The Physical Origin of Waves in Magnetocardiography Technique and their Applications in Imaging

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Abstract

In this research, we propose a theoretical model which helps us to consider evolutions of some special heart cells by using superconducting quantum interface devices (SQUID) in a magnetocardiography (MCG) technique. In this model, each cell has its own special electrical structure including ions and charges. These charges move within or outside the cell and emit some magnetic fields. Also, some charges have spins which emit spinning magnetic fields. Summing over these biofields produces the real biofield of a cell. All cellular magnetic fields are summed and enter into the sensor (SQUID) and form the observed pulse on the scope. On the other hand, each biofield induces a current on the superconductor of detector. To consider evolutions of a special cell, one can produce some currents, equal and in opposite directions of currents which are induced by other cells. These currents cancel effects of other cells and only the current and magnetic field of a desired cell is remained. Thus, one can analyze the behavior of one special cell. For example, if a cell converts to a tumor one, its radiated charges and magnetic fields are changed. These changes could be detected by SQUID and tumors could be diagnosed fast. 886

Key Words: Magnetocardiography, Superconducting Quantum Interface Devices, Biofield, Current, Cells, Cancer.

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Introduction

Recently, by using physical concepts about electromagnetic waves, different medical devices have been built and several medical techniques have been proposed. One of main techniques which may be helpful in detecting and curing heart disease is the magnetocardiography (MCG). In this technique, by using superconducting quantum interface devices (SQUID) and also other sensitive detectors, changes of magnetic fields around the heart cells are measured [1-3]. These changes could be some signatures of heart diseases or cellular destructions. Up to date, many investigators are trying to design some cheapest methods which work in room temperature and measure the amount of heart magnetic field. For example, in one research, authors have introduced a SQUID system design for practical magnetocardiography working in unshielded environment by embedding the whole readout electronics in the cryostat to improve both the stability and the electromagnetic compatibility [4]. In other research, magnetocardiography (MCG) and magnetoencephalography (MEG) signals were detected at room temperature using tunnel magneto-resistance (TMR) sensors. TMR sensors developed with low-noise amplifier circuits detected the MCG R wave without averaging, and the QRS complex was clearly observed with averaging at a high signal-to-noise ratio [5].

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Another group have developed a highly sensitive miniature optically pumped magnetometer based on cesium atomic vapor kept in a paraffin-coated glass container. The magnetometer was optimized for detection of biological signals and had high temporal and spatial resolution [6]. In another paper, a comparison between superconducting quantum interference device (SQUID) and optically pumped magnetometers (OPM) has been done. It was found that the OPM-based system was portable, improved patient comfort, and performed as well as the SQUID-based system at a small fraction of the cost [7]. Another investigators have built critical part of the magnetic sensor that could sense weak magnetic field of heart [8]. In another article, a method of magnetocardiography (MCG) measurement by using an over damped bi-stable model based stochastic resonance (SR) technique for advancing biomagnetic sensors was proposed [9]. Another study has focused on developing a fast and accurate automatic ischemic heart disease detection/localization methodology by using machine learning methods [10]. Another work has validated the feasibility of in-hospital unshielded MCG and tried to assess repeatability and reproducibility of quantitative VR parameters, and consider also possible gender- and age-related variability [11]. Another researchers have presented the use of a portable, unshielded magnetocardiograph (MCG) and identified key characteristics of MCG scans that could be used in future studies to identify parameters that are sensitive to cardiac pathology. To this aim, they have recruited 50 patients with confirmed myocardial infarction (MI) within the past 12 weeks and 46 volunteers with no history of cardiac disease [12]. In other research, by using machine learning model based on magnetocardiography parameters, coronary artery disease in patients with chest pain has been detected [13]. In other investigation, using the magnetocardiography, the forward Problem in a realistic three-dimensional Heart-Torso Model has been solved. The forward problem in magnetocardiography (MCG) is important for understanding the relationship between the electric activity of the heart and the body surface magnetic field (BSM), and providing insight into the clinical application of MCG [14]. Motivated by these researches, we propose a theoretical model which considers the origin of magnetic biofields in magnetocardiography. This study helps us to diagnose diseases by changing in amount of biofields.

