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MEASUREMENT OF THE ELECTRICAL PROPERTIES OF CANCEROUS TISSUES OF BREAST AND THYROID GLAND AT FREQUENCIES (1-300) KHZ[a]

MEDICIÓN DE LAS PROPIEDADES ELÉCTRICAS DE TEJIDOS CANCEROSOS DE MAMA Y GLÁNDULA TIROIDES A FRECUENCIAS (1-300) KHZ

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ABSTRACT: Due to the increasing interest in applied sciences and their impact on the diagnosis of certain diseases such as cancer, the need for discovering new and rapid methods for early cancer detection in hospitals and health centers has grown. Therefore, studying the electrical properties of cancerous and healthy tissues is one of the most useful methods for diagnosis. This research focused on studying the electrical properties (impedance, conductance, conductivity, and permittivity) of human tissues (breast and thyroid) that are cancerous and healthy at frequencies of (1, 50, 100, 150, 200, 250, 300) KHZ. We found that impedance decreases with increasing frequency, and there is a significant difference between the cancerous and healthy tissues, as the impedance in healthy tissues is greater than that in cancerous tissues in both organs. As for conductivity and conductance, they increase with increasing frequency and are greater in cancerous tissues than in healthy ones for the breast, while there is no significant difference in thyroid tissues. Permittivity increases in cancerous tissues more than in healthy tissues in both organs.

KEYWORDS: Electrical properties; cancerous tissues; frequency; thyroid gland; breast.

RESUMEN: Debido al creciente interés en las ciencias aplicadas y su impacto en el diagnóstico de ciertas enfermedades como el cáncer, ha crecido la necesidad de descubrir nuevos y rápidos métodos para la detección temprana del cáncer en hospitales y centros de salud. Por ello, estudiar las propiedades eléctricas de los tejidos cancerosos y sanos es uno de los métodos más útiles para el diagnóstico. Esta investigación se centró en estudiar las propiedades eléctricas (impedancia, conductancia, conductividad y permitividad) de tejidos humanos (mama y tiroides) cancerosos y sanos a frecuencias de (1, 50, 100, 150, 200, 250, 300) KHZ. Encontramos que la impedancia disminuye con el aumento de la frecuencia, y existe una diferencia significativa entre los tejidos cancerosos y sanos, ya que la impedancia en los tejidos sanos es mayor que en los tejidos cancerosos en ambos órganos. En cuanto a la conductividad y la conductancia, aumentan con el aumento de la frecuencia y son mayores en los tejidos cancerosos que en los sanos para la mama, mientras que no existe una diferencia significativa en los tejidos tiroideos. La permitividad aumenta más en los tejidos

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cancerosos que en los tejidos sanos en ambos órganos.

PALABRAS CLAVES: Propiedades eléctricas; tejidos cancerosos; frecuencia; glándula tiroides; mama.

1. INTRODUCTION

Diagnosis of cancerous organs is of great importance and has recently attracted the attention of researchers in searching for fast, effective, and accurate methods to diagnose cancerous tissues. The electrical and insulating properties of biological tissues were one of those methods for many reasons, including low cost, fast results, and simple calculations, in addition to the electrical properties of biological tissues that researchers have studied for over a century (Mathloom *et al.*, 2025). First and foremost, they determine the paths through which current flows through the body. As a result, it is important to examine a wide range of biomedical applications, including electrical stimulation and diagnosis and treatment of various physiological conditions that involve weak electrical current. Basic biological processes can be understood by understanding electrical properties. Bioimpedance studies have long been important in biophysics and electrophysiology. Second, information about the conductivity, permittivity, and magnetic permeability of tissues or organs is needed to evaluate the response to electrical, magnetic, or electromagnetic stimulation. The diversity of cell shapes, their location within tissues, and the different properties of the cell membrane and external cellular media make it difficult to describe the interaction microscopically (Miklavčič *et al.*, 2006). Thus, field distributions in biological systems are often described using macroscopic descriptions. Moreover, even at the macroscopic level, electrical properties are complex. The frequency of the applied field may affect it (whether a tissue is a perfect conductor, a perfect insulator, or a poor conductor), the orientation of the tissue concerning the applied field (directional anisotropy), or time and space (change in tissue conductivity during electrical permeability) (Khuda, 2017). One of the most important applications of electrical properties is in disease diagnosis, including early detection and diagnosis of cancerous tumors (Joines *et al.*, 1994). Most researchers have focused on studying the genetic aspect of cancer, although only 15 % of detected tumors have a genetic origin. Since cancer is a broad term, describing it as a purely genetic disease is inaccurate. The first step in combating cancer cells is to understand their behavior. The disease develops due to a complex network of environmental factors, genetic defects, metabolic changes, and electrical imbalances that are not noticed at first until it develops and becomes more widespread. However, the interaction of different electrical changes and their effects on each other are rarely studied. Every human cell has electrical properties essential for proper behavior inside and outside the cell (Mahdia & Mathloom, 2024). In many countries, cancer incidence has risen to the top of the list of causes of death in recent years. Among the most common malignancies affecting women are breast cancer and thyroid cancer. Many cancer patients are already diagnosed with distant metastases, and many go on to develop metastatic disease after surgical removal of the primary tumor. In medical treatment, measures are taken either to halt the progression of the disease (primary prevention) or to prevent its further development (secondary prevention). Since the speed of detection of the disease determines the effectiveness of secondary prevention measures, advanced techniques are needed to identify potential cellular problems in the early stage of the disease incubation period (Di Gregorio *et al.*, 2022). Thyroid nodules can be found on high-resolution ultrasound examinations in 19 % to 68 % of randomly selected individuals, with a higher prevalence in women and the elderly (Hong *et al.*, 2012). This percentage is considered low in the field of medicine. The distinction between benign and malignant thyroid nodules is the most important issue. This distinction reduces the likelihood of unnecessary surgical intervention while ensuring that the patient receives appropriate care. Only patients who already have malignant nodules should undergo surgery; others should receive more conservative treatment (Hamberger *et al.*, 1982).

