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CASE STUDY OF HIGH BLOOD GLUCOSE CONCENTRATION EFFECTS OF 850 MHz ELECTROMAGNETIC FIELDS USING GTEM CELL

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Abstract—The effect of 850 MHz electromagnetic radiation on diabetic blood at 2 W and 60 W power levels was investigated and compared with normal blood cells. The power levels respectively represent radiations from a cell phone and the cell phone tower, both operating 850 MHz. A GTEM cell was designed for the tests to generate the desired uniform electromagnetic field and power in a shielded environment. Blood samples, having normal and high glucose concentrations, were placed in the usable area inside the GTEM cell for 10, 30, 60 minutes and the glucose levels and red and white blood cell viabilities were monitored and compared with the controls. Results show that the 850 MHz exposure significantly influences the blood cell counts and the glucose level in both normal and high glucose blood samples. In cell survivability analysis in normal blood samples it was found that the white blood cells are significantly higher than the control at 60 min exposure from cell phone radiation, while both the white and red blood cell are significantly higher following a 30 min exposure from tower radiation. For high glucose blood tests at 30 and 60 min exposure times, the tower radiation for 60 min and the cell phone radiation at both the exposure times show significantly changes in white blood cell counts, whereas there was no effect in red blood cells. Also, for 30 and 60 min exposure times, the glucose

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level in normal blood samples increased from cell phone radiation and decreased due to tower radiation. Finally, in high glucose blood samples, the glucose level decreased significantly for a 30 minute tower exposure, while the glucose level increased significantly for the cell phones exposure duration of 60 min and for tower exposure duration of 10 min. Electromagnetic radiation effects on cells can be better analyzed through a combination of the frequency, power and test duration as a single factor as opposed to the effects of frequency alone.

1. INTRODUCTION

Exposure to electromagnetic (EM) radiation can have harmful or helpful effects on biological systems. The use of mobile telephony devices, for example, could carry risks of developing brain tumor [1, 2]. On the other hand, exposure to EM radiations have improved soybean germination rate [3], and significantly influenced the growth and metabolism of various microorganisms [4], including the growth enhancement of the cyanobacterium *Spirulina plantensis* by 50% [5]. Also, extremely high frequency exposure can enhance the growth of nitrogen-fixing microorganisms in rhizosphere of pine seeds [6].

The effects of EM radiation have also been studied on living organisms [7–12], and in diabetic blood cells [13, 14]. Study of sugar levels on blood samples is important since both the red and white blood cells require D-glucose uptake for survival and function [15–21]. Previous research suggests that electromagnetic waves could affect the percentage content of the red and white blood cell counts [22, 23].

Studies of the effects of EM field on sugar laden blood have produced mixed results. Havas and Stetzer have shown that in an environment without electromagnetic fields, type I diabetes required less insulin, and type II diabetes have lower levels of plasma glucose [24–26], while research with electromagnetic pulses show a decrease in the glucose levels of type I diabetes in treated mice, primarily due to a decreased binding affinity between insulin and its receptor [27, 28]. It has also been shown that electromagnetic radiation influences the glucose concentration, dielectric and electrical properties of the blood [29, 30]. Electric field effect on insulin chain-B under static and oscillating conditions showed that the electric field caused a destabilizing effect on the peptide [31–33]. However, not much work has been done on the effects of cellular phone radiation at 850 MHz on the diabetic blood cells. With the recent proliferation of cell phones and cell phone towers, this research topic is of concern to many and needs renewed attention.

In this paper, we report on the studies of the response of high glucose laden blood to 850 MHz cellular phone radiation using an in-house built GTEM (GHz transverse electromagnetic) cell. Cell phones operate in both 850 and 900 MHz frequency range. The 850 MHz band provides better range as compared to the 900 MHz band [34], and, as a result GSM service at 850 MHz band is widely being used in many countries, specifically in the USA, Thailand, Brazil, El Salvador, and Canada. The radiation power of a cell phone tower is about 60 W, and the maximum pick power of the cell phone handset is 2 W [1]. Our study is therefore related to the effects of not only the cell phones operating at 850 MHz but also the radiation from the tower operating at 60 W.

The choice of the GTEM cell as the electromagnetic radiation source was due to the fact that large test areas such as an anechoic chamber or open area test site (OATS) are not efficient for experiments when the biological samples are very small. For small samples a well-defined area with minimum interference and reflection of the EM signal area is required, such as the GTEM cell, which was designed in house for this study. The pyramidal chamber, shown in Figure 1, provides a uniformity of EM fields in a closed environment [35], and operated up to 18 GHz [36], which is well above the operational frequency of TEM cells ($\sim$ 100 MHz) [37]. The design of GTEM cell and its characterization is not included here.

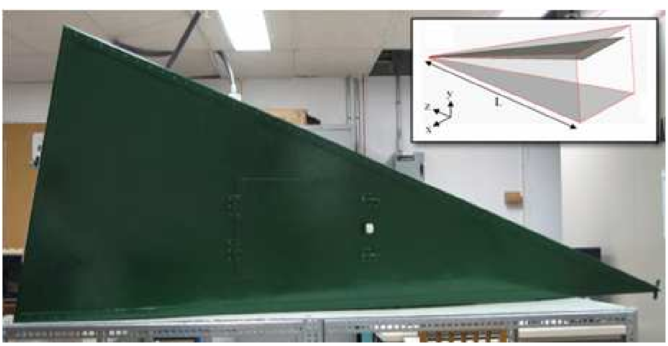


Figure 1. Laboratory designed and constructed GTEM cell.

2. MATERIALS AND METHODS

Three types of samples, we call the control blood (CB), normal blood (NB) and high glucose blood (HGB) were studied. The objective is to investigate the properties of these samples under electromagnetic radiation and to monitor changes in the blood glucose level, as well count the white blood cell (WBC) and red blood cell (RBC) levels before and after exposure to the cell phone and tower radiation.

