Non-invasive method for screening and early detection of breast tumors using thermal field analysis

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Abstract **– The paper refers to general presentation of international and European evaluation regarding breast cancer incidence and mortality as well as recommendations for prevention, screening, detection and treatment.**

The past years international research development in biomedical engineering has put a particular emphasis on the thermography use in breast pathology diagnosis and its main advantages, such as: an early diagnose of the breast cancer, in that stage when the mammography or ultrasounds can not easily detect the changes of the tissue; a totally non-invasive interaction with human body; very low costs and possibilities for the women to do a self thermographic test.

We also present some important results of our research within the field of breast tumor detection using the numerical analysis of the thermal inverse problem.

Keywords: ***breast cancer, screening programs, non-invasive detection, thermal analysis.***

I. INTRODUCTION

Our first goal is to present the breast cancer impact and the potential for the development of international and European programs for breast tumors screening and diagnosis.

The possibility of building multidisciplinary teams for breast cancer detection and care is also analyzed and part of our research work on non-invasive early detection of breast tumors locations and dimensions solving the direct and the inverse problem of thermal field on breast surface.

A. Breast cancer evaluation

Worldwide, breast cancer is the most frequent cancer in women. The highest incidence rates are observed in North America, whereas the lowest risk of breast cancer is observed in Asia and Africa. Breast cancer is also the most common cancer in females in Europe. It is estimated that in the year 2000 there were 350,000 new breast cancer cases in Europe, while the number of deaths from breast cancer was estimated at 130,000. Breast cancer is responsible for 26.5% of all new cancer cases among women in Europe, and 17.5% of cancer deaths.

There are several etiological factors that are associated with occurrence of breast cancer, such as: age at menarche and menopause, childbearing, breast-feeding, hormonal status, consumption of alcohol and type of diet, obesity, radiation, and genetic susceptibility. The screening programs can reduce mortality from breast cancer.

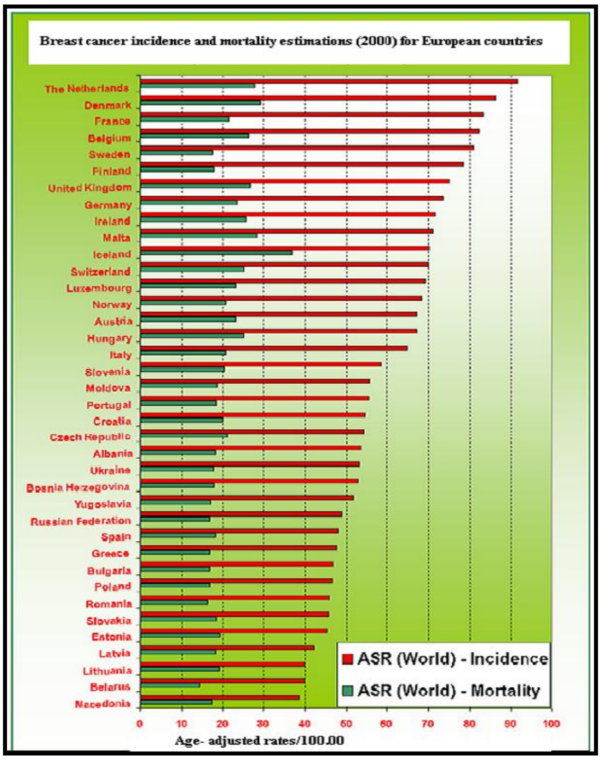

Fig.1. Breast cancer incidence and mortality rates in Europe

Nowadays the priorities for breast cancer research (extending knowledge of cancer epidemiology and cancer risk factors, early detection methods, diagnosis, treatment, survival and palliative care, including translational research under the Seventh Framework Program of the European Community for Research and Technological Development; encourage cross-national and cross-sectional cooperation-fostering a multidisciplinary approach).

B. Thermograph used in breast cancer diagnosis

The abnormal thermical differences that appear between certain regions of the breast could be created by a modified metabolism or vascularisation. The thermical differences are reflected on the breast surface that could serve to the breast cancer detection. The thermical asymmetries that appear and time-evolution of the thermal field are also important factors for the diagnose of these tumors. The thermography was proved to have great for breast tumor early, detection, with non-invasive interaction with human tissue.

