a neatly marked decline of interest, some disappointment and even mistrust followed in eighties to end in total rejection of the method as quite irrelevant in breast cancer diagnostics (12), still accepting some usefulness of it in peripheral blood circulation, rheumatological, orthopedical and dermatological disorders.

The rather restricted acceptance of thermography by medical profession was to some extent brought about by technical imperfections, and partly by unfounded great expectations regarding sensitivity, specifity and topological and morphological information thermography should provide. The rather subtle social processes involved in accepting a new method by the orthodox medical establishment could also exert some influence (1). Last but not least the rather unclear understanding of mechanisms of skin temperature contrast formation and the difficulty of assessing the very complex thermal pictures could be esteemed as essential drawbacks.

Nowadays the conspicuous technical and computing developments of thermal cameras are a big bonus. Also the functional rather than morphological nature of thermal pictures is better understood now than in the glorious sixties and seventies period. (23). One can observe a new arousal of interest regarding medical thermography even in the hitherto most difficult field of breast malignancies detection and evaluation (18, 20, 31). However the two just mentioned difficulties seem to present still quite a problem for actual and potential users in the medical thermography applications.

Thus it seems worthwhile to discuss these two topics more in detail.
In the first part the thermal and non-thermal mechanisms of thermographic skin temperature contrasts will be considered; in the second – the possibility of a simplification of diagnostic assessment, thanks to transforming thermal temperature pictures onto the maps of pixels classified into a few diagnostic level classes and a practical realization using a computerized procedure, developed under the Committee for Scientific Research in Warsaw, Poland grant Nr 8T11E 040 10.

1 The thermal and non-thermal factors of skin temperature contrast formation

I would dare say, "at the beginning there was contrast". Contrast, that is differentiation in space or time, is indispensable condition of any perception.
Temperature contrasts relevant for thermography may have thermal or non-thermal sources in deeper tissue layers. In the thermographic literature one reads almost exclusively about thermal origins. Thus from these I would like to start our consideration of temperature contrast formation (cf fig.1).

Fig. 1

In this case the focus (inflammatory, tumor etc.) is regarded as a source of heat related to increased blood flow and/or metabolism. The skin temperature contrast is thus created in two ways: through heat convection by blood and by tissue conduction and/or as the result of surface vessels reaction.
In the first case contrast propagation towards the surface is realized without the intermediary of energy transformation. In the second one – there are the biochemical and/or nervous conductance processes staying in between (cf fig. 1).

1.1 Thermal factors of skin temperature contrast

1.1.1 Convection and conduction

Convection of heat by blood flowing through the focus area is a mechanism with minor loss as compared with conduction on the same distance in tissue (27). The skin contrast is related to the temperature increase in the focus and to the existence of favorable systems of perforators. Anyway the surface temperature contrast created by convection is bound to be

poorer than deep contrast on the level of the focus. This case seems to be rather simple and it does not demand more elaborated discussion.

However, the occurrence of measurable contrasts by means of conduction is more controversial. Most of the authors believe that this is the most important mechanism. As far as I know there are very few papers analyzing this issue quantitatively?

How I would like to present some ideas which occurred to me while reading the most important papers on this subject available to me (6, 7, 19, 21).

Fig. 2

Fig. 2 presents the scheme of Nilsson and Gustaffsson's experiment (19). Titanium capsule, seized 4 by 12 mm, heated electrically was implanted chronically into the subcutaneous tissue on different depths a = 4.7 to 7.9. After 30 minutes of heating the distribution of temperature on the shaven skin was measured. It should be stressed that the thermal conductance is about 44 times larger for titanium than for tissue. Thus the conditions for heat propagation to the surface are more favorable in case of titanium source than in case of tissular heat source.

Fig. 3

Fig. 3 shows joined results compiled from results of Gautherie et al. with these of Nilsson-Gustaffsson (7, 19). On the abscissa the titanium source specific heating power (mW/cm^3) is expressed as multiple of the maximum tumor specific heating power equal to 71 mW/cm^3 as found by Gautherie et al. (7)[2]. It can be seen that the titanium source with specific heating power, equal to tumor's maximal one (i.e. 71 mW/cm^3), placed at 7.9 mm depth cannot induce any substantial surface contrast whereas analogous source at 4.7 mm depth can induce, by means of conduction, only about 2° excess of surface temperature. On the other hand, however, it is known that an excess surpassing 2° is quite frequently found above tumor lying deeper than 5 mm. Furthermore, the maximum temperature excess above the titanium heater with specific heating power of 71 mW/cm^3 was only about 1.3° at 5.4 mm depth as seen from fig. 4.

