

The Dielectric Properties of Rat Kidney upon Exposure to Low Static Magnetic Field Intensities

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Abstract— the aim of the present work is intended to evaluate the effect of static magnetic field (SMF) on rat's kidney. The rats were exposed to SMF of intensities of 10, 14, 18 and 22 milliTesla (mT) for a whole week for one hour daily. The dielectric properties, permittivity (ϵ'), electrical bioconductivity (σ), loss tangent ($\tan\delta$), and relaxation time (τ), were measured to the rat's kidneys over frequency range of 1 kHz to 1 MHz, before, immediately after exposure, and after one week of exposure. The results showed that there are significant differences in the dielectric properties of samples under investigation compared to the control (no SMF irradiation). The relaxation time showed significant variants of rat's kidney upon irradiation to SMF intensities, especially the 10 mT dose.

Index Terms— Bioconductivity, Cole-Cole diagram, Dielectric properties, Dipolar relaxation time, Kidney loss tangent, Static magnetic field.

1 INTRODUCTION

There is an increasing awareness about the effect of alternating magnetic field (AMF) and static magnetic field (SMF) on living organisms [1-6]. Enormous expansions of researches that focused on understanding rule of SMF on biological systems [5, 7-10]. Thus, the continually investigations on the influence of these fields on life is crucial to avoid its danger if exist or gain its advantageous if so [11].

Dielectric properties of biological systems have been widely used to investigate the responses of biological systems at wide ranges of frequencies from DC and few hertz to orders of GHz [12-20]. Moreover, the dielectric properties were used as a powerful tool for studying cellular parameters [21-23], morphology [24, 25], and cell disruption [26]. They were also used to investigate cellular activation and communication such as kidney, liver, lung and other organs [19, 27, 28]. Measurements of dielectric constant ϵ' , dielectric loss, ϵ'' , dissipation factor $\tan\delta$ and bioconductivity σ have provided important information about biological tissue [29, 30].

The present paper intended to demonstrate that the dielectric properties can be a valuable for investigating the response of biological cell, kidney for example, upon exposing to low intensities of SMF.

2 MATERIALS AND METHODS

2.1 ANIMAL

The experiments were carried out using 54 adult albino rats weighing 120 g each on average and they were purchased from the holding company for biological products and vac-

cine, Cairo, Egypt. The rats were housed individually in plastic boxes and received the same diet and treatment during the course of experiments. The guides of the national research council of dealing with experimental animals were applied.

2.2 SMF IRRADIATION

The experiments were carried out using 54 adult albino rats weighing 120 g each on average and they were purchased from the holding company for biological products and vaccine, Cairo, Egypt. The rats were housed individually in plastic boxes and received the same diet and treatment during the course of experiments. The guides of the national research council of dealing with experimental animals were applied.

An electromagnet device that constructed in the Department of Physics; Faculty of Science, Benha University was used as a SMF generator. The samples were divided into three groups, containing six rats each i.e. 18 rats in each group. The first group which was not exposed to SMF intensities was called the control group, and the two other groups were exposed to SMF intensities of 10, 14, 18 and 22mT. One of the two exposed groups, (exposure group), was examined immediately after exposure, and the second group (recovery group) was examined after seven days of recovery. All groups were investigated at the same condition.

The cylinder bore of the electromagnet was 200 mm in diameter. A uniform magnetic field was produced over a diameter of 200 mm around the centre of the bore. Rats were caged and placed in the centre of the bore of the electromagnet. SMF exposure was performed, as described in [31], for an hour daily over one week. The temperature inside the irradiation chamber was measured through the use of a thermocouple thermometer.

2.3 DATA ACQUIRING

Kidney tissue suspensions were measured at room temperature 293 K by impedance meter (Model PM 6304) at frequency

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range of 1 kHz to 1 MHz. The data acquired includes the capacitance (C in Farad), resistance (R in ohm), impedance (Z in ohm), and delay angle (θ). These data were used to calculate the dielectric parameters as well be shown later. The electrode used to acquire the data consists of two parallel platinum electrodes with diameter of 1×10^{-2} m and area of 45×10^{-6} m². These data were acquired before (the control sample), immediately after applying SMF doses (exposed sample) and a week after exposure (the recovery sample).