2.1. Blood Preparation

The normal blood (NB) samples were drawn from six non-diabetic volunteers. Then by adding alpha-D-glucose (96%) to these samples, the HGB samples were prepared. Ninety six (96) NB and HGB samples were prepared for 6 tests as combinations of power level and testing duration. In each test the blood samples were prepared from each volunteer. All the samples were put in dielectric blood collection tube filled with 0.5 ml of blood. Samples exposed to 10, 30, 60 minutes of electromagnetic radiation were the treated sample, while the untreated samples were the controls. The glucose levels for the control and the treated samples were monitored through ACCU-CHEK Advantage blood glucose meter.

2.2. GTEM Cell Design and Characteristics

The gigahertz transverse electromagnetic (GTEM) cell is a pyramidal quadratic chamber, which provides the uniformity of the electromagnetic fields [35]. The GTEM cell can be primarily used to generate uniform electromagnetic fields and measure electromagnetic radiation for the electronic devices [38]. The GTEM cell is designed based on waveguide concept. Thus, the GTEM cell characteristic impedance is theoretically 50 Ohms, where depends on the geometrical parameters of the structure [36]. The GTEM cell mainly consists of an inner conductor, called septum, outer conductor, pyramidal RF absorbers and 50 Ω resistance (a number of resistors in parallel). The septum location is at three-forth of the total cell height. The designed GTEM cell has the width/height ratio of two-third. The angle between the septum and the cell floor is 15°. The angle between the septum and the cell ceiling is 5°. The testing area inside the GTEM cell is one-third of the cell volume between the septum and the cell floor. The pyramidal RF absorbers are placed at the ended wall inside the cell to terminate the electromagnetic waves for high frequency. The resistors are connected between the septum and outer conductor for terminating low frequency current [36].

The GTEM cell used in this study has the width of 117.4 cm, height of 79.4 cm and length of 222.1 cm. To evaluate the uniformity of electromagnetic field inside the GTEM cell, the return loss and voltage standing wave ratio (VSWR) was monitored through the Agilent (Hewlett-Packard) 8753D network analyzer. The results of the return loss and VSWR are shown in Figures 2 and 3, respectively. The return

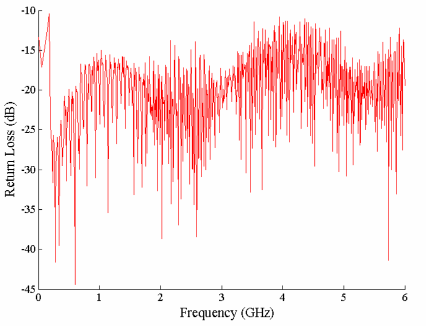


Figure 2. Measured return loss from 0–6.0 GHz of the GTEM cell.

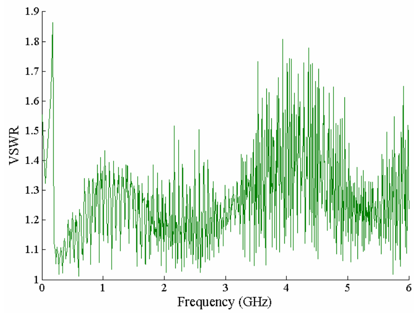


Figure 3. Measured VSWR from 0–6.0 GHz of the GTEM cell.

loss is better than 10 dB and the VSWR is lower than 2 from 0 to 6 GHz frequency range. These results ensure that the electromagnetic fields inside the GTEM cell is uniform as well as there are no undesirable effects from the resonance inside the cell, where the GTEM cell can provide excellent EM shielded environment for this study.

2.3. Exposure Dosimetry

The specific absorption rate (SAR) level of the electromagnetic field inside the testing at 850 MHz and at 2 W was simulated to determine the field dosage on the treated blood sample. A dielectric tube made from polystyrene of relative permittivity 2.55 of thickness = 0.1 cm, and height = 4 cm, was filled with 0.5 ml of blood [height = 0.8 cm, $\varepsilon_{r\ \mathrm{nucleoplasm}} = 120$, $\sigma_{\mathrm{nucleoplasm}} = 0.31$ S/m, blood density = 1049 kg/m^3) [39, 40] was simulated by placing it in the in the area under test inside the GTEM cell. The SAR levels of 924 observation points in the sample were determined through the CST Microwave Studio Simulation Suite which is based on the Finite Integration Technique (FIT) that uses the Perfect Boundary Approximation (PBA) methods [41]. The SAR uniformity is shown in Figure 4. The average SAR level is 0.109 W/kg and is due to the field as coming from the top to bottom of the blood sample. In addition, the SAR level for power level of 60 W was also simulated. The average SAR level at 60 W is 1.308 W/kg with the same uniformity as shown in Figure 4. The same SAR uniformity obtained is due to the same uniformity of the electromagnetic field inside the GTEM cell (the same field frequency at 850 MHz), only power level increased to 60 W. This SAR computation was used in cell viability and glucose level observations of blood following electromagnetic exposures at 850 MHz.

2.4. 850 MHz Radiation System

The experimental setup with the 850 MHz uniform EMF system is shown in Figure 5. This system consists of an R&S SML01

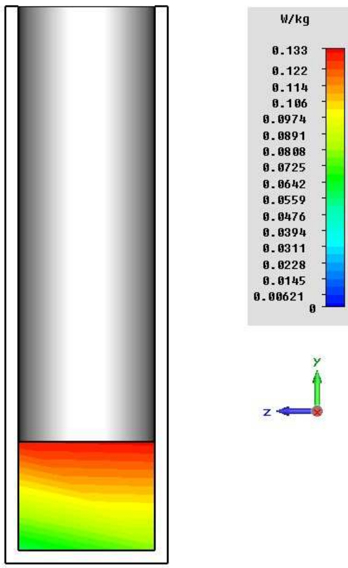


Figure 4. Cross-sectional view of simulated SAR level distribution of electromagnetic fields at 850 MHz inside the treated blood sample.