Fig. 4

From this figure one can see also that the 5° excess was found only at specific heating power 4.6 times surpassing the maximum tumor level.

[2] the exact value was 70.8 mW/cm^3

Fig. 5

Another approach is presented on fig. 5. Here the theoretical maximum heating powers, for various spherical sources, are confronted with the line representing the minimum heating power necessary to induce a surface temperature excess of 0.5° calculated as function of source depth as established by Nilsson and Gustaffsson (19). The crossing points of solid lines with dotted one correspond to cases in which maximum theoretical power of the tumor equals the minimum power necessary for appearance of 0.5° excess. So they correspond to the lowest diameter limit for delectability by conduction. Thus, for instance, the surface tangent spherical tumor with specific heating power equal to say 15 mW/cm^3 can induce by conduction a surface temperature excess of 0.5° starting from 16 mm diameter. The corresponding minimum diameter for spherical tumor of say 75 mV/cm^3 is 7 mm (cf fig. 6).

Fig. 6

One can calculate from results of Nilsson and Gustaffsson (19) that when the depth of titanium source was increased by 70% there was necessary 400% heating power increase to maintain the 0.5° temperature excess.

Notice that the half-degree criterion of detectability is indeed a very poor one as physiological surface temperature differences may often reach or even surpass one centigrade, depending on the body site.

The level of maximum surface temperature excess above the focus is also related to heat conductance of intermediary tissues. Calculations show, however, that this influence differs surprisingly from what could by expected at the first sight.

The Nilsson-Gustaffsson's formula (19, equation (4)) can be simpler rewritten as

$T_{max} = F(K) / K$

Where F (K) is a slow increasing function of tissue thermal conductance K which itself can vary 3-5 times by the transition from the state of complete arrest to complete patency of blood flow (4, 22). One can see from this that T_{max} must decrease with increasing tissue thermal conductance. Two practical implications of this are illustrated on fig. 7 and fig. 8.

Fig. 7

Fig. 8

Fig. 7 shows that an inflammatory aureole around the focus will work towards diminishing the surface temperature excess as compared with analogical focus without such aureole. Fig. 8

shows that an adipose tissue layer above the focus will work towards increasing the surface temperature excess. Both implications are rather surprising but they have a smart experimental support offered independently by Onai et al. (21).

Fig. 9

Fig. 9 presents their experimental scheme and results. The copper bar of 10 mm diameter immersed in temperature regulated water bath, 40-40.8°, served as heat source simulating the focus. The bar top shielded with polystyrene foam was covered successively with paraffin, acrylic or copper and lastly again paraffin layers. Onai et al. have found that the surface temperature of paraffin was neatly lower in case of copper plate than in case of acrylic plate. This puzzling result can be explained as follows (cf fig. 10).

Fig. 10

Thermal drop Δ T on tissue thermal resistance R, in an arbitrary direction from the focus towards the surface, can be considered as the resultant of perpendicular drop $\Delta T_{\perp}$ and parallel drop $\Delta T_{=}$. These are proportional to the respective equivalent resistance $R_{\perp}$ and $R_{=}$. One can see that the lower $R_{=}$, as compared with $R_{\perp}$, the greater mass of tissue will be engaged in cooling down the focus hence the lower surface temperature. A similar reasoning shows (cf fig. 11) that the lower thermal resistances, between site 1 deep in tissue and site 2 on the

Fig. 11

Surface and vice versa, the lower the surface temperature differences t_1-t_2 hence poorer contrast.

To close the discussion about convection and conduction one should mention that in both cases the deep temperature contrast Δ T is bound to be attenuated while propagated towards the surface, independently of the kind of intermediary tissues. Both these processes are passive ones, i.e. neatly dissipating the energy (cf fig. 12).

