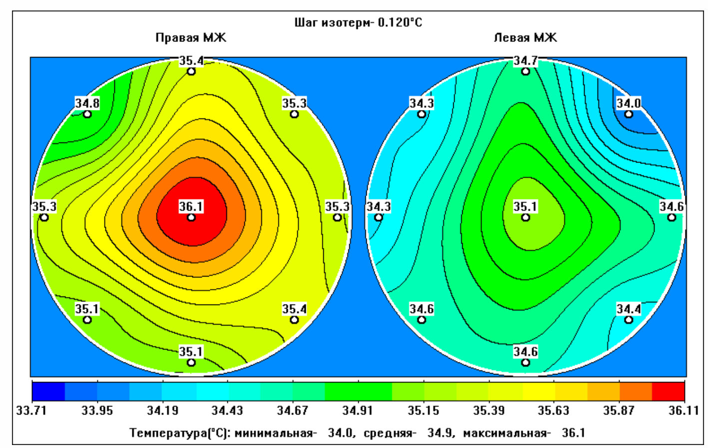
ESHO 2014 – Turin, Italy

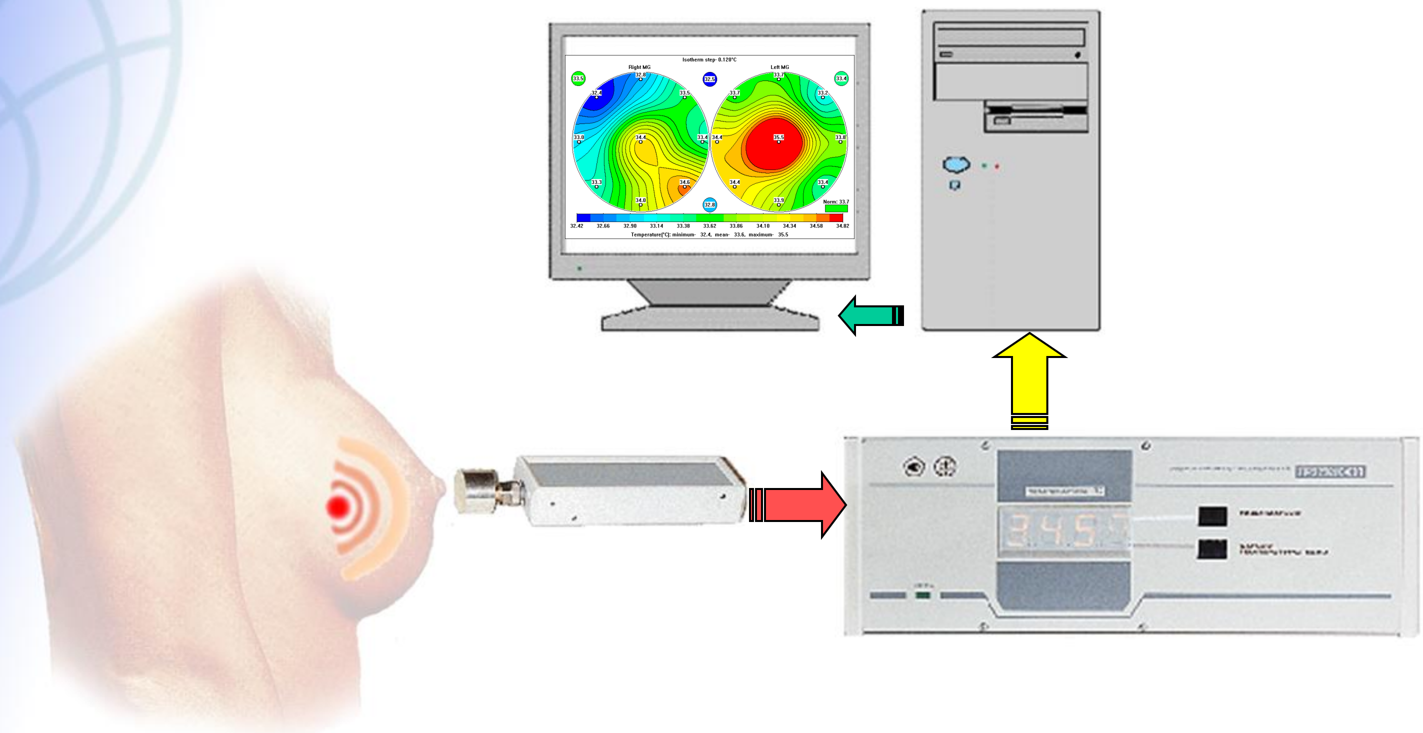
Microwave radiometer for medical application

S. Vesnin, M. Sedankin, L. Ovchinnikov

RES Ltd, Moscow – Russia

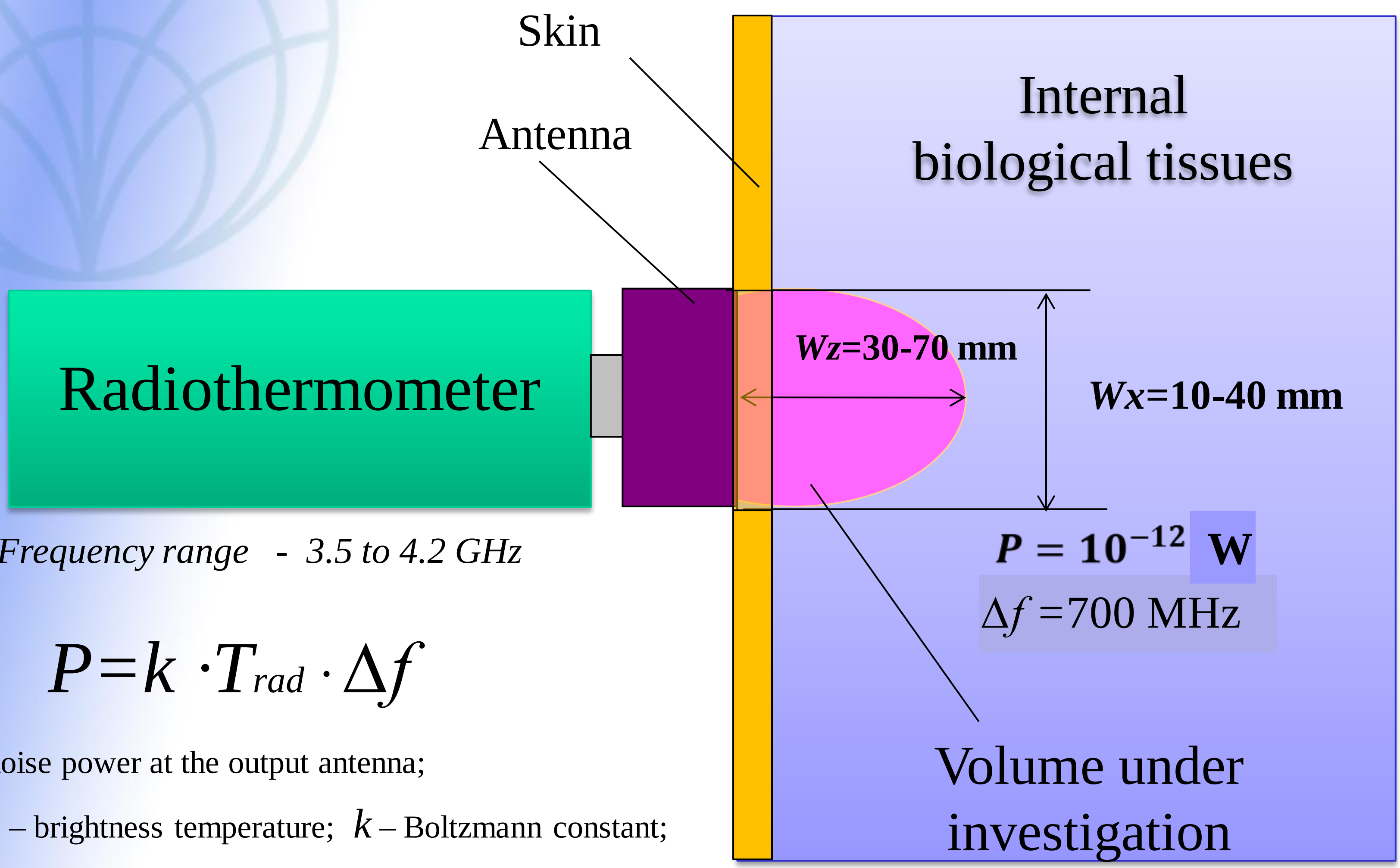


Microwave Radiometry Principles



The microwave radiometer receives and evaluates the natural electromagnetic radiation from the patient's internal tissues at microwave frequencies

Basic principle of microwave radiometry



$P = 10^{-12}$ W

Δf =700 MHz

Frequency range - 3.5 to 4.2 GHz

$$P = k \cdot T_{rad} \cdot \Delta f$$

P – noise power at the output antenna;

T_{rad} – brightness temperature; k – Boltzmann constant;

Δf – receiver bandwidth.

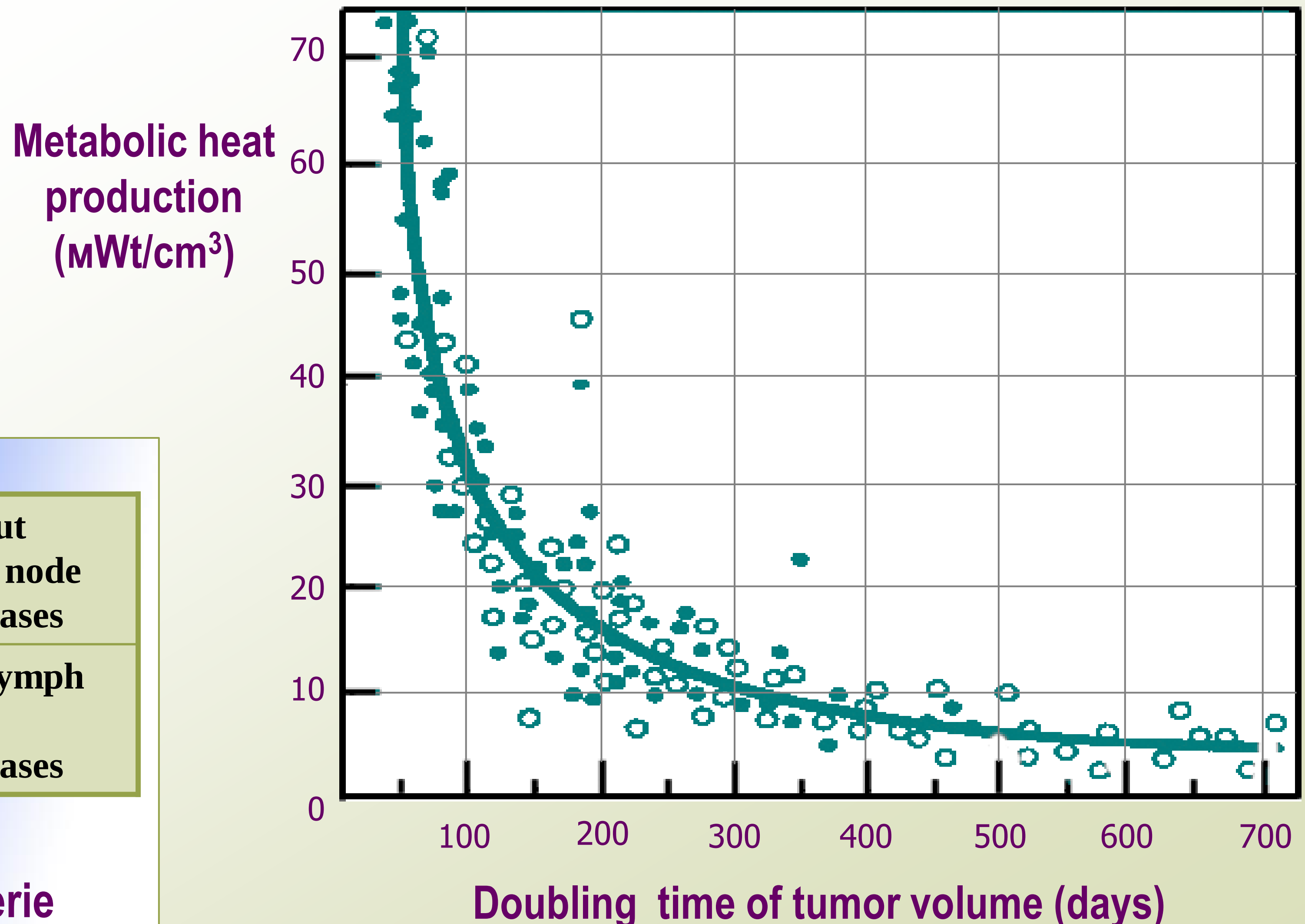
M. Gautherie Investigations

The French scientist M. Gautherie made dynamic observation on1245 patients with temperature changes of breasts, without clinical and X-ray mammography breast cancer symptoms during 12 years.

