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The Functions of Electrical Activity of the Heart

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Abstract Many reports in the literature have separately discussed the operation and analysis of cell membrane potential and of electrical activity of the heart. More studies have provided detailed, in-depth explanations on the former, while fewer have been written on the latter. There has even been no generally accepted name for "electrical activity of the heart," so we refer to it here as Cardio-*emf*. As we all know, the liver is located beside the heart, and both organs are connected through blood that has high electrical conductivity. From the point of view of an electrical circuit, the membrane potential of the liver cells and the Cardio-*emf* are electrically connected, or it can be said that both are in the same circuit. Therefore, to say there is no mutual effect between them would completely overturn the theories on circuits and electronics. This manuscript demonstrated and proved that the Cardiac electrical activity (cardio-*emf*) could influence directly the movement of the liver cells in synchronized manner so absorption and secretion from the liver cells would be in phase. By extrapolation of such an analysis, novel functions of the cardio-*emf* has been discovered.

Keywords Cardio-*emf*, Coulomb's Law, membrane-*emf*, Capacitor, ECF&ICF

Knowledge on the cardiac electrical activity could be dated back more than 160 years ago. Form the work of Dr. Augustus Waller, he proposed the ways to monitor the electricity of the heart and he was widely recognized as the father of electrocardiography(ECG),which is the milestone in advancing the diagnosis of the heart diseases.

In 1995, Dr. Bill Zheng and Dr. W. Ma have suggested a hypothesis about the cardiac electrical activity may control the liver cells to absorb and secrete through their membrane voltage. In 2014, the hypothesis, which may lead to research development that save thousands of lives, have been proven by Dr. Zheng and Dr. Ma with assistance from an Experienced Electronic Engineer.

Full text of the manuscript will be presented as follow.

Coulomb's law is the foundation for electricity, and therefore, we try to employ it to investigate the electrical mechanisms of the electrical activity of the heart [2].

1. The Cardio-*emf* or the Electrical Activity of the Heart

The main function of Cardio-*emf* is to make the heart muscles contract so as to keep blood flowing. Aside from this, could there be other unidentified functions?

To be concrete, we use the liver as a model organ to explain how Cardio-*emf* may impact liver function, and we assume that the liver cannot function without Cardio-*emf,* so the factors should be considered as follows.

A) To reduce the power lost on transmission, the path of the current must be as short as possible, so **the model organ will be close to the heart**.

B) Aside from having a short distance, a material with high electrical conductivity, or with low resistance, is also very important to decrease the power loss. As is generally known, blood is the substance in the human body with least resistance, so the model organ must be the **organ with the highest amount of blood influx**.

C) Since the supposed model organ must rely on Cardio-*emf,* therefore **the model organ will cease activity when heart failure occurs**.

D) Cardio-*emf* is available 24 hours a day, so **the model organ must work 24 hours a day**.

To meet the above four conditions, it is necessary to use the liver as the model organ.

Before exploring how Cardio-*emf* controls the operation of liver cells, **it is necessary to study the electrical characteristic of the cell membranes.**

2. Cell Membrane and Capacitor Analysis

First of all, we should discuss the structure of the cell membrane from the perspective of an electrical device. As shown in the sectional view in Figure 1, the cell membrane has a structure that is almost identical to that of a capacitor (on the right), and the only difference is that the two electrodes of the "cell membrane capacitor" are the liquid extracellular fluid (ECF) and the intracellular fluid (ICF). As

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for the dielectric, the lipid bilayer is made of an organic solid, which is always associated with ultra high electrical resistance (for lipid bilayer = 100GΩ). Therefore, the capacitance can be expressed using the following formula.