Fig. 12

1.1.2 Temperature contrast propagation with the intermediary of biochemical processes

There exists still another, non-convective and non-conductive, possibility of temperature contrast propagation. It is the influence of shifted focus temperature on the affinity in the enzyme-substratum reactions (cf fig. 1).

The temperature coefficient Q_{10} of chemical reactions rate equals 2-4, in biologically relevant temperature range as established by Van't Hoff and Arrhenius. It means that 10° temperatures increase results in two-four-fold increase of reaction rate (9, 21). In other words temperature increase resulting in some 3% enhancement of mean kinetic energy leads to 100-300% increase of reaction rate, a disproportionably great effect indeed. Moreover, Q_{10} is different for various reactions, which can result in metabolic disequilibrium (9). The temperature effect on enzymatic reactions can be ever more dramatic with Q_{10} values possibly surpassing 20 (9). A strong temperature dependence was found e.g. for acetylcholine-cholinesterase in various fish species (9). Fig. 13 presents three types of such temperature-affinity characteristics found for various enzymatic systems in different fish species crabs and rabbits, adapted from (9, fig. 7-14, 7-15, 7-16 and 7-33).

Fig. 13

I could not find any such information concerning the Primates. Nevertheless, it seems justified to admit, as working hypothesis, the existence of analogical dependencies in man. The rate of acetylcholine-cholinesterase reaction has a key position for synaptic conductance and for smooth muscle contraction. The strong temperature effect on this reaction's rate could possibly lead to disproportionately great changes in superficial vascular tonus resulting in amplification of skin thermal contrast as compared to the one existing deep on the focus level. This possibility has not yet been considered, as far as I know. I believe that it could be a fruitful subject for investigation.

1.2 Non-thermal factors o skin temperature contrasts

Non-thermal factors of skin temperature contrasts are presented on fig. 14. Since they are mentioned in astonishingly few papers (3, 11, 14, 26) only an outline will be given here.

In this case the focus can be considered rather as a tissue irritation spot than as a heat source.

Fig. 14

1.2.1 Humoral-hormonal effects

The mechanical and electro-chemical impinge of the focus can often result in inflammation (16, 29). The damage of the cellular membrane results in its polarization changes: potassium leaves and sodium enters the cell. Potassium inhibits the smooth muscle contraction. The concentration increase of extra cellular potassium can be considered as the possible factor of vascular contraction. The tissue irritation can also be accompanied by local increase of calcium concentration (29) as well as in pH, pCO_2, pO_2 changes, histamine and heparin release from mast cells, serotonine release from platelets and activation of kallikrein with kinins formation (3, 12, 14, 17, 32). All these are factors, which can possibly result in superficial vascular reactions with temperature contrast, probably greater than in case of thermal conduction or convection.

1.2.2 Nervous reflex

We are considering nervous reflex as the last but probably very important factor of thermographic symptomatology (cf fig. 14). The one-neuron, axon, reflex seems to play an important role in eliciting symptoms in the vicinity of the focus. The multi-neuron reflex, in the other hand, provides remote symptoms possible even in different dermatomes. Perhaps in this direction one should search for the key to thermographic diagnosis of deeply located disorders (1, 9, 10, 11, 12, 14, 17, 25, 26).

These reflexes can be elicited in biochemical or mechanical ways, through the pressure exerted by the focus on vascular autonomic ganglia, possible also by intermediary of piezoelectric effects (28, 30).

Bearing in mind the threshold and facilitation and irradiation phenomena as well as the amplifying quality of motor end-plate (33) one can suppose that neurogenous vascular reactions can easily result in superficial thermal contrasts greater than in case of convective-conductive phenomena. All these non-thermal mechanisms have not yet been much explored but they undoubtedly represent a fruitful field for future study.

1.3 Final remarks

1.3.1

I would like to stress that thermal contrast is a common result of irritating factors and of the reaction of injured tissue and the whole organism as well. Thus superficial thermal contrast

bears the information about both these sources. To decipher both these information seems to be one of the main subjects for future thermographic research.

I think that it will require especially the development and wider use of functional thermographic tests. I believe that the first steps in this direction are encouraging. I should mention here the long-year patient work on *Regulationsthermographie* of late dr Schwamm (25, 26) and Jutta and Arno Rost (23) among many others.