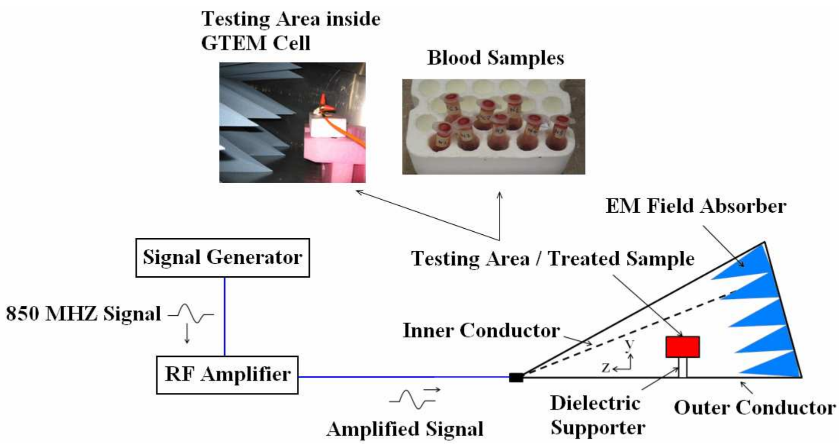


Figure 5. Exposure setup with the signal generator and RF amplifier system delivering the EM wave to the treated samples firmly placed in the usable area inside the GTEM cell.

signal generator (9 kHz to 1.1 GHz, Rohde & Schwarz GmbH & Co. KG, Munich, Germany), AR 150W10000M3 amplifier (150 watts, 80–1000 MHz, Amplifier Research, Souderton, PA, USA), dielectric supporter, and the in-house designed GTEM cell.

The electric field was measured with AR FL7004 electric field probe (100 kHz to 4.2 GHz, 0.5–300 V/m Amplifier Research, Souderton, PA, USA). The E-field was 18.68 V/m at an operating power level of 2 W, and at 60 W, the E-field was 58.91 V/m.

2.5. Experimental Procedures

Five samples of each normal blood (NB) and high glucose blood (HGB) sample were placed on the test area inside the GTEM cell for 10, 30, 60 minutes, while three control blood (CB) samples were kept in the room condition. The treated samples were subjected to a cell phone radiation (850 MHz, 2 W) and the tower radiation (850 MHz, 60 W). The red and white blood cells were counted immediately after treatment and compared with the control samples. The glucose levels were measured three times in each sample, both before and after treatment and compared with the controls before and after treatment. All experiments were conducted at the temperature of 25.5°C. The

Table 1. Glucose levels and cell viability results for normal blood samples in repeat experiments with cell phone radiation (850 MHz, 2 W).

Source	Samples	Glucose Level (mg/dL)						Viability (cell/mL)	
		Before Treatment			After Treatment				
		1st time	2nd time	3rd time	1st time	2nd time	3rd time	RBC ($\times10^9$)	WBC ($\times10^6$)
Cell Phone: 10 min	1	95	98	97	91	91	94	5.70	4.90
	2	94	95	93	97	95	94	5.60	4.10
	3	94	92	93	95	95	96	5.10	5.00
	4	93	97	96	95	95	96	6.00	4.80
	5	97	96	96	97	96	93	5.50	4.70
	Control 1	91	95	96	97	97	97	5.10	4.80
	Control 2	97	98	94	95	93	93	5.80	5.00
	Control 3	97	96	98	94	93	93	5.60	5.10
Cell Phone: 30 min	1	89	87	88	78	73	77	4.20	4.20
	2	87	90	89	73	76	73	4.30	5.40
	3	85	90	89	75	73	75	4.40	5.40
	4	86	86	88	75	75	74	3.90	5.70
	5	89	85	87	74	73	77	3.80	5.10
	Control 1	85	87	87	72	73	71	4.00	5.10
	Control 2	88	85	86	70	71	72	4.10	5.40
	Control 3	85	86	86	73	73	73	4.10	5.20
Cell Phone: 60 min	1	96	98	101	74	79	79	4.20	5.10
	2	98	95	98	76	78	79	3.90	4.80
	3	97	95	101	75	76	76	3.90	4.80
	4	97	97	99	79	78	77	4.40	5.50
	5	97	95	95	70	71	76	4.40	5.40
	Control 1	94	93	95	81	82	84	3.80	4.60
	Control 2	93	94	94	80	81	82	4.40	4.50
	Control 3	94	93	95	83	83	83	4.40	4.80

Table 2. Glucose levels and cell viability results for normal blood samples in repeat experiments with tower radiation (850 MHz, 60 W).

Source	Samples	Glucose Level (mg/dL)						Viability (cell/mL)	
		Before Treatment			After Treatment				
		1st time	2nd time	3rd time	1st time	2nd time	3rd time	RBC ($\times 10^9$)	WBC ($\times 10^6$)
Tower: 10 min	1	101	100	103	93	93	95	5.50	5.40
	2	98	99	103	93	93	95	5.50	5.50
	3	99	97	103	93	91	92	5.50	5.30
	4	100	104	104	94	95	93	4.80	5.50
	5	99	102	101	96	90	93	5.00	5.40
	Control 1	101	100	104	93	94	94	4.60	5.20
	Control 2	103	99	98	90	94	93	4.70	5.30
	Control 3	97	97	100	88	85	87	5.50	4.70
Tower: 30 min	1	96	93	97	91	90	93	6.00	5.50
	2	94	94	93	90	92	91	4.20	5.80
	3	95	97	95	90	91	91	4.70	5.60
	4	93	96	97	91	90	90	4.70	5.70
	5	94	93	93	93	93	92	4.20	5.60
	Control 1	94	98	95	83	84	82	4.20	5.00
	Control 2	95	92	96	86	85	84	4.20	5.10
	Control 3	92	92	98	85	82	85	4.60	5.30
Tower: 60 min	1	106	102	106	96	94	96	4.00	4.10
	2	102	107	103	93	95	97	4.10	5.00
	3	100	103	104	95	92	96	3.90	4.80
	4	103	103	104	90	93	95	4.60	5.10
	5	101	100	103	92	95	95	5.00	5.30
	Control 1	103	100	103	92	94	93	4.00	4.80
	Control 2	104	103	102	93	93	95	4.70	4.10
	Control 3	102	108	105	92	91	92	4.40	4.80

measured temperature of all samples before the treatment was 26.6°C, while that of all samples after the treatment was 25.6°C. This ensures that the all samples were not heated up by the electromagnetic wave. Therefore, any changes in the cell viability and glucose levels from the experiments were not because of the thermal effects.

