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Researching on the solution variation of double-concave disc-shaped vesicle of alcoholism blood cells

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ABSTRACT

The physical model of the interaction between ethanol and blood cells has been established by the biomembrane surface elasticity theory. Under the universal equation of double-concave disc-shaped bubble, the analytical solution has been deduced. It confirmed theoretically that ethanol could lead to the larger volume of red blood cells. The fluorescence experiment result verified this conclusion. When ethanol goes into the red blood cells, the changing osmotic pressure causes cells' vertices moving to the center, and double-concave disc surface will be the spherical one. It results in the larger volume of the red blood cell and smaller surface area, and thus causes the ratio of the surface area to volume decrease significantly. So the resistance tensile capacity of red blood cells reduced. Alcoholism can cause blood viscosity and the clinical test result coincide this conclusion. This study can give certain reference for the research of mutual function mechanism between ethanol and blood cells.

1. Introduction

Ethanol did harm the multiple organs in the body. Whether you drank a large number of alcohol once a time or long-term drinking, ethanol can cause extensive damage to the body [1]. Although people knew the damage of the neurotoxicity by the drunkenness of the drunkard that clarifies the nature of the neurotoxin effect induced by ethanol. Ethanol damaged liver has been conscious of the medical, but the damage mechanism has not been resolved. Alcohol disease was also endangering the health of alcoholics. The experiments in vitro show that ethanol affected the survival of a variety of cells, but the damage mechanism has not been completely revealed.

Mature erythrocyte showing disc-shaped as double-concave or single-concave [2], a larger ratio of surface area to volume was beneficial to deformation, gas exchange and portability of the cell. Erythrocyte membrane was composed by a large number of phospholipids arranged in double-molecular layer, in the middle of the layer that embeds in unesterified cholesterol and glycolipid molecules. The "head" of the phospholipids (carboxyl-terminal) faced the cytoplasm, another side faced the plasma. Long tail of the phospholipids with acyl (N-terminal) wove into a mesh, which became a core of membrane, which was lipophilic but hydrophobic. Under normal temperature, the hydrophobic core existed in a liquid crystal state. This was beneficial to the flexibility and deformation of erythrocyte, which was a very important physiological function of erythrocyte, the inner surface layer of erythrocyte membrane had a scaffold protein and formed a network-like structure, that was very important to regulate the deformation properties of erythrocyte. The special configuration of membrane proteins gave erythrocyte a strong deformation, so that it can through the capillaries and spleen much smaller in diameter than erythrocyte, and did not suffered by the mechanical damage (Fig. 1).

In recent years, research on the structural characteristics of ethanol molecules in the liquid environment were studied, and concluded that the ethanol molecules could form clusters [3–5]. In this paper fluorescence spectroscopy and fluorescence mechanism were used to discuss the erythrocyte membrane liquidity, permeability and the failure of the membrane function act by ethanol, and revealed the damage mechanism from the nature.

2. The physical model of interaction between ethanol and erythrocyte

2.1. The universal equation of double-concave disc-shaped bubble

In 1973, according to the theory that erythrocyte may be analogous to the lamellar phase liquid crystal, Professor Helfrich presented an equation to describe the free energy density of liquid crystal bubble, that is [6]:

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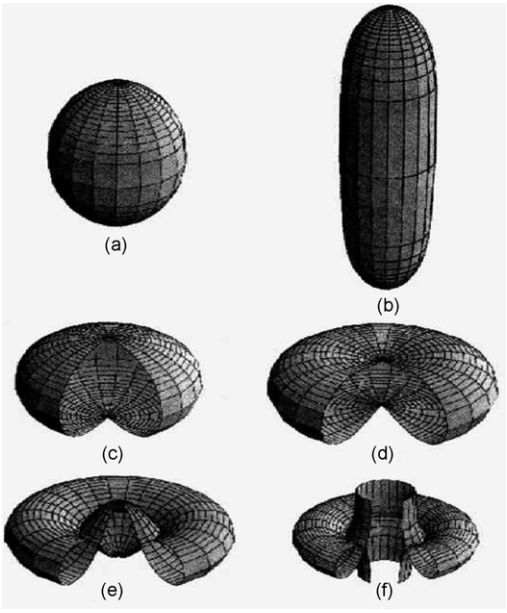

Fig. 1. Non-trivial solution graphs of vesicle.

$$\frac{1}{\rho}\frac{d}{d\rho}\left\{\rho\ \cos\varphi\left[\cos^2\varphi\frac{d^2\varphi}{d\rho^2}-\frac{\sin 2\varphi}{4}\left(\frac{d\varphi}{d\rho}\right)^2+\frac{\cos^2\varphi}{\rho}\frac{d\varphi}{d\rho}-\frac{\sin 2\varphi}{2\rho^2}\right.\right.$$
$$\left.\left.-\frac{\rho\Delta p}{2k_c\cos\varphi}-\frac{\lambda\sin\varphi}{k_c\cos\varphi}-\frac{\sin\varphi}{2\cos\varphi}\left(\frac{\sin\varphi}{\rho}-c_0\right)\right]\right\}=0 \quad (1)$$