1.3.2

In this presentation various factors are considered separately, which is artificial. One should be cautious however not to be led to false conclusion by this analytical approach. Thus, for instance, the inflammatory aureole on one hand works against the superficial temperature excess owing to his quality of better heat conductor. On the other hand however this very aureole is an additional source of heat, which works for the superficial temperature excess. Each of these factors can possibility prevails or they can conceal each other depending on momentary and local conditions.

2 The conception of *natural* normal values and the transformation of the thermal maps onto diagnostic level classified pixel values maps

2.1 The second difficulty in thermographic diagnostic evaluation seems consist in:

- The quite complicated pattern of surface temperature distribution with no clear indication about which local values should be treated as normal and which – as pathological, and how to discriminate these conditions from one another;
- Medical thermography being essentially not morphology but rather function assessment procedure, is especially suitable for reactivity tests with some pharmaceutical or physical load e.g. chill, warming etc. to take its full diagnostic advantage; this demands again the appropriate discrimination criteria with tedious collecting of *normal* and *pathological* cases without any certainty about an absence of some disfunction hidden in organism or in the considered part of the body, approved as *normal.*
- Considering the large skin temperature differentiation on the human body (see for instance (24), and the great hormonal and neurogenic dynamics of the blood circulatory system (15), one should have discriminating mean or local values of temperatures and/or

of some other derivative index, e.g. thermographic index of inflammation of Collins and Ring (5) or some provocation test quantitative results. This demand looks like an impossible task, when approached in the typical way of selecting appropriate normal and pathological groups etc.

- The anatomical reference of particular thermal features is often doubtful and at times simply impossible, particularly when the skin temperature is not much differentiated from the background.

2.2 The conception of *natural norm* – a proposal

To be free from these difficulties one proposes a functional receipt for discrimination between whichever quantitative thermographic parameter, primary, as the minimal, maximal, mean, temperature – for a group of thermal image pixels or only for one of them – or derivative, as thermographic index, temperature change velocity after cooling or after other provocation etc.
Consider a set of measured values of some quantitative thermal parameter – as numerous as possible;
Create a corresponding statistical distribution histogram;
If the distribution looks more or less statistically homogenous, with only one modal value, one cannot establish a natural norm on it;
If there are more component homogenous subsets suitable for a neat discrimination, with distinctly differentiated modal values, there is a possibility to determine a *natural norm* on it. This can be done by choosing a threshold point, arbitrary or by a formal cluster analysis, still on an arbitrary assumption about the 1^{st} or 2^{nd} kind of error value one agrees to accept;
Repeat this using two parameters. If the discrimination of subsets is still possible for two of them, see if the differentiation is better in the two-parameter case than in the single one;
If so, repeat this adding the another one, and so on, till the differentiating effect ceases to improve; then stop the procedure;
Observe under which subset fall the results obtained from testing a small group with typical clear disorders you wish to discriminate.

2.3 Methodology and material

The device was a second hand thermo – camera AGEMA 870 coupled with a visual camera PANASONIC model WV-BP31212E with a 5V40 optics, both coupled by two dedicated interfaces to the PC[3];

The room was thermally stabilized between 19 and 21 centigrade;

The integrated thermo-visual system was assisted by a dedicated program controlling the measurements, creating the data basis end analyzing the results (2);

Both hands of a group of 859 persons with peripheral circulatory disorders of different degree and etiology (Raynaud's syndrome, diabetes, angina pectoris), aged 16-63 y. and a group of 94 healthy volunteers aged 22-67 y. were tested using a special stand, created for the purpose of comfortable for the patient immobilizing his hands during the 10 minutes of temperature restoration measurements;

After an initial hands temperature standardizing 37 centigrade, 5 minutes water bath, they were allowed to accommodate to the thermography room temperature during 30-minute period, with hands hanging freely and not touching anything,

Then the initial thermogram of both hands was taken followed by a 5 minutes, 15 – centigrade and then immediately 5 minutes, 37 – centigrade water baths;

Afterwards the hands were carefully dried with a very soft paper wiper, a series of 11 thermograms were automatically taken on 30 s., 60 s., and then on each 60 next second till the 10^{th} minute after the bath;

