COMPARISON OF THE EFFECT OF DIAGNOSTIC X-RAYS ON THE RADIOFREQUENCY DIELECTRIC PROPERTIES OF BOVINE LIVER WITH BOVINE KIDNEY TISSUES.

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Abstract

The radiofrequency dielectric properties of X-irradiated and non-irradiated bovine liver tissues have been investigated. The relative permittivity, ε^1 ,the dielectric loss factor,ε^{11} and a.c conductivity, σ of the irradiated and non-irradiated liver tissues were measured in the frequency range 1.0 to 50.0MHz using a Marconi Q-meter, TF 1245 working in conjunction with an oscillator, TF1246 at a temperature of 28 ± 0.5°C. The liver tissues were irradiated using a 3-phase diagnostic X-ray machine, Watson Px304 (Picker International Ltd, UK). The irradiated tissue X-ray doses ranged from 0 to 6.25mGy and were determined by thermoluminescence Dosimetry (TLD) technique using the LiF TLD discs and Automated SOLARO TLD Reader. The results of the investigation were compared with results of published work on the radiofrequency dielectric properties of bovine kidney tissues and found to be in good agreement. The dielectric technique is therefore useful in investigating the mechanism of mammalian tissue radiation damage at the molecular and cellular levels.

Keywords; *Dielectric, permittivity, x-rays, tissues and radiofrequency*

Introduction

Interest has been developed over the years in studying the dielectric properties of biological materials including tissues, resulting in a detailed understanding of the structural characteristics and functional behaviour of a number of Biomaterials at the molecular level (Fricke and Morse, 1925; Schwan 1957; Stoy *et al*, 1982; Gabriel *et al*, 1983; Laogun *et al*, 1983; 1997 and Laogun 1986). A full understanding of the dielectric properties of tissues and proteins, requires a knowledge of the dispersion properties of permittivity and conductivity, as they will facilitate a good insight into their material composition and molecular structure (Grant *et al*, 1978).

The dielectric method of investigating structural and molecular characteristics

of biological tissues is a well established technique (Fricke and More, 1925; Debye, 1929); Fricke and curtis, 1935; South and grant 1972; Essex *et al,* 1975 and Kyber *et al,* 1991). The technique is useful in studying the radiofrequency dielectric dispersion properties of tissues, which provides information concerning the structure of cellular membranes and tissue properties (Grant *et al* 1978; Pethig 1979; 1991, and Agba 1999).

As stated previously (Laogun *et al,* 2005), data on dielectric properties of tissues is necessary in understanding the basic biophysical interaction mechanisms of electromagnetic field with living tissues (Stuchy, 1979; Schwan and foster, 1980 and Stuchly *et al*, 1982). Also,the data is needed for dosimetric calculations for microwave and radio frequency radiations (Stuchly, 1979; Zyweitz and Knoche, 1986). Dosimetry will facilitate the calculation of specific absorption rate (SAR) of radio frequency or microwave radiations in the irradiated body.

The use of diagnostic X-rays for clinical investigations has become very common recently in almost all hospitals and in some clinics all over Nigeria including other parts of the world. There is therefore concern as to the effects of X-ray exposure dose rates such as those encountered by patients in diagnostic radiology departments. In this regards, emphasis is on producing maximum benefit from radiology with a minimum amount of radiation consistent with good quality control in medical X-rays. (Mattson 1994; Hendee *et al*, 1977). For effective radiation monitoring and protection from medical X-rays, one would need to understand the nature of change or effects that may take place at the molecular or cellular levels as a result of the interaction X-rays with mammalian tissues, since most of the observed biological effects of X-radiation are expected to result from the changes that may have taken place at the molecular and cellular levels, in the irradiated tissues. In a similar manner to non-ionizing electromagnetic radiations, information on the dielectric properties of x-irradiated bovine tissues could help in understanding the basic biophysical interaction mechanism of ionizing electromagnetic radiations with tissues (Agba, 1999, and Laogun *etal,* 2005).