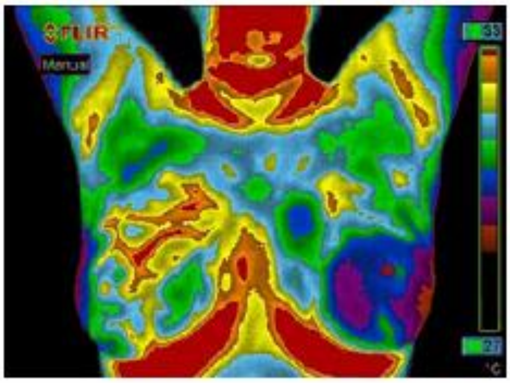

Fig.2. Breast thermography image

An extended number of papers (for ex. [1-3]) where focused on the relation between tumor presence and temperature distribution on breast surface, mathematical and numerical models for thermal field beeing developed. The problem of tumor dimensions and position is very complex and, as a consequence, not enough analysed. Research teams [4] studied the computerized detection of breast cancer with artificial intelligence and thermograms, presenting the concurrent use of thermography and artificial neural networks (ANN) for the early diagnosis of breast cancer. It has been reported that breast thermography itself could detect breast cancer up to 10 years earlier than the conventional methods such as mammography, in particular in the younger patient. However, the accuracy of thermography is dependent on many factors such as the symmetry of the breasts' temperature and temperature stability, the physiological state and the microclimate of the investigation room.

II. QUALITATIVE ASPECTS OF THERMAL ANALYSIS

One of the main functions of the blood flow within a biological system is the capacity of heating or cooling a tissue, with respect to the local temperature. The difference of temperature between blood and tissue can be considered a proof for this function of releasing or absorbing the heat.

Based on this presumption, Pennes [1948] proposed one of the most known models of thermal transfer within alive systems: « Pennes' thermal equation ». He suggests that the effect of the blood flow can be modelled as a heat source term added to the traditional equation of thermal conduction.

For Pennes equation we analyzed Finite Element Method. The experimental results have proved that Pennies equation corresponds to the best model for thermal field within the breast tissue:

We developed algorithms for rapid solving of Pennes direct problems:

- using the rare matrix techniques to solve the equations system; an iterative Gauss-Seidel method with supra-relaxation has been preferred.
- algorithms used to recalculate only the equations system coefficients that have been changed during the search process;
- partition of the system matrix into sub-matrices associated to the search area and the rest of the tissue.

III. RESULTS

A. A two-dimensional example

We consider the simple breast shape showed in Fig. 3. We use a triangular mesh with nodal elements of first order.

The healthy region of the breast is considered to be homogenous, and its thermic characteristics, different from the tumor parameters are introduced. The equivalent thermal conduction coefficient contains the effects of convection, radiation and evaporation. We chose a tumor placed in the region of triangles around a certain node. The isotherms are plotted in Fig.4.

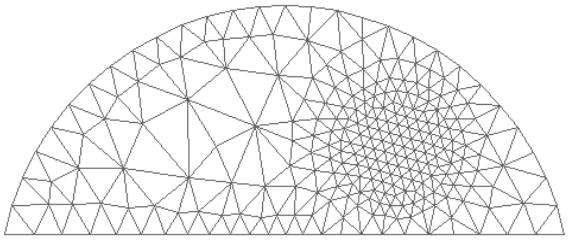

Fig.3. Breast and the investigated region.

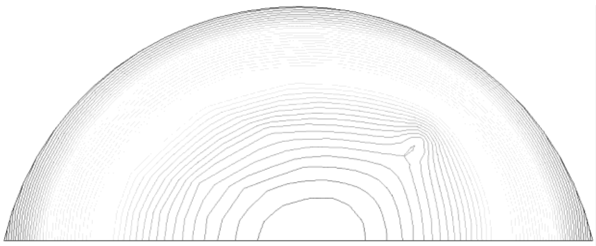

Fig.4. Breast temperature scale
(the presence of the tumor is obvious).

