REVIEWS

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Impedance Tomography in Diagnosing Breast Cancer

Tomografia impedancyjna w diagnostyce raka sutka

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Abstract

This study presents the use of impedance tomography in diagnosing breast cancer. Described are physical basics of the test, positive and negative features of the method and its diagnostic value. Selected systems of impedance mammography are also presented as well as results of clinical trials concerning clinical use of impedance tomography with ultrasongraphy and X-ray mammography in diagnosing breast tumors. Neoplastic tissue has a lower electrical impedance in comparison with surrounding healthy tissue. This observation, allows using electrical impedance for diagnosing neoplasms. This article is literature review on the subject (**Adv Clin Exp Med 2005, 14, 6, 1313–1317**).

Key words: impedance tomography, impedance mammography, breast tumor.

Streszczenie

W pracy przedstawiono zastosowanie tomografii impedancyjnej w diagnostyce raka sutka. Opisano podstawy fizyczne tomografii impedancyjnej oraz jej zalety i wady. Zaprezentowano wybrane systemy mammografii impedancyjnej. Przedstawiono wyniki badań z wybranych ośrodków nad zastosowaniem klinicznym tomografii impedancyjnej w połączeniu z badaniem ultrasonograficznym i mammografią rentgenowską w diagnostyce guzów sutka. Uważa się, iż tkanka nowotworowa ma zmniejszoną impedancję elektryczną w porównaniu z otaczającą zdrową tkanką. Spostrzeżenie to umożliwia zastosowanie metod wykorzystujących impedancję elektryczną do diagnostyki nowotworowej. Artykuł jest przeglądem literatury z tej dziedziny (**Adv Clin Exp Med 2005, 14, 6, 1313–1317**).

Słowa kluczowe: tomografia impedancyjna, mammografia impedancyjna, guz sutka.

Breast cancer is the most common neoplasm in women. Its early diagnosis plays the key role in improvement of the prognosis. Currently a standard screening test for breast cancer is mammography which has high sensitivity but low specificity. The second feature requires women to be put to an unnecessary stress associated with biopsy and elevates the costs.

Neoplastic breast tumors have lower electrical impedance than the surrounding tissue [1, 2]. Measurement of tissue impedance *in vivo* is possible with invasive methods (electrode insertion into the body) and noninvasive. Noninvasive methods include Electric Impedance Tomography (EIT) and Electrical Impedance Mapping (EIM).

Imaging Method Using Impedance Tomography

Electrical Properties of Tissues

Tissue model used in impedance tomography consists of extracellular fluid, cellular membranes and intracellular fluid. Such model is characterized by electrical resistance and electrical capacitance. Tissue impedance Z is a sum of electrical resistance R and the capacitance component jX, where X is reactance:

$$Z = R + jX$$

Tissue impedance depends on the frequency of the current flowing through it. Changes within the range 10 Hz–10 kHz are a result of ionising of the environment and above 10 kHz are caused by relaxation of structures.

Measurement of Tissue Electrical Properties *in vitro*

First impedance measurements were performed in 1920s. The studies showed that neoplastic tissue has statistically significant lower impedance than healthy tissue, especially at current frequencies from 100 Hz to 10 MHz. The observation described above is coherent with the proposed model because in the neoplastic tissue damage of the cellular membranes, an increase in intracellular tissue volume and changes in cells position can be seen [1].

Invasive Measurements of Tissue Electrical Properties *in vivo*

Tissue impedance measurements can be invasive and noninvasive. In the invasive technique electrodes inserted to the lesion allow for impedance measurement (Fig. 1). Data from multicenter trials show that neoplastic tumors have lowered impedance values in comparison with a healthy tissue [3]. Differentiation between benign and malignant tumors can be performed with the use of impedance measurement. Differences between the impedance values of a malignant and benign tumor have been shown, however the opinions of the authors differ on this subject. In some studies the capacitance of a malignant tumor is smaller than this of a benign tumor and in others the result is opposite. It is necessary to conduct further experiments in this field.