When $\rho\neq 0$ and $\cos\varphi\neq 0$:

$$\cos^2\varphi\frac{d^2\varphi}{d\rho^2}-\frac{\sin 2\varphi}{4}\left(\frac{d\varphi}{d\rho}\right)^2+\frac{\cos^2\varphi}{\rho}\frac{d\varphi}{d\rho}-\frac{\sin 2\varphi}{2\rho^2}$$
$$-\frac{\lambda\sin\varphi}{k_c\cos\varphi}-\frac{\sin\varphi}{2\cos\varphi}\left(\frac{\sin\varphi}{\rho}-c_0\right)-\frac{\rho}{2k_c\cos\varphi}\Delta\tilde{p}=0 \quad (2)$$

Which

$$\Delta\tilde{p}=\Delta p+\frac{2k_cK}{\rho^2}$$

We cannot obtain the exact mathematical solution for this higher-order differential equation, but people still get some interesting special solution, such as Ford general solution [7], Red blood cell solution [8], Cylinder-type general solution [9–11], etc. Solution in red blood cells had a very important significance on the biological function of red blood cells.

2.2. The analytical solution of the equation with double-concave disc-shaped bubble

Natio, Okuda, and Ou-Yang [12,13] found a solution that could describe double-concave disc-shaped bubble, its specific form was as follows:

$$\varphi=\arcsin\left[\rho(a\ln\rho+b)\right]=\arcsin\left[a\rho\ln\frac{\rho}{\rho_0}\right]$$
$$\rho_0=\exp\left(\frac{-b}{a}\right) \quad (3)$$

The dimensionless of a was reciprocal of the length, which was decided by the symbol of the equation and the bubble.

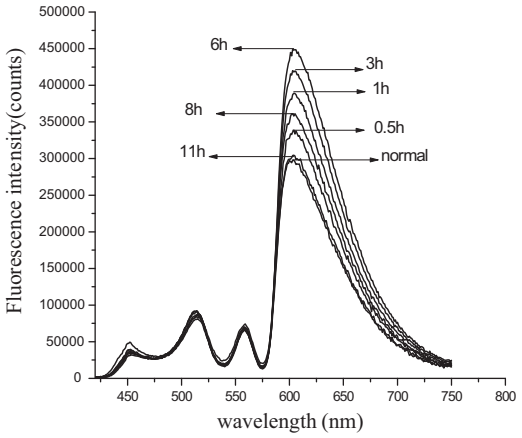

Fig. 2. The fluorescence spectra of normal and alcoholism whole blood.

Derivative (2) and substitute it into (1) that was:

$$\sin\varphi=\frac{\rho}{\rho_0}+c_0\rho\ln\rho=c_0\ln\left(\frac{\rho}{\rho_0}\right)$$
$$\rho_B=\exp\left(\frac{-1}{c_0\rho}\right) \quad (4)$$

When c_0 was within the area, and at the same time ρ was in $(0,\infty)$ which could take different values, within the framework, Eq. (4) would give different graphs, which were different shapes of the bubble. Identified the shape and the membrane surface of the bubble with c_0 and A_0.

Usually, in order to make out the identification, for each kind of shape was given a scalar invariant $c_s=c_0\rho_s$, because the value of $\sin\varphi$ is limited between −1 and +1. Therefore, there were a variety of graphics in different areas of ρ.

For (4), draw the following graph:

(a) Class prolate $c_0\rho_s=-0.72$, $\sin\varphi=\rho-0.6\rho\ln\rho$, $\rho\in[0,1]$
(b) Covered cylinder $c_0\rho_s=-2.06$, $\sin\varphi=\rho-0.99\rho\ln\rho$, $\rho\in[0,1]$
(c) Class flat ellipsoid $c_0\rho_s=0.46$, $\sin\varphi=\rho+0.5\rho\ln\rho$, $\rho\in[0,1]$
(d) Double-concave disc $c_0\rho_s=1.51$, $\sin\varphi=\rho+1.8\rho\ln\rho$, $\rho\in[0,1]$
(e) Self-inverted pairs of concave disc $c_0\rho_s=2.72$, $\sin\varphi=\rho-3.2\rho\ln\rho$, $\rho\in[0,1]$
(f) Self-node-shaped cylinder $c_0\rho_s=3.28$, $\sin\varphi=\rho+3.60\rho\ln\rho$, $\rho\in[0.301,1]$

3. The experimental results of interaction between ethanol and erythrocyte

3.1. The fluorescence spectrum of normal blood and alcoholism blood

Alcoholism blood solution was excited by the laser with 407 nm at different time (hours, figure that using h) and recorded the fluorescence spectra, shown in Fig. 2, in which the Normal indicated the normal fluorescence spectrum.

As we could see from the figure, each spectrum had three peaks, which were located at 510 nm, 556 nm, 605 nm. Through the literature, we obtained the conclusion that the peak located at 556 nm was not the characteristic fluorescence emitted by fluorophores, but the illusion caused by absorption. And the peaks in 510 nm, 556 nm was too close to the incentive light, encouraging greater impact on light. So in the experiment we only discussed the changes in the 605 nm. The peak located at 605 nm was mainly excited by