2.4 CALCULATED PARAMETERS

The dielectric properties were calculated using the following equations:

$$\epsilon' = \frac{Cd}{\epsilon_0 A} \quad (1)$$

$$\epsilon'' = \epsilon' \tan \delta \quad (2)$$

$$\tan \delta = \tan(90 - \theta) \quad (3)$$

Where A is the area of electrode in m², d is the distance between the two electrodes in m, C is the capacitance in farad and R is the resistance in ohm of the samples under investigation. ϵ' is the dielectric permittivity, ϵ'' is the dielectric loss. $\tan \delta$ is the dissipation factor, which represents the durability of dipolar oscillation, is used to describe the loss of the permittivity.

$$\sigma = \frac{d}{A} \times \frac{1}{R} \quad (4)$$

$$Z' = Z \cos \theta \quad (5)$$

$$Z'' = Z \sin \theta \quad (6)$$

Where σ is the bioconductivity, Z' and Z'' are the real and imagery part of the impedance respectively. The data of Z' and Z'' were used to plot the Cole-Cole semicircle which identify and represent the equivalent circuit in the sample. From the Cole-Cole diagrams, one can extract the value of relaxation time using the following formula.

$$\tau = \frac{1}{2\pi f} \left[\frac{(Z_s - Z')^2 + Z''^2}{(Z' - Z_\infty)^2 + Z''^2} \right] \frac{1}{2(1-h)} \quad (7)$$

Where τ is the relaxation time, f is the oscillation frequency, $h = 2\alpha$, where α shows the deformation of the semicircle in the Cole-Cole diagram, i.e. it is the angle from the main Z' axis to the centre of the semicircle arc. The value of α lies between 0 and 1 where, if $\alpha=0$, the Cole-Cole plot follows the Debye theory [31]. When $1 > \alpha > 0$, the data deviate from the Debye model.

4 RESULTS AND DISCUSSION

The results show significant variations in the dielectric parameters of rat's kidney upon exposure to SMF intensities of 10, 14, 18, and 22 mT compared to the control (unexposed). The permittivity ϵ' data of rat's kidney after the recovery period (a complete week) behave similar to the control at most SMF intensities. The permittivity at intensity of 18 mT showed a peak to far right to the control and the rest of data from other intensities with the highest values post exposure and remarkably the lowest during recovery. At intensity 10 mT, the data showed a behaviour similar to that of the control which previously confirmed at [11].

Frequency dependence of relative permittivity for the exposure, recovery and control samples are shown in (Figure1).

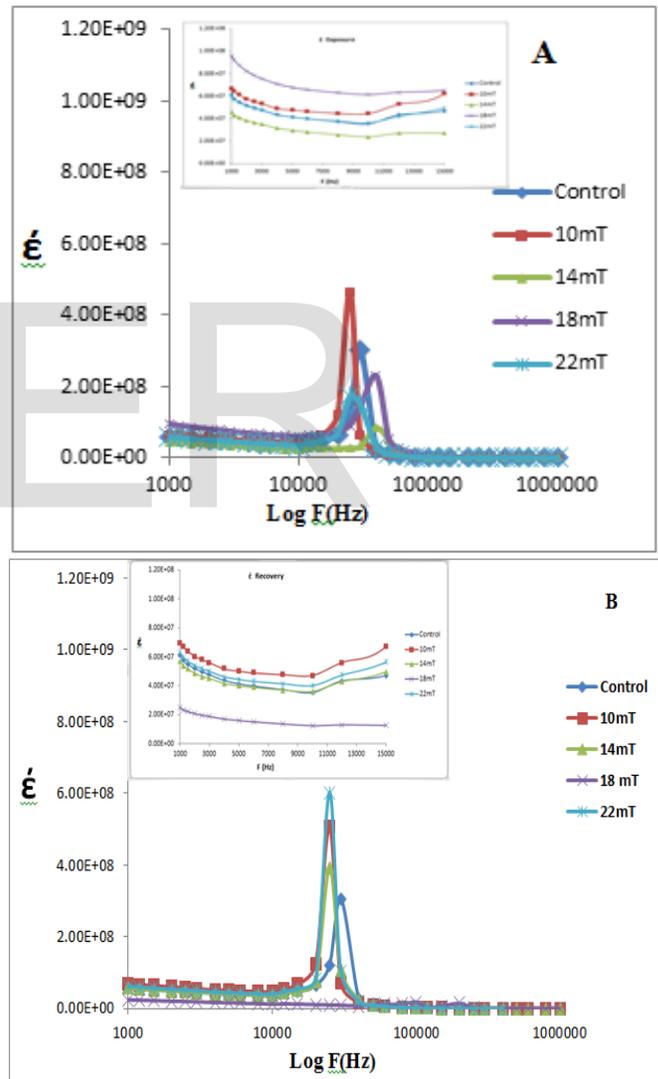


Figure (1): The permittivity versus the logarithmic frequency at the labelled SMF intensities of the rat's kidney of the exposed (A) and recovery (B) compared to the control.