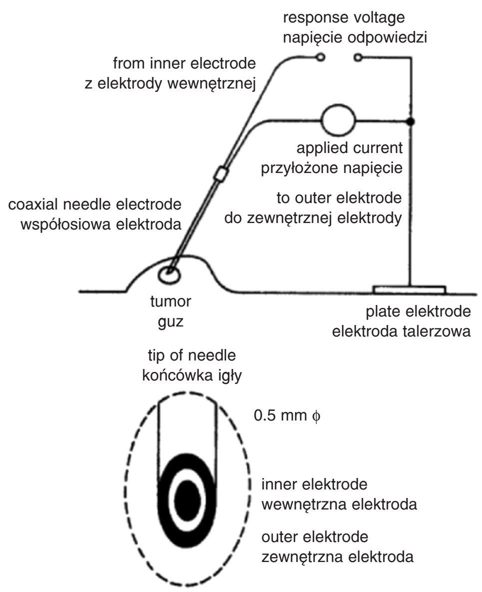


Fig. 1. Tissue impedance measurement *in vivo* using three-electrode invasive method

Ryc. 1. Pomiar impedancji tkanki *in vivo* metodą inwazyjną trójelektrodową

The instruments for invasive tissue electric impedance measurement are relatively inexpensive to build and results can be read immediately. The problem is localization of the lesion in order to puncture it. Because of invasive character of the examination the physician should consider its necessity in diagnosing breast tumors.

Noninvasive Measurements of Electric Tissue Properties *in vivo*

Theoretical Basics of Graphical Imaging by Electrical Impedance Methods

The noninvasive method of tissue impedance measurement uses a large number of electrodes. They are positioned on the surface of the body and many measurements are performed. The results are then processed by a computer which generates a two- or three-dimensional image. Generated image shows tissue impedance properties in the examined area.

The methods of Electrical Impedance Mapping (EIM) consist of making measurements with the use of electrodes positioned in one plane parallely to body surface. The results of the examination are presented as a two-dimensional image parallel to the body surface. Electrical Impedance Mapping can be classified with respect to the used current frequency, number and position of electrodes on patient's body and the type of induction signal. Induction signal can be of constant current or constant voltage. In current driving-mode method a constant current is flowing between two electrodes and the potential is measured on other electrodes. In voltage driving-mode, a constant voltage is set on two electrodes and current flowing through other electrodes is being measured [4].

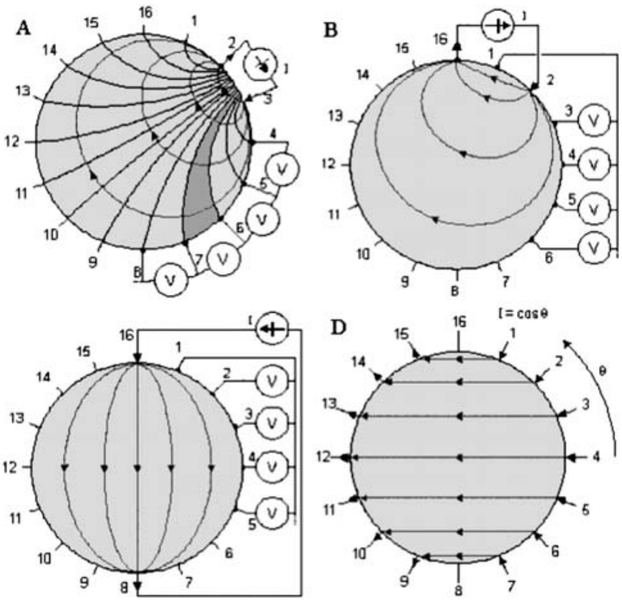


Fig. 2. Induction signal pattern in impedance tomography (A – neighbouring method, B – cross method, C – opposite method, D – adaptive method)

Ryc. 2. Wzorce sygnału pobudzenia w tomografii impedancyjnej (A – metoda sąsiadów, B – metoda krzyżowa, C – metoda przeciwległa, D – metoda adaptywna)

Opposite to Electrical Impedance Mapping methods, Impedance Tomography allows for generating image perpendicular to the body surface and for creating three-dimensional images. The electrodes are positioned around the examined body fragment. After completing measurements, impedance parameters of the tissue located between the two electrodes are calculated. Impedance tomography can be classified in similar ways as electric impedance mapping and additionally with respect to the induction signal patterns. Four basic induction signal patterns are shown in Fig. 2. In the neighbouring method the difference of potentials is calculated between neighbouring electrodes, in cross method between the chosen electrode and all others. The opposite method consists of sending current between opposite electrodes and in adaptive method the direction of current between all the electrodes is parallel.