Information on the dielectric properties of mammalian tissues exposed to ionizing electromagnetic radiations including x-rays is very scarce in literature. Recent efforts in this direction include the works of Agba (1999) and Laogun *et al,* (2005) who have reported on the influence of x-rays on the dielectric properties of mammalian tissues and bovine kidney tissues respectively.

The present work is aimed at investigating the effect of diagnostic x-rays on the radio frequency dielectric properties of bovine liver tissues using

the same experimental conditions of Laogun *et al,* (2005) and comparing the results with the published results of Laogun *et al,* (2005) who investigated the influence of x-rays on the radio frequency dielectric properties of bovine kidney tissues. This work is expected to provide additional information on the nature of biophysical interaction mechanism of x-rays with mammalian tissues at the cellular level.

Theory of Tissue Dielectric.

The electrical conductance, G, (Siemens) and capacitance, C, (Farads) of tissues at a given frequency of measurement defines their dielectric properties (Pethig 1991). These two parameters are defined (Pethig 1991) by:

$$G = k\sigma \text{ and } C = K\varepsilon_o\varepsilon_r \qquad (1)$$

where K is the measurement cell constant, σ is the conductivity of the sample, is the relative permittivity of the sample, $\varepsilon_o = 8.854x10^{-12} F/M.$

For biological tissues, the relative permittivity is complex and can be given by;

$$\varepsilon^* = \varepsilon^1 - J\varepsilon^{11} \qquad (2)$$

Where ε^1 is the real part of the permittivity and ε^{11} is the imaginary part or the loss factor of the permittivity and it is given by;

$$\varepsilon^{11} = \frac{\sigma}{2\pi f \varepsilon_o} \qquad (3)$$

where f is the frequency of the applied electric field during measurement. The dielectric properties of tissues which exhibit a wide spread in effective relaxation times in often represented by the complex empirical cole-cole equation (Schwan 1957, Stoy *et al* 1982).

$$\varepsilon^* = \varepsilon_\infty + \frac{(\varepsilon_s - \varepsilon_\infty)}{1 + (jf/f_R)^{1-\alpha}} - \frac{j\sigma_o}{2\pi f \varepsilon_o} \qquad (4)$$

where σ_o is the conductivity at very low frequencies, f_R is the relaxation frequency of tissues, ε_s is the lower frequency limit of the permittivity measurement, ε_∞ is the upper frequency limit of the permittivity measurement and σ is the relaxation spread parameter and it takes values from $0 \le \alpha \le 1$.

The dielectric properties can also be expressed in terms of a complex conductivity σ^* (Stoy *et al* 1982) as;

$$\sigma^* = \sigma^1 + j2\pi f \varepsilon_o \varepsilon' \qquad (5)$$

Equation (5) can be rewritten as an empirical complex conductivity equation (Stoy *et al,* 1982);

$$\sigma^* = \sigma_\infty + \frac{(\sigma_s - \varepsilon_\infty)}{1 + (-jf/f_R)^{1-\alpha}} + j2f\varepsilon_o\varepsilon_\infty \qquad (6)$$

Where σ_∞ *and* σ_s are the upper limit Value of the conductivity measurement and lower limit value of the conductivity measurement respectively. Eqns (5) and (6) can be analyzed using numerical routines (Stoy *et al,* 1982).

2.0 Materials and Methods.

The liver tissues were excised from five

freshly slaughtered adult cows at a government abattoir in Benin city, Nigeria. Before they were slaughtered, the cows were inspected and certified healthy by a veterinary doctor attached to the abattoir. The methods of preparation and determination of the water content of the liver tissues followed those of Laogun *et al* (2005). The average water content of the liver tissue was found to be 65.7 5% as against the kidney tissue water content of 78.6 3% as determined by Laogun *et al* (2005). To ensure that the dielectric permittivity of the tissue does not change markedly from its in vivo value (Rajewsky,1938; Stuchly *et al,* 1982), all tissue samples were used for dielectric measurements within 12 hours.

