Electromagnetic Imaging for Breast Cancer Research

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***Abstract* — Breast cancer is a serious potential health problem for all women. The current screening and imaging techniques such as X-ray mammography, clinical examination, ultrasound, and MRI, even combined in some way, provide only 73% accuracy in detecting breast cancer. This motivates researchers with biomedical background to investigate new techniques to advance the screening techniques aiming for early detection of breast cancer. In particular, the electromagnetic (*EM*) community has been researching potential techniques for breast cancer detection. Potential *EM* techniques are discussed in this paper.**

***Index Terms* — Biomagnetics, biopotential, breast cancer, diffuse optical tomography, electrical impedance tomography, microwave imaging, radiometry.**

I. INTRODUCTION

Several research works were focused on using microwave imaging of breast cancer leading to develop ultra-wideband radar systems, fast imagining algorithms, signal processing methods, measurement of breast tissue electrical properties techniques, broadband antennas, etc. [1]-[11]. However, several limitations and challenges were reported for realistic implementations in clinical trials. The main reported challenge in recent years was the lack of high contrast between malignant tumors and healthy tissue as was strongly believed to exist in the past [8]-[10]. In addition, other challenges originally existed such as the unknown internal inhomogeneous breast structure, the lack of exact pathological structure of healthy breast tissue even in the same woman, the multiscale aspect of tumors, ducts, lobes, fatty regions, etc.

Biopotential mapping of malignant tumors using electrodes is another potential technique for breast cancer detection [12]-[20]. There is a lack of fundamental understating of the biophysics involved in this technique, which was the focus of recent efforts [19]-[20].

The above two methods are just examples, and there are other *EM* methods that are under investigation for several years; e.g. the radiometry [21]-[24], the electrical impedance tomography (EIT) [25]-[28], the diffuse optical tomography (DOT) [29]-[33], the biomagnetics [34]-[35]. Each technique presents its existing challenges that still hinder its implementation in the clinic; however, some of these methods are more advanced than others. In addition, the recent advances in nanotechnology fabrication and characterization have opened new directions for research efforts to detect and treat breast cancer at early stages and with minimally invasive procedures [11]. Other *EM* and non-*EM* techniques were summarized in chapter 1 in [36]. The following sections present brief overviews of potential *EM* techniques for breast cancer detection and imaging.

II. MICROWAVE IMAGING TECHNIQUE

This section summarizes the recent progress in the key components of microwave imaging of breast cancer. The main motivation of using this technique was based on the claim that the electrical properties of malignant breast tissue are almost 5 to 10 times larger than those of normal tissue. Also, using microwave imaging is safe for the patient; it is non-invasive and non-ionizing with few centimeters wave penetration depth in breast tissue.

In microwave imaging systems, the transmitting antennas illuminate the breast with signals operating in microwave frequencies (e.g. 1GHz-10GHz) with the receiving antennas collecting the signals scattered from the breast. These signals contain information about the tumor size, shape, location and electrical properties.

The first near-field microwave imaging system used in clinical trials was developed in Dartmouth College by Meaney *et al* [1-2]. The system consisted of a circular antenna array of 32 monopoles operating in the frequency range 300MHz - 1000MHz. The system was first used to image the breasts of 43 healthy patients with no tumor. This study concluded a high correlation between the average electrical properties in both breasts and the increase in average and local electrical properties with the increase in radiographic breast density.

The clinical trial in [2], examined 80 patients with abnormal mammograms and 50 patients with normal mammograms. The tissue permittivity and conductivity in the suspicious region, in the mammogram, were reconstructed using the measured microwave data. The results showed that 1 cm diameter or more cancerous tumors exhibited larger conductivity, almost twice, compared to the healthy background tissue. This ratio was statistically larger than that of benign tumors or that exhibited from healthy women [2].

Another ultra-wideband microwave imaging system was developed by Klemm *et al* at the University of Bristol [3]-[4]. This system operated at 4.5GHz-10GHz obtained using cavity-backed patch antennas instead of the monopole antennas of Meany *et al* system previously discussed. Also, Klemm *et al* system employed a three dimensional hemispherical antenna array versus the two dimensional circular array of Meaney *et al*. The Klemm *et al* system was used in preliminary clinical trials [3].

In addition to the above hardware systems, several works were published on several hardware or software key components in microwave imaging for breast cancer. Only few are listed here due to the space limitation; for advancing the antennas [5], for computational imaging algorithms [6]-[7], for measurements of electrical properties of healthy and cancerous breast tissue [8]-[10], on increasing the contrast between malignant and healthy tissues using carbon nanotubes [11]. More citations on *EM* and non-*EM* works were given in [36].

III. BIOPOTENTIAL TECHNIQUE

Recently, the biopotential detection of breast cancer has been explored [12]-[20]. When cancerous cells divide, their membrane potential changes upon modifying the concentration of their internal ions. These ion concentration changes lead to imbalances in the charged ions in the surrounding breast tissue which causes biopotential differences at the breast surface. A map of biopotential electrodes were positioned on the breast with reference electrodes placed on the palms of the hands [12]. The health breast was used as a reference for comparison.