X-ray mammography and clinical examination were carried out annually.

Breast cancer was detected in 501 patients (40.2%) during 8 years of tests

Metabolic heat production as a function of doubling time of tumor volume



○	Without lymph node metastases
●	With lymph node metastases

M. Gautherie

The tumor growth dynamics is characterized by the doubling time of a tumor (mass or number of cells). The doubling time can vary widely (from 3 days to hundreds of days), but it is constant for a specific patient, and can be represented by an exponential curve. Also tumors with short doubling time can have a high specific heat generation (Watt/cm^3). When the tumor grows rapidly, energy consumption increases and heat generation rises.

Therefore, most of dangerous tumors (short DT, i.e. rapid growth) can be detected by thermal methods. These cases are about a quarter of all breast cancer patients.

Mathematical model of microwave radiometry

$$T_{Я} = \int_{-\infty}^{\infty} T(r) \cdot W_n(r) dV$$

$$W_n(r) = \frac{\sigma \left| \overline{E}(r) \right|^2}{\int_{-\infty}^{\infty} \sigma \left| \overline{E}(r) \right|^2 dV}$$

COMSOL MULTIPHYSICS

CST

SIMULATION

Bioheat equation heat and mass transfer

FEM

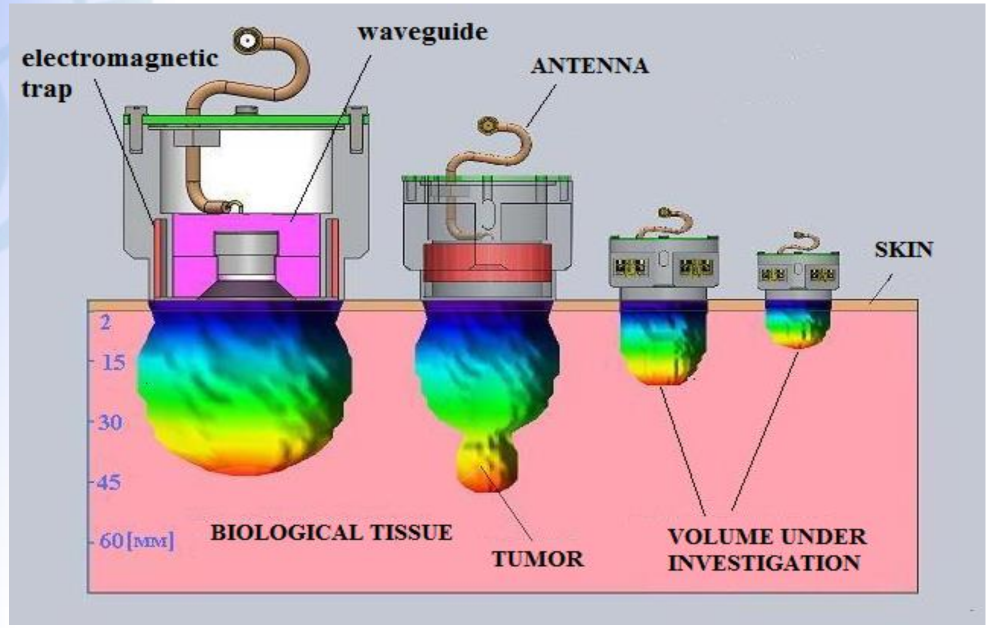
Equations Maxwell

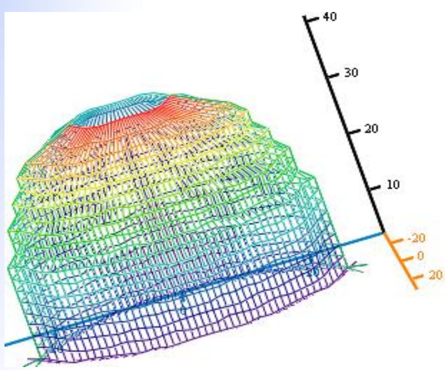
FIT (FDTD)

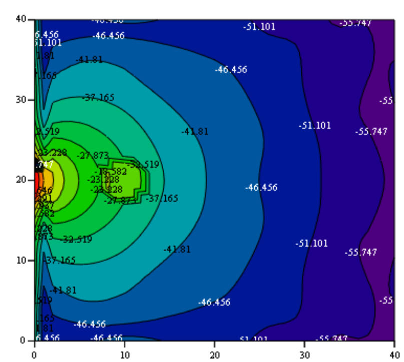
σ – electroconductivity

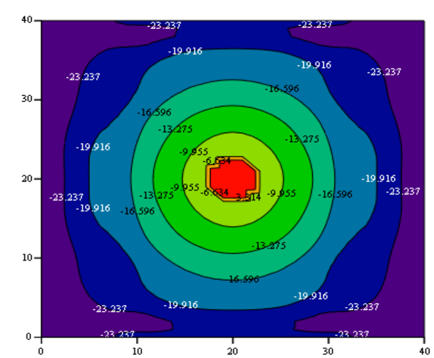
E(r) – the vector of the electric field created by the antenna in tissues.

Methodology for designing antenna applicators for medical purposes

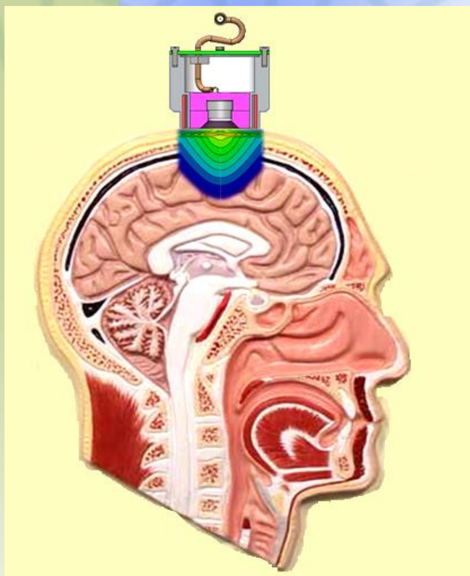


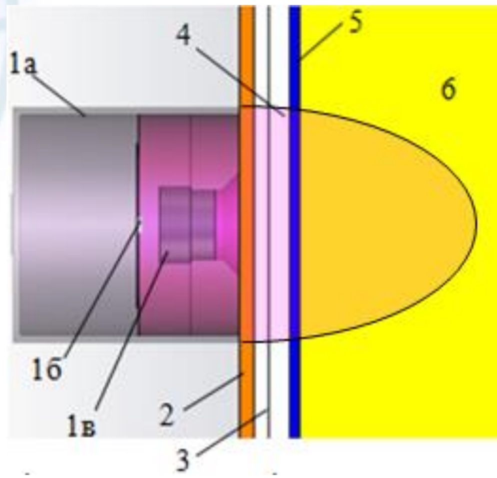


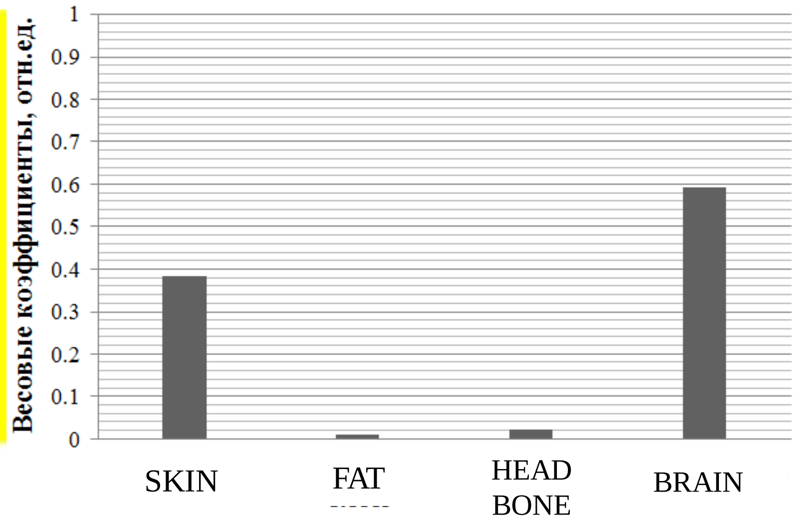




Efficiency of the antenna applicators







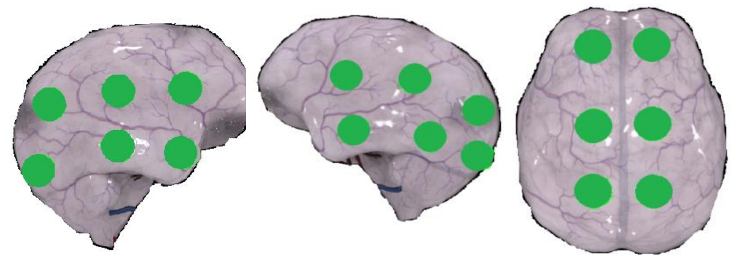
1a – antenna-applicator, 1б – excitation system of electromagnetic waves, 1в – IR-sensor; 2 – skin; 3 – fat layer, 4 – skull bones; 5 – cerebrospinal fluid layer; 6 – proper brain

Electrophysical simulation parameters 3.6 GHz	Skin	Fat	Bones skull	CSF	Brain
Permittivity	52.0	5.164	5.16	61.83	50.56
Conductivity, [Sm/m]	2.76	0.161	0.163	3.22	3.03
thickness of the layer of biological tissue *h*, mm	2	2	3	1.5	93.5