Tissue dielectric measurements were carried out following the methods of Laogun *et al,* (2005) at a room temperature of 28 5°C using a resonance technique involving a commercially available magnification meter (Marcon instruments Co; UK). This consist of a Q-meter TF 1245 working in conjunction with oscillator TF 1246 covering the frequency range 0.01-50MHz. The sample cell used in the experiment consist of two parallel circular brass electrodes of diameter 0.2cm mounted centrally at the ends of a Perspex cylinder of diameter 0.3cm with an inter-electrode distance of 3.0cm. The cell constant of the sample cell used in determining the tissue dielectric parameters was determined from the dielectric measurements on air and distilled water, which was cross checked by similar measurements on glycerol at the measurement temperature of 28 0.5°C. Details of the dielectric measurement technique has been reported else where (Laogun, 1986; Laogun *et al,* 1983 and Agba, 1999).

The liver tissue samples were x-irradiated using a diagnostic x-ray machine (Watson Px 304, Picker International Ltd, Wembley, UK) located at the Radiology Department, University of Benin Teaching Hospital, Benin City, Nigeria. The sample tissue

Table 1: Mean Values of Dielectric Permittivity, ε' with Standard Deviation (SD) For X -Irradiated and Non -Irradiated (Control) Bovine Liver Tissues at Selected Frequencies.

Dielectric Permittivity, ε'							
Frequency (MHz) / Tissue Dose (mGy)	1.0	3.0	5.0	10.0	20.0	40.0	50.0
0(Control)	585.1 ± 38	558.5 ± 35	505.3 ±32	398.9 ±28	301.6 ± 20	292.6 ± 18	290.8 ± 18
0.17	531.9 ± 35	492.0 ± 30	452.1 ±30	372.3 ±28	292.6 ± 20	276. ± 17	269.4 ± 15
0.75	478.7 ± 30	468.7 ± 30	438.8 ±30	345.9 ±25	280.9 ± 20	260.0 ± 15	252.7 ± 15
1.40	452.1 ± 30	452.1 ± 30	425.5 ±27	330.3 ±25	270.6 ± 15	240.5 ± 15	239.4 ± 10
6.25	425.5 ± 30	425.5 ± 30	398.9 ±25	319.1 ±25	266.0 ± 15	239.0 ± 10	230.4 ± 10

Table 2: Mean Values of the A.C Conductivity with Standard Deviation for X-Irradiated and Non-Irradiated (Control) Bovine Liver Tissues at Selected Frequencies.

a.c Conductivity σ (mS/m)							
Frequency (MHz) / Tissue Dose (mGy)	1.0	3.0	5.0	10.0	20.0	40.0	50.0
O (Control)	52.8 ± 18	147.0 ±15	205.0 ± 20	203.4 ±26	232.8 ±30	276.8 ± 30	299.9 ± 35
0.17	53.5 ± 10	160.9 ±15	207 ± 20	217.5 ±25	250.4 ±30	290.0 ± 25	303.3 ± 25
0.75	56.1 ± 10	183.9 ±18	241.3 ± 25	233.7 ±20	269.8 ±30	288.3 ± 25	322.7 ± 20
1.40	65.8 ± 9	193.6 ±16	257.2 ± 25	255.5 ±25	283.2 ±49	297.1 ± 20	336.2 ± 30
6.25	69.92 ± 10	198.7 ±18	258.7 ± 20	279.9 ±20	293.8 ±25	348.4 ± 28	356.0 ± 30

does was obtained from direct dose measurement using thermoluminescence Dosemitric Technique (TLD) incorporating the LiF TLD discs and an automated SOLARO TLD Reader (Vinten Co, UK).

