SOCIETY FOR SCIENCE AND EDUCATION
UNITED KINGDOM

JBEMi JOURNAL OF BIOMEDICAL ENGINEERING AND MEDICAL IMAGING

ISSN: 2055-1266
VOLUME 2 ISSUE 6

Correlation between Different Erythrocytes Sedimentation Rates and Bio Impedances Surface Acoustic Wave

Mohamed A. A. Eldosoky
Dept of Biomedical Engineering- Helwan university, Egypt
hm1_eldosoky@hotmail.com, mohamed_eldesouky@h-eng.helwan.edu.eg

ABSTRACT

RBCs with their shapes, volumes and concentrations are very important indicators for the normal and abnormal healthy body. Plasma had electrical characteristics different from the red blood cells. Consequently, the impedance of the plasma- RBCs is proportional to the number or the volume of the RBCs with the plasma. This paper had presented new proposed method for classification of the RBCs by using surface acoustic wave and the bioimpedance so it can be called bioimpedance surface acoustic wave.

Keywords: Bioimpendance, Erythrocytes Sedimentation Rate, RBCs, Surface acoustic wave.

1 Introduction

Blood is the vital liquid in the human body. The major part of it with more 99% is called RBCs. Any variation in the shape or the volume or the number of them in the blood is inherent with not only the blood diseases but also the human organs. Due to the difference in the electrical characteristics between the RBCs and the plasma (the RBCs have conductivity with lower values than the plasma), the impedance of RBCs-plasma is related to the blood cell concentrations and volumes [1].

Recent researchers had proposed mathematical models including the relations between the permittivity and the volume fraction regardless the number and the volume of the cells [2]. These investigations also had proved that the electrical polarization formula of the cells is the milestone parameter for estimating the electrical characteristics of the plasma-RBCs solution [3].

In [4], the researchers had tried to estimate the impedance of the solution as a tool for determining the solutions' concentration at three different frequencies for determining the parameters of the equivalent circuit of the cell.

The applications of bioimpedance for detecting the blood diseases are numerous. These applications had depended on determining the variation of the electrical blood characteristics as compared to the normal cases [5,6,7,8]. Microcytes and macrocytes are two phenomena as examples of the volume variations and so the impedances of the RBCs that are referred to certain diseases or drinking alcohol or wines [9].

DOI: 10.14738/jbemi.26.1711
Publication Date: 21th December 2015
URL: http://dx.doi.org/10.14738/jbemi. 26.1711

This paper presents a model that can be used for diagnosing the variations in the erythrocytes sedimentation rate (ESR) and classifying the shapes, the volumes and the volume fractions of the RBCs. These are the main parameters related to the RBCs beside the hemoglobin as in the CBC lab test. This process had been done by using the surface acoustic wave (SAW) as known with its sensitivity to the electrical properties of the medium solution. Depending on the phenomena of Erythrocytes sedimentation rate (ESR), during the time progressing the concentration of the RBCs within the blood samples changes along the blood sample so does the electrical impedance that can detected by using SAW. This model had proved the SAW's ability to classify the RBCs with different volumes not volume fractions only.

2 Mathematical Model

For the plasma-RBCs solution with volume fraction, Φ, number of particles, *N* as a volume of each particle, V_p, the permittivity and the conductivity of this solution was calculated by the following equations [3]:

$$\varepsilon(\omega) = \varepsilon(\infty) + \frac{\varepsilon(0)-\varepsilon(\infty)}{1+j\omega\tau} \quad (1)$$

Where $\varepsilon(\infty)$ and $\varepsilon(0)$ are the dielectric constants at infinity and zero frequencies, respectively. τ is called the relaxation time for the particle as function of its size, volume fraction, rigidity of the particle.