3. RESULTS AND ANALYSIS

As stated earlier, the results in this study were analyzed in terms of radiation from a cell phone (850 MHz, 2 W) and the tower (850 MHz, 60 W). The pre and post treated cell viability and the glucose levels for the samples are shown in Tables 1–4.

Literature survey shows that the normal red blood cell and white blood cell counts for an average adult are in the 4,300,000–11,000,000 cells/mL and 4,300,000,000–6,000,000,000 cells/mL ranges, respectively. However, Tables 1 and 2 show that the total cell count for both red and white blood cells are lower than the normal values. This could be due to the fact that a large number of cells died in the few hours outside of the body. This is not likely to effects our experimental results since we compare our results with a control sample where cells have expired through the same process.

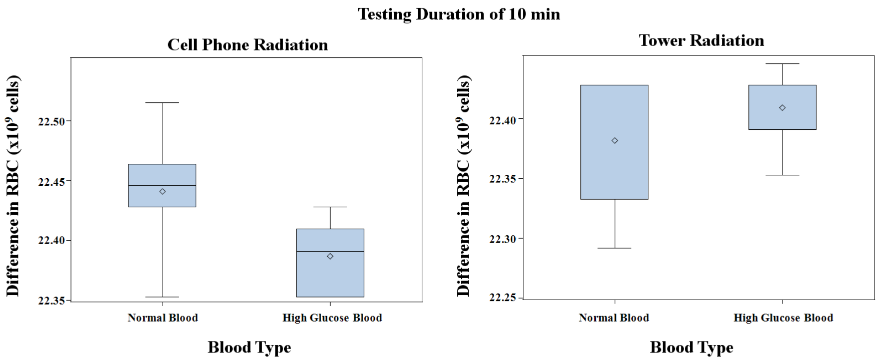
To evaluate the blood cell the RBC and WBC counts, the

Table 3. Glucose levels and cell viability results for high glucose blood samples in repeat experiments with cell phone radiation (850 MHz, 2 W).

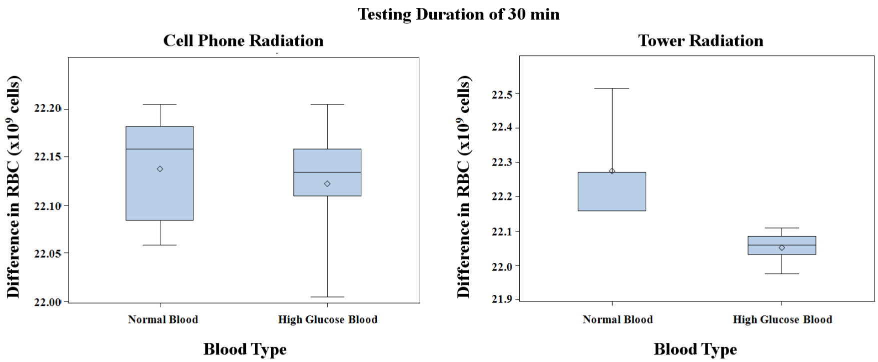
Source	Samples	Glucose Level (mg/dL)						Viability (cell/mL)	
		Before Treatment			After Treatment				
		1st time	2nd time	3rd time	1st time	2nd time	3rd time	RBC ($x10^9$)	WBC ($x10^6$)
Cell Phone: 10 min	1	183	188	182	175	170	172	5.10	4.10
	2	181	182	185	170	172	172	5.30	5.10
	3	188	186	183	166	166	168	5.50	4.80
	4	181	188	186	172	171	171	5.40	4.80
	5	187	183	184	172	172	172	5.10	4.70
	Control 1	183	188	182	170	173	170	5.00	4.80
	Control 2	184	181	181	172	172	170	5.10	4.90
	Control 3	182	181	184	175	177	175	5.80	4.70
Cell Phone: 30 min	1	210	213	214	203	200	201	4.10	5.60
	2	212	213	212	201	205	204	3.60	5.30
	3	209	212	210	201	202	203	4.20	5.10
	4	212	209	210	203	204	204	4.40	4.90
	5	209	213	211	207	204	206	4.00	5.50
	Control 1	209	214	211	206	202	202	4.10	5.00
	Control 2	209	214	213	205	206	207	4.00	5.30
	Control 3	214	214	212	202	202	207	3.90	5.10
Cell Phone: 60 min	1	181	184	183	170	166	175	3.80	5.20
	2	186	186	186	166	176	168	4.20	4.80
	3	187	187	188	174	177	180	4.00	5.80
	4	188	179	180	166	164	178	4.80	5.30
	5	189	183	184	170	174	174	3.80	5.30
	Control 1	192	190	183	174	176	176	4.20	4.80
	Control 2	188	191	183	171	170	174	4.20	4.40
	Control 3	180	183	184	163	170	181	4.50	4.30

Table 4. Glucose levels and cell viability results for high glucose blood samples in repeat experiments with tower radiation (850 MHz, 60 W).