The tissue samples were divided into 5 batches. One batch was used as control sample while the others were irradiated with x-ray dose of 0.17,0.75, 1.40 and 6.25 mGy respectively.

3.0 Results and Analysis

The experimental results and analysis carried out in this work on liver tissues are presented in tables 1 to 3 and figs 1&2. The relevant results of Laogun *et al,* (2005) on kidney tissues are reproduced here as tables 5&6 for the purpose of comparism only.

Table 3: Dielectric Parameters Obtained from Dielectric Dispersion and Cole-Cole Plots of ε'' Against ε' for X-Irradiated and Non-Irradiated Bovine Liver Tissues.

DOSE (mGy)	ε_s	ε_∞	$\Delta(\varepsilon_s - \varepsilon_\infty)$	F_R(mHz)	τ (nS)	α
O	585 ±50	200 ±20	385 ± 35	6.5 ± 0.3	24.5 ±1.5	0.16 ± 0.01
0.17	531 ±45	210 ±5	321 ± 36	6.5 ± 0.3	24.5 ±1.5	0.17 ± 0.01
0.75	478 ±40	220 ±20	258 ± 30	7.0 ± 0.3	23.0 ±1.0	0.18 ± 0.01
1.40	452 ±40	200 ±20	252 ± 30	7.0 ± 0.3	22.7 ±1.0	0.19 ± 0.01
6.25	425 ±30	200 ±15	225 ± 25	7.5 ± 0.4	21.2 ±1.2	0.19 ± 0.01

Figure 1 gives the relative permittivity, ε', dispersion for the x-irradiated and non-irradiated bovine live tissues. It can be observed that there are noticeable differences in the ε', dispersions between the x-irradiated and non-irradiated liver tissues. Figure 1 also shows that, the x-irradiated tissues exhibited a lower dielectric decrement, Δ, than the non-irradiated tissues. The decrement thus, decreases with increase in x-radiation dose. Figure 2, shows the a.c conductivity dispersion curves of x-irradiated and non-irradiated liver tissues. The figure shows that x-irradiation increases the a.c tissue conductivity.

The dielectric data in the figures was analyzed on the basis of the empirical Cole and Cole (1941) equation for the complex permittivity ε^*, which is given by

$$\varepsilon^* = \varepsilon^1 - J\varepsilon'' = \varepsilon_\infty + \frac{(\varepsilon_s - \varepsilon_\infty)}{1+(jf/f_R)^{1-\alpha}}$$

$$in\ which\ \varepsilon^1 = \varepsilon_\infty + \frac{\Delta}{1+4\pi^2 f^2 \tau^2}$$

$$and\ \varepsilon'' = \frac{2\pi\Delta f\tau}{1+4\pi^2 f^2\tau^2} = \frac{\sigma}{2\pi f\varepsilon_o}$$

σ is the a.c conductivity, Δ, is the dielectric decrement, $(\varepsilon_s - \varepsilon_\infty)$, where ε_s *and* ε_∞ represent the low and high frequency limits of ε' respectively and f_R is the empirical relaxation frequency from which the relaxation time, τ was obtained. α is a parameter which measures the spread of relaxation times. As slated earlier, it varies between 0 and 1, and for a simple single relaxation (Debye relaxation), $\alpha = 0$ and $\alpha = 1$, for infinite distribution of relaxation times.

The dielectric parameters obtained from the permittivity, dispersion curves and the Cole-Cole plots against are shown in table 3. The table shows that both the dielectric decrement and relaxation times, decreases with increase in radiation dose, while the relaxation frequency and the Cole-Cole spread parameter, increases with increase in x-irradiation dose.