A clinical experiment was performed on 101 women, 49 with malignant tumors and 52 with benign tumors [13]. The results showed a sensitivity of 90% and a specificity of 60% [15]. More interesting, the sensitivity was found to increase when only considered patients with tumors less than 2.5cm in diameter. The claim was that the increase in sensitivity for smaller tumors was due to the activity while growing compared with larger tumors [15]. A larger clinical trial involved 661 patients in eight different centers in Europe as reported in [16]. An overall sensitivity of 90% and specificity of 55% were also reported.

Recent work has been published on using the semiconductor diffuse-drift technique to model the biopotential generated from growing breast cancerous cells [36], [19]-[20]. Despite the experimental work published in [12]-[18], the fundamental understanding of the electrophysiological activities of breast cancerous cells was lacking. The computational model presented in [36], [19]-[20] showed the increase of the biopotential with the increase of the number of cancerous cells in the breast, which is proportional to the tumor size. The work in [36], [19]-[20] discussed in depth and great details the dependence of the biopotential on the tumor random shape type (i.e. papillary, comedo, and compact), and the random percentage of cell division types (i.e. polarizing, hyperpolarizing, and quiescent).

IV. MICROWAVE RADIOMETRY TECHNIQUE

Cancerous tumors, which exhibit enhanced metabolism that increase their temperature up to 3 °C, radiate at all frequencies, especially in the infrared spectrum [21]-[24]. However, due to the attenuation of waves in the infrared range, the radiation in biological tissue was proposed to be measured using microwave radiometry [21]. In a clinical trial, four breast cancer patients had tumors at depth of 5-30 mm were correctly detected using one or two radiometers. However, the fifth patient who had a tumor at depth of 30-40 mm was not detected [22].

A primary challenge in microwave radiometry of breast cancer was due to using low sensitivity antenna with respect to the small microwave signal emitted by the elevated temperature [21]. However, it was improved upon using active antennas [23].

The brightness temperatures of malignant tumors were numerically calculated showing that brightness temperature of tumors exhibit a unique resonant behavior dependent only on the tumor shape, size, and electrical properties rather that its burial depth in the breast [24].

V. ELECTRICAL IMPEDANCE TOMOGRAPHY

Electrical impedance tomography (EIT) is a way to measure the impedance of the breast [25]-[28]. This method is performed at low range of frequencies ~100 Hz to 1MHz where the electrical properties of malignant and healthy tissues differ drastically [25]. Upon applying currents and measuring the induced voltage differences across the sensors, or vice versa, the impedance of the breast can be mapped [25]. Due to the contrast in electrical properties between malignant and healthy tissue in the above frequency range, tumor regions exhibit different effective impedances compared to the health tissue.

To the best of the author's knowledge, the only commercial EIT system approved by the FDA is the TransScan T-Scan 2000 [25]. It was approved only to be used in conjunction with the X-ray mammography and not independently [25]. In case of a suspicious mammogram, a positive EIT detection will confirm the malignancy of the tumor; however, a negative EIT detection does not mean that the woman has no cancer but further tests are needed [25]. The system consists of a 16×16 electrode array with a reference electrode to be handheld [25]. To have the breast surface be as flat as possible, the patient lies on her back in the supine position. The EIT probe scans over the breast and the currents are measured in complex numbers at different positions. The applied voltages have magnitudes between 1 and 2.5 Volts [25]. A two dimensional map of the breast impedance is then produced in real time where tumors appear as bright spots due to their large conductivity [25]. Despite of the EIT simple idea, the use of the system has limitations due to the interferences from muscles and bones.

VI. Diffuse Optical Tomography

The light is used to image the optical properties of the breast. This method is known as diffuse optical tomography (DOT) [29]-[33]. When comparing the DOT with the microwave imaging, clearly the obtained resolution is higher. The DOT uses frequencies in the near infra-red (NIR) range from about 650 to 950 nm [29]-[30]. These frequencies represent a spectral window where the absorption is minimum and the penetration of light through the biological tissue is maximum.

There are several DOT systems being tested in clinical trials [31]. The Laser Breast Scanner (LBS) built at the University of California Irvine's Beckman Laser Institute, the DOT system at Dartmouth College, the University of Pennsylvania DOT system, and the Advanced Research Technologies (ART) system [31]. In parallel to the advances in DOT systems, there have been significant advances in the associated imaging algorithms [32]-[33]. Similar to other imaging modalities, the DOT imaging algorithms typically involve the challenging solution of the inverse scattering problem [32]-[33].

VII. Biomagnetics Technique

Few preliminary experimental studies showed elevated magnetic fields detected from malignant breast tumors when compared with benign tumors [34]-[35]. The biomagnetic fields from 11 patients with invasive breast carcinoma and 10 with benign breast tumors were reported [34]. The results showed that invasive breast carcinoma produced larger magnetic field than benign tumors. To the best of the author's knowledge these results were unrepeated in other clinics. Also these results were obtained using a small number of patients. The sensors used in these experiments were the SQUID type and the other biomagnetic signals generated from the heart of the patient, for example, were ignored [34-35].

VIII. Conclusion

Potential *EM* techniques for breast cancer detection and imaging are still under research investigations. These techniques include the microwave imaging, the biopotentials, the radiometry, the electrical impedance tomography, the diffuse optical tomography, and the biomagnetics. These techniques have demonstrated potential advantages over the X-ray mammography but in the mean time they still suffer major challenges that prevent them from being used in clinical trials. Ongoing research to advance these techniques is presented in the enriched publications in the literature.

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