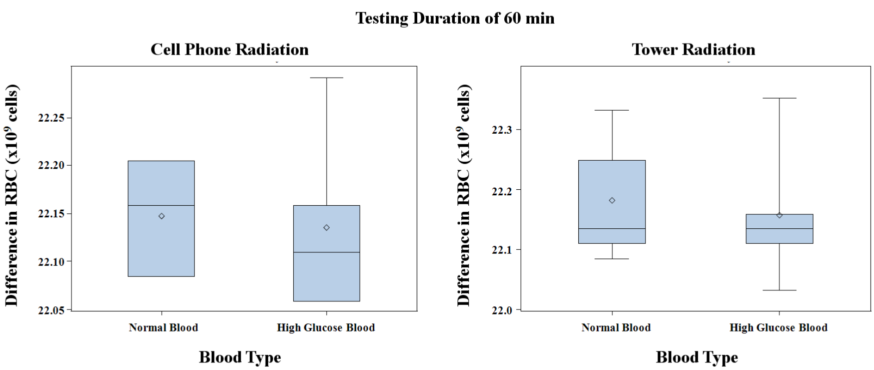
Source	Samples	Glucose Level (mg/dL)						Viability (cell/mL)	
		Before Treatment			After Treatment				
		1st time	2nd time	3rd time	1st time	2nd time	3rd time	RBC ($x10^9$)	WBC ($x10^6$)
Tower: 10 min	1	154	157	157	140	141	139	5.30	5.30
	2	159	158	159	142	142	139	5.50	5.60
	3	158	158	157	140	143	141	5.60	5.10
	4	157	157	156	142	142	142	5.50	5.20
	5	155	158	159	142	142	139	5.10	5.00
	Control 1	159	159	159	142	142	142	4.10	5.00
	Control 2	154	154	159	140	142	142	5.20	5.00
	Control 3	157	154	159	142	142	142	4.80	5.00
Tower: 30 min	1	133	137	137	134	131	137	3.80	5.30
	2	135	141	141	134	131	134	3.90	5.10
	3	138	131	135	131	131	132	3.70	5.50
	4	138	138	135	138	135	133	4.00	4.10
	5	134	138	131	132	130	137	3.50	4.40
	Control 1	134	137	139	134	132	135	3.30	4.00
	Control 2	136	135	137	133	132	132	3.30	4.20
	Control 3	135	137	136	133	136	132	3.50	4.70
Tower: 60 min	1	203	205	211	197	199	198	4.10	5.00
	2	211	205	213	204	203	203	4.20	4.80
	3	213	209	209	196	197	199	4.00	5.30
	4	203	208	205	200	201	198	5.10	5.90
	5	207	208	214	196	200	199	3.70	5.00
	Control 1	207	204	204	196	199	195	4.30	4.50
	Control 2	206	213	203	195	195	198	4.20	4.80
	Control 3	203	204	207	197	195	201	4.70	4.10



(a) 10 min Treatment

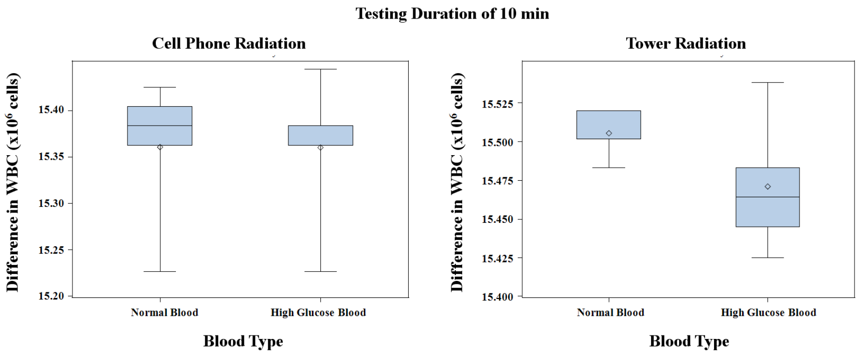


(b) 30 min Treatment

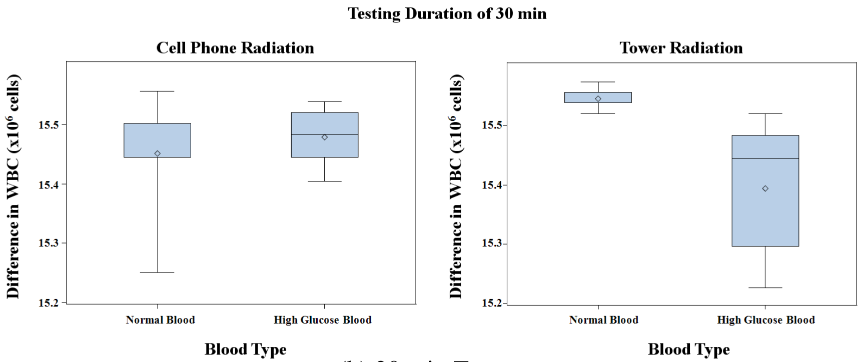


(c) 60 min Treatment

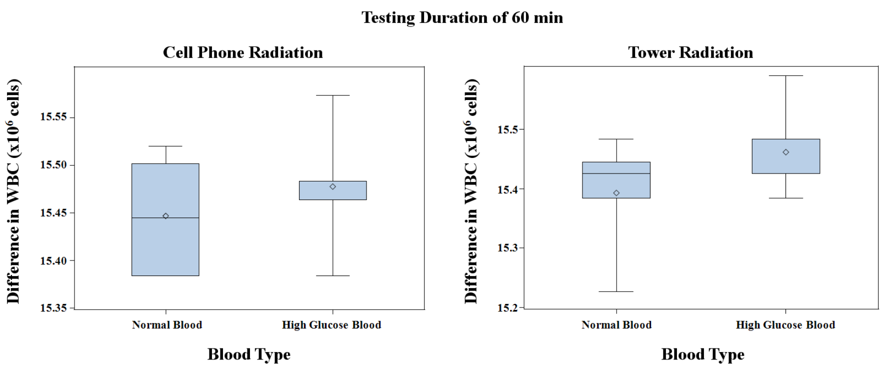
Figure 6. Comparison of the red blood cell count in the samples exposed to cell phone and tower radiation: (a) 10 min, (b) 30 min and (c) 60 min exposure durations.