Table 5: Mean Values of Dielectric Permittivity ε' with Standard Deviation (SD) for X-Irradiated and Non-Irradiated (Control0 Bovine Kidney Tissues at Selected Frequencies (*et al;2005*)

Dielectric Permittivity, ε'							
Frequency (MHz)		1.0	2.0	5.0	10.0	20.0	50.0
	0 (control)	1570 ± 100	1303 ± 80	878 ± 52	612 ± 40	418 35	372 ± 28
X-ray	0.17	1440 ± 90	1210 ± 70	810 ± 50	550 ± 40	390 ± 30	370 ± 25
Dose (mGy)	0.75	1280 ± 75	1037 ± 60	600 ± 40	420 ± 33	372 ± 27	319 ± 25
	1.40	1215 ± 70	980 ± 60	559 ± 35	400 ± 35	330 ± 25	319 ± 25
	6.25	1100 ±65	930 ±55	525 ±30	380 ±35	319 ±25	266 ± 20

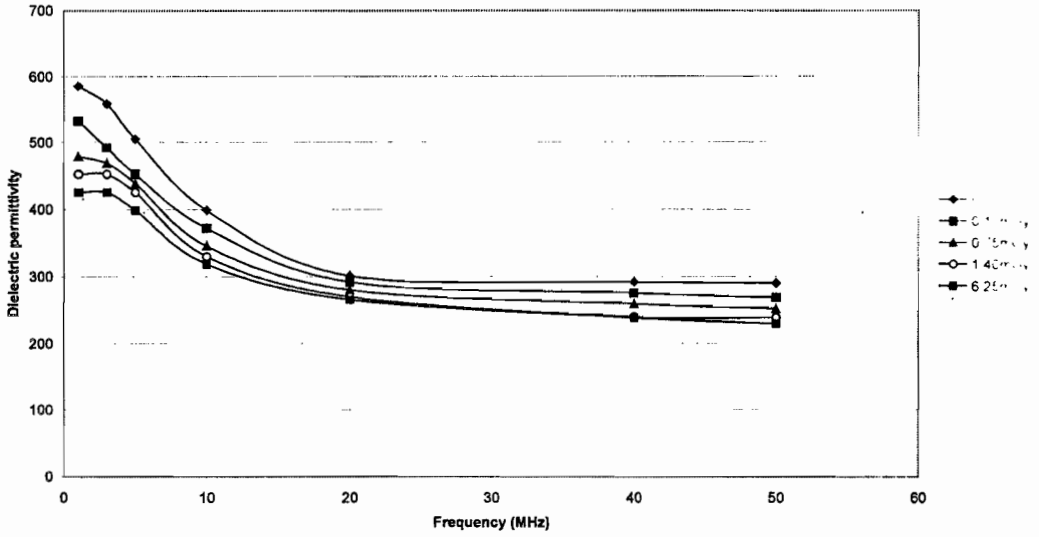

Fig. 1: The Dielectric permittivity of x-irradiated and non-irradiated (Control) bovine liver tissues at some selected frequencies