These data show increase of the permittivity at SMF intensities of 10 mT and 18 mT after exposure compared to the control sample (Figure1-A) which recovers back to the control after one week, which is

illustrated by the recovery plot (Figure1-B). The 18 mT data showed much less permittivity than all samples including the control. Consequently, the data of $\tan\delta$ of the exposure sample show similar behaviour to that of the permittivity in terms of the control, exposure and recovery samples.

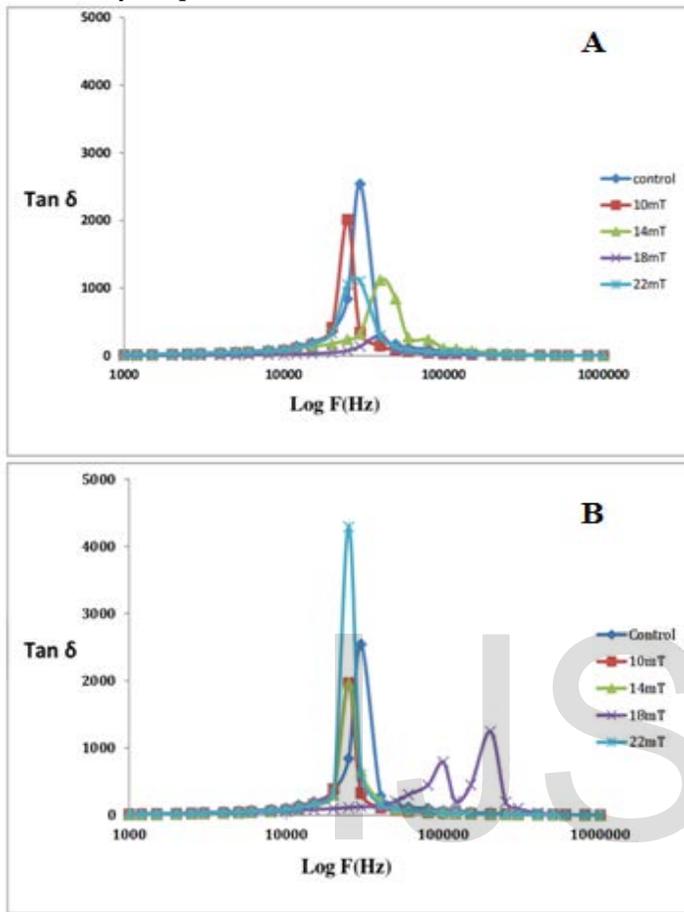


Figure (2): The behaviour of $\tan\delta$ as function of frequency of the rat's kidney of the exposed (A) and recovery (B) data compared to the control.

Two relaxation processes detected in the 18 mT of the recovery sample indicated by two peaks in $\tan\delta$, which highlights the behaviour of ϵ'' data, versus frequency (Figure 2B). The first peak represents relaxation process relating to the overall molecular dipole dynamics under the applied frequency, which is shifted to the right compared to the rest of data samples. The second peak shows the relaxation process at higher frequencies which could be due to smaller molecular dipoles orientation under applied frequency.

Furthermore, the bioconductivity as function of applied frequency of the exposure and recovery samples compared to the control was plotted in Figure 3.