Breast cancer continues to pose a serious threat to global health, with 2.3 million new cases identified in 2020 alone. It causes approximately 685,000 deaths annually, or 16 % of cancer-related deaths among women, despite advances in treatment (Yun *et al.*, 2018). Improving treatment outcomes and survival rates requires early detection (Sung *et al.*, 2021). However, radiation exposure, reduced sensitivity in dense breast tissues, and access issues are some of the drawbacks of the standard screening techniques used today, such as mammography. Despite their enhanced capabilities for early detection, these gold–standard clinical criteria–mammography, MRI, and ultrasound–have their limitations (Farag *et al.*, 2018).

According to studies, women would prefer to know if they have breast cancer, but they encounter obstacles such as lengthy wait periods, a lack of specialists, trouble visiting clinics, and the pain or shame of showing their breasts to medical personnel (Arnold *et al.*, 2022). These elements, in addition to the anxiety associated with going to screening facilities or clinics, may keep women from getting routine screenings, which could result in delayed diagnosis and worse outcomes.

Early diagnosis is considered one of the most effective methods for combating this disease, although it is not always possible. More academics are now focusing on identifying and avoiding the onset of the disease rather than trying to find a cure. Warburg's hypothesis in 1924 suggested that the formation of cancerous tumors results from mitochondrial dysfunction (MacKinnon *et al.*, 2023). This was one of the first indications that shifted the focus away from genetic origins. The discoveries by Frick and Morse regarding the distinctive use of the electrical properties of tumors as a diagnostic tool and classification criteria proposed after a few years of their discovery that cancerous breast tissues have higher capacitance and resistance than normal breast tissues (Crowley, 1973; Mathloom *et al.*, 2024). There is some evidence that the electrical impedance of malignant breast tumors is lower than that of the normal tissues around them (Abidor *et al.*, 1979). Conductivity can be used to differentiate between malignant tumors (cancerous) and benign tumors (non-cancerous) in thyroid tumors (Zou & Guo, 2003).

Bioresistance research has long been important in biophysics and bioelectrical science; isolated studies of cell suspensions were one of the first evidence for the existence of a cell membrane. We need information about the specific conductivity and reactive permeability of tissues or organs to study the response of tissues to electrophysiological stimulation. In addition to the various properties of the extracellular medium, the distribution of the response is often described by microscopic techniques, which are complicated by the diversity of cell shapes and distribution within tissues. Consequently, the distribution of fields in biological systems is often described using macroscopic techniques. Furthermore, electrical properties are complex even at the macroscopic level. Tissue properties can be affected by the frequency of the applied field (since tissues are neither perfect conductors nor perfect insulators), by the angle of the tissue concerning the applied field (inhomogeneous behavior), or by time and space (such as changes in tissue conductivity during electrical permeability). Any material, including biological tissues, can be classified based on its electrical properties as either a conductor or an insulator. While in an insulator, the electrical charges in a conductor move freely, when an electric field is applied the charges are stationary and cannot move freely. Statistics of relative permittivity and conductivity are only available at frequencies above 100 Hz (Hong et al., 2012).