The differences between the healthy and malignant breast tissue is represented in Fig.5.

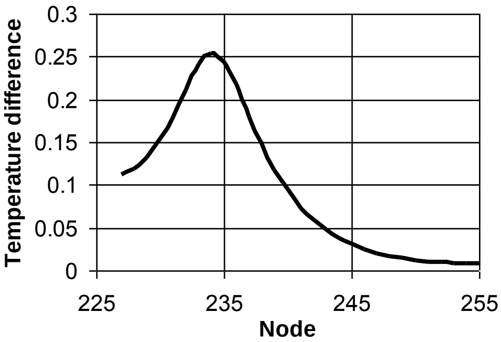

Fig.5. Difference of the temperature (breast contour is counter-clockwise covered).

We randomly modify the temperatures field on the breast surface with a certain error that represents the measurements error of the infrared camera. Then we search for tumors that contain the triangles around the nodes placed in the suspicious region; for these nodes we determine the thermal fields on the breast surface and we compare them with that one obtained for the chosen node. For a maximum measurement error of 0.03 ^{o}C we localize the tumor, by using an iterative method.

B. A three-dimensional example

The 3D model was obtained after geometrical transformations applied to initial shape.

We analyzed the thermal field inverse problem solution in order to detect of the tumor shape and position. Solving the inverse problem involves a huge computational effort due to the direct problem solving. We retain the temperature field on the breast surface and we compare it with the thermal field of the measured values, determining the error in a convenient chosen metric.

We adopted an error that depends on the number of nodes on the breast surface, the trial number, the measured temperature value, for the nodes placed on the breast surface, and the calculated temperature value for the respective nodes.

In order to reduce the computation time, we recalculate for the matrices associated to the equation we considered only those coefficients that correspond to the tumor location. Initialization of Gauss Seidel procedure is made using the final value of the previous search.

In order to eliminate useless searches, we propose a search area, indicated by the location of the thermal abnormality on the breast surface. For each test, we determine the error and then we place the tumor location with respect to the error size. We retain the most convenient locations. Obviously, the errors within the thermal measurements can induce wrong locations. The algorithm models the error, modifying the measured data. If the tumor position is maintained, beginning with a certain error, we can decide that it is a correct location. Otherwise, the detection can not be made.

Anyway, the evolution of the thermal field on the breast surface must be continuously checked and, in the case of any suspicion for a tumor existence, more precise investigation methods should be used (ex. mammography).

The shape and the position of the tumor are discretised by the generated tetrahedral mesh. In order to limit the searches number, we propose the following aspects:

- Only conex tumors (without metastasis) are admitted. This is hypothesis sustained by the purpose of the thermographical investigation: the early detection of the breast tumors;
- The search is done within a soft or manual implemented search area, following the analysis of the temperature field on the breast surface. The center of the area with highest temperatures defines the axis of the search cylinder (orthogonal on the thorax), and the radius of the cylinder is arbitrary chosen (for example, a quarter of the big axis of the breast contour on the thorax).
- Development of a data base regarding the tumors detection. This data base allows a first estimation of the tumor location and a decrease of the search area.
- The possible tumors shapes placed in the search area can be limited. In the current variant, following the increasing tumor order, we chose tumors that occupy: a tetrahedron (with its weight center in the search area); two tetrahedrons with a common surface (with the surface weight center outside of the search area); tetrahedrons with a common edge (the edge center placed in the search area); the tetrahedrons with a common node (the node placed in the search area).

Let's consider a tumor that occupies a tetrahedron (Fig. 6a-b). Using the method for solving the Pennes' direct problem, and using the software specially developed to solve this problem, we obtain the temperature fields on the breast surface, given by this tumor. Then we modify the computed values in a random manner, imposing a limit given by the measurement error.

A set of tumors with different shapes and positions is generated, for each tumor the thermal field on the breast surf is determined. The most probable tumor is the one with the smallest error.

The altering error for the temperature on the breast surface is diminished (for example being divided by 2). If, for 4 successive errors, we obtain the same tumor, we can admit that this tumor is the one we are looking for, and the measurement error of the camera should be less than the first admitted error in the chosen series of the 4 errors.

