Microwave Imagistic and Data Processing Software for Early Breast Cancer Detection

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Abstract

Microwave employment in cancer detection is a new noninvasive technique meant to uncover very early tumor cells in breast tissue. Medical microwave imagistic in breast cancer detection implies special processing and fuzzy procedures to display the temperature map and to highlight the inner structure atypical development. Our research regards a practical realization of the installation and the dedicated software meant to assist medical decision in breast cancer diagnosis.

Keywords: Microwave imagistic, medical software, breast cancer, fuzzy systems, image processing.

1 Introduction

Constant efforts made in order to early detect the most osteophyl cancer diagnosed amongst women, which is breast cancer, are directing towards discovering new, non-invasive techniques. With an incidence depending on antecedents, race, life quality, environment conditions, medication, it arises to all ages, not forgiving patient ignorance. Yearly mammograms are recommended starting at the age of 40, and about every three years for women in their 20's and 30's, with special care at increased risk persons (family history, genetic tendency, past breast cancer) that should have additional tests or more frequent exams [1].

Medical images of living tissue become available using any of the existing techniques [2] ÷ [6] such as: PET (Positron Emission Tomography), CT (computed X-ray tomography), ultrasound, conventional scintigraphy or MRI (Magnetic Resonance Imaging). These techniques are powerful and have great advantages, but suffer important drawbacks, which limit their use. They are *invasive*, *non-portable* and *discontinuous* in their survey, with *high costs* in the medical monitoring. Our study regards easily repetitive noninvasive ways of cancer detection, accessible for all the possible subjects. The main advantage of noninvasive methods is the possibility to be repeated as often as necessary, for growth rate or remission survey, essential in diagnosis. Actually, there are some noninvasive methods of breast abnormal area detection, conceived utilizing the optical reflection, and respectively infrared body emission.

A steady, *completely* non-invasive technique, the thermography, is a well-known malignant activity detection method [7]. Yet, the novelty in our approach consists in an extended study of measuring the *human body microwave emission* that indicates the temperature, which is higher when a process of abnormal tumor cell is developing. A multi-disciplinary team, in the scientific research laboratory of the Medical Bioengineering Faculty, University of Medicine

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and Pharmacy, Iasi, Romania [8], implements a complex installation of microwave radiometry, in order to investigate all the different aspects of this new approach.

2 Shielded Installation for Microwave Imaging

Our research [9] ÷ [13] first focused on the detection of the microwave emission in a protected zone, using a special constructed shielded room.

Microwaves are emitted (as we all know) by mobile phones and, as well, by many other electronic devices that we are using. In order to make accurate radiometric measurements in accordance with actual literature specifications [14] ÷ [18], this shield was conceived, made by special protecting materials.

Fig. 1. Shielded room against the spurious microwave signals for radiometric operations, during the construction

Each patient is registered with its anamnesis, in order to make possible the diagnosis, and the further survey of the treatment or of the tumor growth/decrease dynamic.

For every patient is realized: a video, an infrared image and a number of microwave domain measurements (with the special dedicated radiometer) in this shielded room. It was noticed that symmetric temperature recordings, increase the possibilities of having a normal situation, but asymmetric body/breast microwave radiations, generally might be accompanied by malignant processes. Histological exams came to complete the preliminary results.

3 Microwave Field Imaging Software

The graphic representation of the measurement results in different points may be displayed by the help of a software application named BCT_Analysis (Breast Cancer Thermography Analysis) that we designed. The application BCT_Analysis permits the temperature map display for the studied area, but also, the patient anamnesis and registration, structuring a database with important disease history indices and an image database to be further compared, during diagnosis and surveyed treatment.

In BCT_Analysis program, the temperature measurement may be accomplished in two ways: by a fix positioning of a given number of measurement points, or by variable positioning of the measuring points. In this second case, a correlation has to be made to the real position of the human body that is examined; therefore a reference system has to be settled. A raster image was introduced in the process of acquisition, to be superposed to the photo image. The image normally has a certain degree of symmetry (to be estimated or computed), as humans have not entirely symmetric shapes (it is important, because symmetric disposal on breasts influence the probability of certain diagnostics).