Data below this frequency are either very rare or nonexistent for most tissues. Effects of electrodes can lead to large experimental errors in this frequency range, which is why capacitive components account for only about 10 % of published results, not a lack of interest. Impedance In most tissues, at frequencies below 100 Hz, the impedance is almost completely independent of resistance. Most tissues have a frequency between 100 Hz and 100 kHz, except for heterogeneous tissues. An abnormal mass of tissue surrounded by one or more types of normal bodily tissue is known as a tumor. It grows at the expense of healthy tissue and serves no practical purpose. As previously emphasized, the electrical conductivity and permeability of many tumors differ greatly from that of the surrounding normal tissue. We have attempted to diagnose tumors using this information. Imaging and electrical impedance measurement methods have been developed and tested to detect malignant tumors. There is some evidence that the electrical impedance of malignant breast tumors is lower than that of the surrounding normal tissue. Electrical impedance can be used as a marker for breast cancer, but further research is needed to determine whether impedance measurements can distinguish between benign and malignant lesions. It is commonly known that the electrical properties of biological tissues vary greatly depending on their structural composition. Human tissues consist of a collection of cells surrounded by fluid. The fluid inside the cells is contained by the membrane of each cell. Water, ions, and other fluids inside the cells are mostly resistive. The membrane has both capacitive and resistive properties and is composed of a thin layer of lipids containing leaky ion channels. The electrical resistance of human tissues is complex and can be represented as a series because it consists of both capacitance and resistance (Mathloom *et al.*, 2021).

This study aims to identify the electrical properties of cancerous and healthy tissues and to compare them in terms of values (impedance, conductivity, permeability, and permittivity) for the diagnosis between affected and healthy tissues.

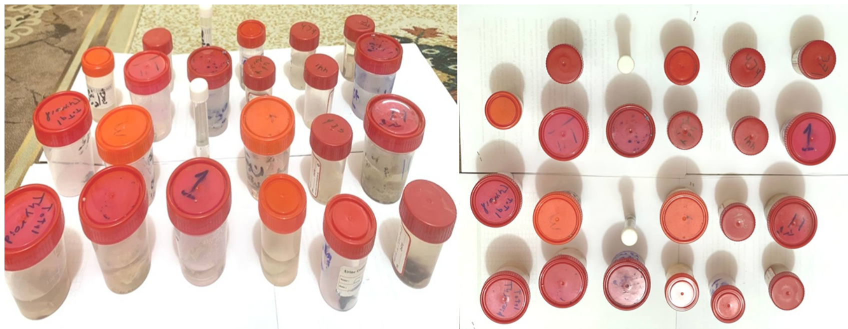

Figure 1: Breast and thyroid samples that were collected and examined appear. Author's Own Work

Figure 2: LCR meter im3536. Author's Own Work

2. METHOD OF WORK

2.1. Collecting samples

A total of 24 samples were collected for both breast and thyroid tumors, for males and females ages ranging from $(30 - 43)$ years with 12 samples for each organ. Six cancerous samples were diagnosed through histological analysis of the breast and six cancerous samples from the thyroid. Six non-cancerous (benign) samples were also collected from the breast and six non-cancerous (benign) samples from the thyroid (as a control unit). This resulted in 12 cancerous (malignant) and 12 healthy (benign) samples. The samples were fixed in a $10\,\%$ formalin solution for a period not exceeding 24 hours.

2.2. Measurements

The samples were dried to remove the water, and then a section measuring $(1 \times 1/2 \times 1/2)$ cm in length, width, and thickness was taken from each infected and healthy sample. The measured samples were placed between two copper plates, and measurements were made using scanning technology at a frequency ranging from 1 to 300 kHz using an LCR Meter, a general-purpose device that provides a wide range of testing frequencies with an accuracy of $0.05\,\%$. It is ideal for evaluating the electrical properties of living tissues because it has a wide frequency.

3. RESULTS

The current results indicated at 1 kHz frequency the impedance decreased significantly in thyroid cancer patients compared with the control group, while the permittivity increased significantly in thyroid cancer patients compared with the control group, on the other hand, the conductance and conductivity did not record significant differences between the two groups. About other frequencies, the study showed a significant decrease of impedance in thyroid patients to control, with except 300 kHz frequencies not recording significant difference, while the other parameters decreased in all frequencies were significantly increased in thyroid cancer patients compared with the control group at p. value < 0.05, as in Table 1.

Table 1: It illustrates the studied electrical properties of the thyroid gland.

