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Electrical properties of Brain Tissues of Irradiated Rats within $(1x10^{-4} - 5)$ MHz

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ABSTRACT

X-ray radiation exposure to brain tissues can cause a serious damage, and therefore, studying the radiation effects becomes essential. In this study, thirty albino male rats were divided into two groups, control (6 rats), and 24 rats that their whole body were subjected to 4 Gy radiation. The irradiated rats then sacrificed (4 rats each) in different periods 1, 4, 9, 16, 23, 30 days. The electrical impedance, conductivity and relative permittivity of the brain tissues are calculated in frequency range 0.0001MHz and 5 MHz. Additional measurements at selected low, intermediate and high frequency are considered. The results show significant differences between the control and irradiated tissues. This occurs highly in brain conductivity and less on the relative permittivity. The changes in the electrical properties due to whole body exposure indicate that 4Gy of X-irradiation has affected brain cells more rapidly at 9 days and did not induce acute and immediate cell death, so they gradually recover after weeks later.

Keywords: irradiation; brain tissue; conductivity; permittivity

1. Introduction

Today, the use of radiation on medicine becomes important, and thus, minimizing the side effect needed. More attentions were paid to the deleterious effects of x-ray radiation proportionally with the wide use. Radiation, as a non-discriminating agent, affects every component of the targeted tissue and is equally likely to damage both the parenchymal and vascular tissues. The severity of radiation damage depends upon the radiation dose, duration and the size of the exposed area [1,2]. A number of animal experiments have been carried out in order to elucidate the effects of radiation on the brain and its underlying mechanisms [3,4]. A number of animal experiments have been carried out in order to elucidate the effects of radiation on the brain and its underlying mechanisms [5-13]. It has been proposed that higher radiation doses cause glial cell depletion, leading to white-matter necrosis, while lower doses damage endothelial cells and have a longer latent period to occurrence [14-17]. For studies on the biological effects of radiation on brain tissues, accurate information about the dielectric properties of tissues is important. The biological tissues have complex electrical impedance, which are depend on the frequency and the specific tissue type. The electrical impedance of tissue is a function of its structure and it can be used to differentiate between normal and cancerous tissues in a variety of organs. However, different types of tissues are known to have different electrical properties [18-22]. These properties determine the energy deposition patterns in tissue upon irradiation. They also reflect the molecular mechanisms that underlie the absorption of radiation by the tissue. Although a dielectric investigation for molecules of biological interest can yield much useful information [23]. Another area of importance is the evaluation of the biological effects of radiation which cannot be put on a quantitative basis unless the electrical properties of the tissue are identified. Several studies have modeled the human head as a homogeneous tissue sphere with dielectric properties appropriate for brain tissue, the calculated results depend critically upon the assumed dielectric properties of brain tissue [24- 27]. In this paper, the brain tissue of two different groups, control and irradiated tissues were studied within 30 days to investigate their conductivity and permittivity.

2. Materials and Methods

Thirty male albino rats weighing 130 g on average were divided into two main groups: Group I consisting of 6 non-irradiated rats, which we refer to as control group, and group II comprising of 24 irradiated rats. Furthermore, group II was evenly divided into 6 subgroups, each of 4 rats. All subgroups were whole body X- rays exposure to single dose (4Gy) - X rays from a clinical therapeutic 6 MV linear accelerator facility at faculty of Medicine, Alexandria. The rats were Sacrificed according to specified time post-irradiation according to the experimental (1, 4, 9, 16, 23, 30 days). Each fresh brain was excised within minutes after the animals were sacrificed. Each excised sample is measured between 0.0001MHz and 5MHz for 92 frequency points using a capacitor cell technique. The capacitor cell used in the present work consists of two circular parallel silver electrodes with a silver chloride coating, having a diameter of 1.0 cm. The two electrodes are enclosed in chamber made of Plastic Glass (Lucite) [28]. One of the electrodes is fixed at the bottom of chamber and the other electrode is adjustable to accommodate a variety of tissue sample sizes. To facilitate measurements, a Computer-controlled automatic scanning and data recording are performed with an impedance LCR meter (*HIOKI 3532*-50 LCR meter 42 Hz to 5 MHz HiTester, Japan). The measurements of electrical impedance, conductivity ($\boldsymbol{\sigma}$) and relative permittivity (ϵ_r) have been studied. The measured complex impedance is

