HYBRID MCG AND ECG APPROACH TO MEDICAL DIAGNOSIS IN HUMAN HEART

T. Doi, S. Hayano, and Y. Saito

College of Engineering, Hosei University,
Kajino, Koganei, Tokyo 184, JAPAN

Abstract—This paper proposes one of the novel approaches for human heart diagnosis. Synchronizing with blood pressure pulse, it is possible to measure the electrocardiogram as well as magnetocardiogram. Taking a gradient of electric potentials of the electrocardiogram yields an electric field vector arrow map. Similarly, taking a rotation of the magnetocardiogram yields an electric current density vector arrow map. Taking a correlation of both maps, it is possible to estimate the electric power density distribution in the human heart. Finite elements (FEM) simulation of this power density distribution shows that the power density distribution corresponds to the electrical conducting path. Thus, it is possible to examine the human heart condition, because most of the human heart problems is caused by the electrical conducting path defect.

I. INTRODUCTION

With the developments of modern SQUID flux meter, the magnetocardiography (MCG) and magnetoencephology (MEG) are intensively studied for the medical applications of human heart's and of human brain's functional operation, respectively. Particularly, the signals of MCG are relatively large compared with those of MEG so that MCG may be considered as one of the most effective methodologies for the human heart diagnosis. A method of MCG diagnosis is to plot the current density vector arrow map taking the rotation of measured magnetic field normal to the body surface above human heart. According to the previous investigations, it has been clarified that the method of current density vector arrow map is quite effective to the human heart diagnosis.[1] On the other side, electrocardiography (ECG) is currently used as a quite popular and standard method for human heart diagnosis.[2]

In this paper, we derive the electric field vector arrow map from ECG taking the gradient of electric potentials measured on the body surface above human heart. After taking rotation of the MCG for current density vector arrow map, a correlative analysis between the current density and electric field vector arrow maps is carried out. As a result, it is found that our correlative analysis based on the MCG and ECG provides the most promizing result for human heart diagnosis. By means of finite element simulation, it is revealed that our correlative analysis yields the electrically conducting paths of human heart.

II. HUMAN HEART DIAGNOSIS BY COMBINING THE MCG AND ECG

A. Macroscopic electrical activity of the heart

The pattern of heart activation is both regular and repetitive. It begins at a specific site known as the sino-atrial (SA) node and spreads in a well defined manner to the rest of the heart. Since mechanical contraction of each muscle fiber of the heart is electrically initiated, the consequence of normal activation is the coordination and cooperation of all cardiac fibers so that the heart contracts and pumps efficiently. From this, it is obvious that electrical abnormalities will generally give rise to mechanical abnormalities, i.e. clinical pathology. An important property of the signal heart cell is its sensitivity to electrical stimuli from neighboring cells. An adequate (transthreshold) stimulus will initiate a stylized phasic response which, is equivalent to time-varying source of electrical motive force. As its consequence, the cell participates in the propagation of the electrical impulse because its own activity is capable of exciting its neighboring cells. Currents generated by an active cell extend throughout the body, in viewpoint of the latter's good conductivity. Thereby, electrical potentials as well as magnetic fields appear on the body surface which arise from a superposition of the fields from active cellular sources. The essence of the "regular problem" is the electromagnetic field description of the body surface's electrical potentials and magnetic fields, given a description of the sources in the heart. Each surface potential signal constitutes an ECG, also each magnetic field signal normal to the surface constitutes an MCG.

B. Electrical conduction system

The electrical activity initiating the heartbeat takes place at SA node. This region of the heart is located at the endocardial surface of the right atrium at the junction of the superior vena cava. The tissue in this

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region, about the diameter of pencil lead and 2.4cm in length, is highly specialized. These cells do not remain at rest but slowly depolarized until threshold is reached whereupon (self) excitation takes place. Such cells, known as pacemakers, are responsible for initiation of the heartbeat through excitation of their neighbors. The concatenation of activity works contiguously until all tissue has been excited. Atrial activity is conducted to the ventricles only through specialized tissue constituting the atrioventricular (AV) junction. This tissue is characterized by its very slow propagation velocity. Once the impulse reaches the ventricular exit, it propagates at an elevated velocity through the conduction bundles of His and a network of Purkinje fibers which convey the impulse to many endocardial sites in the left and right ventricles and the septum. Functionally, the AV delay serves to separate in time atrial from ventricular contraction. The conduction tissue is characterized by its relative high velocity of 2m/s, in contrast with the 0.5m/s of ventricular muscle; it is specialized for conduction and contains little contractile elements. The consequence of excitation of many endocardial sites at nearly the same time is broad depolarization waves throughout the ventricles leading to a uniform and sequenced muscular contraction.

C. Modelling of conducting system and FEM simulation

As described above, the conducting system of human heart may be regarded as one of the materials having larger conductivity compared with the other parts so that we consider a rectangular prism which is composed of the two materials. One has a large conductivity and the other has a small conductivity. Further, frequency of the electrical pulse exciting the movement of heart muscle is relatively low, i.e. about 1Hz, therefore, the system is assumed to an electrostatic system governed by a following Laplace equation:

$$\nabla\cdot(\kappa\nabla\phi) = 0, \tag{1}$$

where κ and ϕ denote the conductivity and electric potential, respectively.