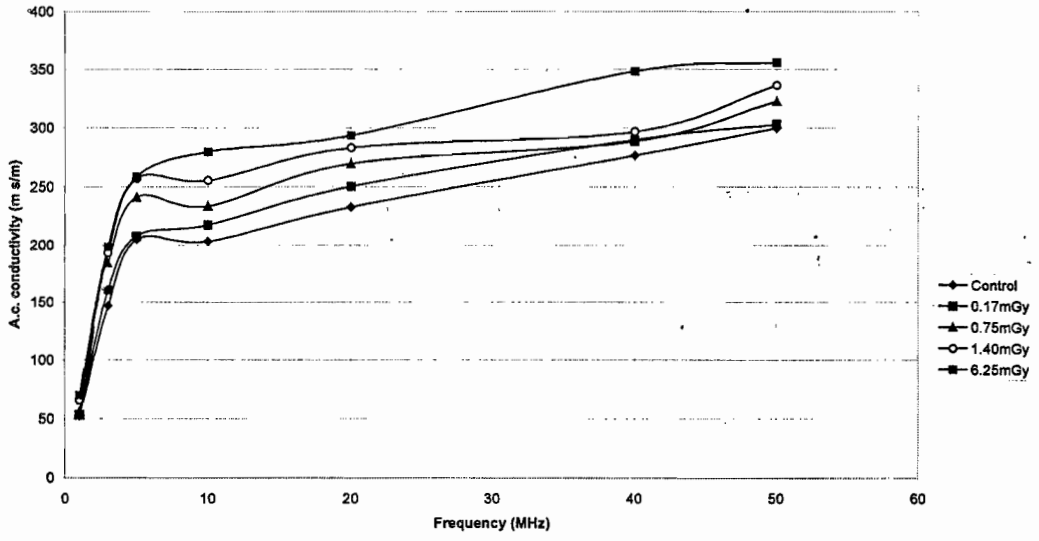

Fig. 2 The a.cconductivity (m s/m) of x-irradiated and non-irradiated (control) bovine liver tissues at some selected frequencies

Table 6: Dielectric Parameter Obtained from Dielectric Dispersion and Cole-Cole Plots of ε'' *against* ε' for X -Irradiated and Non -Irradiated Bovine Kidney Tissues. (Laogun Et al, 2005).

DOSE (mGy)	ε_s	ε_∞	Δ $(\varepsilon_s - \varepsilon_\infty)$	F_R(MHz)	τ (*nS*)	α
0	1570 ± 100	370 ± 20	1200 ± 100	4.0 ± 0.2	39.8 ± 2.0	0.18 ± 0.01
0.17	1440 ± 90	370 ± 20	1070 ± 90	4.0 ± 0.2	39.8 ± 2.0	0.20 ± 0.01
0.75	1280 ± 75	320 ± 20	960 ± 75	3.5 ± 0.2	50.0 ± 2.5	0.22 ± 0.02
1.40	1215 ± 70	300 ± 10	915 ± 70	3.0 ± 0.2	50.0 ± 2.5	0.22 ± 0.01
6.25	1100 ± 65	260 ± 15	840 ± 65	3.0 ± 0.2	55.0 ± 3.0	0.22 ± 0.01

Discussion and Conclusion

As stated previously (Agba, 1999; Laogun et al, 2005 and Schwan, 1957), the main processes responsible for the β -dielectric properties of mammalian tissues at radiofrequencies are structural relaxations due to the capacitive charging of cell membranes, which is referred to as Maxwell-Wagner polarization and the dielectric relaxation of the tissue proteins themselves. Pethig (1991) also showed that, dielectric properties of tissues depend on the integrity of the cellular membranes, and the dielectric dispersion reflects the time it takes to charge up the cell membranes through the resistances of the cytoplasm and to the external fluids (Schwan and Cole-Cole, 1960). At higher frequencies, the effect of membrane charging falls, due to the short-circuiting effect of membrane capacitance (Pethig, 1991) and the dielectric permittivity ε' is contributed mainly by the relaxations of sub-cellular organelles and tissue proteins which depend very little on cell membranes (Stoy et al, 1982). This may explain why ε' values of both the x-irradiated and non-irradiated tissues appear to level off at higher frequencies. This is consistent with the findings of Laogun et al, (2005) on the kidney tissues.

A comparison of the results of Laogun et al, (2005) with this work has revealed that, most permittivity dispersion parameters of bovine kidney tissues are larger than those of liver tissues in this work, in the frequency range 1.0 to 50.0MHz. This may be attributed to differences in their cellular and tissue morphology or ultrastructure (Scheeps and Foster, 1980; Dissado, 1990 and Schwan, 1985) resulting in different characteristic polarization of cell membranes and relaxation of tissue proteins (Pethig, 1991 and Schwan and Cole, 1960). At radiofrequencies, tissue dielectric properties also depend strongly on water content (Stuchly et al, 1982; pethig; 1991 and Robinson et al, 1991). The bovine kidney tissues has an average water content of 78.0% (Laogun et al, 2005) compared to 69.7% for our liver tissue samples. The higher water Content in kidney tissues than in liver tissues may also explain the higher kidney tissue permittivity ε' and conductivity σ, values than those of liver tissues obtained in this work.