The Model

A superconducting quantum interface device (SQUID) is built from a looped or coli with the genus of superconductor which two insulator junctions are attached to it. Any weak magnetic field could induce a current within the superconductor. According to the lenz law, this current is opposed by another current which moves in opposite direction and emits a magnetic field to cancel effect of induced magnetic field. This current produces two potentials in two sides of junctions. By measuring these potentials and currents, one can obtain the amount of magnetic field (See Figure 1).

This superconducting quantum interface device could detect any weak wave which is emitted by the heart. A heart is formed from different cells which each of them may emit a type of magnetic field. Amount of radiating biofields depend on ions which move within or around the cells, number of charges on the cellular membranes which oscillate and spinning particles which form bio-matters within the cells. Motions of charges or ions around or within the cells or cellular structures cause to the radiation of some biofields which could be taken by a superconductor. Also, some blood cells including the hemoglobin have more role in emitting magnetic fields. Because, hemoglobin molecules contain iron atoms which act like the antenna and receive or send electromagnetic waves. These biological antennas could interact with ions and charges around the cells and take their waves from them. Then, these molecules may send these absorbed waves out of the heart. In fact, maybe, hemoglobin molecules act like the transformer or transmitter or even a device for stringing the absorbed waves from heart cells. Because, the structure of hemoglobin molecules not only contain iron atoms which act like the electromagnetic antenna, but coils several times which strength the power of magnetic field. A sensor like the superconducting quantum interface devices (SQUID) could take all of these magnetic fields and present on the scope (See Figure 1). However, maybe, we only need to consider evolutions of one special cells. In these conditions, we should produce some currents which emit some magnetic fields in opposite directions of magnetic fields of other cells and cancel their effects. In these conditions, only magnetic field of one special cells remains and we can analyze its evolution (See Figure 2).

