New Proposed Algorithm for Determining the Electrical Characteristics of the Prolates and Oblates RBCs

Mohamed A.A. Eldosoky
Dept of Biomedical Eng.
Helwan University, Egypt

ABSTRACT
Shapes and volume fractions (number and volume) of the red blood cells (RBCs) are important indicators for checking the patient cases. Microcytes, macrocytes, Elliptocytosis, oblate, and prolate are different RBCs shapes related to the blood diseases.

The structure, the volume and the number of RBCs cell have direct effects on the electrical characteristics of RBCs. Many mathematical algorithms had been proposed for estimating the characteristics of nonspherical shapes. Unfortunately, many assumptions had been imposed to overcome the complexities of these algorithms. Besides these algorithms had been simulated the RBCs with spheres shapes only, where they are very complicated to apply for any other shapes. In this paper, the electrical characteristics of the oblate and the prolate RBCs had been estimated as function of the characteristics of the spherical RBCs. These characteristics include the relaxation time, the membrane capacitance of the cell, the low and very high frequencies permittivity and the conductivity.

Keywords
Volume fraction, permittivity, oblate RBCs, prolate RBCs, membrane capacitance.

1. INTRODUCTION
Variation of the electrical characteristics of tissues is the milestone for diagnosing them. One of these analytical diagnoses is the blood analysis that depends on the concentrations of its internal vital components, such as: RBCs and WBCs. In this kind of analysis variation of the shapes, the volumes and the concentrations are the main parameters that reveal whether the normality of blood or not [1].

As a principle of the electricity, the electrical characteristics of any solution are related to the concentration of molecules within it. This principle has a good reaction as applying it in the biomedical applications for the reasons mentioned above.

Different methods had applied this principle of bioimpedance [2]. One of these sensing methods depends on transmitting signal and detecting the returned signal as interacting with the cells inside the solution so the equivalent electrical characteristics is an image of the internal structure of this solution [3].

The permittivity, the conductivity, the relaxation time, and the volume fractions are the main parameters that applied for simulating the interaction between the waves and the blood cells [4].

The main problem is for the RBCs except the spherical ones, where all parameters such as the relaxation time, the permittivity and the conductivity have three components, which are x, y and z.

In this paper, new algorithm had been proposed to deal with the nonspherical cases, such as oblate and prolate types. This algorithm depends on determination of the effective permittivity of the RBCs-plasma solution as function of the volume fraction and the polarization factors of the oblate and the prolate RBCs. Depending on this calculated effective permittivity, the volume fraction of the spherical RBCs can be estimated for applying the other equations that calculated the other electrical characteristics. This algorithm can be extended to apply any volume fractions at any frequency.

2. MATHEMATICAL ALGORITHM
Any cell is consisted of an internal vital liquid surrounded with a membrane. The electrical permittivities of these components (cytoplasm, and membrane) are: εCp, and εm, respectively [5,6].

Two main models had been proposed for calculating the effective permittivity of liquid including number of cells with volume fraction, ϕ. These models are called single and double models [5].

Firstly, in each model, the effective permittivity of the cell is calculated as a function of the equivalent permittivity of the membrane (as a function of its radius and thickness) and the characteristics of the internal material (cytoplasm). This is called Maxwell- Wagner model [5] with the following equation:

$$\varepsilon^* = \varepsilon^*{}_a \frac{(2\varepsilon^*{}_a + \varepsilon^*{}_p) - 2\phi(\varepsilon^*{}_a - \varepsilon^*{}_p)}{(2\varepsilon^*{}_a + \varepsilon^*{}_p) + \phi\,(\varepsilon^*{}_a - \varepsilon^*{}_p)} \quad (1)$$

$$\varepsilon^*{}_p = \varepsilon^*{}_m \frac{2(1-v)\varepsilon^*{}_m + (1+2v)\varepsilon^*{}_{cp}}{(2+v)\varepsilon^*{}_m + (1-v)\varepsilon^*{}_{cp}} \quad (2)$$

Where

$$v = \left(\frac{R}{R+d}\right)^3 \quad (3)$$

R and d are the radius of the cell and the thickness of the cell membrane, respectively.

ε^* and $\varepsilon^*{}_p$ are the equivalent permittivity of the solution-cells and the cell only, respectively.

