ABSORPTION OF ULTRASOUND IN HUMAN BLOOD
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ABSTRACT: Ultrasonic absorption is determined in human blood and its constituents such as RBC, hemoglobin and plasma using ultrasonic interferometer technique at the frequency of 3 MHz. The study suggests that when an acoustic wave passing through a blood sample it encounters three different media namely plasma, cell wall and hemoglobin. These media have their own acoustic impedance values. The acoustic power loss is dependent upon the mismatching of the acoustic impedance values of these three media.

1 - INTRODUCTION

Absorption of ultrasound plays an important role in understanding the molecular architecture and cellular assembly of the biological systems which carryout life processes. In the past, extensive work had been done on ultrasonic absorption in biological fluids, cell suspensions and tissues.

Carstensen et al /1/ determined absorption of ultrasound in blood, plasma, albumin and hemoglobin and concluded that the absorption is proportional to the protein concentrations. They also reported that similar molecules like albumin and hemoglobin have similar absorption but the large plasma proteins have different characteristics. They attributed the absorption of blood to the presence of proteins in blood and plasma.

Urick /2/ reported that the greater part of absorption of sound in aqueous suspensions of small spherical particles can be attributed to the viscous drag between the fluid and particles in the sound field.

Recently Ahmed Waheedullah et al /3/ proposed a mathematical model for the ultrasonic absorption in human erythrocytes suspended in plasma, considering the plasma to be micropolar fluid as far as high frequency oscillations are considered.

Perusal of literature reveals that still it is a moot point to take decision about the mechanism of ultrasonic absorption in biological suspensions such as erythrocytes in plasma. In view of this, an attempt is made to study ultrasonic absorption in human blood and its constituents such as RBC, hemoglobin and plasma using ultrasonic interferometer technique at the frequency of 3 MHz.

2 - THEORETICAL CONSIDERATIONS

The absorption of sound by a medium containing a suspension of particles which are small compared to the wavelength of sound, is still an unsolved problem in acoustics. This problem has been dealt theoretically by several workers. Of all, the most general approach is that of Epstein /4/, considering the longitudinal and progressive wave passing through a medium containing spherical particles which are small compared to the wavelength of sound. Epstein proposed an expression for the absorption coefficient in suspension carrying the spherical particles. According to him the absorption coefficient.

$$\alpha = \frac{V_p}{2c} \frac{(d-1)^2}{d^4} \frac{m}{M_e} \frac{(\omega/\omega_0)^2}{1+(\omega/\omega_0)^2} \alpha_0$$

(1)
where \( V_p = \frac{4}{3} \pi a^3 N \), volume concentration of particles; \( a \) = radius of the particle; 
\( N \) = No. of particles per ml; \( C \) = Velocity of sound; \( d_1 \) = density of the fluid; 
\( d_2 \) = density of the particle; \( d = d_1/d_2 \), the ratio of the density of the fluid to that of particle; 
\( \eta \) = coefficient of viscosity of the medium; 
\( \omega = 2\pi \nu \) where \( \nu \) - frequency of the sound wave; \( m = \frac{4}{3} \pi a^3 d_1 \); 
\( M = \frac{4}{3} \pi a^3 d_2 \); \( M_e = M + m \left[ \frac{1}{4} + \frac{9}{4} \frac{1}{(d_1 a^2 \omega^2 /2 \eta^2)^{1/2}} \right] \); 
\( R_e = 6 \pi a \left[ 1 + (d_1 a^2 \omega^2 /2 \eta^2)^{1/2} \right] \); 
\( \alpha_0 = \frac{R_e}{M_e} \).

This theory gives the total absorption of sound in suspensions.

Sewell /5/ obtained an expression for the absorption of sound waves in a fluid medium in which solid (rigid) spheres were suspended. The coefficient of absorption according to Sewell, can be written as

\[
\alpha = \frac{N \pi d^2}{4} \left[ \frac{123}{C d} + \frac{3(2,930)^{1/2}}{C} + \frac{7,444}{C^4} \right]
\]  

(2)

Where \( N = \) number of particles per ml; \( d = \) diameter of the particles; 
\( C = \) velocity of sound; \( \omega = \) pulsatance and; 
\( \eta = \) Kinematic viscosity.