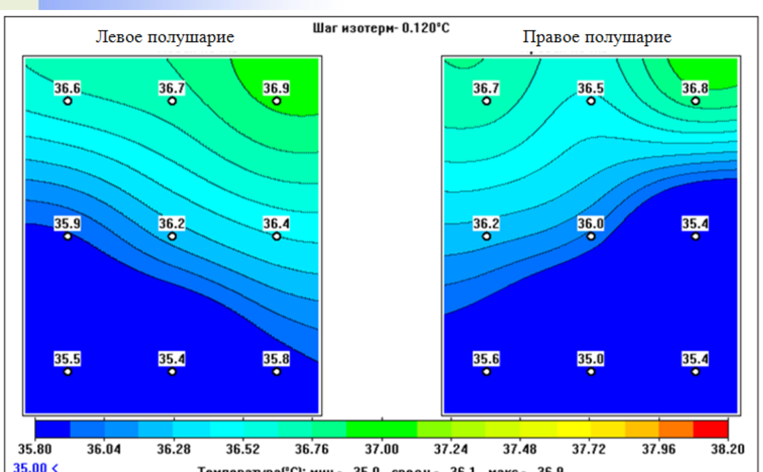
Efficiency of the antenna applicators

Brightness temperature measurements of brain

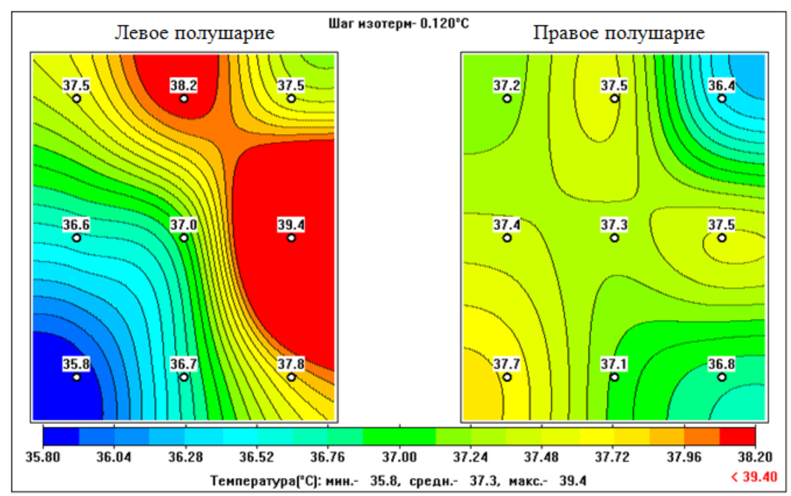
Scheme for measuring the internal temperature human brain



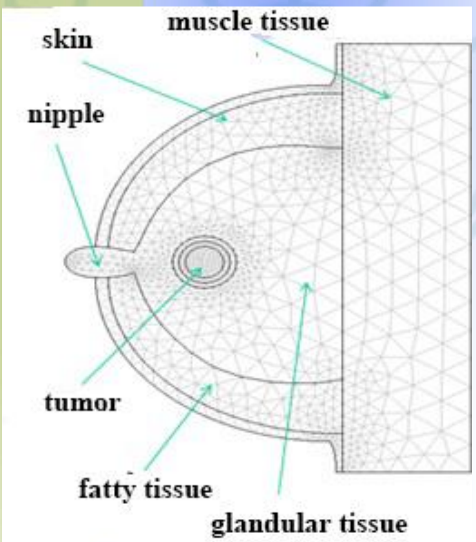
Typical thermal field of brain healthy person (25 years)



Typical thermal field of the human brain in the presence of cerebral infarction in middle cerebral artery (left hemisphere)



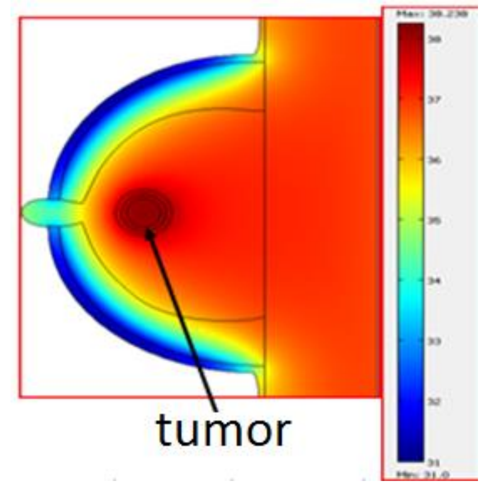
Creating a mathematical model of microwave radiometry



Solving equations of heat and mass transfer:

$$\nabla \cdot k\nabla T + Q_{met} - \rho_b c_b \omega_b (T - T_b) = 0$$

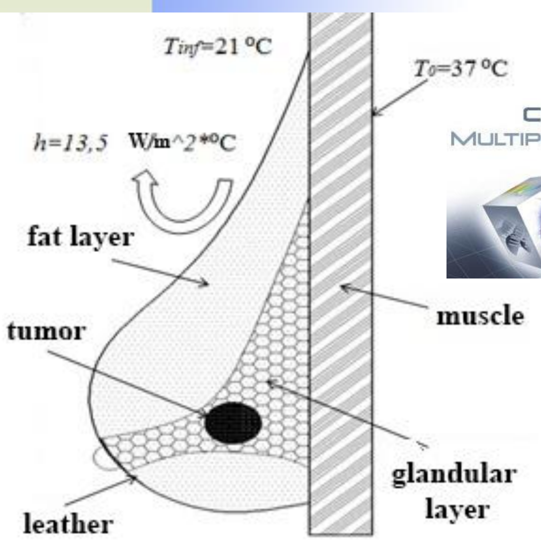
k – thermal conductivity of tissue[W/m·^{0}C],
Q_{met} – specific heat[Вт/м^2],
$\rho_b c_b \omega_b$– blood flow parameters[W/m^3·^{0}C],
T_b – arterial blood temperature[^{0}C],
h_a – heat transfer coefficient[W/m^2·^{0}C],
T_a – ambient temperature[^{0}C].



$$k\nabla T \cdot \bar{r} + h_a (T - T_a) = 0$$

$$\vec{n}(k_1 \nabla T)_1 = \vec{n}(k_2 \nabla T)_2$$
$$T_1 = T_2$$

external boundary conditions for continuity of biological layers



Analyzed about 30 different models.

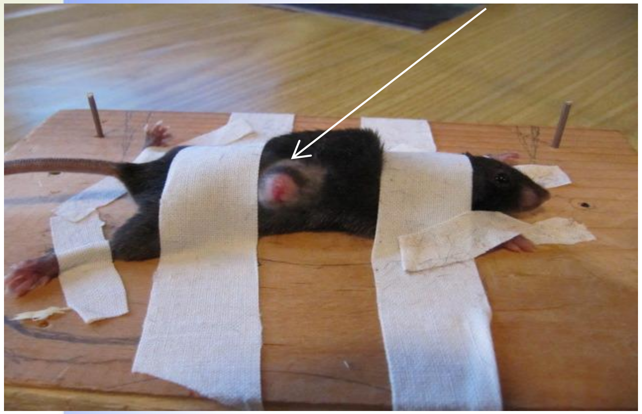
Thermal parameters of biological tissue	Tumor	Glandular tissue	Skin	Fat	Muscle
specific heat(*Qmet*, [W/m^2])	65400	700	1620	400	700
blood flow parameters (*ρbcbωb*,W/m^3·^{0}C)	48000	2400	9100	800	2400
thermal conductivity (*k*,[W/m·^{0}C])	0.511	0.3	0.376	0.21	0.55

Examples of application

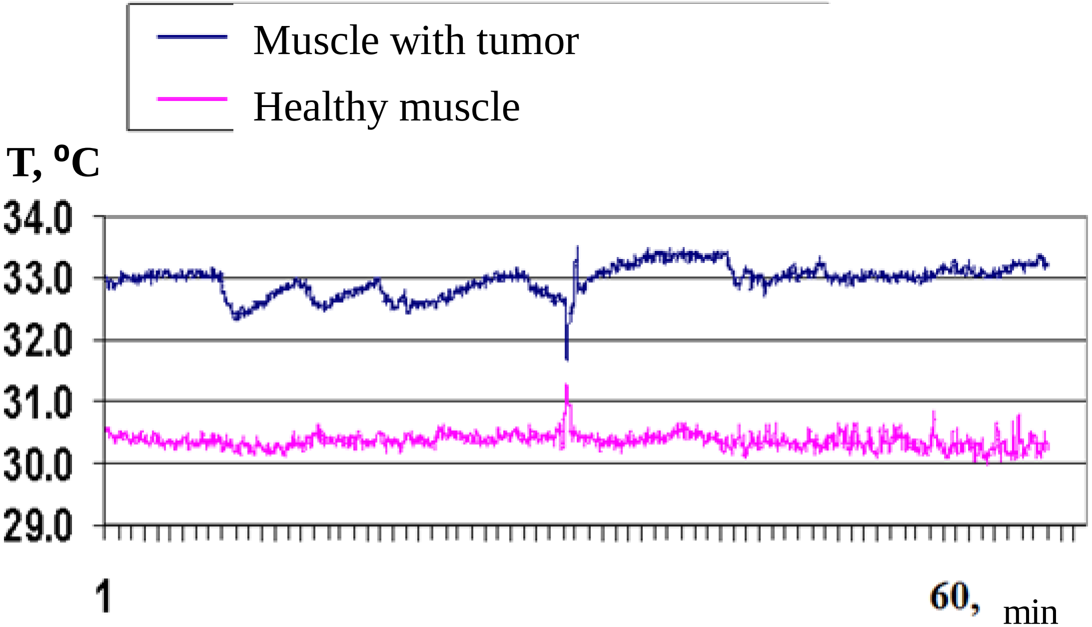
Register thermogram

Fixing labs. animal

TUMOR



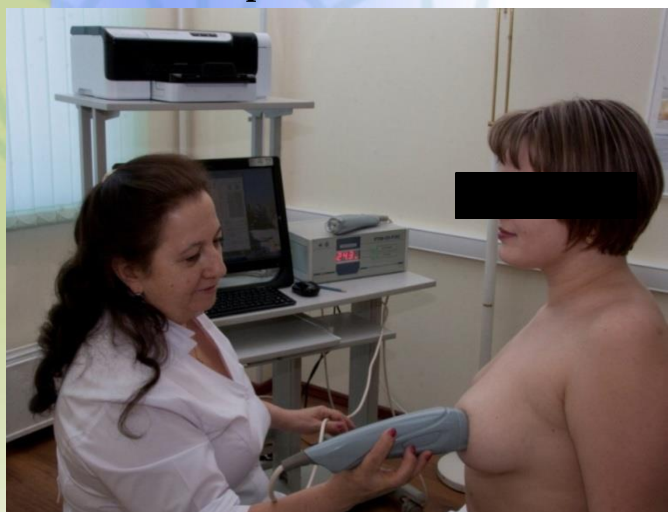
Two-channel signal recording



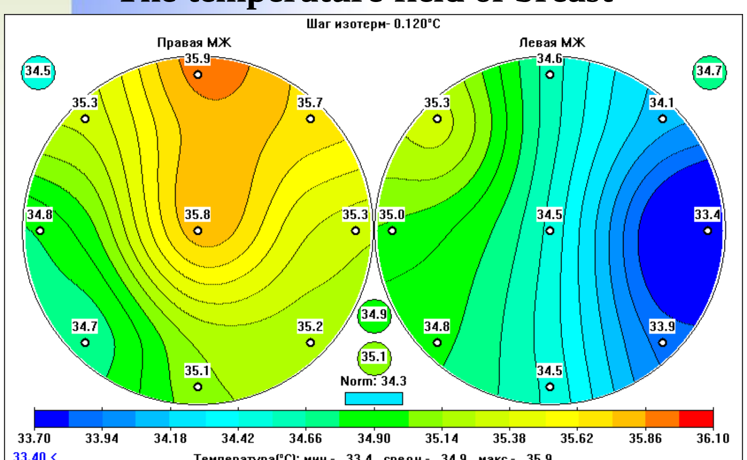
Features reception signal (broadband microwave radiation biological object own), allows you to get a fundamentally new information about the processes of metabolism, perfusion (microcirculation) and cell kinetics malignancies.