$\Delta\varepsilon$ and τ are two milestone parameters that determine the behavior of the tissue as exploring to any wave. Their relations are:

$$\Delta\varepsilon = 9\phi\, RC_m / 4\varepsilon_0 \quad (4)$$

$$\tau = RC_m \left(\frac{1}{2\sigma_2} + \frac{1}{\sigma_1}\right) \quad (5)$$

C_m is the capacitance of the membrane. σ1 and σ2 are the conductivity of the cell and the solution respectively.

The frequency response of the permittivity has the following equations [7,8]:

$$\varepsilon(\omega) = \varepsilon'(\omega) - j\varepsilon''(\omega) \quad (6)$$

$$\varepsilon(\omega) = \frac{\Delta\varepsilon}{1+\omega^2\tau^2} - j\frac{\Delta\varepsilon\ \omega\ \tau}{1+\omega^2\tau^2} \quad (7)$$

Where τ is the relaxation time and $\Delta\varepsilon$ is the difference in the dielectric constants [7].

The main problem associated with this model is its limitation for the spherical cells with low volume fractions (less than 0.2) [9].

Given the nature of the RBCs, their volume fractions are between to 35% to 55% in normal case as well their nonspherical structure. So three dimensional structure will be formed either for the relaxation times and the polarization factors.

As a modification of the above model [6], the effective permittivity of any solution with nonspherical cells is given by:

$$\varepsilon * = \varepsilon_a * + \frac{\Phi\varepsilon_a *}{3} \sum_{k=x,y,z} \frac{(\varepsilon_p * - \varepsilon_a *)}{\varepsilon_a * + A_k(\varepsilon_p * - \varepsilon_a *)} \quad (8)$$

Ak is the axial polarization factor of the cell as function of its shape [6].

But the problem still exists is how to deal with the rest parameters such as: τ and $\Delta\varepsilon$ for studying the behavior of the cells at any frequency range.

As applying Eqn. (8) for calculating the effective permittivities for three types of RBCs with different shapes under the conditions of : the same volume, and the same surrounding medium (plasma with permittivity = 78.6).

Here the milestone parameter is the volume fraction, ϕ. Fig.1 describes the response of the equivalent permittivities of the oblate and the prolate cells as compared to the reference cells (sphere). As instance, for 65 as a permittivity value, the corresponding values of the volume fractions were 0.3 and 0.6 for the oblates and prolates, respectively as compared to the reference cell (sphere) with its value is equal to 0.4 as a volume fraction.

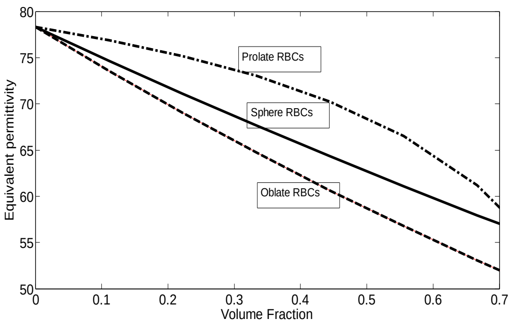


Fig.1. The equivalent permittivity of the oblate and prolate cells with the same volume as compared to the spherical cells at different volume fractions.

Since the equations of the dielectric response are for the spherical cells only, we will get the dielectric response of the prolate and the oblate cells in terms of the spherical ones. This is done by calculating the equivalent volume fraction of the spherical cells that gives the same equivalent permittivity of the oblates and the prolates RBCs for the same volume as shown in Fig.1.

From this point, the proposed algorithm had been applied for deriving the electrical characteristics of oblate and prolate RBCs inclusive $\boldsymbol{\Delta\varepsilon}$, $\boldsymbol{\tau}$, and membrane capacitance, Cm of the cell membrane. In the second part of this paper, new method of the RBCs Sedimentation had been proposed by using the surface acoustic wave (SAW) depending on the mechanical and the electrical of the cells. So this method can be used as a tool not only for calculating the Sedimentation rate but also for diagnosing the blood cells.

3. RESULTS

3.1 The Effect of Polarization Shape on The Estimated Electrical Parameters

Since any other shape except the sphere has asymmetrical polarization, the other parameters such as $\Delta\varepsilon$, τ, and Cm aren't calculated directly. So for calculating these parameters for any cell, firstly we will calculate the effective permittivity of these cells at volume fraction, ϕ. Secondly, the equivalent volume fraction, ϕequivalent of the sphere cells (for the same equivalent permittivity) will be determined. Then the other parameters will be calculated as function of

this ϕequivalent . Fig.2 shows the normalized values of $\Delta\varepsilon/\Delta\varepsilon(sphere)$ for the oblate and the prolate shapes.