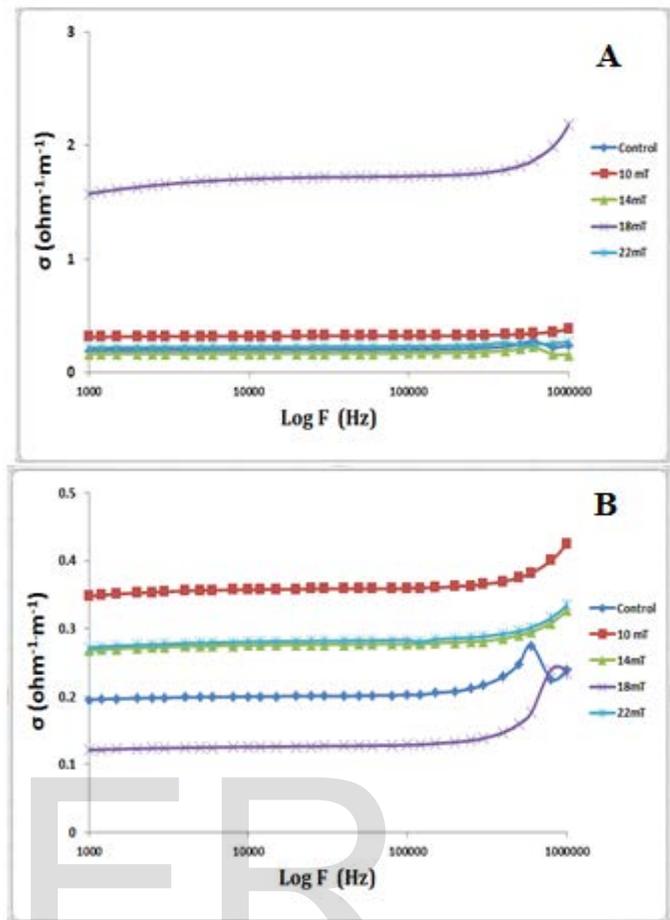


Figure (3): The bioconductivity as function of frequency of the rat's kidney of the exposed (A) and recovery (B) data compared to the control.

At SMF intensity of 18mT, the sample show extraordinary behaviour in the bioconductivity. This could be due to cell membrane disruption and consequently membrane permeability increased [33]. After the recovery period, the bioconductivity values of the 18 mT intensity showed the lowest values compared to the control. At intensity of 14 mT and 22 mT the bioconductivity values decreased and recovered back compared to the control. It is noticed that the 10 mT values possesses comparable behaviour to the control.

The increment in bioconductivity and permittivity of rat's kidney especially at 10 and 18 mT intensities immediately after SMF exposure may be due to disturbance in ion permeability and of kidney cell membrane but cannot be due to thermal effects of SMF as represented by [34, 35]. It can be due to changes in electrical bioconductivity of some cell ions, such as Ca^{+} , Na^{+} and K^{+} ions, as reported by [36-38] respectively.

After a complete week of recovery, the kidney electrical properties were recovered to normal at almost all SMF intensities apart from the 18 mT which showed considerably decrement of bioconductivity and permittivity which could be owed to changes of ion accumulation or ion rearrangements of the kidney cells.

Otherwise, it could be due to disruption of the de-polarization of ions beside the cell membrane during recovery to regular cell membrane behaviour (the control).

The previous explanation of the behaviour of the rat's kidney post the recovery period is supported by the relaxation time data, which indicates variation of dipole relaxation time over the different SMF intensities. Particularly the 18 mT exposure showed the longest dipole relaxation time after the exposure and the shortest relaxation time post the recovery period.

Figure 4 shows the Cole-Cole diagrams of the control, exposure and recovery samples. The points represent the measured data and the dashed line and its angle (α) were done manually. The Cole-Cole diagrams of the individual data represent a unique semicircle which differs from sample to another giving rise to significant variation of the relaxation time.

The data points illustrate the kidney data under investigation while the right hand side data points represent the effect of the electrode polarization [39].

Figure 5 and table 1 show the variation of relaxation time and the angle α in different samples.

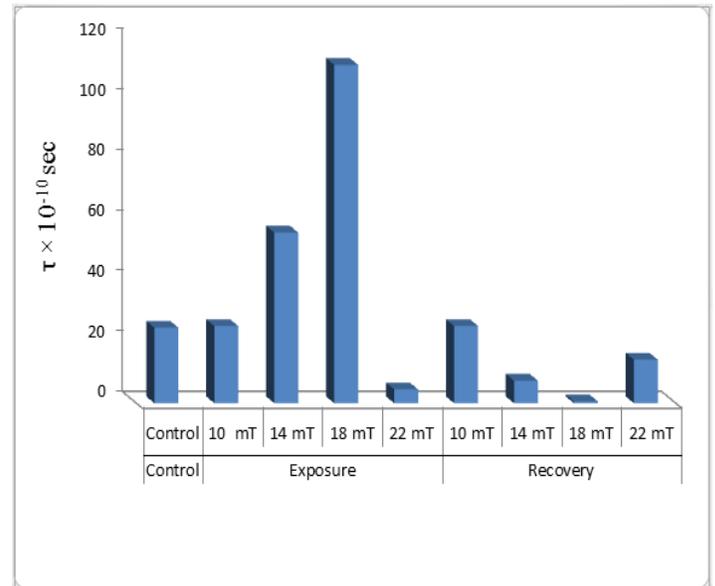


Figure (5): The relaxation time (τ) of rat's kidney exposed to SMF intensities of 10, 14, 18 and 22mT for the exposure and recovery samples compared to the control.