$$Z^* = Z' + jZ'' \qquad (1)$$

where Z' and Z'' are measured resistance and reactance of impedance data. The conductance (*G)* and capacitance (*C)* in terms of Z-components are given [29,30] as:

$$G = \frac{Z'}{[(Z')^2+(Z'')^2]}$$
$$C = \frac{Z''}{\omega[(Z')^2+(Z'')^2]} \qquad (2)$$

The conductivity ($\boldsymbol{\sigma}$) and relative permittivity (ϵ'), which depending on the nature of the sample and relating to cell constant factor($\frac{\boldsymbol{d}}{\boldsymbol{A}}$), calculated as:

$$\sigma = \frac{d}{A} . G$$
$$\epsilon' = \epsilon_r = \frac{d}{A} . \frac{C}{\epsilon_o} \qquad (3)$$

where *d* is the average separation between the electrodes and approximately the average length of specimens between (≈ 0.45 cm and ≈ 0.55 cm) and ***A*** is the surface area of electrode unit, which a cross-sectional area of the sample.

3. Results and Discussion

Impedance measurements of brain tissues were measured at 37 ^{o}C, for 4 Gy irradiated rats at several periods (1, 4, 9, 16, 23 and 30days) Figure 1 (a), which indicates all curves, shows alterations in the brain tissues which are due to the effects of radiation. Figure 1 (b), which indicates the impedance decrease as time increased reaching their lower reduction values at (9 days), then progressively approaching non-irradiated level at the end of (16 and 30 days). The reduction curves for irradiated samples below the non-irradiated curves, which may relate to the change in the ionic properties of cellular material. It can also be explained as alterations in sub-cellular structures. The results reveal that the transient effect of 4Gy dose has affected the brain cells. The obtained results showed relative change compared to control, and the tissue starts partially recover after days later. For additional insight and understanding, electrical property (*conductivity and permittivity*) is examined in this paper to clarify the relationship between radiation-induced change and electrical property. The conductivity curves of rat brain tissue are shown in Figure 2 (a). The spectral conductivity curves show no clear shift between non-irradiated and irradiated tissues. Changes in conductivity of tissue were appeared in Figure 2 (b) which shows clear separation especially in conductivity occurs at (9 days) then nearly approaching to non-irradiated level at the post-irradiation (16 and 30 days). The results showed the brain cells effect in early days and a start recovery after 9 days. The Figure 2 (b) indicates that the recovery samples exhibited close behavior to control. The results suggest that even the very high radiation doses used here did not induce acute and immediate neuronal cell death [31].

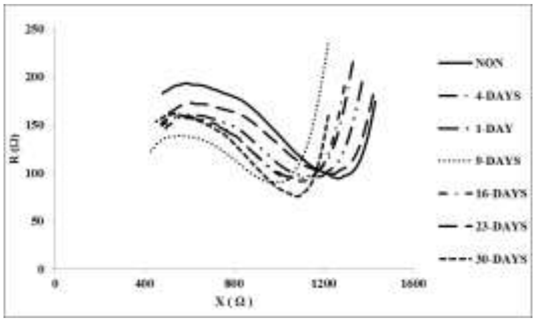

Fig. 1. (a) Plot of complex impedance plane of the brain grouped separately by time post-irradiation for single doses 4 Gy

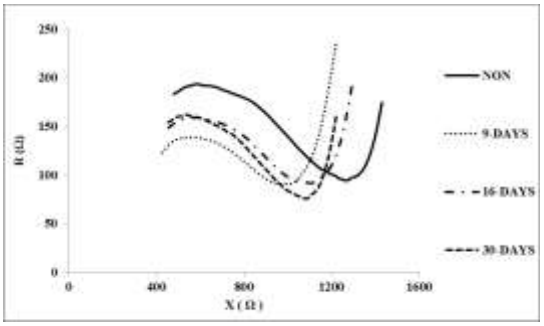

Fig.1. (b) Plot of spectral data in the complex impedance plane of the brain grouped separately by 9, 16 and 30 days post- irradiation for single doses 4Gy.