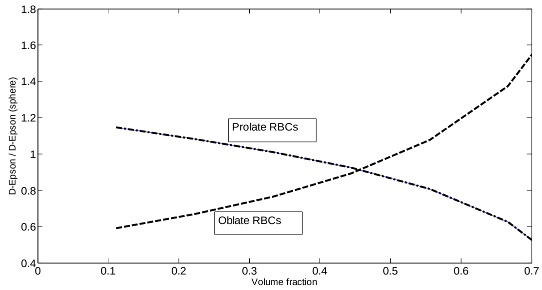


Fig.2. $\Delta\varepsilon/\Delta\varepsilon(sphere)$ for the oblate and the prolate cells.

Although the similarity of the sizes and the numbers of the cells, but the difference is clear in the rest of the calculated values as a mirror of the polarization effect of these cells. Permittivity of the membrane (the membrane capacitance) is an important parameter associated with the normality of the cell. For the different cells with the same volume fractions and the same volumes, the differences in the values of membrane permittivities are shown in Fig.3.

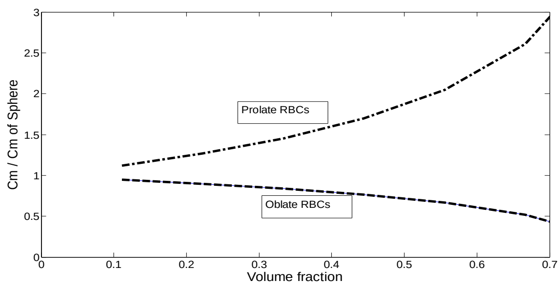


Fig.3. C_m of the prolate and the oblate cells

Relaxation time is an important parameter that describes the ability of the cell to return to its normal case after the polarization case. Accordingly, the return time is function of the shape and the volume fraction as a response to the degree of freedom of the cells in the liquid.

Fig.4 shows the variation of the relaxation time from shape to another as compared to the reference case (sphere). For the prolate case, a positive correlation between the relaxation time and the volume fraction had been shown.

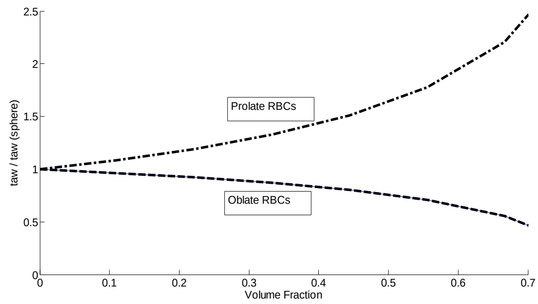
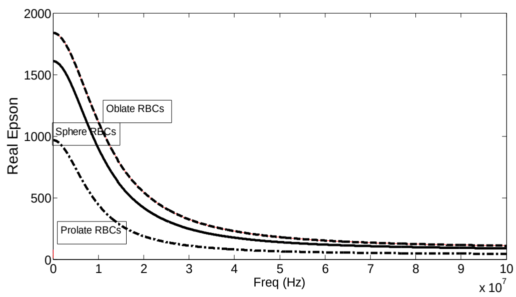


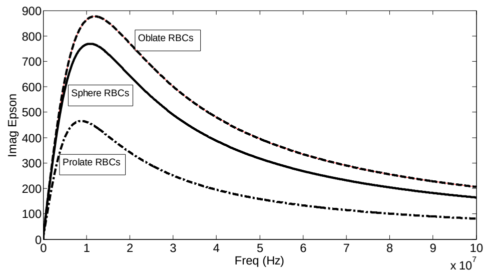
Fig.4.taw/taw (sphere)

3.2 Responses at Different Volume Fractions

As mentioned before, the normal volume fraction of the RBCs is between 35% to 55%. So in this part the dielectric response as a function of the frequency will be studied for three different shapes of RBCs. Figs.5 and 6 show the real part, the imaginary part of the permittivities and the conductivities of the RBCs cells for three different shapes of cells. The volume fractions here are 35% and 45% for all cases, respectively.



a)