(a) 10 min Treatment



(b) 30 min Treatment



(c) 60 min Treatment

Figure 7. Comparison of the white blood cell count in the samples exposed to cell phone and tower radiation: (a) 10 min, (b) 30 min and (c) 60 min exposure durations.

Restricted Maximum Likelihood (REML) Linear Mixed Model was used. The mean number of the cell counts of each treated group was compared with that of the associated control group. The level of significance was set at $\alpha = 0.05$. The SAS statistical analysis software was used for the statistical analysis. The comparison of the RBC and WBC viability between normal and high glucose blood samples are shown in Figures 6 and 7, respectively.

The p-values in Table 5 show the comparison of the cell counts between the treated samples and their corresponding controls. The results show that in the normal blood, the survivability of WBC at cell phone radiation for 60 min treatment was significantly higher than the control, while there was no change at 10 and 30 min exposure. For RBC counts there appears to be no significant link between cell phone or tower exposure and treatment duration, with one exception. For the tower radiation, in normal blood sample, both WBC and RBC were significantly higher than the control for 30 min exposure with no significant change at other testing durations. In the high glucose concentration survivability of WBC, there were significant differences in WBC counts only for cell phone radiation at 30 and 60 min and tower radiation for 60 min, while there were no effects observed in the RBC

Table 5. Red and white blood cells viability for various testing combinations against respective controls.

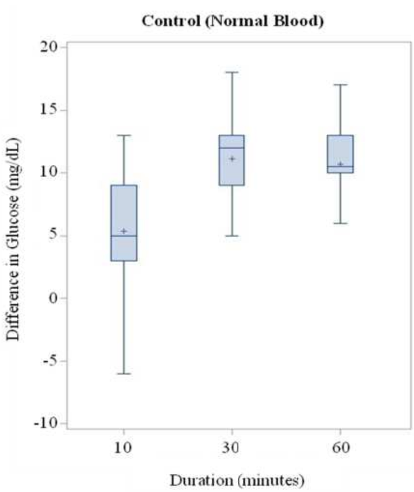
Blood type	Radiation	Test Duration (minutes)	RBC p-value	WBC p-value
NB	Cell Phone	10	0.1807	0.1066
NB	Cell Phone	30	0.7006	0.8134
NB	Cell Phone	60	0.5844	0.0116*
NB	Tower	10	0.8397	0.0603
NB	Tower	30	0.0274*	0.0427*
NB	Tower	60	0.9000	0.1996
HGB	Cell Phone	10	0.2386	0.3604
HGB	Cell Phone	30	0.0525	0.0184*
HGB	Cell Phone	60	0.2552	0.0014*
HGB	Tower	10	0.1074	0.1686
HGB	Tower	30	0.5638	0.4916
HGB	Tower	60	0.4812	0.0036*

'*' means that the cell viability of the treated samples was significantly higher than that of its control.

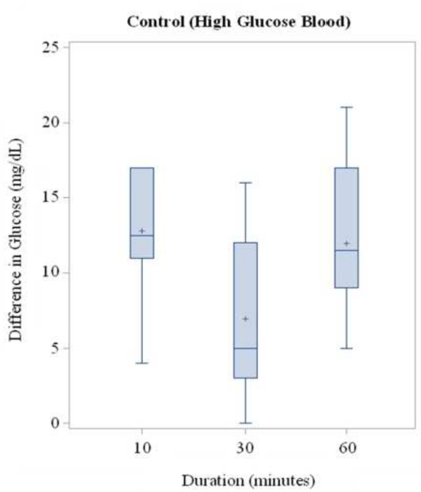
and WBC at other exposure durations. This suggests that for a short exposure period (10 min) both cell phone and tower did not influence changes in the red blood and white blood cells, and that there may be an energy (power x time) effect on WBC counts. At low power level or a short duration of exposure the cell does not absorb sufficient energy to show any effects.

For glucose level analysis, the Repeated Measures REML Linear Mixed Model was used. As mentioned in the Section 2.1, the glucose level was measured three times in each sample both before and after treatment. Three glucose level measurements were taken per sample and were used individually in the investigation. The level of significance was again set at $\alpha = 0.05$. The analysis was also evaluated through SAS software.

In order to reduce the number of parameters influencing the model, the measurements taken after exposure to the radiation were subtracted from those taken before, resulting in the difference between pre- and post-treatment, which is statistically justifiable, because of the relatively small variation within samples that does not influence the variation between samples. The changes in the measured glucose level before and after treatment in the control, NB, HGB samples at each testing combination shown in Figures 8–10 are indicative of the general distributions of each data group as compared against their



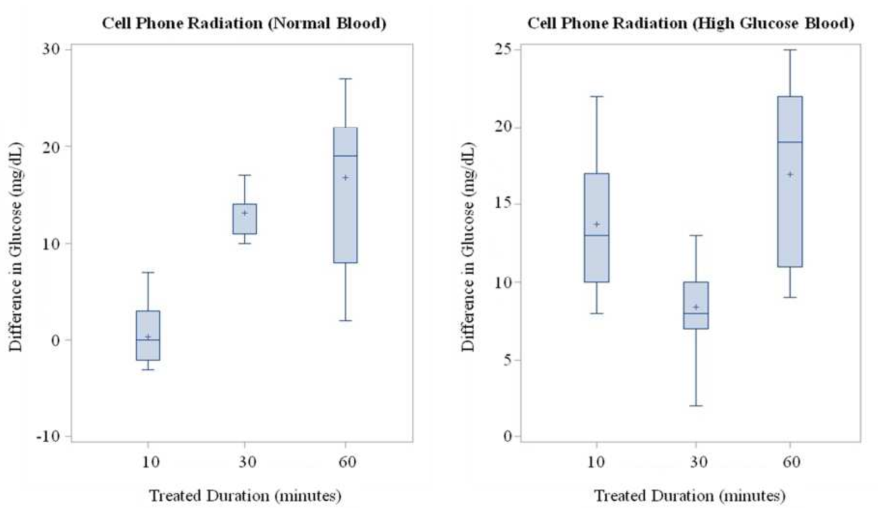
(a)



