Dielectric spectroscopy of in-vitro human blood of diabetic and non-diabetic patients through low level laser therapy

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Abstract. The research work investigates the dielectric properties (dielectric constant, dielectric loss and conductivity) of both diabetic and non-diabetic patients’ blood in order to enhance of low level laser therapy (LLLT). Knowing the dielectric properties of blood, profile dose threshold exposure duration can improve LLLT for diabetic mellitus disease. This was achieved, using impedance analyser 4294A, frequency range 40 kHz - 30 MHz. Measurements were taken before and after blood irradiated with a portable diode-pumped solid state laser of wavelength 532 nm at power of 60 mW in standard cuvettes. Control diabetic patient’s bloods were high in dielectric parameter compared with the control non-diabetic patient’s blood. After exposure for 5 and 10 minute’s duration, the value of dielectric loss for the blood exposed for 5 minutes duration appreciated significantly. This is attributed to the energy acquired by haemoglobin and oxygen activation that increased cell membrane resistance, protecting the K+ ions efflux and thus prevent perilous balance of Ca2+ ions. Laser power of 60 mW for 5 minutes exposure proved effective in LLLT diabetic mellitus therapy.

1. Introduction
Blood represent a unique class of heterogeneous system. It is a complex system that different polarization mechanisms such as dipole, electrochemical, etc. can be observed. Any variation in its morphology/physiology produces corresponding change in its electrical property. Dielectric properties of biological tissues rely completely on the cellular tissue structure. They are considered as good measure of the functional state of the membrane and cytoplasm of the cells (e.g., dipole reaction in cell membrane, conductivity transport in the extra-cellar medium etc.). Knowledge of tissue structure and composition can be obtained by measuring these properties of the tissues [1, 3 & 5]. Few works on blood, addressed electrical impedance, erythrocyte suspension, polarization effect, etc, with near to nothing on diabetic mellitus therapy. According to Zhbanov and Yang (2017), dielectric properties of blood are important for basic research study and copious medical applications such as determination of the blood hematocrit, erythrocyte sedimentation rate, size and shape etc. Desouky (2009) works on dielectric parameters using LCZ meter shows findings are still inadequate since not for the purpose of diabetic blood therapy. This research work focused on the effects of LLL irradiation on diabetic blood through dielectric spectroscopy. To find exposure threshold avoiding inhibitions of blood but optimize the use of LLL in treatment of diabetes mellitus [2, 4 &5].

2. Materials and Methods
The research study involved 64 patient’s blood samples obtained from the Wellness Centre of Universiti Sains Malaysia, Pinang, Malaysia, through “prior consent of the patients”, University clinic
Management and control also Human Ethics approval from JEPeM USM, (USM/JePeM/16060208). Two groups were collected, 32 patients without blood related diseases as non-diabetic and 32 diabetic patients (blood glucose level 4-7.3 mmol/L) with an anticoagulant ethylenediaminetetra-acetic acid (EDTA), then divided into marked designed cuvettes. A portable diode-pumped solid state laser of wavelength 532 nm at power of 60 mW was used for exposure for 5 and 10 minutes.

2.1. Dielectric Spectroscopy Measurements and Evaluations
The samples were studied using the Agilent 4294A impedance analyser at the frequency range of 40 Hz to 30 MHz. The measured sampled factors, the capacitance c and Loss Tangent D were used to evaluate the dielectric parameters like dielectric constant $\varepsilon'$, dielectric loss $\varepsilon''$, conductance G, impedance z, conductivity $\sigma$ (S/m) and the SAR values using equations (1 – 4)

$$c = \frac{\varepsilon'\varepsilon_0A}{d}$$

(1)

$$\varepsilon' = \frac{\varepsilon d}{\varepsilon_0A}$$

(2)

$$\varepsilon'' = \varepsilon' \cdot D$$

(3)

$$\sigma = \varepsilon'_{\omega} \cdot \varepsilon_0$$

(4)

Where, $\varepsilon' = K$ (dielectric constant), D is the dissipation factor, $\sigma$ is the conductivity of the blood or medium (S/m), $\varepsilon_0$ is the permittivity of free space ($8.854 \times 10^{-12} \text{F.m}^{-1}$), $\omega = 2\pi f$ ($f$ is the freq. in Hz).

3. Results and Discussion
This research work presented the results of both blood at the frequency range of 40 Hz to 30 MHz. The tables are extracts at the frequency of 1 KHz were blood polarization mostly starts; dipole orientation and strong ionic conduction interaction resulted when alternating electric field applied.

3.1. Graphical representations of dielectric parameters
Figures 1 (a) and (b) shows the graphic frequency dependence of dielectric constant of blood physiology (diabetic and non-diabetic) of both control and radiated using low level laser. Figures 2 (a) and (b) show a decay trend of dielectric loss with increased frequency in all blood cases. The dielectric loss decayed rapidly up to slightly above 1 kHz and then maintained a constant flow down the frequency range. The dielectric constant also decayed rapidly to slightly above 1 kHz and then maintained a constant flow above 10 kHz in Figures 1 (a) and (b). This is because the dipole orientation and ionic conduction within the blood interact strongly at microwave frequencies. Since blood molecules are of permanent dipoles and rotate to follow any alternating electric field applied. As the frequency increases towards 10 kHz the slow mechanisms drop out in turn, leaving the faster ones to contribute to low and constant flow after the frequency. In Figure 1 (a), the $\varepsilon' r - D1$ and $\varepsilon' r - D2$ represents the dielectric constant of the diabetic blood as 1 and 2 (fasting blood sugar levels of 7.3 mmol/L). And $\varepsilon' r - ND1$ and $\varepsilon' r - ND2$ stand for the non-diabetic blood as 1 and 2 for the controlled blood. Figure 1 (b) shows the radiated blood components, observed that the dielectric constant of the diabetic patients’ as 1 and 2 are exceedingly high compared to the non-diabetic patients’ blood in cases 1 and 2. The permittivity of the blood declined rapidly in a step-like series as the frequency of the within the blood increased.