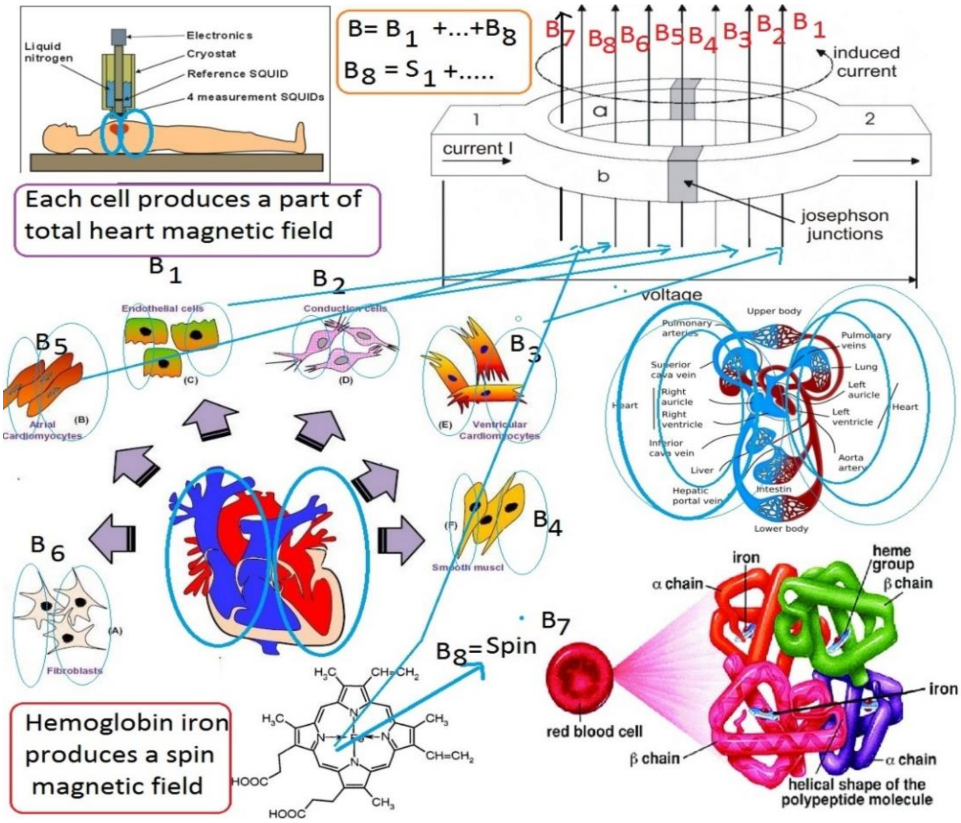

Figure 1. Heart cells emit different magnetic fields which are taken by a superconducting quantum interface device

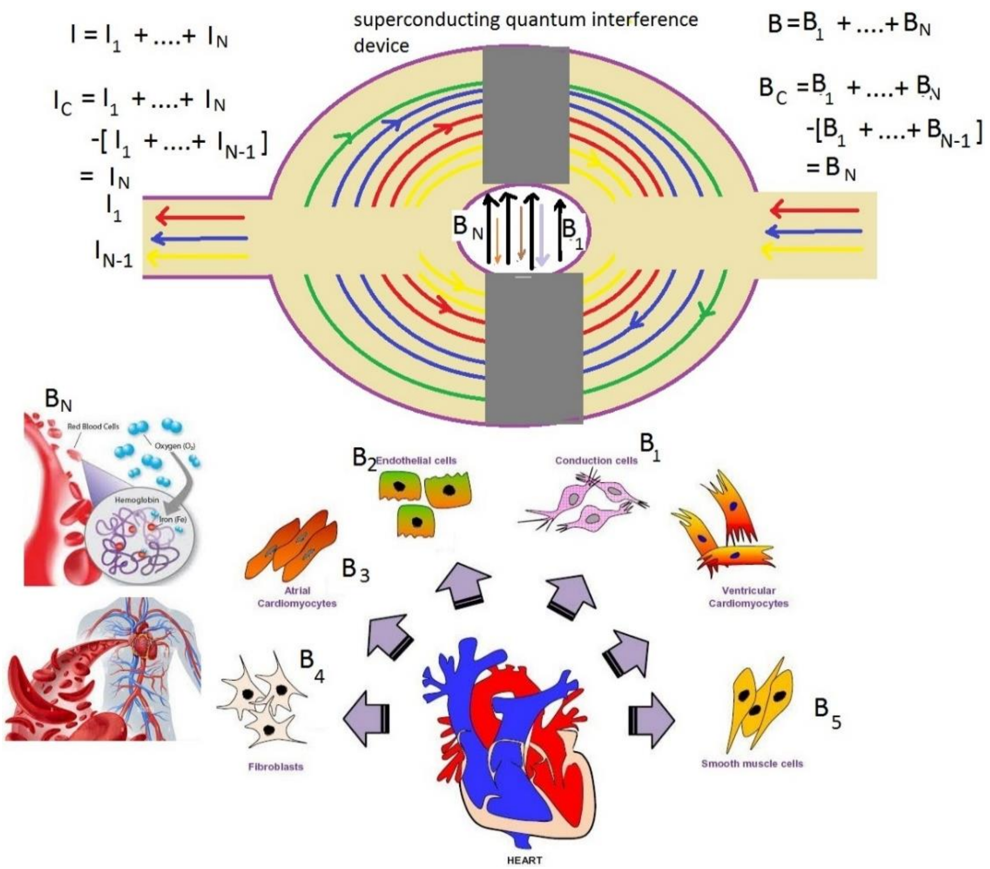

Figure 2. To analyze evolutions of a cell, some currents are produced to remove effects of magnetic fields of other cells