The volume fraction of any solution is calculated by:

$$\Phi = \frac{N*Vp}{V} \quad (2)$$

The general formulation for the effective permittivity ($\varepsilon(\infty) or \varepsilon^*$) for any cell structure as a function of the volume fraction was calculated as shown [10]:

$$\varepsilon * = \varepsilon_a * + \frac{\Phi \varepsilon_a *}{3} \sum_{k=x,y,z} \frac{(\varepsilon_p * - \varepsilon_a *)}{\varepsilon_a * + A_k(\varepsilon_p * - \varepsilon_a *)} \quad (3)$$

A_k is the axial polarization factor of the cell as function of its shape [10].

ε^*_s and ε^*_p are the equivalent permittivity of the plasma and the cell only, respectively.

As shown the last equations had studied the influence of the RBCs through the effect of the volume fraction of the cells without focusing on the effect of the number and their volumes individually.

In this paper new proposed model had been presented. This model had detected the ESR of various kinds of RBCs by using the bioimpenace surface acoustic wave. Surface acoustic wave (SAW) is an acoustic wave generated by using transducers called interdigital transducers (IDTs). The generated wave has two components, which are mechanical and electrical. SAW has its ability to detect the medium characteristics depending on its electrical characteristics. As comparing the transmitted signal on the medium with the received one, the variation in the transmitted signal is related to the medium characteristics. This variation is called the wave's perturbation, which is classified as frequency (velocity) perturbation and amplitude perturbation. The applications of the SAW as a bioimpedance tool were numerous [11]. The associated equations for the time-frequency perturbation was derived in [12]:

$$\frac{\Delta f}{f}(t) = \frac{\Delta v}{v}(t) = -\frac{K^2}{2} * \frac{(\frac{\sigma(t)}{\omega})^2 + \varepsilon_0(\varepsilon(t) - \varepsilon_r)(\varepsilon(t)\varepsilon_0 + \varepsilon_p)}{(\frac{\sigma(t)}{\omega})^2 + (\varepsilon(t)\varepsilon_0 + \varepsilon_p)^2} \quad (4)$$

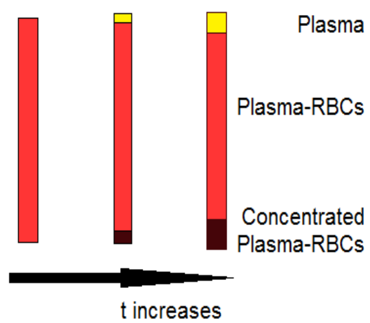
Where $\frac{\Delta v}{v}$ and $\frac{\Delta f}{f}$ are the velocity and frequency shifts, respectively in the received signal as compared to the input or transmitted one. ε_r is the reference solution (the plasma-RBCs). ω is angular frequency, K^2 is the mechanical coupling. ε_p is the dielectric constants of the substrate and ε_0 is the dielectric constant of the free space.

From this equation we can deduce that the response of this SAW is a signal with shifted frequency with Δf but this shifted varies with time, where the during the sedimentation process, the RBCs will separate from the plasma. So two solutions will be formed in the top of the sedimentation tube, which are RBCs-plasma with subscript 1 and plasma solution with subscript 2 as shown in Fig.1. So at any time, the total conductivity $\sigma(t)$ of the solution under the IDT was calculated by:

$$\sigma(t) = \sigma_1\left(\frac{l}{L_1}\right) + \sigma_2\left(\frac{L_1 - l}{L_1}\right) \quad (5)$$

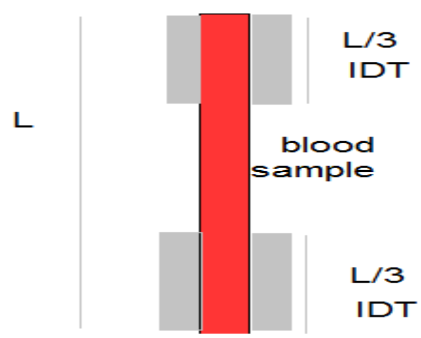
Also the equation of the total dielectric constant of the solution under the IDT, $\varepsilon(t)$ was given by:

$$\varepsilon(t) = \varepsilon_1\left(\frac{l}{L_1}\right) + \varepsilon_2\left(\frac{L_1 - l}{L_1}\right) \quad (6)$$