In Figures 3 (a) and (b) below, the AC conductivity is relative to frequency of the control and radiated blood samples. The conductivity exhibits a sharp peak at frequency 1.00x10^6 to 1.00x10^7 Hz after which it dropped abruptly to negative. The diabetic blood sampled as 1 and 2 ($\sigma – D1$ and $\sigma - D2$ ) formed plateau within the frequency range of 1 kHz - 100 kHz unlike the non-diabetic blood which showed a depressed plot within the region. Slight variation of peak is noticed between the diabetic and non-diabetic blood, demonstrating the high conductivity property of the diabetic blood sample over the non-diabetic blood sample.
Figure 1. Dependence of dielectric permittivity on frequency of (a) different controlled blood physiology and (b) different irradiated blood physiology

Figure 2. Dependence of dielectric loss on frequency of (a) different controlled blood physiology and (b) different irradiated blood physiology

Figure 3. Dependence of AC conductivity on frequency of (a) different controlled blood physiology and (b) different irradiated blood physiology

3.2. Observed dielectric parameters at frequency rate of 1 kHz
Considering tables 1 and 2, dielectric parameters of the diabetic blood has higher value as against non-diabetic, as free radicals are produced in diabetes by glucose autoxidation, polyol pathway or/and non-enzymatic glycation of proteins. The free radicals density increase in the diabetic blood with density dipoles, causing rise to dielectric constant and influences high conductivity, therefore all the calculated values of dielectric parameters are considerably higher than the non-diabetic cases of group 1 and 2.


Table 1. Evaluated dielectric parameters of control blood samples at frequency 1 kHz

| Case | Health profile of Patients. | Dielectric Parameters of blood |
|------|-----------------------------|-------------------------------|
|      |                             | Dielectric constant \( \varepsilon'_r \) | Dielectric loss \( \varepsilon''_r \) | Conductivity \( \sigma \) mho-m⁻¹ |
| 1    | Diabetic                    | 3.96x10⁻⁵                    | 6.77x10⁻⁵                     | 3.43x10⁻³ |
| 2    | Diabetic                    | 4.15x10⁻⁵                    | 8.48x10⁻⁵                     | 4.28x10⁻³ |
| 1    | Non-diabetic                | 3.07x10⁻⁴                    | 5.58x10⁻⁴                     | 2.82x10⁻⁴ |
| 2    | Non-diabetic                | 2.30x10⁻⁴                    | 3.58x10⁻⁴                     | 1.81x10⁻³ |

Table 2. Evaluated dielectric parameters of radiated blood samples at frequency 1 KHz

| Exposure duration | Health profile of patients. | Dielectric parameters of blood |
|-------------------|-----------------------------|-------------------------------|
|                   |                             | Dielectric constant \( \varepsilon'_r \) | Dielectric loss \( \varepsilon''_r \) | Conductivity \( \sigma \) mho-m⁻¹ |
| 5mins             | Diabetic                    | 4.26x10⁻⁴                    | 8.35x10⁻⁴                     | 4.22x10⁻³ |
| 10mins            | Diabetic                    | 4.67x10⁻³                    | 1.01x10⁻⁴                     | 5.10x10⁻³ |
| 5mins             | Non-diabetic                | 2.52x10⁻³                    | 9.27x10⁻⁴                     | 4.69x10⁻⁴ |
| 10mins            | Non-diabetic                | 2.11x10⁻³                    | 4.36x10⁻⁴                     | 2.21x10⁻³ |

In Table 2, results of the non-diabetic blood exposed for both 5 and 10 minutes show decreased values of dielectric constant, with increased dielectric loss and conductivity. In the diabetic blood, values of dielectric constant and conductivity were higher within exposed durations. The dielectric constant declined rapidly in a step-like series as frequency increased. They exhibit significant decreased value of dielectric loss at exposure of 10 minutes, compared to the control patients’ blood in Table 1, due to excessively exposure. The exposure for 5 minutes in Table 2 improved biostimulation effects with dielectric constant and conductivity over the control counterpart in Table 1. Due to diabetic cell membrane correction factor resulted to increased blood dielectric loss after stimulated compared to 10 minutes exposure. Energy acquired by haemoglobin and increase in cell membrane resistance becomes advantageous in protecting the K⁺ ions efflux and prevent perilous balance of Ca²⁺ ions, changes resulted to biostimulation. The dielectric loss is comparably low for the diabetic blood excessively radiated for 10 mins, affected the cell cytoplasm and the membrane developing abnormal notchings.

4. Conclusions

There is frequency dependent of dielectric parameters of blood physiology and behavior by its dipolar and interfacial cell membranes. The diabetic blood presents higher values of dielectric response as against non-diabetic, because in diabetic blood the free radicals are produced by glucose autoxidation, polyol pathway or/and non-enzymatic glycation of proteins. Glucose influx flattens its biconcave disk shape-like and causes the boats of the RBCs. The permittivity declined more rapidly in a step-like series as frequency of electric field increases, not as sharply in non-diabetic blood. The exposure of 60 mW for 5 minutes stimulates the cell membrane then stable blood health condition. Therefore LLL can maintain the cell membrane and yielding a positive influence on the defect diabetic cell membranes.

5. References

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