Mathematical Results

Previously, it has been shown that magnetic field of a current is obtained from below equation:

$$B = \frac{\mu_0 I}{2\pi r} \quad (1)$$

Where I is the electrical current and r is the separation distance from the current. For a charge q which is moving with the velocity V within the sphere with the radius R, the current is obtained from below relation:

$$Q = q\,\frac{4\pi R^3}{3}, I = \frac{d\,Q}{d\,t} = 4qVR^2 \quad (2)$$

A cell at point j is formed from many charged particles and in addition, there are many ions within or around the cell which each of them produces a magnetic field and a current:

$$B'_j = \sum_{i=1}^{N} \frac{\mu_0\, q_{ij} R_{ij}^2 V_{ij}}{2\pi r_{ij}} \quad (3)$$

In addition to the above magnetic field, each charged particles with spin ½ and 1 could emit a spinning field:

$$S_j = \sum_{i=1}^{M} S_{ij} \quad (4)$$

To obtain the relation between spin and magnetic field, first, we obtain the relation between magnetic field and angular momentum which has the same unit with spin:

$$L_{ij} = r_j \otimes P_i \quad (5)$$

Where P_i is the momentum and r_j is the separation distance. We can rewrite the magnetic momentum as below:

$$P_i = mV_i \quad (6)$$

Thus, angular momentum has the below relation with velocity:

$$L_{ij} = r_j \otimes mV_i \quad (7)$$

Using above definition, we can redefine the magnetic field as:

$$B"_j = \sum_{i=1}^{J} \frac{\mu_0\, q_{ij} L_{ij} R_{ij}^2}{2\pi [r_{ij}]^2 m_{ij}} \quad (8)$$

The same equation could be written for spin so:

$$B""_j = \sum_{i=1}^{M} \frac{\mu_0\, q_{ij} S_{ij} R_{ij}^2}{2\pi [r_{ij}]^2 m_{ij}} \quad (9)$$

Where S is the spin of a particle and m is its mass. Thus, total magnetic field of a cell could be obtained by summing over magnetic fields:

$$B_j = B'_j + B"_j + B""_j = \sum_{i=1}^{N} \frac{\mu_0\, q_{ij} V_{ij} R_{ij}^2}{2\pi r_{ij}} + \sum_{i=1}^{J} \frac{\mu_0\, q_{ij} L_{ij} R_{ij}^2}{2\pi [r_{ij}]^2 m_{ij}} + \sum_{i=1}^{M} \frac{\mu_0\, q_{ij} S_{ij} R_{ij}^2}{2\pi [r_{ij}]^2 m_{ij}} \quad (10)$$

Above equation shows that magnetic field of each cell depends on the number of charges, radius of cell, velocity of charges and their angular momentum and spins and also their separation distance from a detector. To calculate total magnetic field which enters into a detector, we should sum over all magnetic fields:

$$B = \sum_{j=1}^{x} \mathcal{N}_j B_j = \sum_{j=1}^{x} \mathcal{N}_j [B'_j + B"_j + B""_j] = \sum_{j=1}^{x} \mathcal{N}_j \left[\sum_{i=1}^{N} \frac{\mu_0\, q_{ij} V_{ij} R_{ij}^2}{2\pi r_{ij}} + \sum_{i=1}^{x} \frac{\mu_0\, q_{ij} L_{ij} R_{ij}^2}{2\pi [r_{ij}]^2 m_{ij}} + \sum_{i=1}^{M} \frac{\mu_0\, q_{ij} S_{ij} R_{ij}^2}{2\pi [r_{ij}]^2 m_{ij}}\right] \quad (11)$$

Where $\mathcal{N}_j$ is the number of one special cell and x is the number of heart and blood cells. Above magnetic field could be measured by detectors; however, if we want to consider evolutions of one special cell, we should remove effects of other magnetic fields. First, we should remember that according to the Lenz law, each of these magnetic fields could induce a current. For example, we can write:

$$I = -\sum_{j=1}^{x} \mathcal{N}_j I_j = -\sum_{j=1}^{x} \mathcal{N}_j [I'_j + I"_j + I""_j] \quad (12)$$

If one produces some currents which cancel effects of some of above currents, then, effects of most cells could be cancelled and only, effects of some special cells remain:

$$I = -\sum_{j=1}^{x-1} \mathcal{N}_j I_j + \sum_{j=1}^{x-1} \mathcal{N}_j I_j + I_x = I_x \to B_x \quad (13)$$