(a)

Figure.1 a) The sedimentation process and formation of three different solutions



(b)

Figure.1 b) SAW with blood sample

As shown in Fig.1a, at the top of the tube during the sedimentation process the RBCs will separate from the plasma. So three liquids will be formed, which are the plasma (top) and the RBCs-plasma (medium) with normal concentration and RBCs-plasma with higher concentration (bottom), respectively. With the progress of the time, the heights of these two liquids vary from time to another. The time rates of changing for the heights are related to the sedimentation velocity, where higher velocity means high rates of these lengths or heights. The sedimentation velocity of the RBCs as function of their radii and the volume fractions was given by [13]

$$v = (\rho_{RBC} - \rho_{plas}) * g * d^2/18\mu(1 + 2.5\Phi) \quad (7)$$

ρ_{RBC} and ρ_{plas} are the densities of the RBCs and plasma, respectively. d is the RBC radius, and μ is the viscosity of the free plasma. g is the acceleration of gravity.

According to the mechanism of the sedimentation process, three sections will be formed (upper medium and lower). So it was assumed that the length of sample is L and assume that this length is divided to three divisions each has length, L/3. The first and the third divisions are under the IDTs of the SAW as shown in Fig1b.

Fig.2 is the flowchart that explain the mechanism of the bioimpedance by using SAW. The problem here is that all parameters in this flowchart aren't constants, where the velocity of the sedimentation is function of the volume and the volume fraction (Eqn.7). The electrical impedance of the medium under the interdigital transducers (IDTs) is related to the permittivity and the conductivity that change with the time. But these electrical parameters depend also on the volume fraction and the polarization factors of the cells beside that they are frequency dependent of the used SAW signal. This process stops when the plasma solution fills the tube under the IDT ($l=L_1=L/3$).

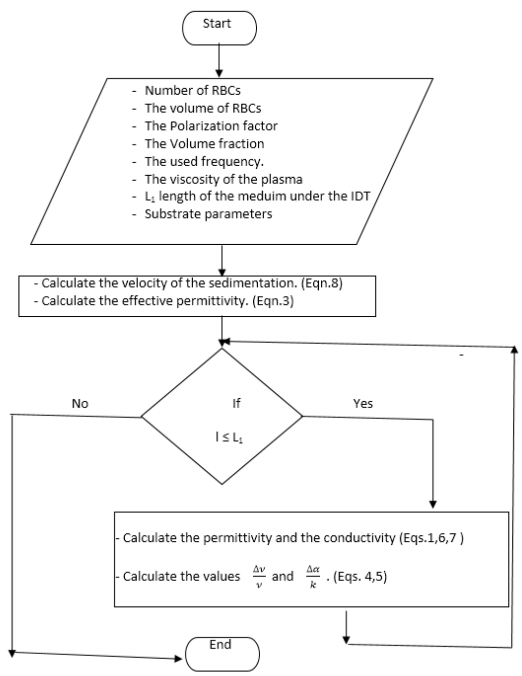


Figure 2: The flowchart of the proposed model

3 Results

As mentioned before this model deals with the mechanical and the electrical properties of the RBCs in the plasma solution. So this section had discussed the relation between the ESR of the RBCs and their bioimpedances by using the SAW at different cases. These cases are related to the diseases affect the formation either the volume or the number of the RBCs. The influence of the drugs or the alcohol was presented also.

3.1 RBCs with the same volumes but with different volume fractions

Figure 3 shows the response of the RBCs-plasma solution with different volume fractions. Four different responses for four different values of volume fractions with the same cells volume as common.

Consequently, different responses will be expected but parallel to each other as indicator that the volumes' cells are equal.