(b)

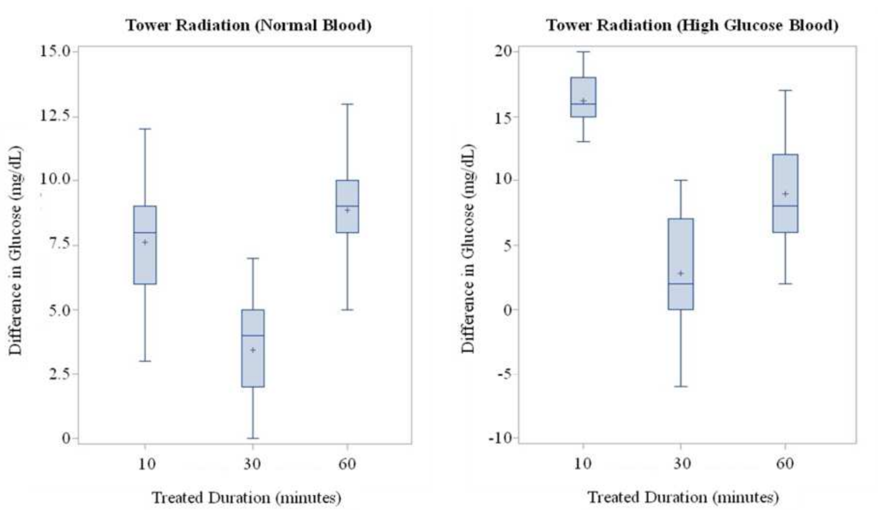
Figure 8. Comparison of the glucose level in the control samples: (a) Normal and (b) high glucose samples.

counterparts of different duration, from which we can determine a preliminary assessment of which durations will likely yield statistically significant effects in the numerical analysis (based on the location of



(a) (b)

Figure 9. Comparison of the glucose level in the samples exposed to cell phone radiation: (a) Normal and (b) high glucose samples.



(a) (b)

Figure 10. Comparison of the glucose level in the samples exposed to tower radiation: (a) Normal and (b) high glucose samples.

the distribution relative to 0) and whether the effects are significantly different from the other durations.

From Figures 8–10, the majority of the data is primarily normally distributed with no distinct outliers. Nevertheless, the Figures 8–10 were merely to give an idea of what the distributions look like and to make sure there are no any blatant errors in the dataset or outliers that would throw off the numerical hypothesis testing. The REML estimations for the mean values of each testing combination of testing duration, exposure level and blood type were generated. Then, the Least Squares Means differences for each testing combination against their respective controls were calculated. Furthermore, the Least Squares Means procedure yielded the t-statistics and p-values for the hypothesis tests with null hypothesis that the testing procedure was not statistically different from the control, as shown in Table 6.

A comparison of the p-values of the glucose level in the treated samples with the control samples for cell phone and tower radiations is shown in Table 6. Out of the 12 tests, 8 are found to be statistically different from the control samples.

A 10 min exposure to cell phone radiation in normal blood samples

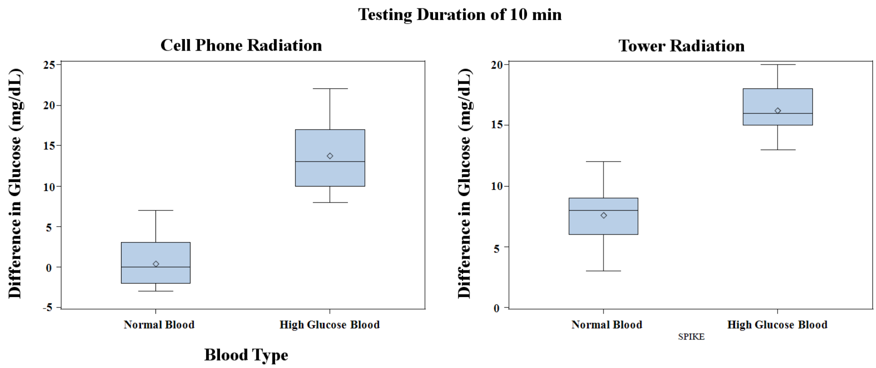
Table 6. Statistical significance testing analysis results.

Blood type	**Radiation**	**Test Duration (minutes)**	**t-value**	**p-value**
NB	Cell Phone	10	2.31	0.0234^{*}
NB	Cell Phone	30	-2.55	0.0127^{**}
NB	Cell Phone	60	-6.22	$< 0.0001^{**}$
NB	Tower	10	-1.21	0.2289
NB	Tower	30	7.92	$< 0.0001^{*}$
NB	Tower	60	2.30	0.0244^{*}
HGB	Cell Phone	10	-0.52	0.6024
HGB	Cell Phone	30	-0.87	0.3887
HGB	Cell Phone	60	-3.25	0.0017^{**}
HGB	Tower	10	-2.41	0.0183^{**}
HGB	Tower	30	2.41	0.0181^{*}
HGB	Tower	60	1.60	0.1141

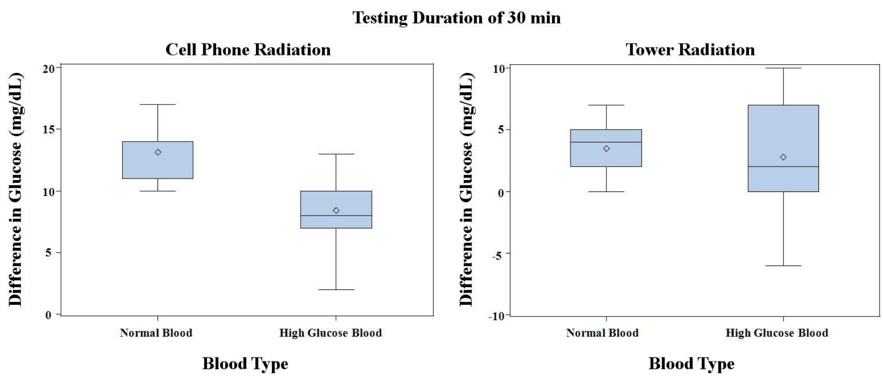
'$*$' means that the glucose level of the treated samples was significantly lower than that of its control.
'$**$' means that the glucose level of the treated samples was significantly higher than that of its control.

show significant decrease, while at 30 and 60 min exposure the glucose level was significantly higher compared to the controls. For the tower radiation, the glucose level in NB samples at 30 and 60 min tests was significantly lower compared with the controls, while there are no changes detected at 10 min treatment.