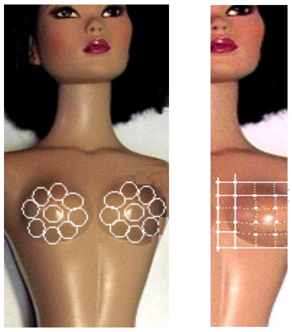

Fig. 2. Breast benchmarks: two methods for systematic measurements.

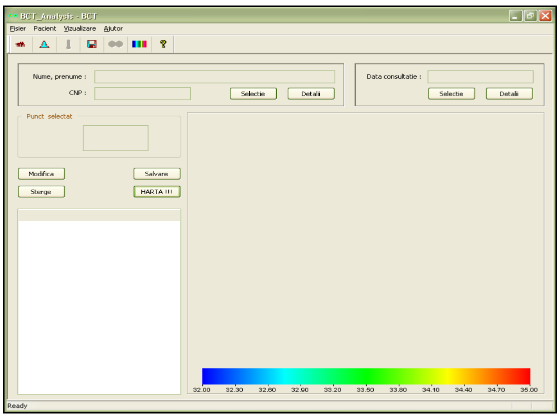

Fig. 3. BCT_Analysis Application

The software is registering the patient anamnesis together with the microwave image acquisition, realizing a flexible, “user friendly” interface, useful in exploiting the patient database.

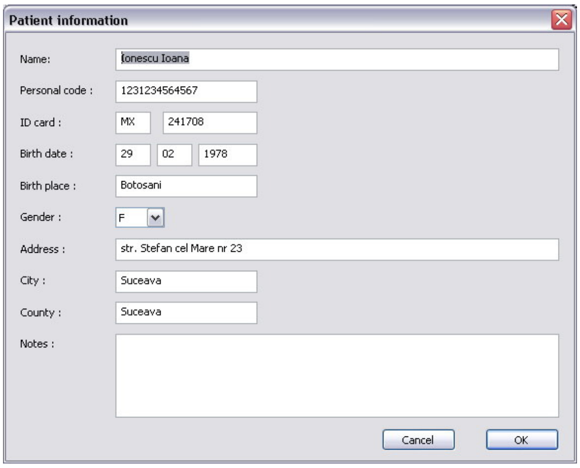

Fig. 4. Dialog window – patient information

In order to acquire the breasts temperature images in the microwave domain, a scale of colors is used in the phase of thermo-graphic map achievement.

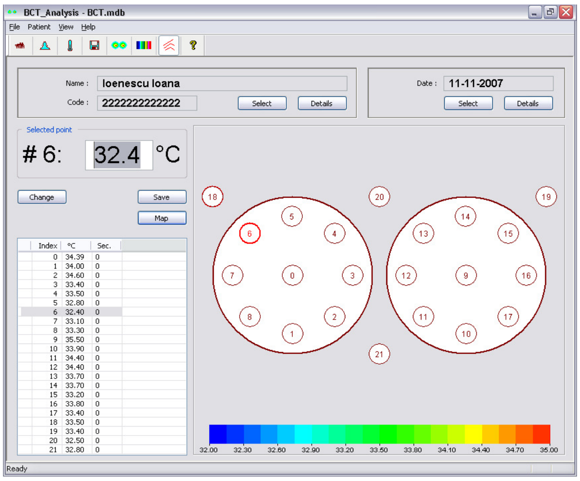

Fig. 5. BCT_Analysis, image window

The application might use an implicit scale for the temperature values: 32 ÷ 35ºC. But, this domain might also be explicitly computed depending on the minima and maxima values of the temperatures that we registered. When a normalization of the image is wished, reported to the medium value of the measured temperatures, the classic formula:

$$I(x,y) = \left(I(x,y) - minI\right)/\left(maxI - minI\right) \quad (1)$$

is replaced by the following one - see equation (2) - where *medI*, *minI* şi *maxI* represents the medium, minimum and maximum value, from the temperature (plotted) image.

Note that image processing [19] ÷ [22] and temperature display on the breast simulated shape is also an important stage for our final 3D positioning [9], but it is not constituting the main subject of the present paper.

$$I = \begin{cases} \dfrac{I(x,y) - minI}{2 \cdot medI - 2 \cdot minI} & ,(medI - minI) > (maxI - medI) \\[2ex] \dfrac{I(x,y) - 2medI + maxI}{2 \cdot maxI - 2 \cdot medI} & elsewhere \end{cases} \quad (2)$$

We are further focusing on the technique of color display in accordance with the real tissue temperature, radiating more heat reported to the normal one, and on the rules extraction for a diagnosis support system. The final plotted image is presenting as shown in Fig.6.