Mean ± S.D at 1 kHz			
Impedance	56549180.0 ± 4832548.3	74752000.0 ± 6416376.0	0.001**
Conductance $*10^{-10}$	3.13 ± 0.76	2.27 ± 1.80	0.335
Conductivity 10^{-6}	0.65 ± 0.15	0.56 ± 0.04	0.225
Permittivity $*10^{-10}$	1.06 ± 0.08	0.81 ± 0.01	0.003**
Mean ± S.D at 50 kHz			
Impedance	1294570.0 ± 146748.4	1688860.0 ± 150132.2	0.003**
Conductance $*10^{-10}$	101.9 ± 25.4	62.9 ± 8.40	0.023*
Conductivity $*10^{-6}$	32.4 ± 3.28	24.8 ± 2.20	0.003**
Permittivity $*10^{-10}$	1.01 ± 0.08	0.79 ± 0.00	0.005**
Mean ± S.D at 100 kHz			
Impedance	654312.8 ± 56481.7	1002464.6 ± 442388.9	0.154
Conductance $*10^{-10}$	191.7 ± 30.3	123.6 ± 42.9	0.022*
Conductivity $*10^{-6}$	64.0 ± 5.13	46.2 ± 5.13	<0.004**
Permittivity $*10^{-10}$	1.00 ± 0.08	0.78 ± 0.00	0.005**
Mean ± S.D at 150 kHz			
Impedance	443092.6 ± 38490.9	618800.0 ± 55047.2	0.003**
Conductance $*10^{-10}$	281.5 ± 36.8	186.0 ± 23.2	0.001**
Conductivity $*10^{-6}$	94.5 ± 7.61	70.4 ± 9.90	0.004**
Permittivity $*10^{-10}$	1.00 ± 0.08	0.78 ± 0.00	0.001**
Mean ± S.D at 200 kHz			
Impedance	320758.6 ± 36626.6	442342.2 ± 39280.9	0.001**
Conductance $*10^{-10}$	419.5 ± 43.2	287.3 ± 31.1	0.001**
Conductivity $*10^{-6}$	131.1 ± 13.3	94.7 ± 8.42	0.001**
Permittivity $*10^{-10}$	1.00 ± 0.08	0.78 ± 0.00	0.005**
Mean ± S. D at 250 KHZ			
Impedance	256093.0 ± 29177.8	334175.2 ± 29629.6	< 0.001**
Conductance $*10^{-10}$	545.8 ± 51.8	399.2 ± 59.1	0.002**
Conductivity $*10^{-6}$	164.2 ± 16.7	125.4 ± 11.1	0.002**
Permittivity $*10^{-10}$	1.00 ± 0.08	0.78 ± 0.00	0.005**
Mean ± S.D at 300 KHz			
Impedance	225798.4 ± 19704.0	375978.8 ± 187983.0	0.149
Conductance $*10^{-10}$	662.0 ± 53.9	502.7 ± 54.8	0.002**
Conductivity $*10^{-6}$	185.5 ± 15.0	144.6 ± 8.37	0.003**
Permittivity $*10^{-10}$	1.00 ± 0.08	0.79 ± 0.00	0.005**

Table 2: It illustrates the studied electrical properties of the thyroid gland.