Table1: values of α and τ for the control, exposure and recovery samples at SMF intensities of 10, 14, 18 and 22mT.

Samples		α	$\tau \times 10^{-10}$ (sec)
Parameters			
Control		58.45	25.00
Exposure	10 mT	36	25.52
	14 mT	60.2	56.44
	18 mT	15.8	111.89
	22 mT	48.4	4.58
Recovery	10 mT	35.2	25.53
	14 mT	47	7.44
	18 mT	79.7	0.612
	22 mT	42.2	14.41

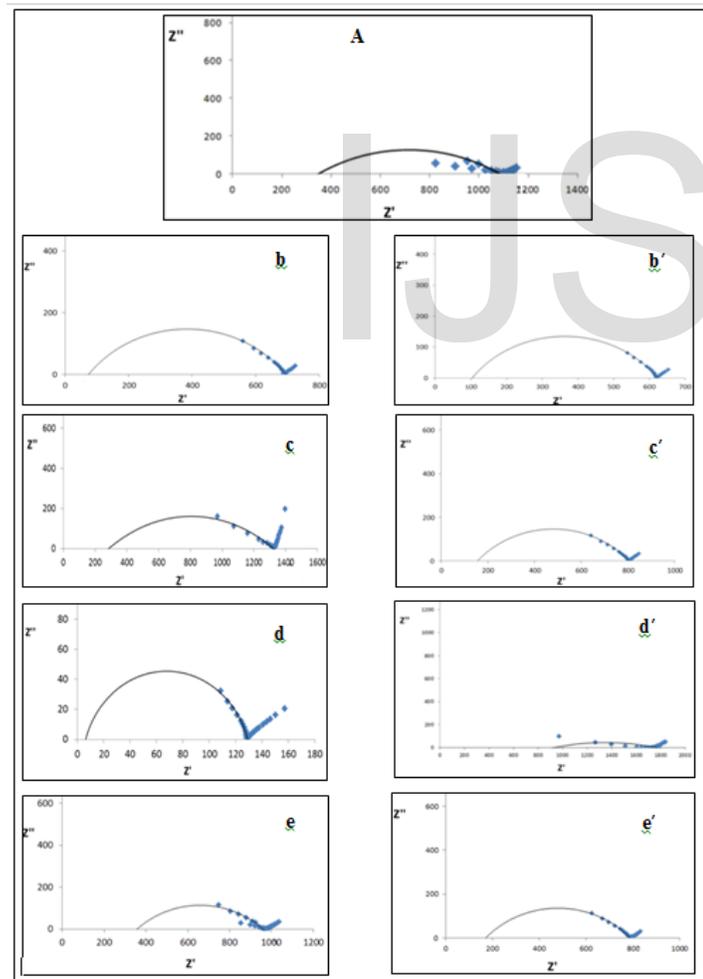


Figure (4): The Cole-Cole diagrams of rat's kidney of the control (A) compared to that exposed to SMF intensities of 10, 14, 18 and 22mT, the exposure (b, c, d, and e) and recovery samples (b', c', d', and e') respectively.

The figure and table show no significant decrease of the relaxation time (τ) of the dipoles, which is the time requires to the dipoles to relax back to thermal equilibrium, was observed in most samples compared to the control. Also, the 10 mT sample showed comparable values to the control pre and post recovery. The 18 mT sample showed the longest relaxation time after exposure and the shortest after a week recovery compared to all the other samples.

5- CONCLUSIONS

This study aimed to evaluating the potential effects of low SMF intensity on biological cells using the dielectric properties. The effect of these intensities on rat's kidney were studied and showed that the dielectric properties can be a powerful tool to follow up that effect. Remarkable changes were observed in bioconductivity, and relaxation time upon exposing to 18 mT intensity. In all obtained data we can conclude that the relaxation time increases increased post the exposure, while decreased after the recovery period. This indicates that polarization of the components of the kidney cell membrane returns to normal condition (control). The 10 mT is the best dose among all tested exposure intensities, compared to the control, which should be taken into consideration when exposing human or animals to low SMF intensities for an hour during diagnosis or therapy.

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