Table 1. The comparison of the calculations of biological membrane capacitance and the electrical capacitor component capacitance

Capacitance		C=εA/d
	Membrane Cross-section	Capacitor Cross-section
C	Cell membrane Capacitance	Capacitor Capacitance
ε	Permittivity of lipid bilayer	Dielectric permittivity
A	Area of cell membrane surface	Area of an electrode
d	Thickness of lipid bilayer	Distance of electrodes

As shown in the above analysis and in the comparison, we can determine that the lipid bilayer has combined with the ECF and the ICF to form a good capacitor, and scientists have proven that the particular ion channel of the lipid bilayer can deliver Na+ in order to charge the cell capacitor. Therefore, from the point of view of an electrical circuit, the membrane potential is a voltage source, so it should be qualified as an electromotive force (*emf*) that can be thought to be a tiny battery. At the same time, scientists have determined that the *emf* of the membrane is 70 mV.

Also in Figure 1, the electric field "↑ E" inside the lipid bilayer/dielectric is polarized by an applied voltage. With respect to the capacitor component, it has only one function, which is to increase the capacitance. However, as for the lipid bilayer, it has another function, to prevent K+ and Na+ from diffusing across the bilayer.

3. Think Positive – Charge

Theory, positive charge = proton.

Every positive charge inside human body may be **regarded to be an atom, a molecule, etc. that has lost a free electron**. An electron has a negative charge, and its diameter is only 1/100,000 that of a hydrogen atom. Given their extremely small sizes, the impact of the mass of the electrons are entirely negligible since they will never lead to motion of the materials.

Therefore, we can draw the conclusion that:

• A positive charge = atom (-e) = molecule (-e) = substance

As a result, positive charges are the main factor to consider that cause physical movement, deformations, and so on.

4. Analysis of Electric Current Flows through a Conductor

Electric current = the flow of a positive charge.

Electron flow = opposite to the electric current's direction, which is the real flow of the electrons. Therefore, inside a normal circuit, only electrons actually move.

Figure 2: Current *I*, flows through a conductor R from top to bottom, and the potential slowly decreases, which observed as Va＞Vb＞Vc＞Vd. This is one of the main phenomena explained through Kirchhoff's voltage law.[1]

Figure 3: Distribution of a positive charge Q "observed" inside the conductor R. It also presents a gradual top-down drop-off (because Q = CV).