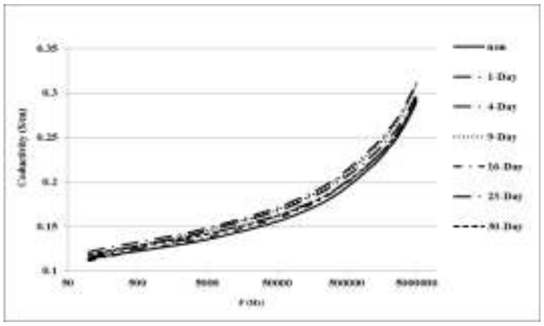

Fig. 2. (a) Conductivity (S/ m) of brain tissues as a function of frequency (Hz) for grouped separately by time post-irradiation for single doses 4 Gy

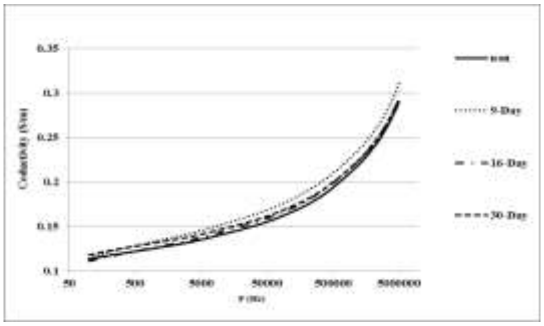

Fig. 2. (b) Conductivity (S/ m) of brain tissues as a function of frequency grouped separately by 9, 16 and 30 days post- irradiation for single doses 4Gy.

In Figure.3, further details represent the comparison of conductivity versus time post-irradiation at low (5kHz), intermediate (100 kHz), and high (1MHz) frequency point. Its noticed that the conductivity at (1MHz) increases with time and reaching a maximum value of 0.242 S/m at 9 days, then its decrease afterward. The increase starts from 0.225 to 0.242 S/m then decrease to 0.218 S/m at 30 days.

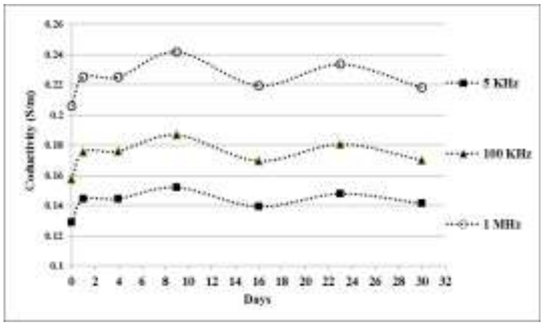

Fig. 3. Conductivity (S/ m) of brain as a function of time post-irradiation (days). The curves at low (5 KHz), intermediate (100 KHz) and high frequency (1 MHz)

Table 1 showed that irradiated samples showed higher conductivity values (Table 1) compared with a non-irradiated value (0.205 S/m). Significant results $p < 0.05$ in conductivity values within 30 days post-irradiated and non-irradiated tissues is detected for rat brain tissues. The conductivity differences between non-irradiated and irradiated samples in 30 days are 9.886 % (p=0.0042), 8.172 % (p=0.0022) and 5.838 % (p=0.0041) for low, intermediate, and high frequency respectively. This comparison indicates that the conductivity is frequency dependence and sustained higher than the non-irradiated.