Examples of applications

Noninvasive measurement brightness temperature breast

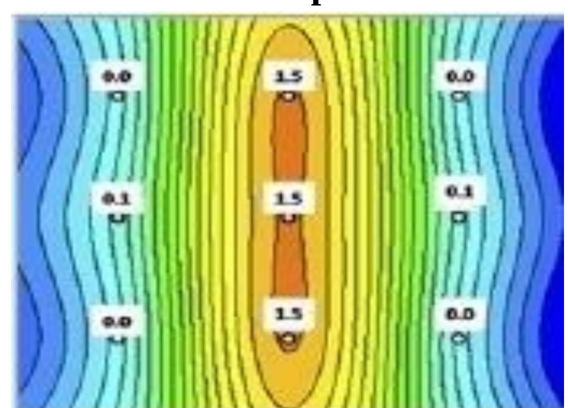


The temperature field of breast



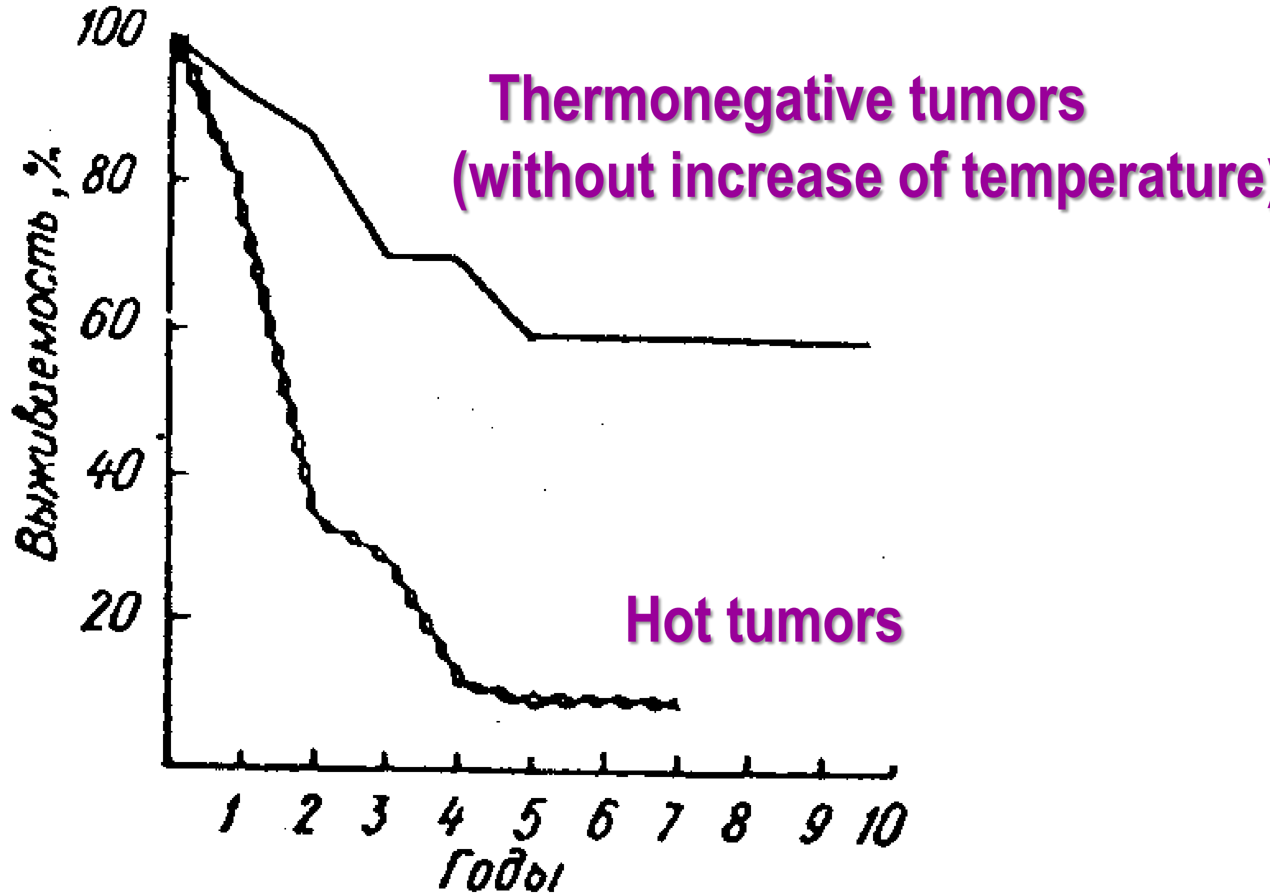
Noninvasive measurement radiobrightness temperature on the projection carotid

Temperature field on the projection of the carotid artery: an increase in temperature 1.5 ^{0} C



Thermal changes start at a stage that is previous to malignant growth, i.e. at the stage of the expressed proliferation and an atypical hyperplasia

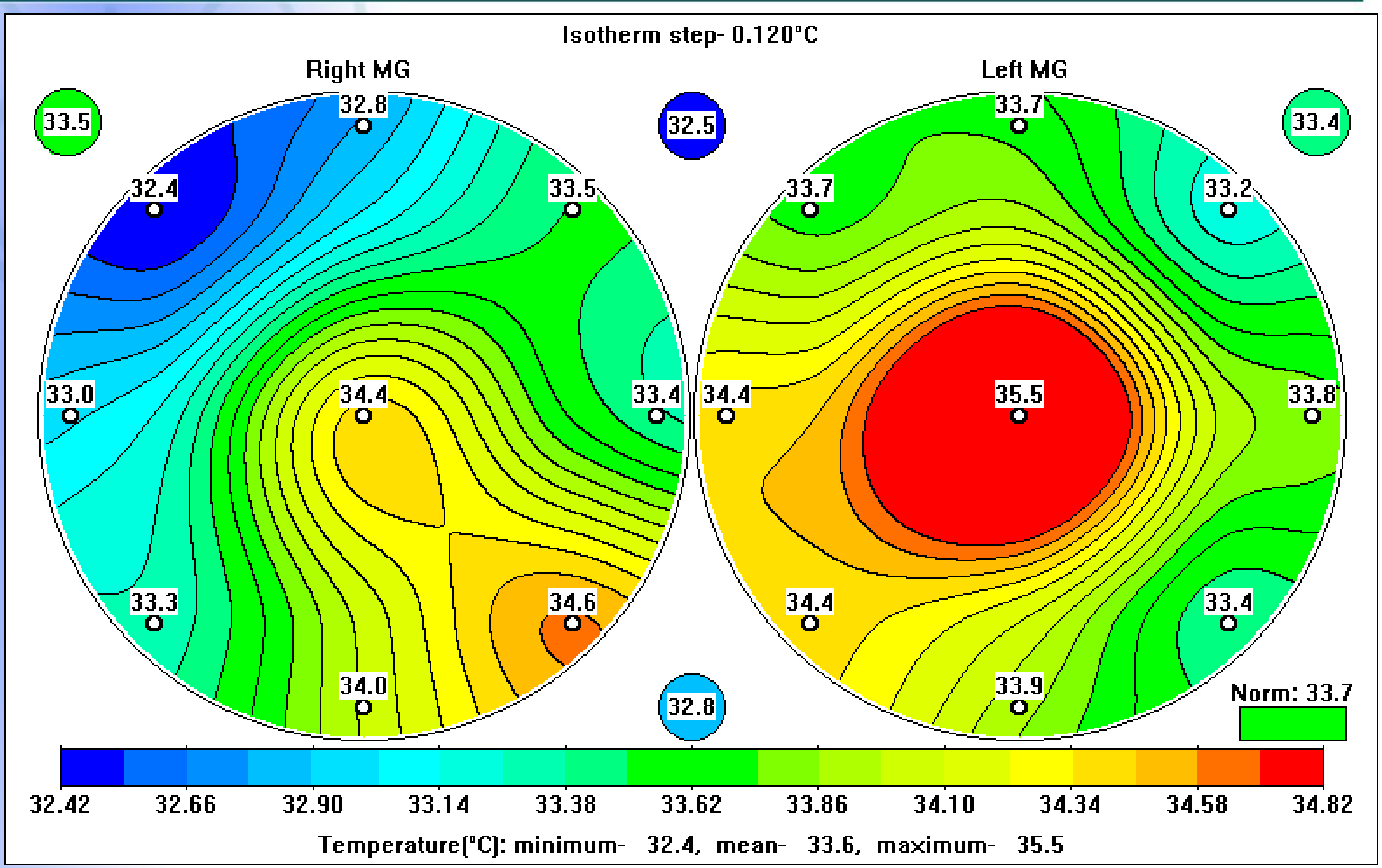
Patients survival with IIIb stage breast cancer depends upon thermal indications



RTM - Diagnosis

The method efficacy is confirmed by clinical trials, carried out on more than 3500 patients

Radiometric Temperature Field

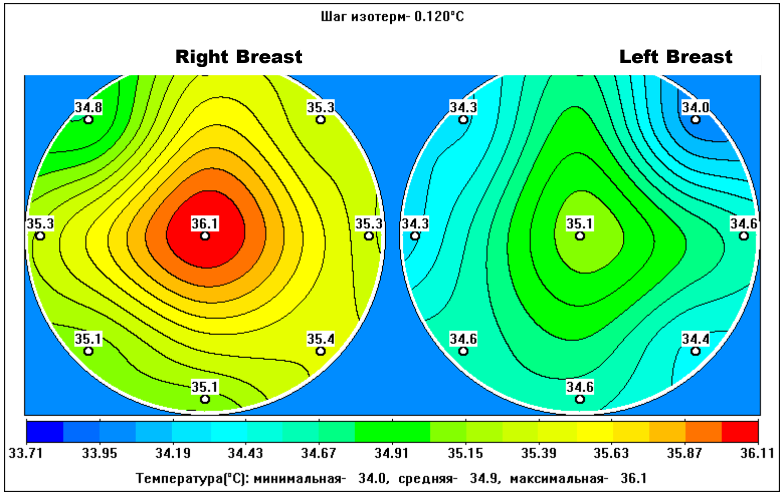


Results of the measurements can be displayed as a temperature field and thermograms

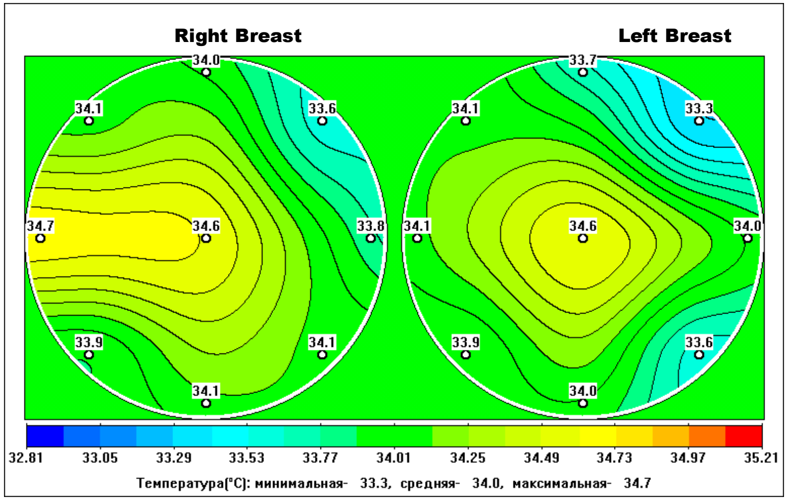
Treatment monitoring

Patient Б.