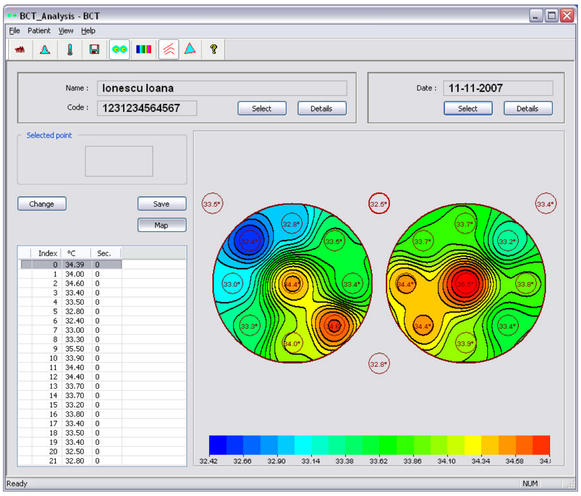

Fig. 6. Final temperature map – an example - software realized in Visual C++

4 Color Map Generation for Temperature Map Design

The microwave map of thermo-registrations is realized using the temperature information obtained with the microwave radiometer we constructed. If a suspicion regarding an inflammatory process is detected, the present preliminary measurements are always followed by further examinations. After indicating the regions where big temperature differences - right side/left side (on the breasts) exist, supplementary measurements (even a biopsy) are to be done in order to have an accurate diagnosis.

The measurements could be realized *in fixed points* (a first method) or *in variable points* (a second method). For every point *I(x,y)*, temperature map gene-ration is accomplished by one of the methods described in the following, A and B, sections.

A. Weight estimation based on minimum distance

The next steps have to be followed:

- The neighbors selection (selection of the points where radiometric measurements were done, next to the current point). The number of the neighbors is denoted n_v.
- The Euclidian distance to every neighbor is computed:

$$d_k = \sqrt{(x_k - x)^2 + (y_k - y)^2}\ , \quad k = \overline{1, n_v} \qquad (3)$$

- Weightings vector computation, depending on distances vector:

$$w_k = d_{\min} / d_k \qquad (4)$$

where

$$d_{\min} = \min_k (d_k) \qquad (5)$$

- if $d_{\min} = 0$, we are situated in a point where a measurement have been done, and *I(x,y)* will be equal to the measured value in that point.
- Temperature value computation for the current point *(x,y)*.

$$I(x, y) = \sum_{k=1}^{n_v} w_k \cdot temp_k \Big/ \sum_{k=1}^{n_v} w_k \qquad (6)$$

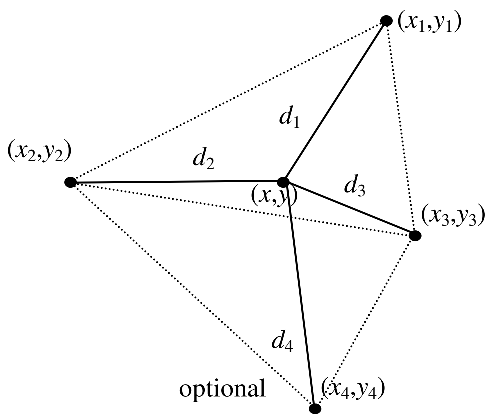

Fig. 7. Temperature - spatial influence, fuzzy computing

Neighbor selection might also be done choosing only the triangle/polygon vertices where the current point is situated or a search within a certain radius might be as well done. Outside those limits, we consider the points too far away, no more able to influence with their caloric radiation the actual measurements in the current point.