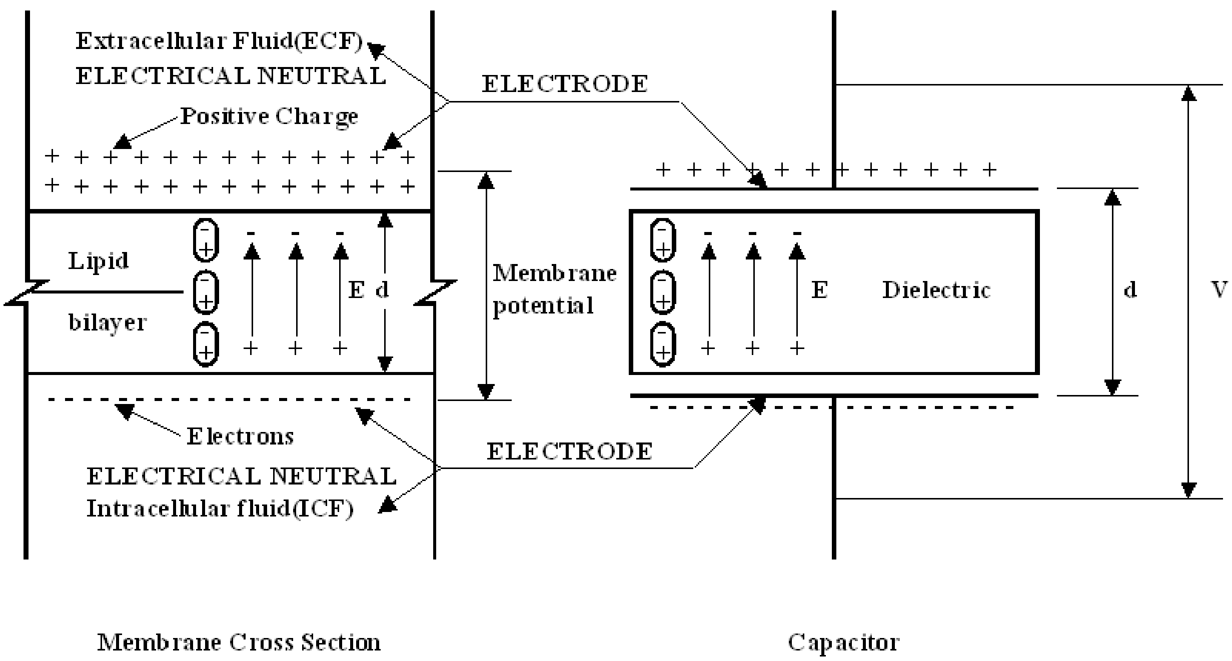

Figure 1. The comparison between the cross-section of the biological membrane and that of the capacitor component. Indicating that the structures of the biological membrane vs electrical capacitor are very similar