Mastitis of right breast before treatment



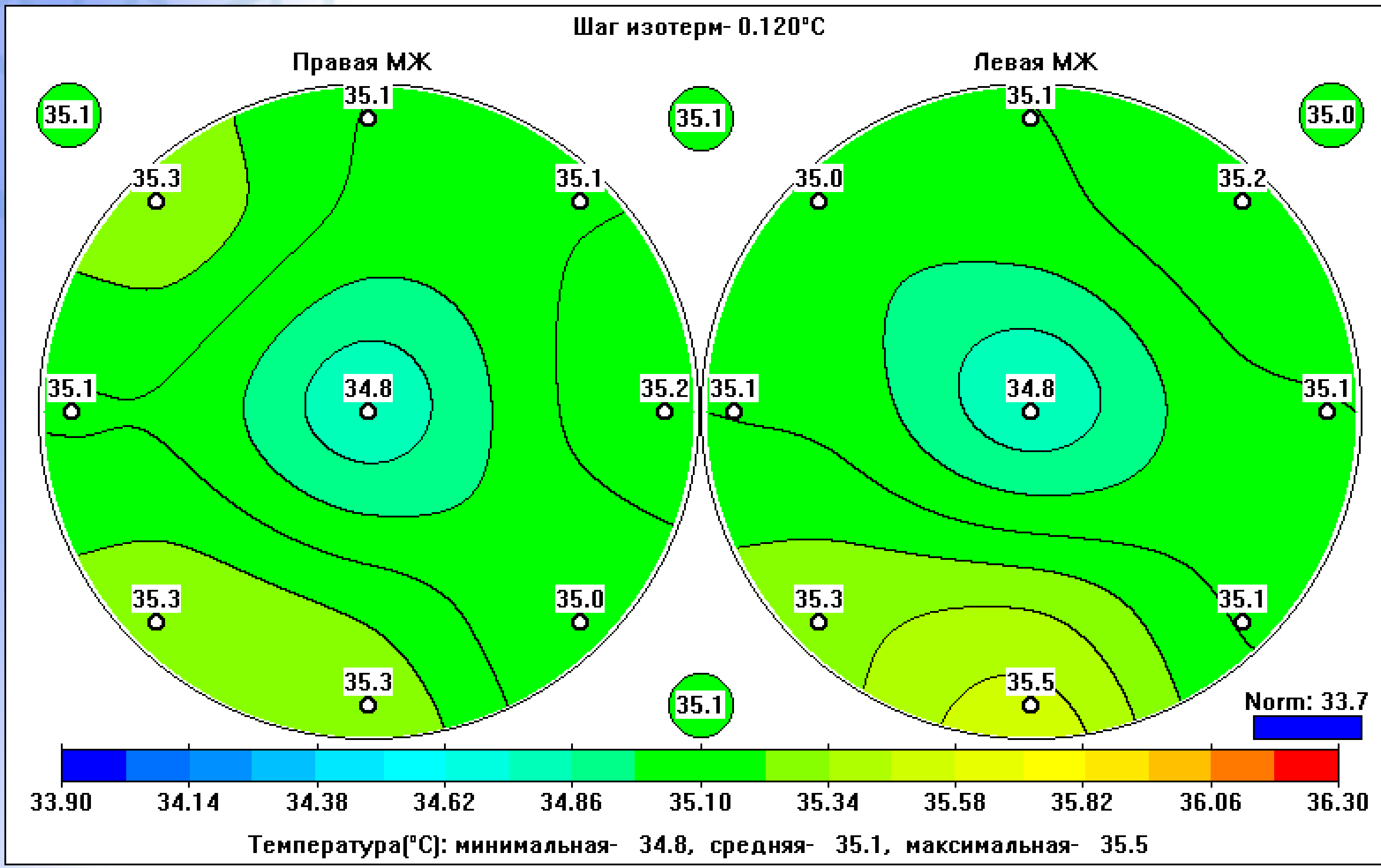
Mastitis after treatment



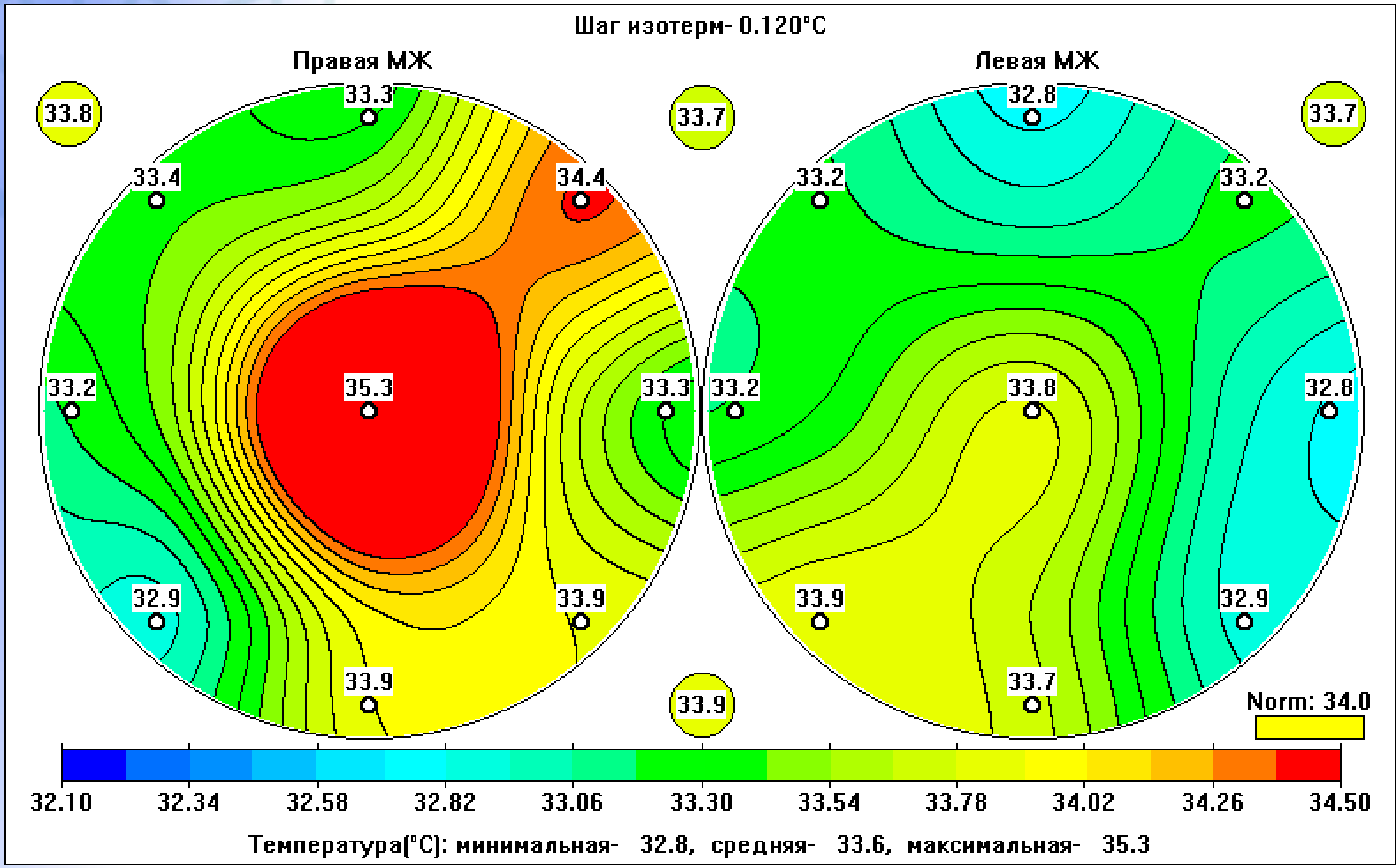
Features of thermal process in breast

Temperature reduction	No temperature changes	Temperature increase
Hypothermia	**Isothermy**	**Hyperthermia**
- Adipose involution - Blood circulation reduction ▪ fibrosis ▪ scars ▪ lipoma ▪ other	Benign changes without proliferation	- Proliferation and atypia - Malignant growth - Inflammation