(If the response is parallel to the response of the normal curves it means equal volumes' cells but different in volume fractions)

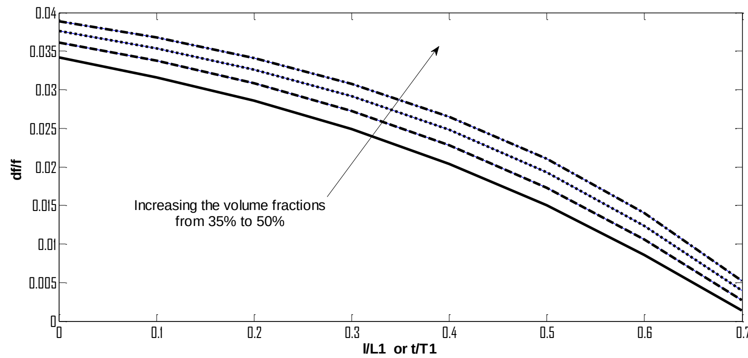


Figure 3.The responses of the RBCs for the same volumes at different volume fractions (0.35, 0.40. 0.45, 0.50)

3.2 RBCs with the same volume fractions but with different cells' volumes

Here lower and higher volumes are the main properties of the Microcytes and macrocytes cells, respectively. As shown the cell's volume is the main parameter that controls the sedimentation velocity. Since the volume fractions are the same, the starting point or the starting impedance is the same. But as changing the time the variation in the impedance depends on the sedimentation velocity that depends on the cells velocity. Higher volumes cells have faster responses than the lower as shown in Fig.4.

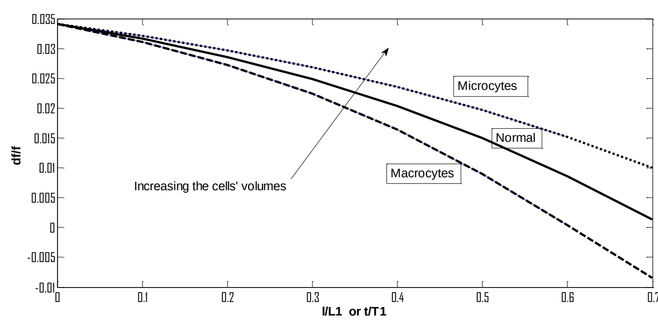


Figure 4 Responses of microcytes and macrocytes as compared to the normal volume of RBCs

3.3 Influence of alcohol on the RBCs formation

Alcohol and wines have an effect not only the RBCs but also on the body organs. The blood with its RBCs are the most effective part. Lake in the number of the RBCs is associated with drinking alcohol due to the problems inherit with the production of RBCs. So as a compensation of this problem an increment in the volume had been shown clearly [14]. Fig.5 shows the response of this model as the raw collected data had been applied. The variation here in both the volume and the number of the RBCs. The variation in both the volumes and the radius is about +0.08 and -0.07, respectively as compared to the normal values.

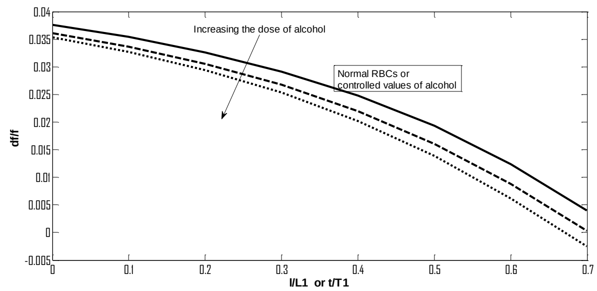


Figure 5. The third application: detection of the RBCs for the alcohol drinkers

4 Conclusion

Surface acoustic wave with its characteristics is a complete bioimpedance system depending on its sensitivity for any variation within any solution. The electrical properties of the RBCs as compared to the plasma was the main point that this model had built on. With the aiding of the mechanical characteristics of the RBCs summarized in the ESR, this model had proved its ability to classify the RBCs and will be a good tool for studying the blood characteristics. In the future, with the aiding of any classification technique as ANFIS, complete blood analysis may be proposed for studying not only the RBCs but also all blood components.

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