Urick /6/ cast Lamb’s theory in a more convenient form to obtain the ultrasonic absorption due to a single sphere small in size compared to wavelength of round free to move in a viscous fluid. According to Lamb.

\[
\alpha = \frac{2\pi k^4 \rho_a^6}{a} \left[ \frac{2\pi k^4 d^6}{a} \right] \left( \sigma - 1 \right)^2 \frac{S}{s^2 + (\sigma + 2\tau)^2}
\]

(3)

Where \( a = \) radius of the sphere; \( k = 2\pi /\lambda \) wavelength number; \( \lambda = \) wave length; 
\( \rho_o = \) density of the fluid; \( \rho_1 = \) density of the particle; \( \sigma = \frac{\rho_1}{\rho_o} \); 
\( \beta = \left( \omega \rho_o /2 \eta \right)^{1/2} \); \( \eta = \) coefficient of viscosity of the fluid; 
\( S = 9/4 \rho a \left( 1 + 1/\rho a \right) \); \( \tau = (1 + 9/4 \beta a) \).

3 - MATERIALS AND METHODS

Human blood samples of volume 25 ml. were collected from Government Blood Bank, Hyderabad, India using Ethylenediamine Tetra-acetic acid (EDTA) as anti-coagulant at the rate of 10mg/10ml. Red blood cells were separated from plasma by centrifuging the blood at the rate of 1500 RPM for about 15 minutes. The cells were centrifuged three times in isotonic NaCl (0.9%) and diluted in plasma to determined ultrasonic velocity and absorption at different concentrations. Hemoglobin was prepared by adding an equal amount of distilled water to the already centrifuged red cells of 85% concentration.

A variable path interferometer operating at fixed frequency of 3 MHz with a least count of 0.001 mm of its micrometer was used to determine the velocity and absorption of ultrasound. The densities of solutions were found using hydrostatic bench.

The velocity \( (c) \) of ultrasound was calculated using the reaction \( C = \sqrt{\omega} \lambda \) where \( \omega \) = frequency of the ultrasound and \( \lambda \) = wave length. The coefficient of absorption \( (\alpha) \) was determined by considering the expression \( I_2 = I_1 e^{-2\alpha \lambda}, \) where \( I_1 = \) entering current intensity, \( I_2 = \) issuing current intensity and \( \lambda \) = distance between the transducer and the reflector over which the acoustic wave travels. Knowing velocity \( (c) \) of ultrasonic wave and density \( (\rho) \) of the solution, the acoustic impedance \( (Z) \) was computed as \( Z = \rho C. \)

4 - RESULTS AND DISCUSSION

Table-1 gives the experimental values of absorption along with the theoretical values calculated, using different theories. The values obtained by Epstein's and Lamb's theories are nearly equal to each other and are approximately ten times less than the experimental results. But values calculated by Sewell's theory are as much as 200 to 300 times larger than the experimental values.

The experimental absorption increases with concentration as predicted by all the theories.
Table 1: Comparison of experimental and theoretical values of absorption of ultrasound in human RBC suspended in plasma.

Frequency: 3 MHz; Temperature: 30°C

<table>
<thead>
<tr>
<th>Fluid</th>
<th>Volume concentration of RBC %</th>
<th>Cell concentration per ml x 10^9</th>
<th>Experimental absorption x 10^{-2} cm^{-1}</th>
<th>Theoretical absorption ((\alpha)) cm^{-1}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Epstein x 10^{-2}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lamb x 10^{-2}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sewell x 10^{-2}</td>
</tr>
<tr>
<td>Plasma</td>
<td>0 (Plasma)</td>
<td>1.50</td>
<td>3.286</td>
<td>...</td>
</tr>
<tr>
<td></td>
<td>13.4</td>
<td>2.71</td>
<td>4.518</td>
<td>0.348</td>
</tr>
<tr>
<td></td>
<td>22.9</td>
<td>3.38</td>
<td>5.629</td>
<td>0.576</td>
</tr>
<tr>
<td></td>
<td>30.0</td>
<td>4.00</td>
<td>6.143</td>
<td>0.748</td>
</tr>
<tr>
<td></td>
<td>35.5</td>
<td>5.60</td>
<td>6.608</td>
<td>0.886</td>
</tr>
<tr>
<td>45.0 (Blood)</td>
<td></td>
<td></td>
<td>7.641</td>
<td>1.117</td>
</tr>
</tbody>
</table>