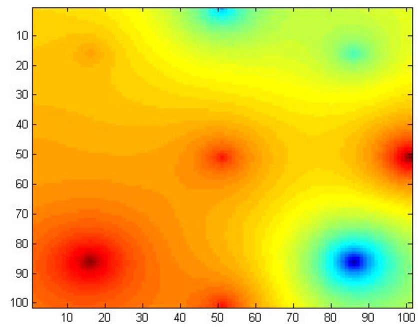

Fig. 8. Frame of microwave image (Method A)

B. Non-linear weighted sum

$$temp_p = \frac{\sum_{k=1}^{n} temp_k \frac{1}{d_k^m}}{\sum_{k=1}^{n} \frac{1}{d_k^m}}, \quad d_k^m \neq 0 \qquad (7)$$

In this second version of estimation for the weights $w_k = 1/d_k^m$, the temperature of a point is influenced by the neighbor points temperatures in a manner proportional with the inverse of the m^{th} power of the distance. Generating the microwave temperature image, we successively tried different values for *m* in equation (7), and the best results were for *m*=3 (Fig. 8, 9, 10, 11, were obtained using a Matlab® sequence of programs).

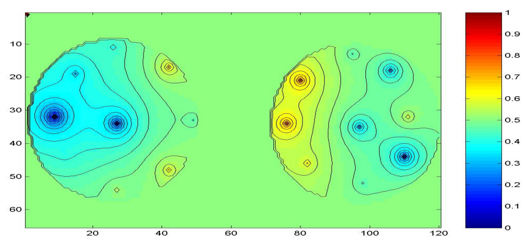

Fig. 9. Frame of microwave image (Method B) the power m=1

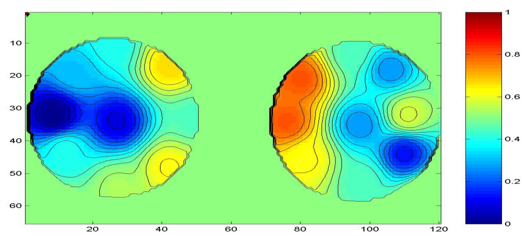

Fig. 10. Frame of microwave image (Method B) the power m=2

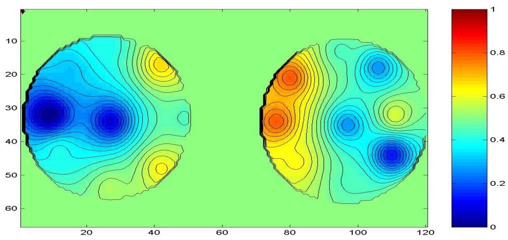

Fig. 10. Frame of microwave image (Method B) the power m=3

5 Towards a Hierarchical Decision Support System

A hierarchical decision support system (HDSS) implies the use of a previous formulated risk estimation fuzzy system. Using fuzzy logic in the module designed for the computation of the left/right side difference, is preferred, because it permits adequate information description (employing linguistic variables as *small difference*, *somehow closed*, *very important/big difference*, etc.) and allows an easy formalization of the expert knowledge on medical diagnosis.

The enclosed fuzzy system model is preliminary to the final software version that will be further done, and the knowledge base structure might be modified according to further physician specifications.

A second order fuzzy model has been conceived, realized by a serial chaining of two different kinds of fuzzy systems: a Sugeno and a Mamdani type, respectively.

The first fuzzy system (Sugeno type) is used in order to ask (or not) more supplementary measurements:

R31: IF current_point temperature t_{pc} is BIG and neighbor temperature t_{nk} is SMALL, THEN β=4

(supplementary measurements are asked in 4 points around the current point).

R32: IF current_point temperature t_{pc} is BIG and neighbor temperature t_{nk} is MEDIUM, THEN β=2.

R33: IF current_point temperature t_{pc} is BIG and neighbor temperature t_{nk} is BIG, THEN β=1

The membership functions used for the description of fuzzy linguistic attributes SMALL, MEDIUM, BIG associated to the input temperature are represented in Fig. (11).

Standard deviation is computed using equation (8).

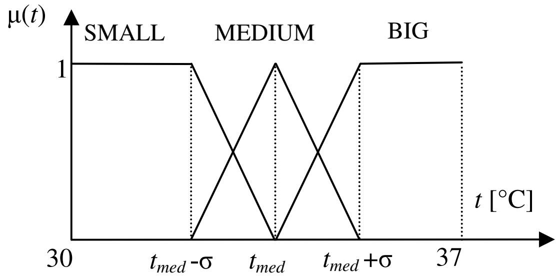

Fig. 11. Membership functions for temperature differences

$$\sigma = \sqrt{\sum_{k=1}^{n} \frac{t_k - t_{med}}{n-1}} \tag{8}$$

Table 1: Fuzzy inference rules for the symmetry index estimation in a Sugeno system

t_{nk} \ t_{pc}	SMALL	MEDIUM	BIG
SMALL	0	2	4
MEDIUM	1	0	3
BIG	4	2	1

The rules output represents an index for the asymmetry evaluation; when this index has a small value (decreasing to zero) a high symmetry area is identified (e.g. high symmetry area and small temperature, gives a small risk area). When the defuzzification value of the output singletons is high, (big asymmetry implying high risk) supplementary investigations in that area are requested.