The thermo-visual unit measured the temperatures, using the carefully checked up external temperature standard AGEMA radiator and an appropriate calibration using a set of 15 calibration curves obtained previously for different temperature ranges, in a separate experiment; the thermal range was set on 20 centigrade;

An IR temperature reference AGA model 22 was always present in the field of the camera

The program calculated for each pixel, on both hands, the actual temperature, and the temperature restoration index (see fig.18 for a definition);

The minimal, mean and maximal temperatures were calculated as well, for regions of interest chosen by the operator;

[3] Produced for this KBN program by B. Więcek from the Institute of Electronics, Technical University of Łódź, Poland

The distribution curves from the whole group d-base content were drawn without any discrimination as to a disorder etiology, sex and age. Such discriminations are still possible with the program, but were precluded for clarity of the conception demonstration. Only one group of 14 Raynaud's syndrome was included to demonstrate the pathology group localization procedure in the general population distribution.

2.4 Results and discussion

The results are presented on figures 15-19. Figures 15 and 19 present distributions obtained with the minimal possible interval width for the mean fingers temperature and a temperature restoration index respectively.

Fig. 15-19

All parameter value distributions presented demonstrate heterogeneous nature, with two quite distinct modal values. Thus they could be treated a superposition of two more or less homogenous subsets. The localization of a group of explicit pathological results as well as the general physiological considerations allows one to take the left subset as subset of pathological values, and the right one as non-pathological.

Thus the mean, minimal and maximal finger temperatures as well as the temperature restoration index for fingers can serve to establish a *natural norm*. Four points seem to be worth stressing: First, there remains still the somewhat arbitrary choice of threshold value for discrimination of the *bad* from the *good* results. Secondly, the non-specific nature of thermographic parameters variety. Thirdly, a strong statistics needed for the quantitative parameter values distribution saturation. Forth, simplification of the result form using the natural norm classified maps.

As to the first issue one has to start from the minimal *saddle* value between the modal apexes. This would be the simplest *rule of thumb* approach to the discrimination threshold question. Then there are cases in which one needs especially a grater specifity or a greater sensitivity of the conclusion. In such situations one has to shift the discrimination threshold towards the higher or lower values respectively. This can be done easily using a program function. The result can be observed immediately on the *diagnostic level classified picture.* Generally one can obtain a reasonably good prompt from one's experience. But in a special exacting cases, as a juridical claim, serious aftermaths, therapeutical or prognostic, and lest but not least in the research domain, a quantitative probability estimation of the 1st and 2nd

kind of error would be more advisable. These can be calculated from the program data e.g. using a procedure known from the analysis of a mixture of several radioactive elements decay curves, as the *peeling off* process, quite feasible with the nowadays statistical programs. The examples will be published elsewhere.

The second issue, the non-specifity of thermographic parameters and results is worth some consideration. Because this was one of important objections raised against thermography from medical circles. Here one could say that thermography is not and perhaps will have to bide to be a proper tool to obtain a specific diagnostic conclusion. Happily enough the diagnostic specifity has to rise with the progress of diagnostical process, to be the highest at the very and of it; whereas, at the beginning, the tests need not be very specific, but most sensitive instead; and furthermore cheap and non-invasive, which is just the case with thermography. Thus one should acknowledge the usefulness of thermography as a first contact method, rather than a final one and as a tool to know that there is or there is not some kind of dysfunction present rather than to establish its aetiology. Thus the presented technical system and conceptual approach meets the special features of thermography. Its strongest side being the negative rather than positive result and the establishing of the enhanced risk group rather than assisting a final diagnose.

The third concern refers to the successful use of the *natural norm* instrument. It will work smoothly only with the huge data abundance – several thousands of them will do. This is quite feasible using the program for 2-3 years. In a year one can easily do some 500-1000 examinations of a given body region, feet, hands, breasts, faces etc. The distribution can be assessed for some general parameter, related to the whole region of interest e.g. its mean temperature or thermographic index or else for each pixel in the ROI, as for example the pixel temperature measured at a given time. The coupling of thermal image with the visual one allow for assessing of a parameter value even when the skin portion is not visible on a thermogram, because of its to low temperature.