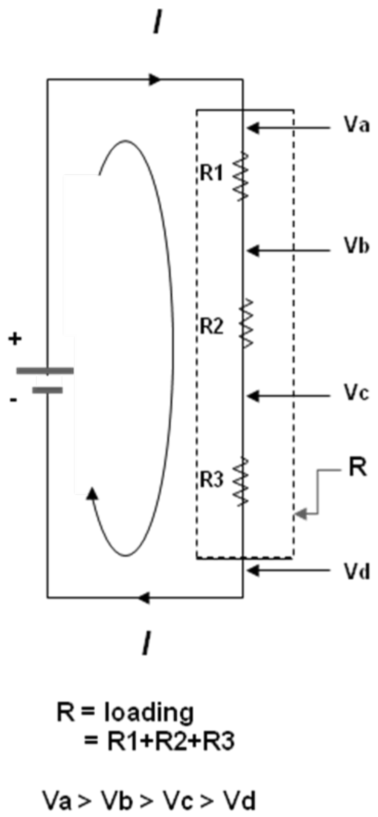

Figure 2. Voltage drop inside the conductor R

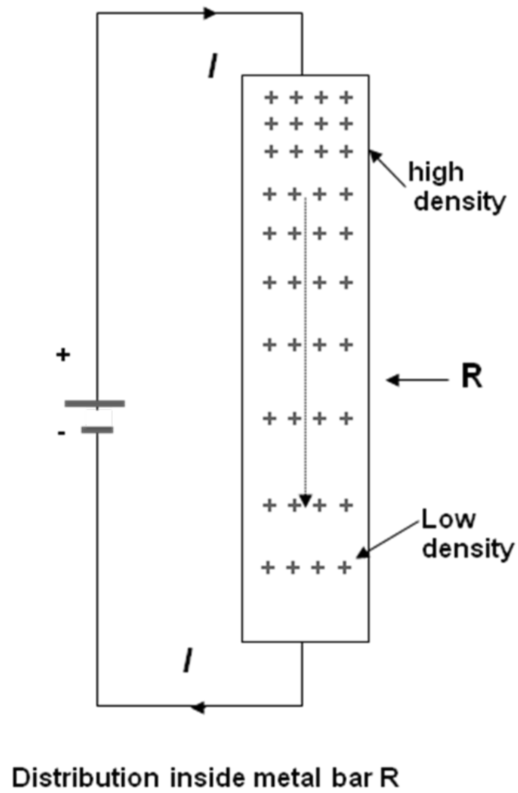

Figure 3. Distribution of positive charges inside conductor R

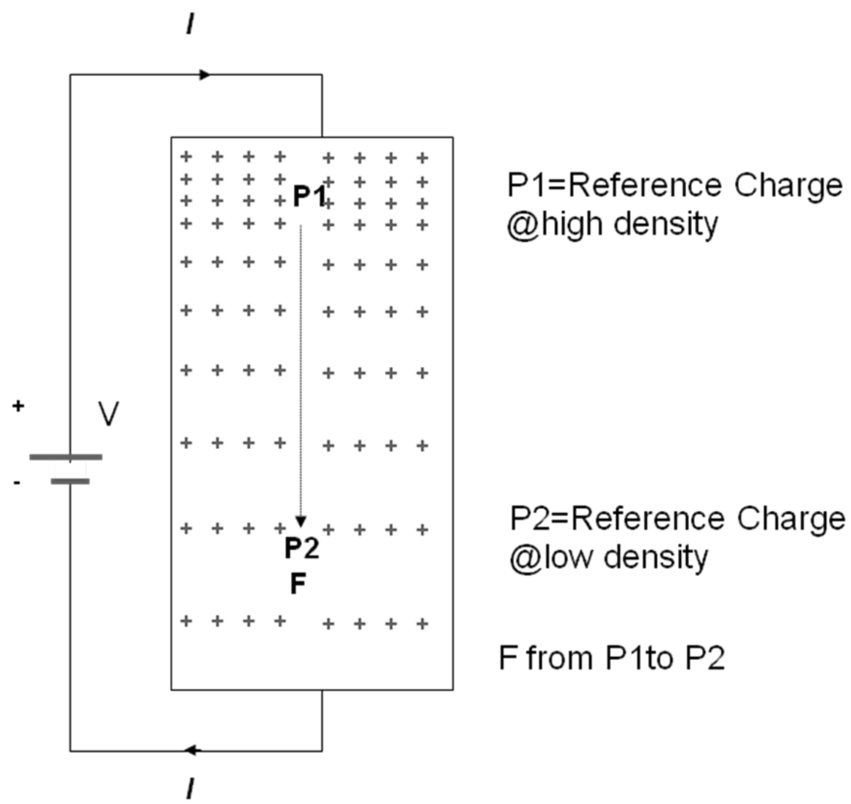

Figure 4. Set a positive charge as a reference between the high low densities

Figure 4: Assuming that we set a positive charge as a reference between the high and low densities, shown as P1 and P2, respectively, according to Coulomb's law (F_c=k qq'/r^2), it is easy to see that the repulsive force of P1 is larger than that of P2. The more positive a charge (+) is, the greater the force that will be generated. Therefore, when **R is liquid**, the positive charge (substance) will flow from a high pressure to a low pressure in a manner similar to how atmospheric pressure acts in a way where air particles move from a high pressure to a low pressure. Just remember that the electric current flows in the same direction as the material, which can also be said to be that the **electric current drives material flow.**

When **R is of a soft tissue**, the tissue will be pressed from the high density region to a low density region, or it can be expressed as a force to push from P1 to P2.

5. How does Cardio-*emf* Make Liver Cells Absorb and Secrete

After having understood the electrical principles of the system, it is very easy for us to explain how hepatocytes operate. For ease of explanation, the present function can be simplified according to the following diagram.

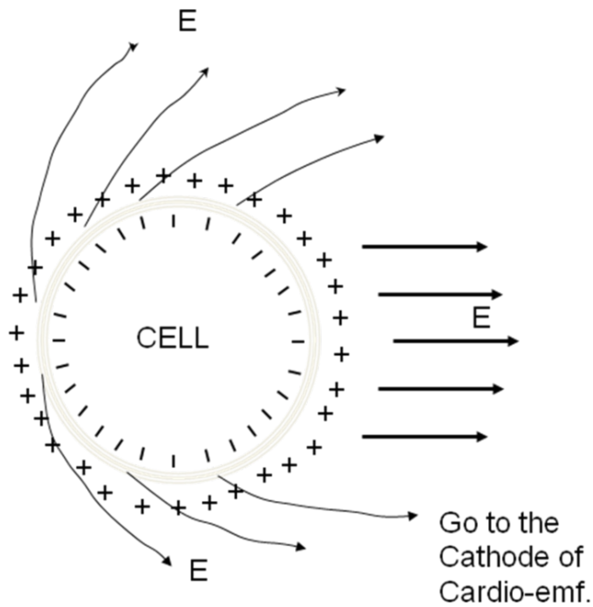

Figure 5. Demonstrated a single liver cell generates a electric field due to the Coulomb force from the cathode of cardio-*emf*