Above equation shows that by producing some currents on the superconductor of detector, we can cancel effects of non-desired cells and only, effects of desired cells remain. However, values of these produced currents should be equal to the values of induced currents by cellular magnetic fields and in opposite directions. This technique helps us to consider any minor change in behavior of any heart cell. For example, if a cell converts to a tumor one, its mechanism may change. If this cancerous cell obeys of the Warburg effect, its radiated ions and charges and mechanism of respiration is different respect to normal cells. These changes in ions and charges cause to a change in cellular magnetic fields. This change could be detected by SQUID and help in diagnosing and curing cancers in their initial stages. In table 1, we present mass, charge, spin and size of charges, ions, hemoglobin and some cells which may contribute in cardiac magnetic field. By increasing charges, reduction of mass and increasing spins, radiated magnetic field increases. Also, by increasing the separation distance between cells and superconducting quantum interface device, less amount of magnetic fields could enter into the detector. On the other hand, amount of radiated magnetic fields are so weak (less than nano tesla) which only superconductors could detect them (See Figure 3).

Table 1. Physical properties of charges, ions and some cells and molecules within or around a heart

	Mass	Charge	Spin	size
Sodium	22.98976928 u	+1	½,3/2	227 pm
Calcium	40.08 u	+2	1,0,1/2,3/2,7/2	231 pm
Potassium	39.98 u	+1	1/2	280
Hemoglobin (Iron, $Fe^{2+,3+}$)	120 g.l^{-1}	+2,+3	0,1,...	5 nm
Cardiomyocyte	-	More negative but depend on the ions	Depend on ions and charges	100-150 µm

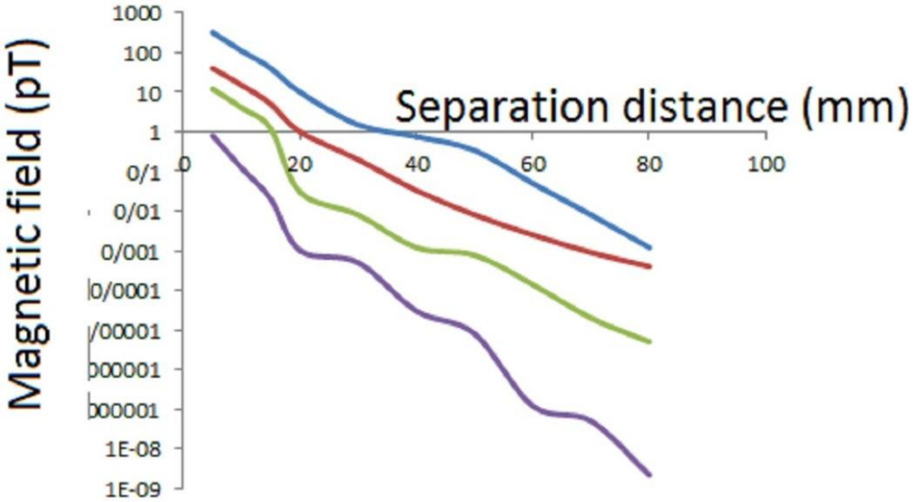

Figure 3. Predicted magnetic fields of four types of cells versus the separation distance from detectors. Blue color corresponds to iron ions within the hemoglobin and or freely moving along vessels. Red, green and purple colors may correspond to calcium, potassium and sodium respectively. Although, completion between these charges are closed and maybe, sometimes potassium or sodium become more effective

Conclusions

In a magnetography, the magnetic field which enters to a sensor could be divided into several biofields which each of them corresponds to an special cell. These magnetic fields are produced by motions of charges around the cells and their spins. Any change in radiated ions and charges from a cell cause to a significant change in its biofield. To consider these changes, effects of other biofields of other cells should be removed. To this aim, some currents are induced on the superconductor of sensor which emit magnetic fields in opposite directions of fields of other cells and remove their effects. This technique helps us to obtain the pure magnetic field and the current of a cells and consider its evolutions.

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