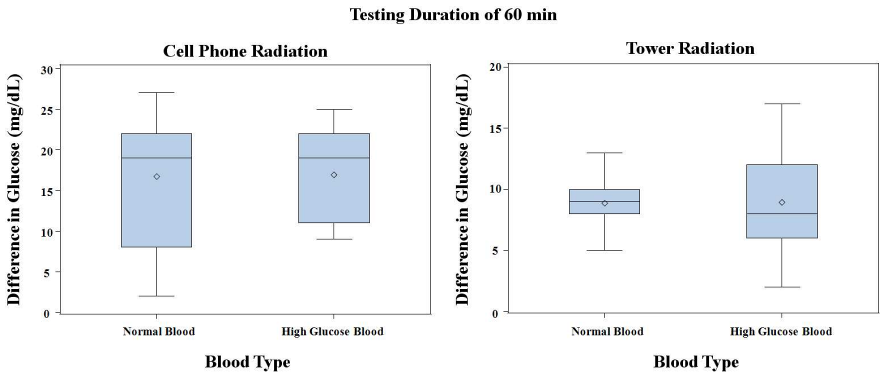
In the high glucose blood (HGB) samples, a 60 min exposure of cell phone radiation shows a significantly higher glucose level than controls. For the tower radiation, the glucose level in the HGB samples at 30 min test was significantly lower than the controls, while at 10 min treatment the glucose level was significantly higher when compared with the controls. These results also corroborate our initial assertion that effects on glucose level could be due to the total energy deposited (power x time) rather than power level or time of exposure alone. Thus in the tower radiations a difference in the glucose level can be observed in both short and long testing durations.



(a) 10 min Treatment



(b) 30 min Treatment



(c) 60 min Treatment

Figure 11. Comparison of the glucose level in the samples exposed to cell phone and tower radiation: (a) 10 min, (b) 30 min and (c) 60 min exposure durations.

Table 7. Testing combinations for normal vs. high glucose concentration.

Radiation	Test Duration (minutes)	t-value	p-value
Cell Phone	10	-8.15	$< 0.0001^{*}$
Cell Phone	30	5.57	$< 0.0001^{**}$
Cell Phone	60	-0.2	0.8429
Tower	10	-15.88	$< 0.0001^{*}$
Tower	30	0.62	0.5357
Tower	60	-0.05	0.9612

'$*$' means that the glucose level of the HGB samples was significantly higher than that of NB samples.
'$**$' means that the glucose level of the NB samples was significantly higher than that of HGB samples.

Using the same procedure as for the testing combinations against their controls (Repeated Measures REML Linear Mixed Model), the least squares means differences for each normal blood testing combination against its high glucose blood counterpart were calculated. The comparison of the glucose between normal and high glucose blood samples are shown in Figure 11. The respective t-values and p-values were generated and shown in Table 7.

Table 7 shows the p-value results of the glucose level in the normal blood (NB) samples as compared with the high glucose blood (HGB) samples for each testing combination. There were 3 significant differences.

For the cell phone radiation, the glucose level in the HGB samples at 10 min exposure was significantly higher compared to NB samples, while at 30 min treatment the glucose level was significantly lower. For tower radiation, the glucose level in the HGB samples at 10 min test was significantly higher when compared with the NB samples. As our initial statement, these results also suggest that due to the total energy deposited to both NB and HGB samples at long exposure period, there is no significant difference in the glucose level.

4. DISCUSSION AND CONCLUSION

The effects of electromagnetic radiation on biological subjects have been studied earlier, the range of studies include an increased risk of carcinogenesis and brain tumor, have been reported [1, 2] as well as changes in blood sugar levels [24–26]. In this study, we have exposed normal and sugar laden blood to electromagnetic fields at 850 MHz frequency, and two power levels and exposure durations of 10, 30 and 60 min using an in-house designed GTEM cell. The statistical analysis of the results were also calculated and compared with controls. The objective was to characterize cell viability, blood sugar response to 850 MHz cellular phone and tower radiations.

As with previously reported results [22, 23], our study of the diabetic cells also shows cell survivability under electromagnetic radiations. Radiation from a cell phone (850 MHz, 2 W uniform electromagnetic field) either significantly decrease or increase the blood cell counts in both normal and high glucose blood samples and is a function of the power level and testing duration. The effects previously has been attributed to many factors, including i) false signal from oscillating ions that affect the electrochemical balance of the plasma membrane and cell function [10], ii) the cell membrane effect [11], iii) the dielectric and electrical properties of the blood [29, 30]. Discrepancies could also be due to the blood type, since blood samples used in each test come from different individuals, where the reaction mechanism is different, resulting in different response to the exposure.

The general conclusion is that electromagnetic fields is likely to affect the blood sugar properties, but it is difficult to point down the exact parameters that causes the effects. This is because of the different frequency, power levels and treatment durations involved. The fact that glucose levels do change as a result of EM radiation, however, is encouraging due to the fact that the parameters involved in the experiments can be isolated and used as a treatment methodology. While the limited sample size makes it difficult to say for certain that there were definitive differences between the tests/controls and the normal/diabetic samples, some of the p-values were significant enough to suggest that the differences do exist, which merits further investigation. For definitive answers in term of frequency, treated duration and power analysis, more studies with larger sample size for better accuracy are required. Based on these experiments we suggest that analysis should not be on the basis of frequency alone but should be a combination of the frequency, power and test duration.

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