The problem of calculating tissue impedance on the basis of collected results from the mathematical point of view is a non-linear one, reverse and ill-posed. Most of the solutions are based on the finished elements method.

Examples of Impedance Mammographs

Example of an Impedance Mammograph is, constructed in Dartmouth College, a 16-electrode impedance tomograph imaging female breast in two dimensions (Fig. 3). Induction signal is constant current and the finished-elements method is used in calculations. The electrodes are positioned in a cap with changeable size. During the examination the patient is lying on a table and the examined breast is inserted into the cap. The measurements are performed at 10 different current frequencies in the range 10 kHz–1 MHz. One examination takes about 10 minutes. In the study the examinations of 25 breasts were performed (12 healthy, 2 with a malignant tumor, 2 with a benign tumor, 6 with cysts i 3 after radiotherapy). All breasts with tumors were identified as abnormal [5].

In Poland an experimental impedance tomograph allowing for 3-dimensional imaging was built at Gdansk Polytechnical Institute. The parameters are collected from 64 electrodes placed on

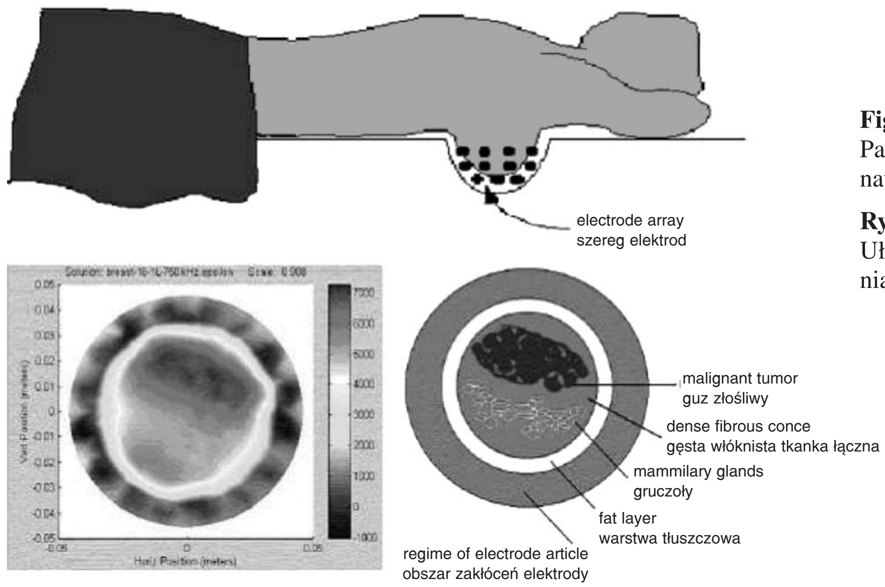


Fig. 3. Impedance tomography. Patient position during the examination, examination results

Ryc. 3. Tomografia impedancyjna. Ułożenie pacjentki podczas badania, wyniki badania a hemisphere. There is a possibility of using a constant current and constant voltage method. Induction signal pattern is sent according to the opposite method. During the test conducting fluid is put between the electrodes and the examined breast, allowing for examining breasts of different shape (the electrodes positions are fixed on the hemisphere). The limitation of this system is a too small number of electrodes, to create a sufficient 3-dimensional image [6].

In the study [7] of Cherepenin et al. an innovative impedance mammograph patented by TCI (Technology Commercialization International Inc, USA) was described. In it the position of electrodes is different than in the systems presented earlier. One electrode is placed on the wrist of the examined patient and the remaining 256 are arranged on an elastic net pressed against the examined breast during the examination. It uses the constant current method. The current is running between the wrist electrode and one of the 256 electrodes on the net. The measurement is repeated for every electrode placed on the net. Reconstruction of a 3-dimensional image from the data achieved in such way is quite easy because it is assumed that the electrodes on the net are positioned on an equipotential plane. The coincidence of the impedance examination results with X-ray mammography and biopsy is about 86% [7].