Table 1 is presenting the inference fuzzy rule of the first fuzzy system; it is asymmetric as it is considered that a higher temperature in a point (in comparison with the symmetric point) may show the presence of a tumor that changes the body normal emission of thermal energy in that specific region.
The fuzzy inference rules follow the consequent pattern:

IF difference $|P_{k\_left} - P_{k\_right}|$ (between the measurements in the left and right parts in symmetric points) is LARGE,
AND current_point temperature t_{pc} is BIG
THEN *risk* is very HIGH.

IF difference $|P_{k\_left} - P_{k\_right}|$ is MEDIUM,
AND temperature t_{pc} is MEDIUM
THEN *risk* is S (SIGNIFICATIVE).

IF difference $|P_{k\_left} - P_{k\_right}|$ is SMALL

AND temperature t_{pc} is MEDIUM
THEN *risk* is SS (SLIGHTLY SIGNIFICATIVE)

Table 2: Inference fuzzy rules for *risk* estimation Mamdani system

diference \ t_{pc}	SMALL	MEDIUM	BIG
ZERO	I	SS	somehow S
SMALL	I	SS	S
MEDIUM	I	S	H
LARGE	I	S	very H

Membership functions used for the description associated to the input fuzzy variable *dt* (*temperature difference*), are the fuzzy linguistic attributes ZERO, SMALL, MEDIUM, LARGE presented in Table 2.

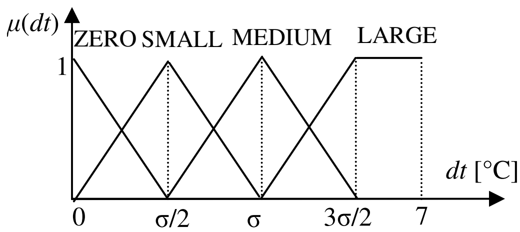

Fig.12 Fuzzy variable *dt* – temperature difference fuzzification

The fuzzification of the linguistic degrees used for the fuzzy variable *dt* (*temperature difference*), is presented in Fig. 12, and the fuzzy functions for the cancer *risk* estimation will be represented using Gaussian functions (Fig. 13), where sigma (σ) is determined respecting equation (8).

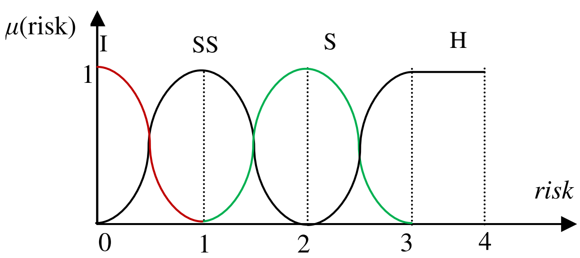

Fig. 13. The fuzzy memberships of the *risk* estimation function use Gaussian shapes

Output variable *risk* has the fuzzy linguistic degrees: I(insignificant), SS (slightly significant), S(significant) and H(high) non-dimensional, used together with the linguistic intensifiers "somehow" and "very".

Equations 9 and 10 express the formulas applied for computing these linguistic intensifiers:

$$\mu_{very}(x) = \mu(x)^2 \quad (9)$$

$$\mu_{somehow}(x) = \sqrt[3]{\mu(x)} \quad (10)$$

Membership functions that are used are Gaussians computed after the general formula:

$$\mu_{gauss}(x) = e^{-\frac{(x-c_g)^2}{\sigma_g^2}} \quad (11)$$

Where c_g and σ_g are: the Gaussian (shape) center and, respectively, the deviation of the values on the Gaussian, around the central value.

The fuzzy operators that are used are the classic operators in the Mamdani sense:
NOT(1-μ), AND: min(μ_A, μ_B), OR: max(μ_A, μ_B).