In the case that was chosen to be modeled an error of 0.6 % is recommended. We should underline that, for great errors, the searching result is very close to the real one, which confirms the efficiency of the procedure for thermal procedure used to determine the location and shape of the breast tumors. The field temperature isotherms on the breast surface, in the presence of the tumor, are given in Fig. 7.

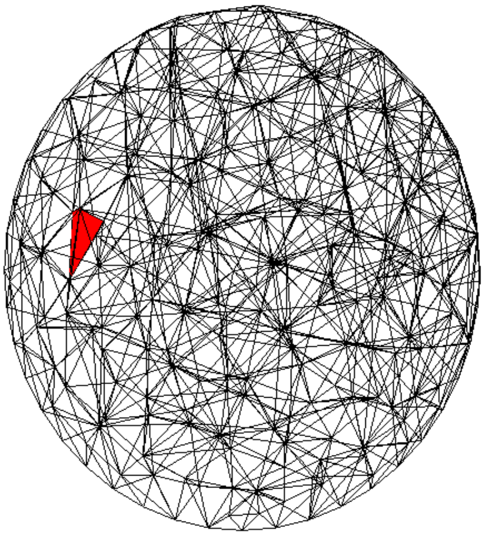

Fig.6a. Tumor that occupies a tetrahedron (xOy plane)

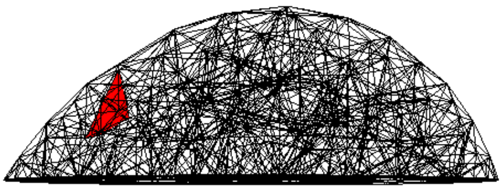

Fig.6b. Tumor that occupies a tetrahedron (xOz plane)

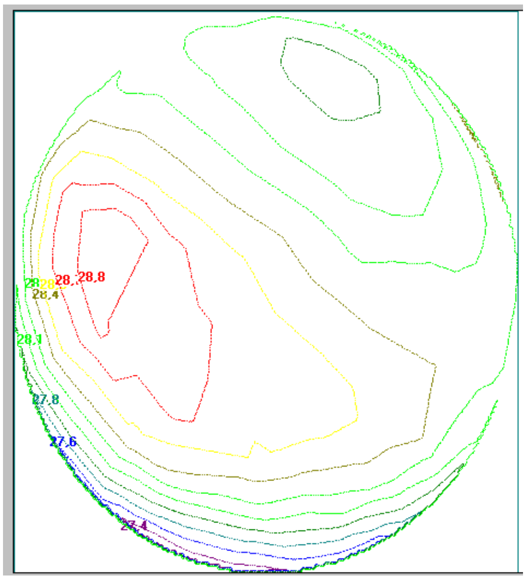

Fig.7. Field temperature isotherms on the breast surface

III. CONCLUSIONS

The high incidence and mortality rates of breast cancer at international level lead to the demand for the development of programs for screening and diagnosis.

Multidisciplinary teams can work for developing non-invasive methods of breast cancer screening and detection.

Thermography was proved to be a very suitable procedure for breast tumor screening and detection, due to its low costs, non-invasive interference with human body and early possibility for diagnosis.

The procedure we proposed starting for thermographic investigations is a non-invasive one, and allows the screening and the detection of breast tumor location and dimensions. It can be repeated later on in order to confirm an early diagnose. If the thermal investigation gives the same results the patient can be directed to more precise, but invasive, investigations (mammography, MRN, etc.).

The huge computational effort comes from the enormous number of direct problems. Within these problems, different positions, shapes and dimensions of the tumor are proposed. Two procedures destined to computational effort reduction were proposed, the iterative one being the most advantageous. For solving the thermal problem with an error that is smaller than 10-7, the number of necessary iterations is between 17 and 50. The tumor search needs 1.4 sec. on a 2.128 GHz processor notebook. For the representative example a two-dimensional model was chosen, but the procedure was also applied for a three-dimensional structure.

We can reduce the effort of computation when decreasing the parameters that describe the inspected area. For this purpose, "zooming" techniques can be used [6] or different categories of sub-domains can be analyzed.

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