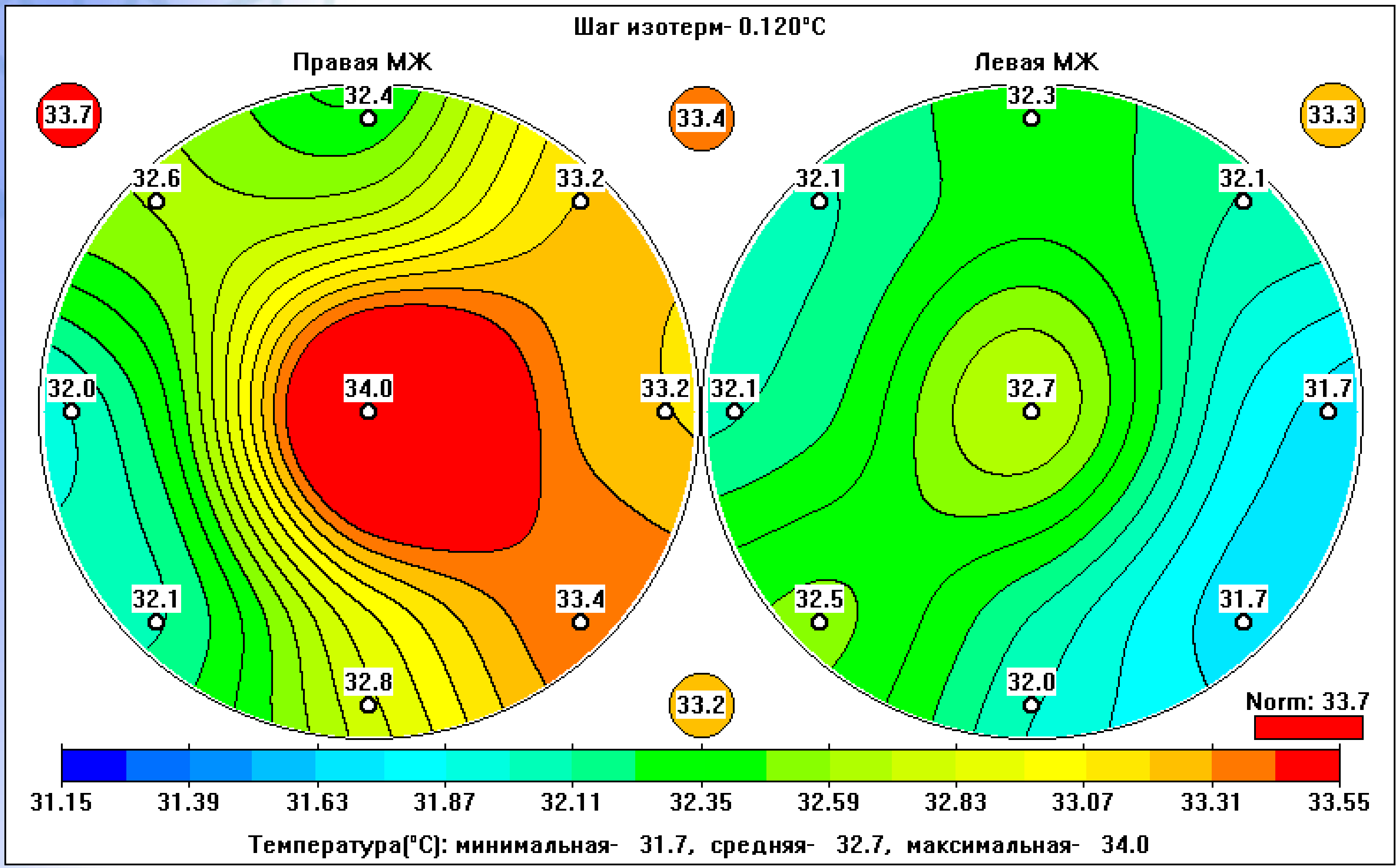
Healthy breast



Breast cancer

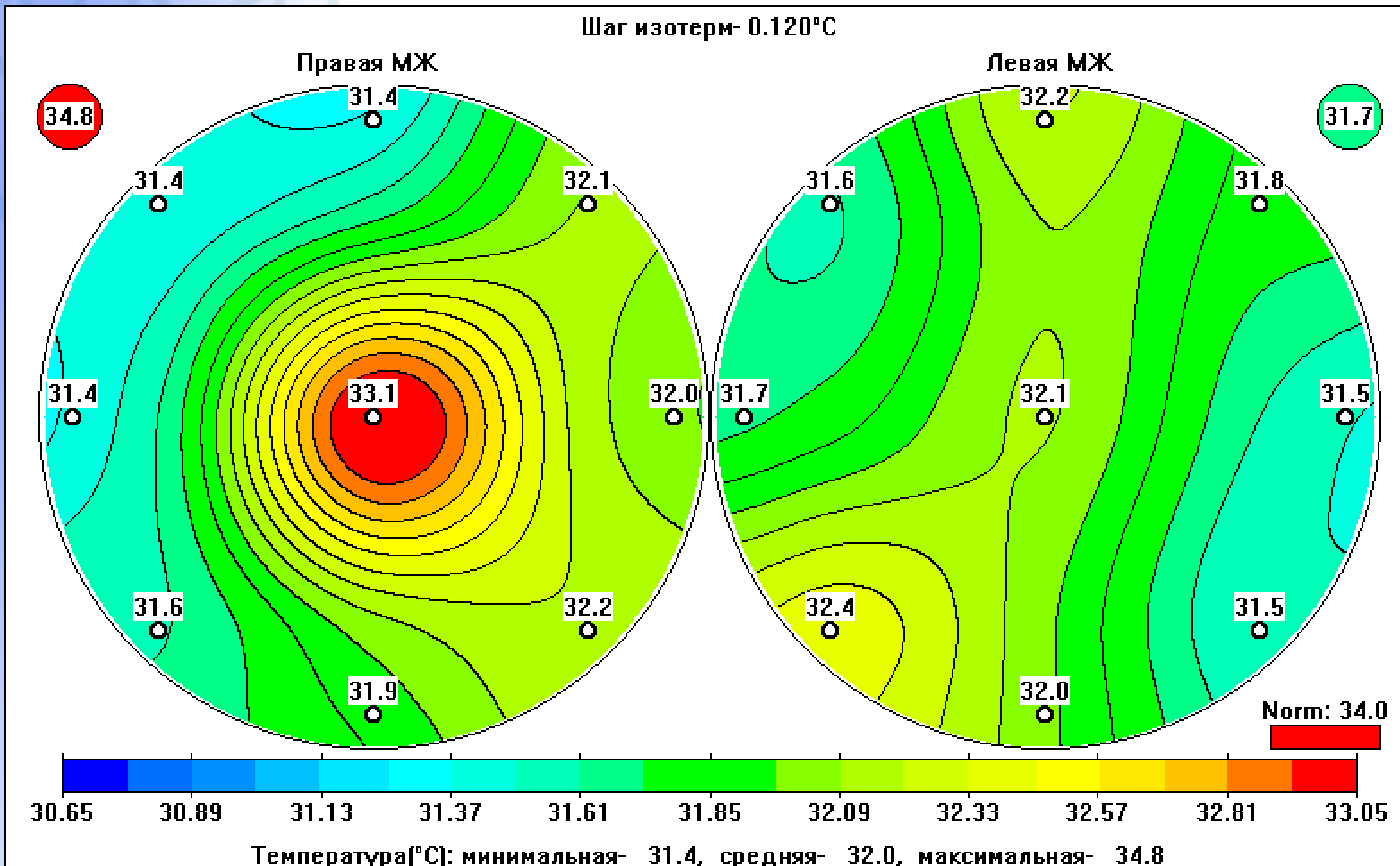


Mastitis

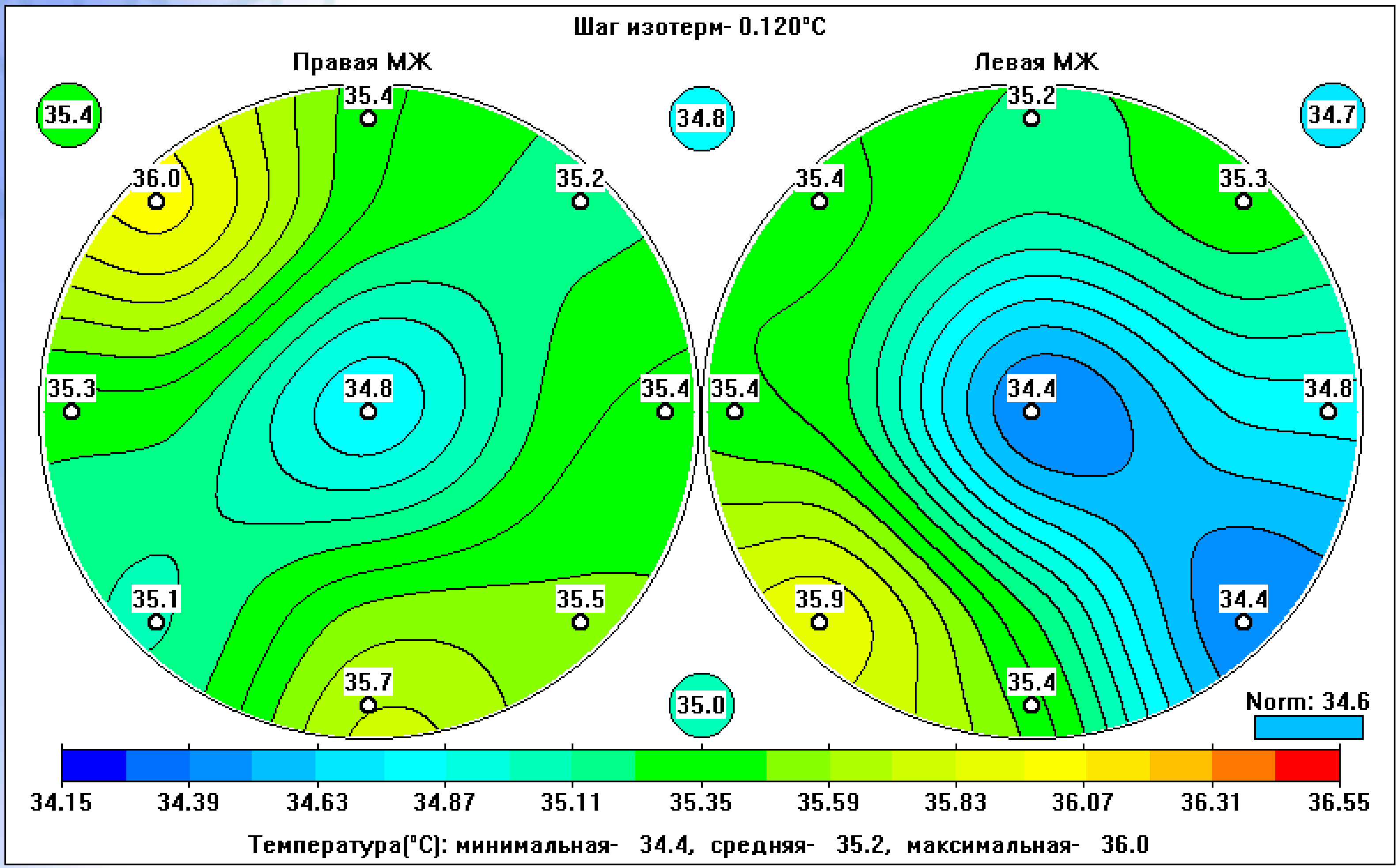


Шаг изотерм- 0.120°C
Правая МЖ
Левая МЖ
33.7
32.4
33.4
32.6
33.2
32.0
34.0
33.2
32.1
33.4
32.8
33.2
32.3
33.3
32.1
32.1
32.1
32.7
31.7
32.5
31.7
32.0
Norm: 33.7
31.15
31.39
31.63
31.87
32.11
32.35
32.59
32.83
33.07
33.31
33.55
Температура(°C): минимальная- 31.7, средняя- 32.7, максимальная- 34.0

Mastopathy with proliferation



Fibroses


Шаг изотерм- 0.120°C
Правая МЖ
Левая МЖ
35.4
34.8
34.7
35.4
36.0
35.2
35.4
35.3
35.2
35.3
34.8
35.4
35.4
34.4
34.8
35.1
35.5
35.9
34.4
35.7
35.0
35.4
Norm: 34.6
34.15
34.39
34.63
34.87
35.11
35.35
35.59
35.83
36.07
36.31
36.55
Температура(°C): минимальная- 34.4, средняя- 35.2, максимальная- 36.0

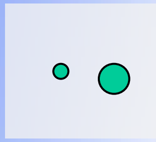
RTM-01-RES Microwave Radiometer Clinical Trials Results

№	Clinical trials sites	Year	Sensitivity %	Specificity %
1	Oncological Hospital # 40, Moscow, Russia	1997	94.2	71.4
2	Mammological dispensary, Moscow, Russia	1998	85.1	76.5
3	Oncological centre, Moscow, Russia	1998	89.6	81.8
4	Main military Hospital (Burdenko), Moscow, Russia	2001	98	76
5	Mammological dispensary, Moscow, Russia	2002	95	57
6	Medical College, Arkansas, USA	2003	85	70
7	Russian Scientific Center for X-ray radiology, Moscow, Russia	2006	96.6	76

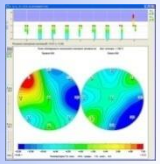
Advantages of microwave mammography

Lack of radiation exposure. It is possible to perform measurements many times with no effect