Figure 5: Since the **outer** positive charges on the cell membrane are free charges, they can generate an electric field due to the Coulomb force, as shown in the diagram. (The lines are drawn in such direction, and we call these the electric force or Coulomb force lines.) Where will the electric force lines, just like arrows, extend to? Of course the destination is the cathode of the Cardio-*emf,* which is created by the activity of the cardiomyocytes. At the moment of a pulse, the cathode is the place that contains the most free electrons, and it is nearest to the liver in human body and is connected with blood. So all of the electric force lines emitted from the free positive charges on the hepatocytes **have no other choice** but to be oriented toward the cathode as per Coulomb's Law. Per our roughly calculations (assume: ε of blood = ε of ECF & ICF), the Coulomb attractive force for the free positive charges on the outer membrane **toward the cathode is 1.6×10^4 times that toward the negative charges of the inner membrane.** If the estimate for cathode is of 1.8×10^{17}e or 0.03 Coulomb, then r = 0.1m. If the estimate for membrane free charges is of 1×10^6e or1.6×10^{-13} Coulomb, then r = 30 μm. After the electric force lines connect (electrically turn on), electrons will rush to all hepatocytes with an electricity or electric field speed of 0.96 c. (For reference, this is the speed of electricity in a bare copper wire, and c = the speed of light). It makes no sense to discuss which electron arrives faster because the distance is too short and the speed is too fast. So we can suppose that all electrons have arrived at the same time, and we just present another drawing of the cell to explain the situation.

Figure 6: When the electron flow arrives at the membrane, it will neutralize part of the positive charges immediately, in which case a current flows in the direction opposite to the electron flow. In accordance with the above discussion, the current will make materials move, so the ECF close to the surface of the bilayer will flow along with the current, and thus the hydraulic pressure around the surface of the outer bilayer will decrease rapidly. At this time, the hydraulic pressure of the ICF inside the cell will push out, widening the volume of the cell, so the cell needs to **absorb** substances from the outside, which is nearly the same as that in the cells. Supposing that N electrons participated in this discharge, then N electrons will be released from the inner membrane. (The number of "positive" and "negative" charges on both electrodes of the capacitor must be equal to each other.) For the same reason, electrons released from the inner membrane **have no other choice** but to exit the cell, moving toward the anode of the Cardio-*emf,* and therefore a perfect closed circuit is completed, as per Kirchhoff's current law [1]. Note that when electrons flow toward the ECF, the current flows from the outside of cell, or it can be said that positive ions (positive charges) flow into the cell. Given that a positive charge can only exist as a physical substance, its speed is very slow, and its motion cannot be compared to that of electricity.

Figure 7: Cardio-*emf* circuit that drives the discharge of 2.5 billion liver cells.

ξ = Cardio-*emf.*
R_E = Contact resistance of the anode to the liver organ.
R_{ECF} = Resistance of the ECF inside the liver organ.
R_b = Resistance of the blood, very small and can be negligible in this circuit.

For ease of discussion, we assume that R_b = 0, (because $R_E \gg R_b$). Therefore, the equivalent circuit is as that shown in the figure. As can be seen in the circuit, **the 2.5 billion liver cells will very easily discharge during**

Cardio-*emf* pulsing. (The voltage of Cardio-*emf* >> 70mV.) Upon discharging, the liver cells begin to expand.

Note: For the cells outside the circuit, the membrane-*emf* can be self-discharging through ECF(R_{ECF}).

Figure 8: After Cardio-*emf* pulsing, the cell membrane begins to replenish the lost charges (recharged by Na+) in order to cope with the next coming of the Cardio-*emf*. At the same time, the intermediate filament between the nucleus and the membrane will be responsible for driving the membrane to its former state. This is equivalent to the secretion of the cells.