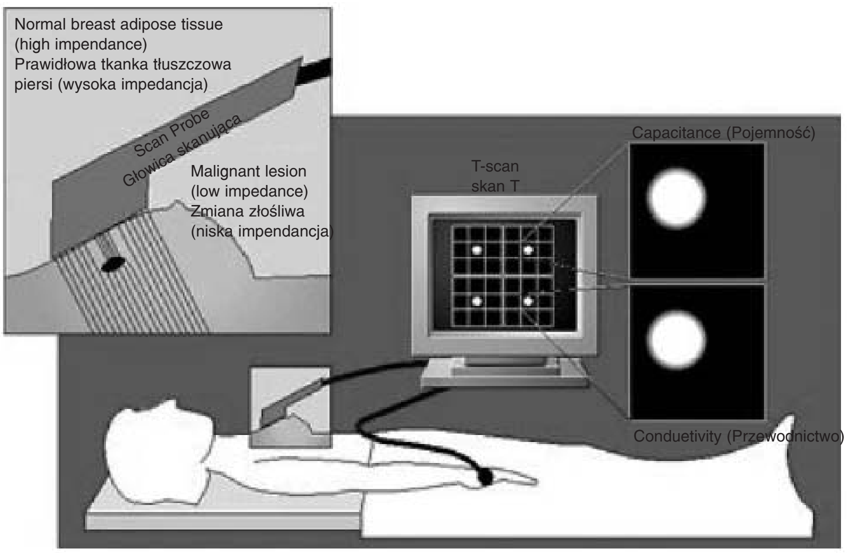
The TS2000 system is the only one available on the market allowing for breast examination with impedance method (Fig. 4). It uses the Electric Impedance Mapping method. The system was designed by Siemens. The core of the system is a scan probe with 256 electrodes (or 64 in the smaller probe). During the test, the reference electrode is placed on patient's hand and the current is running to it from electrodes in the probe. The examining physician after placing conducting gel between the probe and skin moves the probe around the breast similarly to the way it is done in an ultrasonographic examination. The Impedance Mapping method used in TS 2000 also has its limitation. It is impossible to detect a tumor located deeper than 3–3.5 cm and because of two dimensional imaging the number of false positive results, associated with the presence of artifacts (pathological changes in the skin, bones and muscles), is higher. Tumor localization for biopsy is also impossible.

Clinical Results of Impedance Mammography

TS2000 instrument is the only impedance mammograph available on the market, so all the tests were performed on this equipment.

In the study [8] 504 examination results were investigated (179 malignant tumors, 325 benign tumors, all confirmed by biopsy examination). On the basis of the examination results it was confirmed that using impedance mammography with X-ray mammography improves the acuity of the test form 39 to 51% (p = 0.0003) and the specificity of the method from 82 to 88%.

Malich et al. [9] performed examinations of a hundred breasts. The accuracy of the system TS2000 was 81% and the specificity 63%. The kappa coefficient (result similarity probability) between MRI and TS2000 was 0.82 and between ultrasonography and TS2000 – 0.62.



Rys. 4. System mamografii impedancyjnej TS2000 Siemens

Fig. 4. Siemens TS2000 Impedance mammography system

Other Methods of Measurement of Tissue Electrical Properties

The method of Magnetic Induction Tomography (MIT) can also be used for measurement of tissue electrical properties. Magnetic Induction Tomography does not require electrodes to have any contact with the patient's body. During the examination the patient is placed in a changing magnetic field, which induces a current in the patient's body. The probes placed around the patient's body measure disturbances in the magnetic field caused by the induced currents. The main problem in Magnetic Induction Tomography is low ratio of the signal strength to the background. From measured values it is possible to create an image of electrical properties of tissue [10]. This method has not been used in the diagnostics of breast tumors.

Electrical properties of tissues are analyzed for about 70 years. Results of the examinations are encouraging for further studies on invasive and noninvasive methods.

The advantage of invasive methods are: relatively inexpensive equipment and immediate results. The disadvantage of the method is the problem of localizing the tumor in order to puncture it. It is suggested to combine other diagnostic methods allowing for tumor localization (e.g. ultrasonography).

Main problems arising in the noninvasive methods are too low resolution, electrodes adjusting to breast shape, differences of impedance on the electrode-skin boundary. The solution of these problems is associated with increasing the number of electrodes and designing an efficient method of positioning them on the breast.

Preliminary clinical studies show that the method of electric impedance combined with X-ray mammography, ultrasonography and in future thermography opens new diagnostic possibilities and can contribute to improvement in diagnosing breast tumors [11].

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