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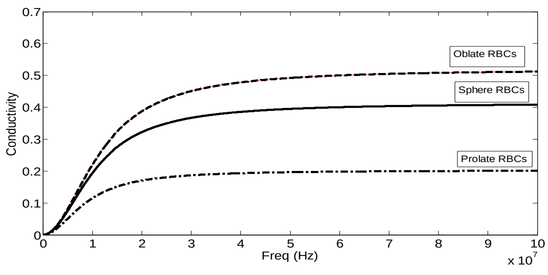

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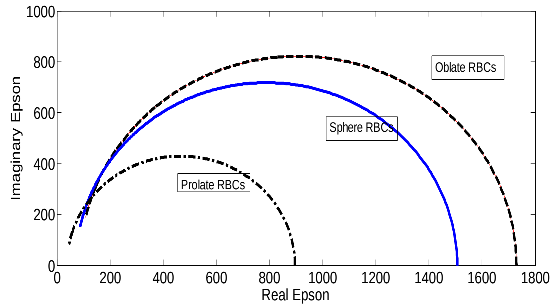
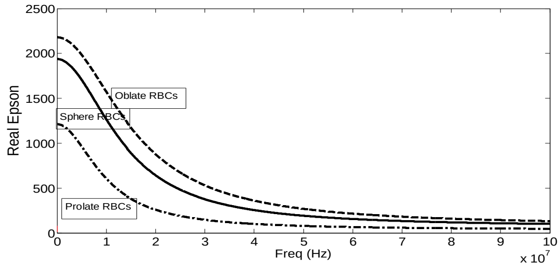
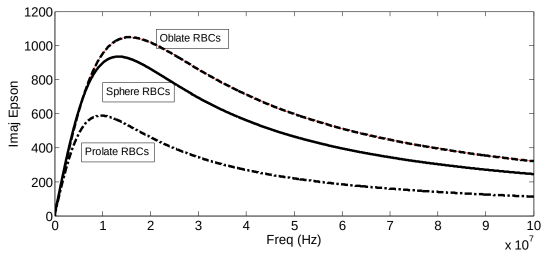


d)

Fig.5 The dielectric response at 35% as volume fraction
a) Real part of Epson b) Imag part of Epson
c)Conductivity d) Real and Imag chart



(a)



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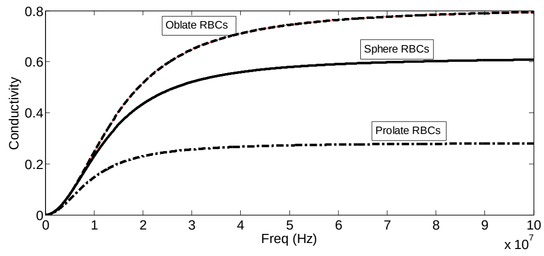

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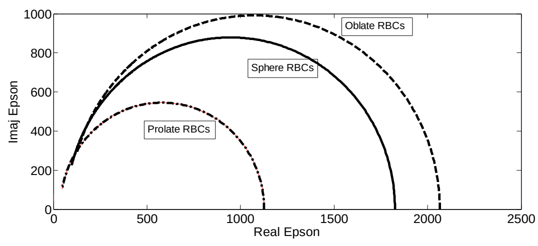
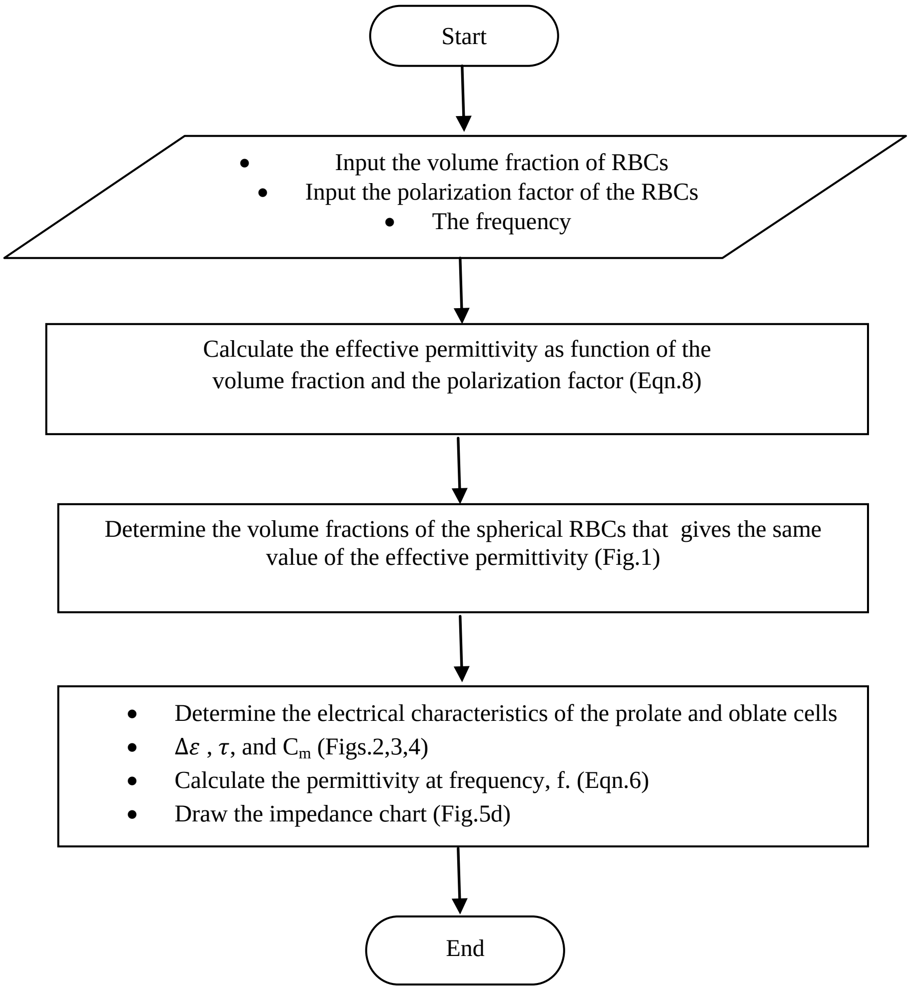