Thyroid Cancer	Patients	control	p. value
Mean ± S.D at 1 kHz			
Impedance	162467.0 ± 1472.2	57600000.0 ± 4874935.8	<0.001**
Conductance $*10^{-10}$	60709.2 ± 560.6	21.1 ± 3.41	<0.001**
Conductivity $*10^{-6}$	287.1 ± 26.2	0.59 ± 0.33	<0.001**
Permittivity $*10^{-10}$	2583.9 ± 257.3	1.18 ± 0.01	<0.001**
Mean ± S.D at 50 kHz			
Impedance	88570.5 ± 4458.6	1432636.0 ± 122800.1	<0.001**
Conductance $*10^{-10}$	99288.9 ± 3082.3	413.1 ± 24.2	<0.001**
Conductivity $*10^{-6}$	525.9 ± 27.1	29.2 ± 2.51	<0.001**
Permittivity $*10^{-10}$	35.1 ± 4.78	0.93 ± 0.00	<0.001**
Mean ± S.D at 100 kHz			
Impedance	69839.4 ± 4161.0	786699.4 ± 68549.7	<0.001**
Conductance $*10^{-10}$	114430.6 ± 4063.4	616.7 ± 43.6	<0.001**
Conductivity $*10^{-6}$	667.0 ± 30.3	53.2 ± 4.63	<0.001**
Permittivity $*10^{-10}$	17.3 ± 1.36	0.91 ± 0.00	<0.001**
Mean ± S.D at 150 kHz			
Impedance	58902.0 ± 4080.6	480296.4 ± 41771.5	<0.001**
Conductance $*10^{-10}$	125798.4 ± 5412.0	887.3 ± 58.1	<0.001**
Conductivity $*10^{-6}$	791.1 ± 30.6	87.2 ± 7.60	<0.001**
Permittivity $*10^{-10}$	12.3 ± 0.74	0.90 ± 0.00	<0.001**
Mean ± S.D at 200 kHz			
Impedance	52190.3 ± 4684.0	364413.2 ± 31912.1	<0.001**
Conductance $*10^{-10}$	134434.8 ± 7553.4	1128.7 ± 86.4	<0.001**
Conductivity $*10^{-6}$	893.8 ± 22.7	115.0 ± 10.0	<0.001**
Permittivity $*10^{-10}$	10.2 ± 0.69	0.90 ± 0.00	<0.001**
Mean ± S. D at 250 kHz			
Impedance	45367.0 ± 3606.6	306202.0 ± 58178.0	<0.001**
Conductance $*10^{-10}$	144783.8 ± 7646.3	1280.1 ± 183.0	<0.001**
Conductivity $*10^{-6}$	1027.7 ± 35.5	136.9 ± 22.0	<0.001**
Permittivity $*10^{-10}$	8.63 ± 0.34	0.90 ± 0.00	<0.001**
Mean ± S. D at 300 kHz			
Impedance	40653.6 ± 3380.9	249463.2 ± 8161.8	<0.001**
Conductance $*10^{-10}$	154297.6 ± 8506.1	1515.1 ± 43.0	<0.001**
Conductivity $*10^{-6}$	1106.0 ± 37.7	163.5 ± 4.07	<0.001**
Permittivity $*10^{-10}$	7.86 ± 0.26	0.89 ± 0.00	<0.001**

The current results indicated at all frequencies the impedance decreased significantly in breast cancer patients compared with the control group, while the conductance, conductivity, and permittivity increased significantly in breast cancer patients compared with the control group at p. value < 0.05, as in Table 2.

4. DISCUSSION

In this scientific paper, we will discuss the results we obtained for the electrical properties (impedance, conductivity, and permittivity) along with the change in frequency from $(1-300)\ kHz$ in cancerous and healthy biological tissues. The results showed that as the water content in the organs or tissues increases, there is a change in the electrical properties of the tissues. Since the water content in cancerous tumors is higher than that in benign tumors, due to the increased blood vessels, free radicals, and the proliferation of cells in cancerous tumors, there is a clear change in the electrical properties between healthy and affected tissues.

Moreover, biological tissues are composed of various types of atoms, each with a different dipole moment, which results in different polarizations and varying electrical responses with changes in frequency. It was found that the electrical impedance of tissues decreases with increasing frequency because the tissues contain free and specific charges, including ions and polar molecules. When the frequency is increased on living tissues, the charges are displaced from their original positions, causing polarization, ion displacement, and the creation of displacement current and conductivity. Numerous studies have shown that cancerous tissues have higher conductivity than healthy tissues. It was found that the difference in electrical conductivity is much greater in the low-frequency range, as at 1 kHz there is a larger difference than at 300 kHz. The results showed that electrical resistance at a frequency of 1 kHz in breast and thyroid tissues exhibited a clear difference between cancerous and healthy tumors. Resistance decreases as frequency increases.

Moreover, there was a significant difference in conductivity and electrical transmission at frequencies $(1-300)$ kHz respectively between the affected and healthy tissues. In the affected tissues, the value of electrical conductivity is higher than in healthy tissues because cancerous tumors contain higher water content and more blood vessels, which aids in electrical conductivity and the movement of charges from one place to another.

As for electrical permittivity, it changes with frequency, increasing but with minimal variation until it reaches 300 kHz, where there is no clear change.

5. CONCLUSIONS

We conclude from this study that there is a difference between the electrical properties measured in the frequency band used, as it was found that there are properties whose value decreases with increasing frequency. In this case, the process of diagnosis and differentiation between cancerous and healthy tissue is facilitated. This method is characterized by speed and low cost, which provides an opportunity for specialists to design devices used for this purpose.

Authors' contributions

Fadhel A. Saleh: Collecting samples from hospitals and supervised the adaptation to the laboratory as well as preparing some of the tools we need in surgery to cut tissues in the research participating in the tissue cutting process and preparing the main design of the experiment as well as repeating the process more than once to obtain controlled results. He also played a role in the literature review of some of the main topics in the research.
Ahmed R. Mathloum: General supervision of the experiment and the measurement process and adjusting the

frequency after calibrating the frequency generator as well as writing the main topics and collecting sources.

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