Fourth, a *natural norm* classified thermogram presents a reduction of the rich information of plain thermogram only to the most immediately useful one. Therefore a serious drawback for the acceptance of thermography by not specialized physicians can be avoided. Thermography proper place being especially at the beginning stage of diagnostic process, this seems particularly important in the first contact cases e.g. family doctors practice.

3 Conclusions

From the above considerations, bibliography data and the own experience gathered with the thermographic system described one can conclude that:

3.1

Heat convection and conductance can be regarded as the important factors in thermographic symptomatology only in cases of greater (diameter surpassing 20 mm), not deeply located foci with extremely great caloric effect (surpassing 60-70 mW/cm_3).

3.2

There are some reasons that much more important role can play: superficial vascular reactions related to deeper temperature shifts by the temperature effect on enzyme reaction rate and in consequence on nervous conductance; superficial vascular reactions elicited on the neuro-humoral-hormonal way by the non-thermal, bio-physico-chemical changes in the focus; axon and viscero-cutaneous reflexes.

3.3

The literature review showed that mechanism mentioned above in section1.4.2, hitherto drawn very little attention. They seem to offer promising directions for further investigations.

3.4

Thermography can be esteemed as a useful diagnostic tool for assessing the presence, intensity and a rather large classification of pathology on the skin surface and in the several centimetre deeper tissue layers as well.

3.5

Thermography does not give information about the topography and morphology of the pathological focus.

3.6

Thermography is much more sensitive than specific method.

3.7

Thermography's proper place is at the first contact and at a starting point of diagnostic process rather than at its final phase.

3.8

The *natural norm* conception proposed can assist and simplify the normal / pathology discrimination.

3.9

The thermo-visual hardware and software system described is a useful tool for establishing the general as well as local thermographic parameters value distribution and the *natural norm* for a given region and thermographic parameter set.

3.10

The conceptual and technical tools presented could help to shift thermography to its more proper place: at the beginning of the diagnostic process rather than at its final phase; for exclusion a dysfunction or confirming its presence rather than to ascertain its aetiology; for establishing an enhanced risk group rather than for the assisting a final diagnose; to serve a first contact eg. Family doctor rather than the highly specialized one.

References

1. Blume S.S.: Social process and the assessment of a new imaging technique Int. J. Technol. Assessment in Health Care, 1993,9,3,335-345.
2. Błaszczyński J., Górski S.: Program wspomagający zintegrowany system termograficzny i wizyjny do diagnostyki ukrwienia obwodowego.

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3. Bossy J.: Bases neurobiologiques des réflexothérapies. Masson, Paris 1975, 79.
4. Bowman H.F., Cravalho E.G., Woods M.: Theory measurement and application of thermal properties of biomaterials. Ann. Rev. Biophys. Bioeng. 1972, 4, 43-80.
5. Collins A.J., Ring E.F.J.,: Measurement of inflammation in man and animals by radiometry. Brit.J. Pharmacol. 1972,44,145-222.
6. Gautherie M., Gairard B.: Fondements thermodynamique et thermocinetiques de la thermographie cutanée des cancers du sein. In: II European Congress of Thermography, Barcelona 1978.
7. Gautherie M., Quenneville Y., Gros Ch.: Puissance thermogene des épitheliomas mammaires. III. Étude par fluvographie de la conductibilité thermique des tissues mammaires et de l'influence de la vascularisation tumorale. Biomédecine 1975, 22, 237.
8. Hagay C., Mayars C., Couthaud M, et al.: Place de la Théléthermographie dans la diagnostic du cancer du sein. III Journée de la Société Française de Sénologie. Saint Cloud 1981, p. 317-331.
9. Hansen K., Schliack H.: Segmentale Innervation, Ihre Bedeutung für Klinik und Praxis. G. Thieme, Stuttgart 1962.
10. Henriksen O., Sejrsen P.: Local reflexes in microcirculation in human cutaneous tissue. Acta Physiol. Scand. 1976, 98, 227-231.