d)

Fig.6 The dielectric response at 45% as volume fraction
a) Real part of Epson b) Imag part
c)Conductivity d) Real and Imag chart

Finally the flowchart of this algorithm is shown in Fig.7



4. CONCLUSION

This paper had presented new proposed algorithm for determining the impedance of two different shapes of the RBCs depending on the electrical polarization that affects the permittivity of RBCs though they have the same volume fractions. This algorithm had facilitated to deal with any nonspherical RBCs to determine their characteristics and it can be used a classification tool for diagnosing the kinds or the shapes of the RBCs.

5. REFERENCES

[1] A. Di Biasio,† L. Ambrosone,‡ and C. Cametti§, "The Dielectric Behavior of Nonspherical Biological Cell Suspensions: An Analytic Approach" Biophysical Journal Volume 99,163–174, July 2010.

[2] M. O. Grimnes S., “Bioimpedance and bioelectricity basic”, Academic Press, New York, 2000.

[3] Shaimaa. Tarek. El Zarie, and Mohamed. A. A. EL-Dosoky," Diagnosis of Blood Diseases Using Shear Horizontal Surface Acoustic Waves", 30th NATIONAL RADIO SCIENCE CONFERENCE (NRSC 2013), National Telecommunication Institute, Egypt, April 16-18, 2013.

[4] S. Giordano, P.L. Palla and L. Colombo., "Effective permittivity of materials containing graded ellipsoidal inclusions" Eur. Phys. J. B **66**, 29–35, 2008.

[5] Koji Asami and Takeshi Yonezawa., " Dielectric Behavior of Wild-Type Yeast and Vacuole-Deficient Mutant Over a Frequency Range of 10 kHz to 10 GHz" , Biophysical Journal Volume 71 October 1996 2192-2200.

[6] V. Raicu a, T. Saibara b, H. Enzan c, A. Irimajiri., "Dielectric properties of rat liver in vivo: analysis by modeling hepatocytes in the tissue architecture", Bioelectrochemistry and Bioenergetics 47 _1998. 333–342.

[7] 1rjan G. Martinsen, Sverre Grimnes, and Herman P. Schwan, " Interface Phenomena And Dielectric Properties Of Biological Tissue" Encyclopedia of Surface and Colloid Science , 2002.

[8] S. Abdalla**.,** **"**Effect of erythrocytes oscillations on dielectric properties of human diabetic-blood" AIP ADVANCES **1**, 012104, 2011

[9] Y. Hayashi a,*, Y. Katsumoto a, I. Oshige a, S. Omori a, A. Yasuda a, K. Asami, "Dielectric inspection of erythrocytes", Journal of Non-Crystalline Solids, 757-762, 2010.