High method sensitivity



Detection of pathologies at an early stage

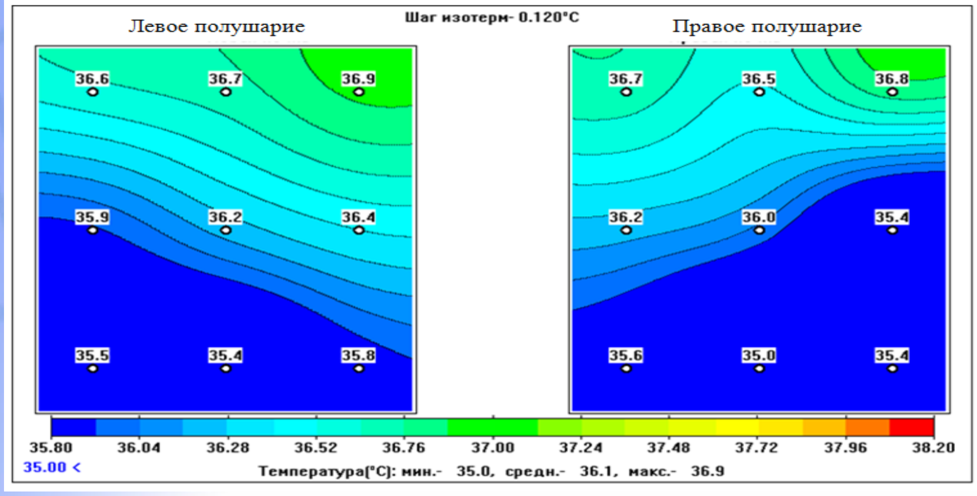


Visual display of the results

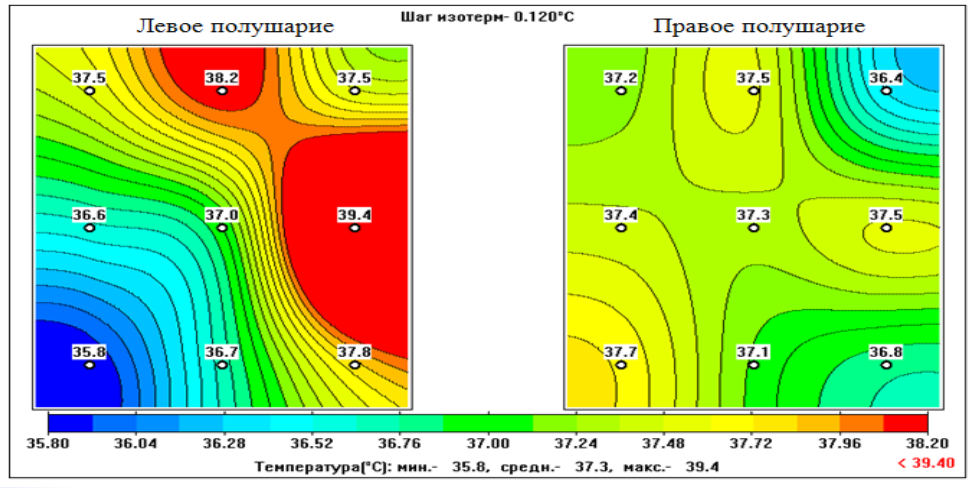
Use on different organs

Prostate Gland
Scar
Skin Neoplasm
Skin Neoplasm (short)
Skin Neoplasm (symmetric pair)
Spine
Sternum
Stomach

Temperature Fields



Healthy person



Ischemic stroke in the left side of the brain

Journal of the American College of Cardiology

Published by Elsevier Inc.
Vol. 59, No. 18, 2012
ISSN 0735-1097/$36.00
doi:10.1016/j.jacc.2012.01.033

First In Vivo Application of Microwave Radiometry in Human Carotids

A New Noninvasive Method for Detection of Local Inflammatory Activation

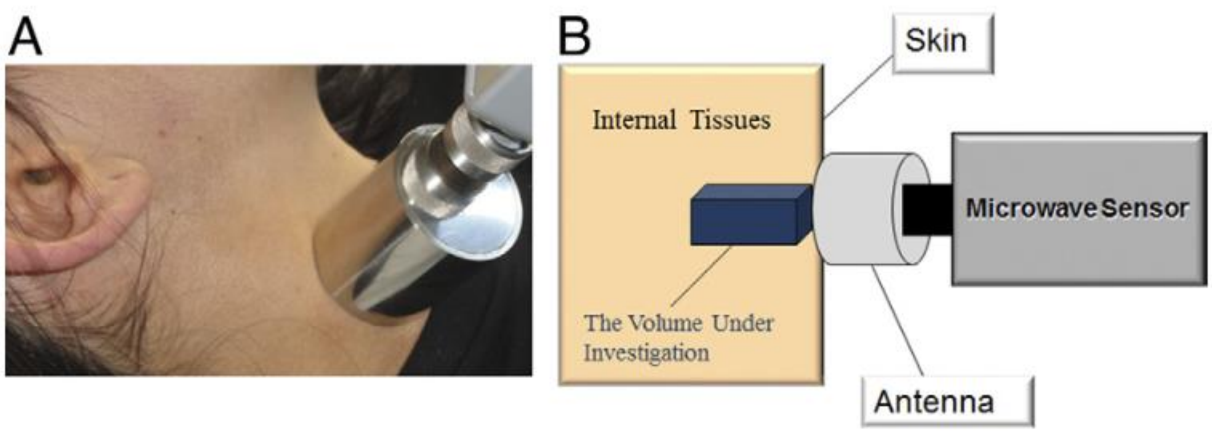
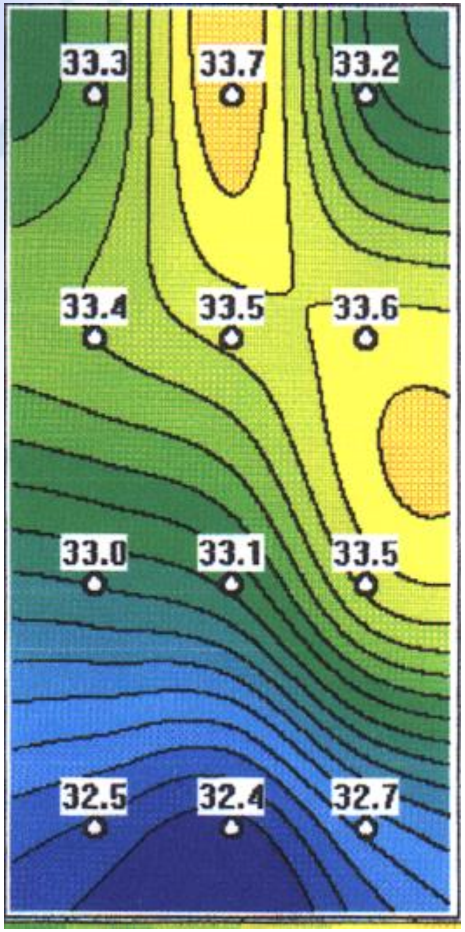
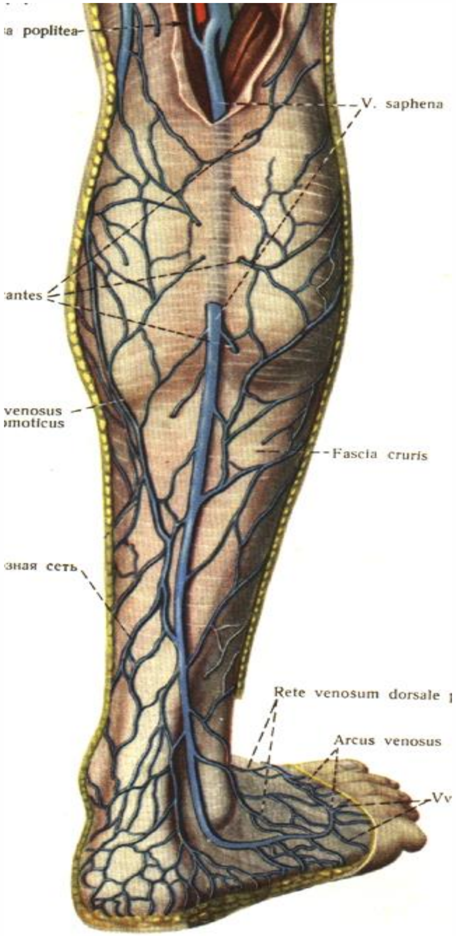


Figure 1 **Microwave Radiometry**

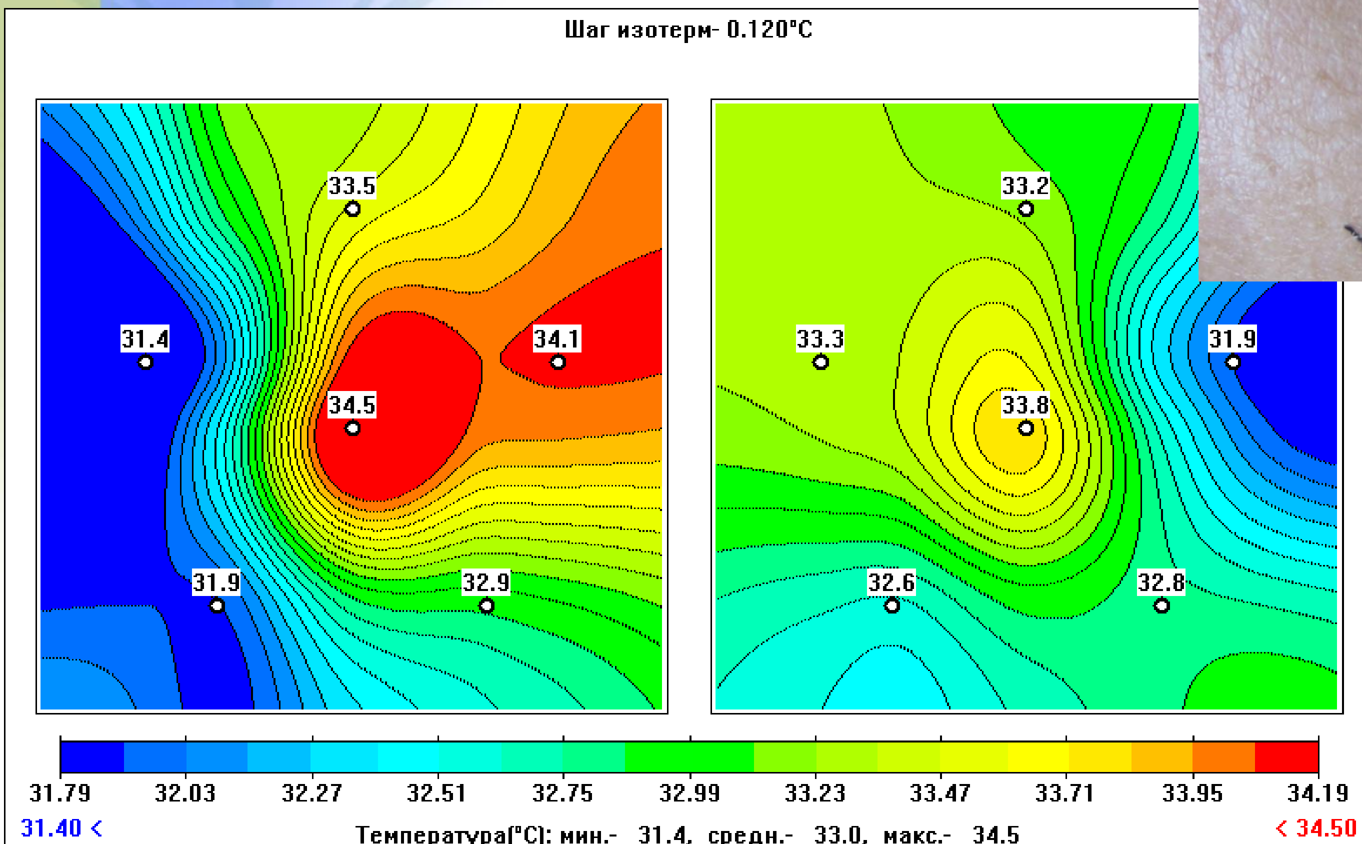
(A) Photograph of the antenna for microwave radiometry measurements placed at a 90° angle. **(B)** Schematic presentation of the system of microwave radiometry. The antenna of the microwave sensor is in contact with the skin above the volume under investigation.