11. Hobbins W.B.: Objective interpretation of the afferent autonomic nervous system. In: Proceedings of the 1973 Annual Meeting of the American Thermographic Society. AGA Lidingö 1975, 67-91.
12. Hobbins W.B.: Sympathetic influence in thermal signals in breast imaging. In: II European Congress of Thermography, Barcelona 1978**.**
13. Hochachka P.W., Somero G.N.: Strategies of biochemical adaptation. W.B. Saunders, Philadelphia 1973.
14. Kellner G.: Anwendungen der Medizinischen Thermographie. Symposium in Baden bei Wien, 1972. AGA Lidingö 1972.
15. Koczocik-Przedpelska J., Górski S.: Relationship between sensory nerve conduction and temperature of the hand.Acta Physiol.Pol, 1993,34,1,21-29.
16. Krylova N.V.: Development of distrophic processes in connection with the peculiatities of microcirculation in malignant tumors. In: 8th European Conference on Microcirculation. Le Touquet, 1974. Karger, Basel 1975, 309-310.
17. Lundborg G.: Structure and function of the intraneural microvessels as related to trauma, edema formation, and nerve function. J. Bone Joint Surg. 1975, 57A, 938-948.
18. Montruccoli G.C. Angiotherrmography and X-ray mammography for early diagnosis of breast cancer. Proceedings of 7th European Congress on Medical Thermology. Vienna, 1-3 may 1997.
19. Nilsson S.K., Gustafsson S.E.: Surface temperature over an implanted artificial heat source. Phys. Med. Biol. 1974, 19, 677-691.
20. Ohashi Y., Uchida O.: The diagnostic significance of thermography in patients with Breast Cancer after surgery. Proceedings of 7th European Congress on Medical Thermology. Vienna, 1-3 may 1997, 70.
21. Onai Y., Uchida I., Tomaru T., Irifune T., Yamazaki Z.: Medical thermography. Ed. K. Atsumi. University of Tokyo Press, Tokyo 1973.
22. Precht H., Christophersen J., Hensel H.: Temperatur und Leben. Springer, Berlin 1955, 367.
23. Rost Jutta: Die Regulationsthermographie. Paradigma Verl. Bellamont, 1997.
24. Rostkowska E. Górski S.: Asymetria temperatur rąk u dzieci uprawiających sport. Wychowanie fizyczne i sport.1996,40,1,45-56.
25. Schwamm E.: Thermoregulation und Thermodiagnostik. Phys. Med. Rehab. 1968, 9, 1-9.

26. Schwamm E.L Die Medizinische Anwendungen der Thermographie. Symposium im Baden bei Wien 1972. AGA Lidingö 1972, 196.
27. Seagrave R.C.: Biomedical applications of heat and mass transfer. The Iowa State University Press, Ames, Iowa 1971.
28. Sedlak W.: Bioelektronika (Bioelectronics). PAX, Warszawa 1979.
29. Selye H.: Calciphylaxis. University of Chicago Press, Chicago 1962.
30. Shamos M.H., Lavine S.: Piezoelectricity as a fundamental property of biological tissues. Nature 1967, 213, 267.
31. Usuki H., Ikeda T., t al. :L Clinico-pathological characteristics of non palpable breast cancer detected by thermography. Proceedings of 7th European Congress on Medical Thermology. Vienna, 1-3 may 1997, 71.
32. Wiegman D.L., Longnecker H., Miller F.N.: Microvascular response to hypoxia, hyperoxia, hypercarbia and localised acidosis. In: 8th European Conference on Microcirculation. Le Touquet, 1974. Karger, Basel 1975.
33. Wilkie D.R.: Muscle. E. Arnold Ltd. 1968.

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Legend to figures

Fig. 1. Thermal causes of skin temperature contrast
Fig. 2. Nilsson-Gustaffsson's experiment scheme
Fig. 3. Detectability of artificial heat source for different calorific effects (compiled from 7.19)
Fig. 4. Temperature profiles over artificial heat source (compiled from 7.19)
Fig. 5. Detectability of spherical foci for various seizes of metabolic rates (compiled from 7, 19)
Fig. 6. Detectability of spherical tumors tangent to the skin surface
Fig. 7. Influence of inflammatory aureole n tumor detectability
Fig. 8. Influence of fatty layer on tumor detectability
Fig. 9. Onai et al. experiment scheme (modified from 21)
Fig.10. Model interpretation of Onai et al. results