Table1. Comparison of conductivity, and permittivity between non-irradiated and irradiated tissues (at 9 and 30 days) for three point frequencies, the differences normalized to non-irradiated value in per cent, based on statistical analysis. (Probability associated with student's t-test)

Conductivity (S/m)

Freq.	**NON-Irrad.**	**9 days**	**Difference in percent %**	**30 days**	**Difference in percent %**
5 KHz	0.129	0.152	18.174 (p=0.011)	0.141	9.886 (p=0.0042)
100 KHz	0.157	0.187	18.736 (p=0.005)	0.170	8.172 (p=0.0022)
1 MHz	0.206	0.242	17.332 (p=0.0028)	0.218	5.838 (p=0.0041)
Relative permittivity(ε′)					
5 KHz	39050	50446	29.183 (p=0.0001)	39405	0.9106 (p=0.7336)
100 KHz	4360	4957	13.684 (p=0.0055)	4314	-1.056 (p=0.6839)
1 MHz	991	1020	2.905 (p=0.2156)	960.	-3.086 (p=0.1587)

In case of relative permittivity versus frequency and time, there is no variance between the curves for non-irradiated and irradiated tissues as indicated in Figures.4(a,b), but as regards to relative permittivity, in Figure.5 which represents the relative permittivity for tissues at low, intermediate, and high frequencies at 30 days. It shows slight change in relative permittivity at low frequency is 0.911% (**p=**0.7336).

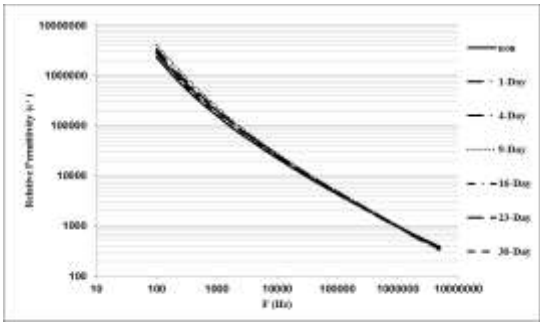

Fig.4. (a) Relative permittivity of brain tissues as a function of frequency (Hz) for grouped separately by time post-irradiation for single doses 4 Gy

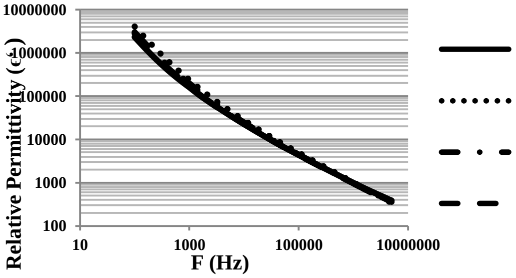

Fig. 4. (b) Relative permittivity of brain tissues as a function of frequency grouped separately by 9, 16 and 30 days post- irradiation for single doses 4Gy.

This little noticeable change of Relative permittivity could be indicated that the severity of radiation dependence on both dose and latent period variations [2, 32]. However, recent studies reported that, the direct effects of ionizing radiation on some organs (as bones covered brain) which are often classified as radio-resistant, cannot be accurately determined if the whole body is exposed to low doses of X-irradiation [11, 33, 34]. We could include that the changes in the impedance, conductivity, and permittivity in brain tissues are due to direct/indirect effects of radiation.

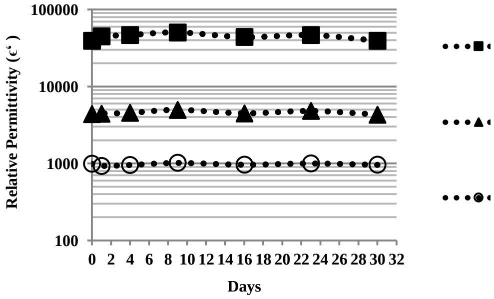

Fig. 5. Relative permittivity of brain as a function of time post-irradiation (days). The curves at low (5 KHz), intermediate (100 KHz) and high frequency (1 MHz)

4. Conclusion

It is well established that 4 Gy of whole-body irradiation will not necessarily reflect the immediate effect of radiation. Several plots including, the complex impedance, conductivity and relative permittivity as a function of frequency and some readings at low, intermediate and high frequency as function of time reveal that the differences between the irradiated and non-irradiated spectra are changed relative to variations in conductivity spectra of brain. No significant change relative to variations in permittivity of brain as whole-body irradiation is observed. Therefore, the little change in electrical properties due to whole body exposure indicate that 4Gy of X-irradiation has affected brain cells at 9 days and did not induce acute and immediate cell death, hence, they recover after days later (within 16 and 30 days).

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