As pointed out earlier (Sato et al, 1977), cell membrane is the major target when mammalian cells are x-irradiated. The x-irradiation of mammalian cells is known to induce conformational change in membrane proteins and a reduction in the surface charge density of tissue cells (Sato et al, 1981). The observed decrease in dielectric permittivity, ε' values following the x-irradiation of the liver tissues, may be due to changes in the components of the cellular membranes together with a reduction in the Maxwell-Wagner interfacial polarization effects at radiofrequencies. This is the same observation made by Laogun et al, (2005) on Bovine kidney tissues. Also, with the increase in tissue x-ray dose, there is a greater reduction in the Maxwell-Wagner effect and a pronounced decrease in the permittivity of the irradiated bovine tissues.

The frequency dependent a.c conductivity, σ represent all the dissipative losses in a tissue sample arising from dielectric polarization, since the movement of polarization charges along with the field constitutes a conduction process. This explains why σ, increases with frequency of measurement, as it reflects the extent to which polarizable charges move in the applied electric field (Pethig, 1991).

The reduction in the dielectric decrement, $\Delta(\varepsilon_s - \varepsilon_\infty)$ following liver tissue irradiation follows naturally from the decrease in the permittivity, ε' of the irradiated tissues. The relaxation time, τ reflects the time required to charge up the cell membranes and as well as the time required for protein molecules to align with the field (Schwan and Cole, 1960). It is observed that the irradiated liver tissues have shorter relaxations than the control tissues and it decreases gradually with increasing x-ray dose. However, as expected, the relaxation frequencies increases with x-ray dose. With increase in tissue x-ray dose, more ions are expected to be produced in the liver tissues giving rise to more available ions to charge up the cell membranes of the irradiated tissues and the time required to charge up the cell membranes of the irradiated tissues is expected to be reduced. This may explain why relaxation time of control liver tissue is longer than those of the irradiated liver tissues and also, the decrease in relaxation time with increase in tissue x-ray dose. However, a look at the relaxation times of the kidney tissues in Laogun et al, (2005) reveals that, the relaxation times of the irradiated kidney tissues are larger than those of the control tissues and it increases with the increase in kidney x-ray dose. Kidney tissue is considered to be moderately sensitive to x-radiation damage, while liver tissue is x-radiation resistant based on morphologic changes (Gainer, 1991). On x-ray irradiation, the kidney tissue will be more sensitive to cellular membrane damage than the liver tissues. This will likely reduce the charging capacity of the membranes of the irradiated kidney more than the liver tissues and it would require more time to charge up the kidney membranes than the liver tissues. At higher tissue x-ray dose, there will be increased cellular membrane damage requiring more time to charge up the membranes, even in the presence of increased ions produced by ionization at the higher x-ray doses. This may explain the increase in the relaxation times of the x-irradiated kidney tissues with x-ray dose as opposed to the decrease in the relaxation time of the x-irradiated liver tissues with x-ray dose as explained earlier on.

The irradiated liver tissues have bigger spread parameter, than the control tissues. is a measure of the spread in the relaxation time and the degree of heterogeneity in the tissue. The ionizations produced in the irradiated tissues will increase the heterogenous distribution of ions, each of which may have its characteristic polarization process. This may explain the observed increase in the spread in the spread parameter, of the irradiated liver tissues. The above observation on parameter, is consistent with the findings of Laogun et al, 2005 on irradiated kidney tissues.

In conclusion, the finding of this work gives support to the work of Sato et al, (1977) that cellular membranes are major targets of X-rays during tissue X-irradiation. It also confirms that the dielectric properties of animal tissues are greatly affected by X-irradiation. The dielectric technique is therefore useful in investigating the mechanism of mammalian tissue radiation damage at molecular and cellular levels.

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