\(\text{plasma} = 0.018 \text{ Poise}; \quad \rho = 1.027 \text{ gm/ml}; \quad \rho = 1.0924 \text{ gm/ml}; \quad \text{Radius} = 2.75 \text{ m}\)

Table 2: Acoustic parameters of human blood and its components

Frequency: 3 MHz; Temperature: 30°C

<table>
<thead>
<tr>
<th>Sample</th>
<th>Density ((\rho)) (gm/ml)</th>
<th>Velocity ((c)) x 10^5 cm/sec</th>
<th>Acoustic impedance ((z)) x 10 gm. cm^{-2} sec^{-1}</th>
<th>Absorption coefficient ((\alpha)) cm^{-1}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemoglobin</td>
<td>1.018</td>
<td>1.499</td>
<td>1.526</td>
<td>2.04</td>
</tr>
<tr>
<td>Plasma</td>
<td>1.027</td>
<td>1.518</td>
<td>1.559</td>
<td>3.286</td>
</tr>
<tr>
<td>Blood</td>
<td>1.052</td>
<td>1.556</td>
<td>1.637</td>
<td>7.641</td>
</tr>
<tr>
<td>RBC (85%)</td>
<td>1.077</td>
<td>1.586</td>
<td>1.708</td>
<td>12.300</td>
</tr>
</tbody>
</table>
Table 2 presents the data of acoustic parameters such as velocity, absorption coefficient and acoustic impedance of hemoglobin, plasma, and erythrocytes at room temperature. It is evident from the data that the acoustic impedance is more in erythrocytes; less in plasma and hemoglobin; compared to whole blood. However, plasma and hemoglobin bear approximately the same value of acoustic impedance. Considerable variance in absorption coefficient is also found in blood components.

It is reported in literature /1/ that the absorption of ultrasound in blood is caused primarily by protein content of blood and also due to the very presence of intact cells in suspension. But the present study suggests that the absorption is due to the viscous interaction between the fluid and the suspended cells. The viscous interaction is due to the larger density of the cells when they fail to execute oscillatory motions set up by the sound waves.

If \( X \) and \( Y \) be the volume fractions of plasma and RBC in blood then if absorption is a linear combination of protein absorption then one should have \( X\alpha_p + Y\alpha_{RBC} = \alpha_B \) where \( \alpha_p \) and \( \alpha_{RBC} \) are coefficient of absorption in plasma, RBC, and blood respectively.

But in the case of experimental absorption it is found that the absorption in blood (\( \alpha_B \)) is always greater than the sum of the absorption in plasma and in RBC i.e., \( (X\alpha_p + Y\alpha_{RBC}) \). For example in human blood (45% plasma and 55% RBC).

\[ \alpha_B = 7.641 \text{ and } X\alpha_p + Y\alpha_{RBC} = 7.230. \]

The excess absorption in blood according to Carstensen et al /1/ is attributed to a mechanism which is unlikely to exist in packed cells or in pure plasma but comes into play when the cells are suspended in plasma. This mechanism, they concluded, produces additional absorption other than the protein absorption. However, when an acoustic wave passes through a blood sample it encounters three different media namely plasma, cell membranes, and hemoglobin. These media have their own acoustic impedance values (Table 2). The acoustic power loss is dependant upon mismatching of the acoustic impedance of these three media. In view of this, the authors are of the opinion that the acoustic impedance values of plasma, cell membrane, and hemoglobin must also be taken into consideration while interpreting the absorption in blood and its constituents. This aspect has not received due attention in the past while interpreting the acoustic power loss in biological suspensions. This also has its own contribution the magnitude of which is dependant upon mismatching of the acoustic impedance.

REFERENCES