For the Sugeno system, a classic defuzzification is used:

$$y_{Sugeno} = \frac{\sum_k \beta_k \cdot \mu^*(x)}{\sum_k \mu^*(x)} \quad (12)$$

$$\mu^*(x) = \min\left(\mu(t_{pc0}), \mu(t_{nk0})\right) \quad (13)$$

For the Mamdani system the method of defuzzification employed is the center of gravity (COG):

$$y_{COG} = \frac{\int \mu^*(y) \cdot y \cdot dy}{\int \mu^*(y) \cdot dy} \quad (14)$$

$$\mu^*(y) = \max\ prod\left(\min\left(\mu(t_{pc0}), \mu(dt_0)\right), \mu(risk)\right) \quad (15)$$

where t_{pc0}, t_{nk0} and dt_0 are the crisp values of the inputs into the system before applying the fuzzy block of processing.

The inference type of processing is max-prod, and the inference rules are connected by the reunion operation max(μ_A, μ_B). The two fuzzy systems outputs are used by a decision support system for the investigation of the *risk* degree (cancer presence risk degree) and the *indications* of further supplementary investigations. The rules of this module from the two levels hierarchic system, is not using the fuzzy logic in the inferential process.

The defuzzified outputs of the fuzzy systems from the first level are constituting inputs in rules of the type:

IF the *asymmetry index* is between [0 1.5] and the *risk* between [0 1] THEN normal pathology….

IF the *asymmetry index* is between [2.5 4] and the *risk* is between [2.5 4] THEN abnormal pathology (compulsory further investigations).

IF the *asymmetry index* is between [3.5 4] and the *risk* is between [3.5 4]

THEN suspicion of breast cancer…

Note: it have to be also considered the cases of a false thermo effects, due to infections, mastitis or collateral traumatisms that we experience sometimes.

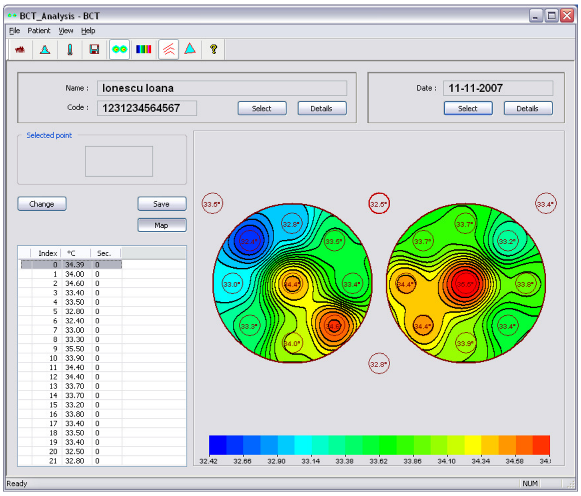

Fig. 14. Microwave temperature images - breast cancer suspicion on inner inferior quadrant in BCT_Analysis software

The fuzzy systems described before represent a theoretical framework for the formalization of the decision support system (DSS) rules. This DSS will contain expert knowledge in the domain of oncology and gynecology, cumulated, resulted, during the tests realized under national research contracts.

Conclusions

This hierarchical system based on the above fuzzy systems is useful in our attempt of generating an accurate temperature map for microwave imaging early breast cancer detection, base for the formalization of rules for a decision support system. The influence of the wormer points on the other neighbor positions is taken into consideration, and an appropriate abnormal cell activity map is plotted. For situating the microwave emissions of the malignant tissue, the body microwave signals are measured with a special radiometer, the patient being placed in a shielded room.

Our previous works considered the results obtained this way and compared them with the results given by a second parallel non-invasive method, the two methods reinforcing each other and influencing the expert's opinion in order to take a decision. The research is continuing due to the very complex aspects implied and the different new technical challenges.

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Our research is an interdisciplinary attempt in order to improve the cancer diagnosis efficiency and the non-invasive methods in breast cancer diagnosis that are presenting incontestable advantages. The project is realized under the scientific management of Medical Bioengineering Faculty, Medicine and Pharmacy University "Gr. T. Popa" Iaşi, in a national Excellence Research Contract, CANCERDET, CEEX 20/2005, further continued in BIOELECTRA. A systematic oncologic survey of the patients is now being developed, in order to permit the formalization of the parameters and to construct the rule-base of a semi-supervised decision support system, helping both patients and physicians.

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