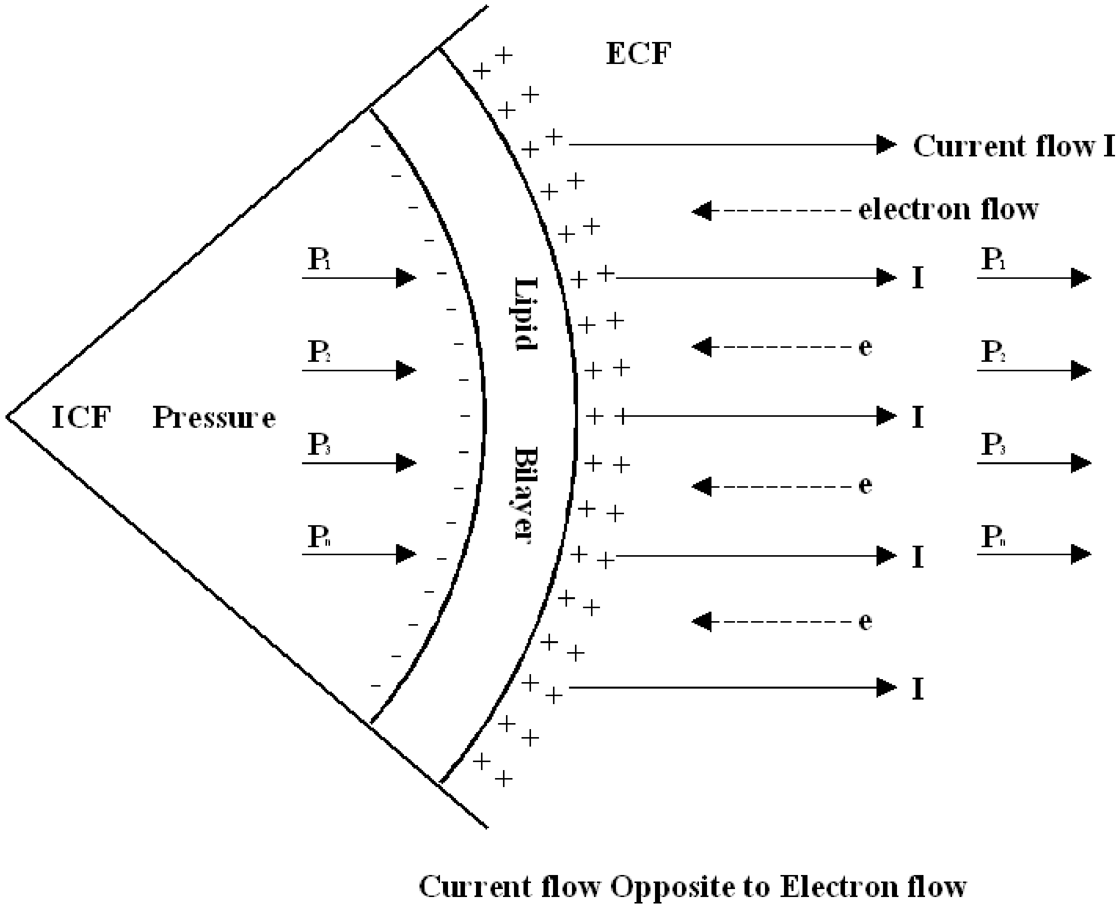

Figure 6. Current Flow cause the cell expand

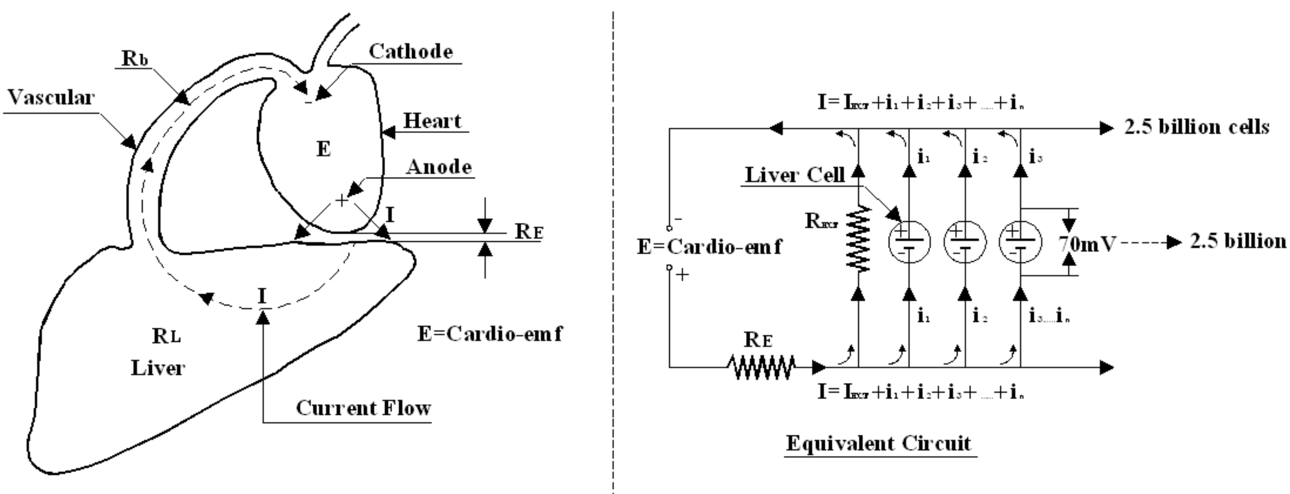

Figure 7. Electrical equivalent circuit of the cardio-emf and the liver organ

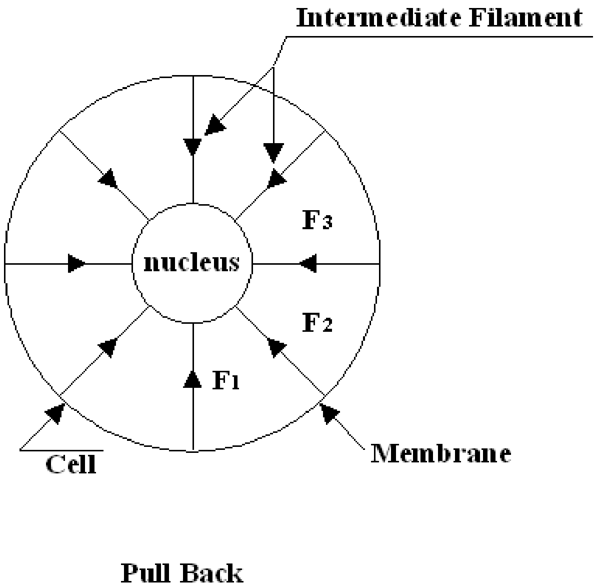

Figure 8. The connection between the membrane and the nucleus is responsible to pull back the cellular volume back to normal, as in the process of secretion

This explains why the 2.5 billion hepatocytes absorb or secrete substances at the same time, impeccably. That is, they are driven by Cardio-*emf*.

6. Conclusions

1) As is commonly known, the main function of Cardio-*emf* is to make the heart contract so as to keep blood flowing. Besides this, the second function is to drive the liver cells, working in phase, in order to increase the efficiency of the organ. Otherwise, many cells may only absorb secreted materials from their neighbors, if a pair of cells absorb and secrete in opposite phases (kiss effects).

2) As far as we know, the main function of the cell membrane-*emf* is to make the cell expand, so as to absorb and to secrete substances.

3) In the past thirty years, all clinical trials on artificial heart are not very successful, the cause of failure might be due to lack of the Cardio-*emf* pulsing system that should be built into the artificial heart. Therefore, the traditional artificial heart could not be fully functioned as a real heart. In contrast, the features of artificial joint design was designed to be very close to the real joint hence the successful rate of artificial joint transplant or replacement is substantially higher. It is estimated that at least 1500 people died in the United States every year because of the shortage of the suitable and transplantable heart. **Redesign of the artificial heart which is associated with the built-in system of Cardio-*emf* could potentially result in saving thousands of lives every year.**

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