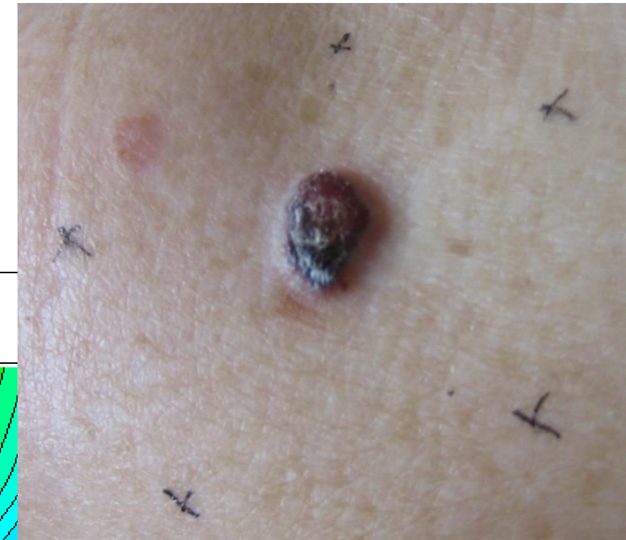
Thermographic profile of internal temperature and shank anatomy in normal





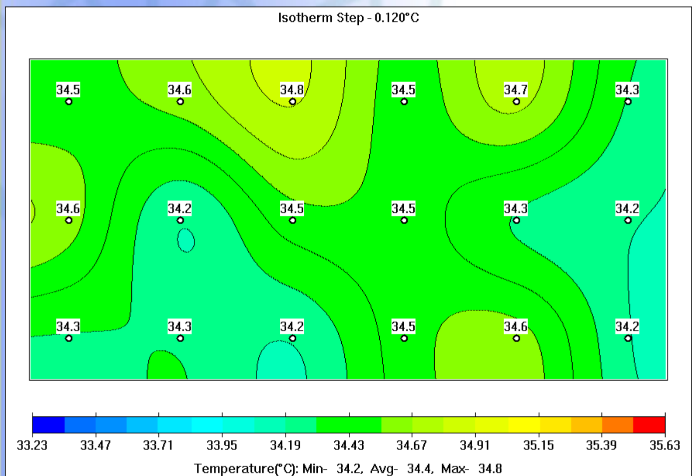
Nodal melanoma of skin in the left deltoid region *pT2N0M0 1cm*

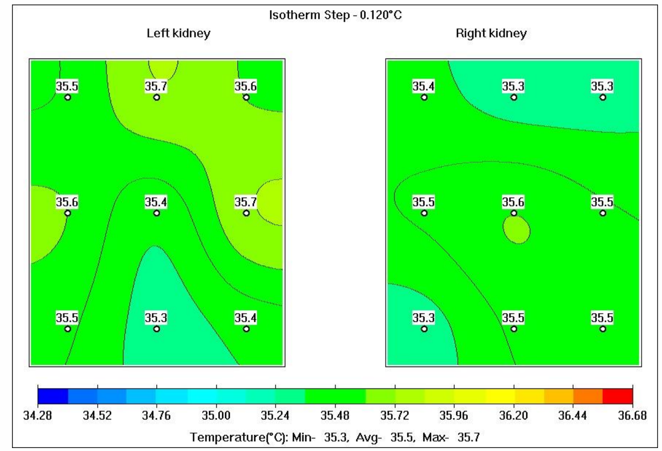




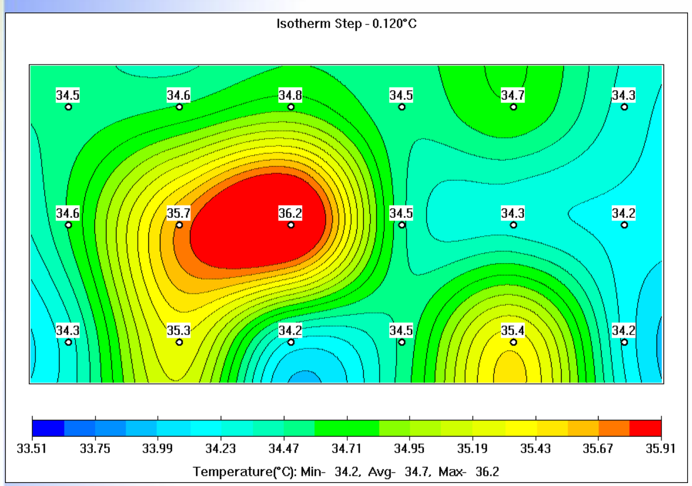
Liver and kidney

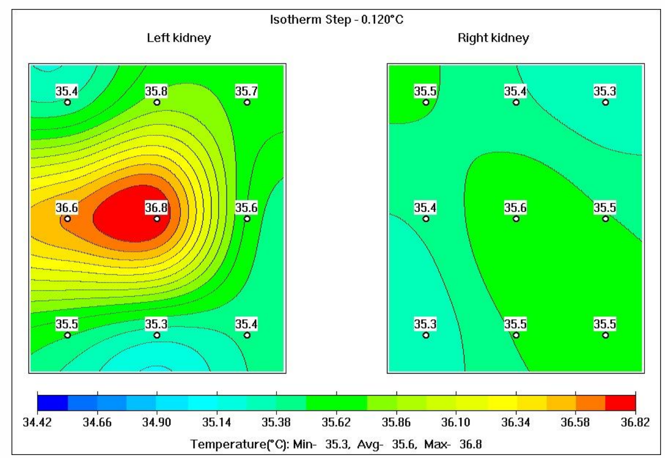
Healthy



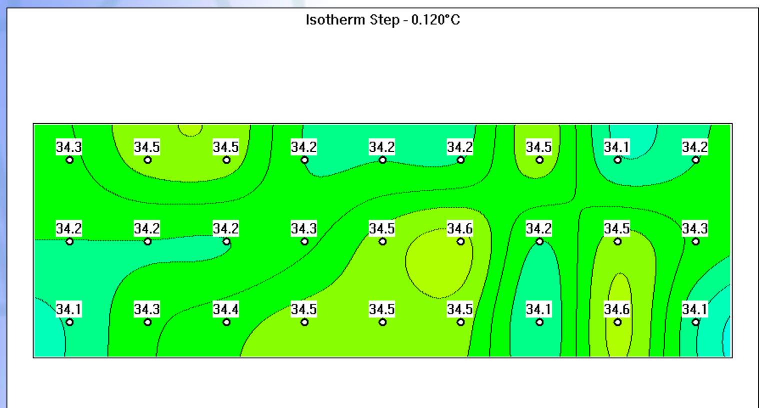


Inflammation

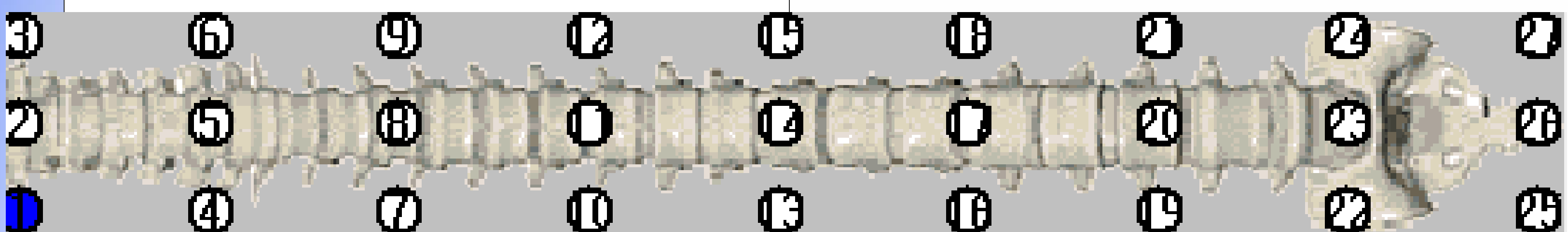


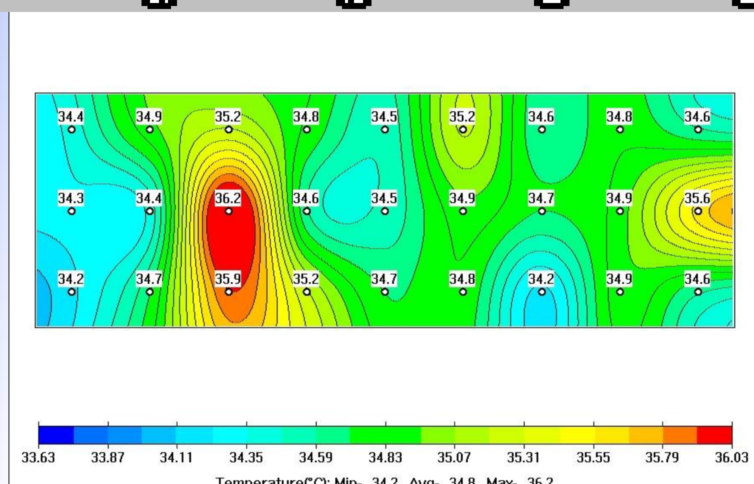


Spine



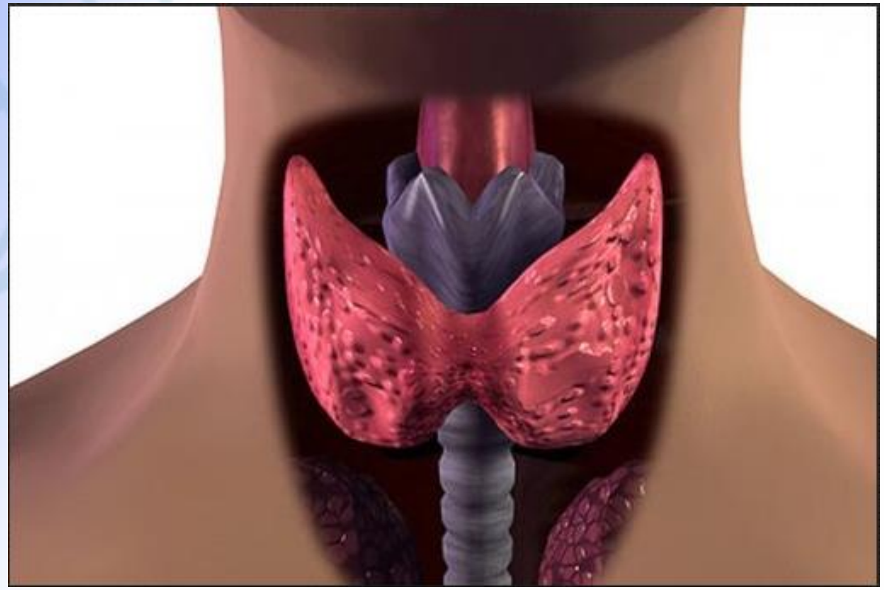
Healthy

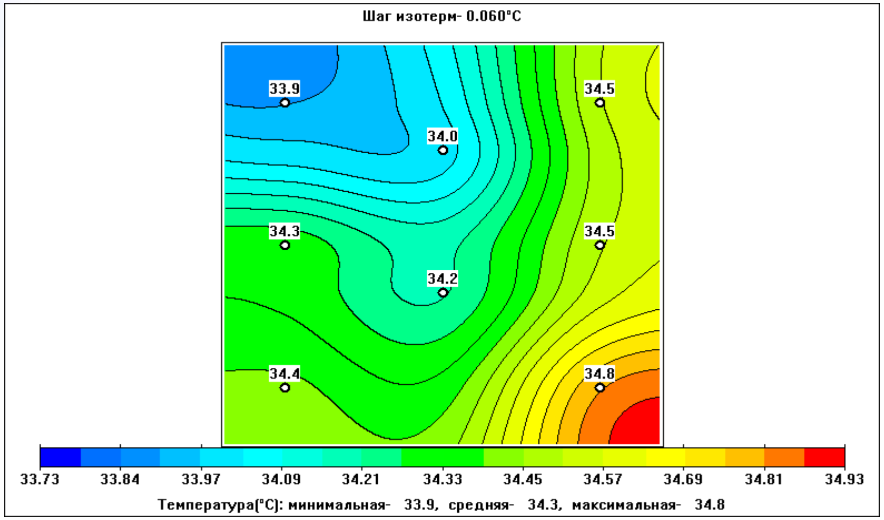




Inflammation

Internal temperatures field of thyroid cancer





Thank you

for your kind attention