Equation (1) is discretized by the finite element method for the target rectangular prism. Imposing the boundary conditions, i.e. one of the discretized points is set to a unit voltage and the other one discretized point is set to zero voltage, we have a following system equation:

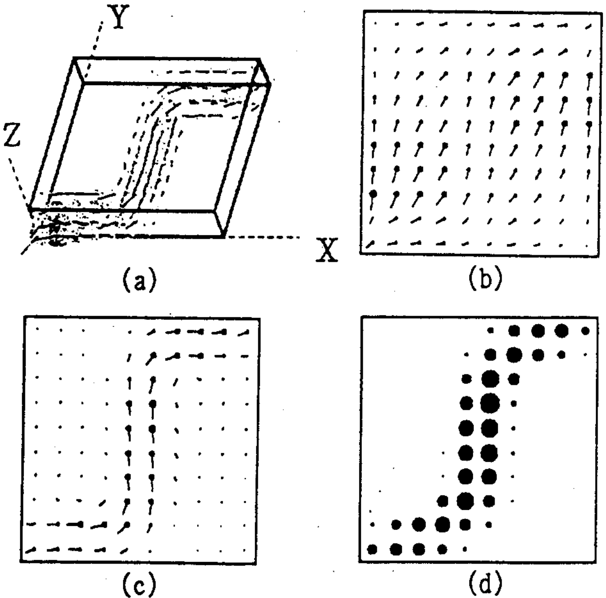
$$CX = Y, \tag{2}$$

where C, X and Y are the system matrix, potential vector and input vector determined by the Dirchlet type boundary condition, respectively.

After solving (2), a current density J distribution in a rectangular prism is obtained by means of the following Ohm's law:

$$J = -\kappa(\nabla\phi). \tag{3}$$

Figure 1(a) shows an example of current density distribution in a rectangular prism. The accompanying electric potentials on the top surface of this rectangular prism correspond to a ECG. Taking a gradient of the potential yields an electric field vector arrow map shown in Fig. 1(b). The current density J in (3) causes the static magnetic field normal to the top surface. This magnetic field distribution corresponds to a MCG. Taking a rotation of the magnetic field yields a current density vector arrow map shown in Fig. 1(c). Finally, taking an inner product between the electric field and current density at each position yields a power density distribution on the top surface. Figure 1(d) shows a power density distribution on the top surface. The comparison of Figs. 1(a) and 1(d) suggests that the current path is projected on the top surface. Thus, the conducting path can be identified by means of our approach with higher accuracy when the conducting path is located in parallel to the top surface.

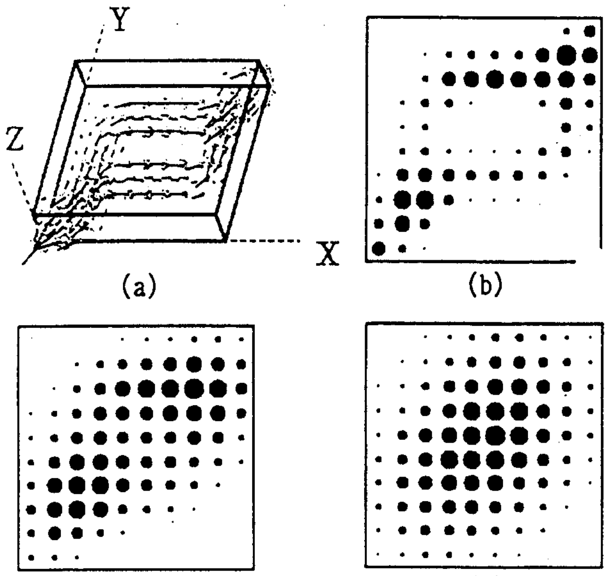


(a) (b)

(c) (d)

Fig.1. Simulated results. (a)Current density distribution; (b)electric field vector arrow map, (c)current density vector arrow map, and (d)power density distribution on the top surface of the thin rectangular prism. The high current density parts correspond to the conducting path and this conducting path is projected on the top surface as the high power density distributed part in (d).

Figure 2 shows the other simulated examples. Figures 2(a), 2(b), 2(c) and 2(d) are the current density distribution, power density distribution on the top surface of a thin rectangular prism, power density distribution on the top surface a rectangular prism having three times thickness of 2(b), and power density distribution on the top surface of a rectangular prism having seven times thickness of 2(b), respectively.



(a) (b) (c) (d)

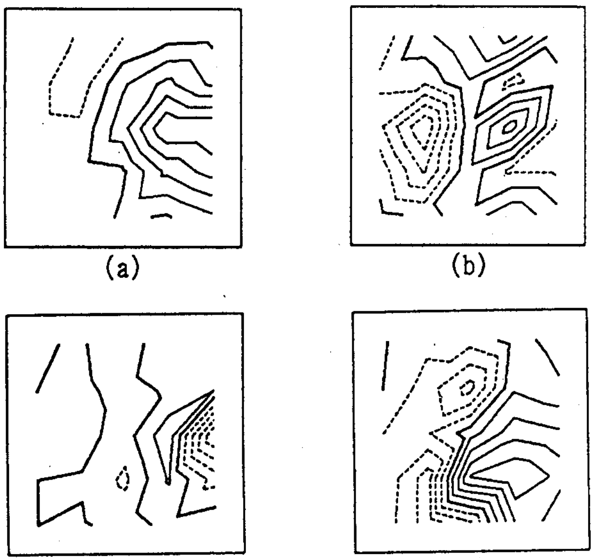
Fig. 2 The other simulated examples. (a), (b), (c) and (d) are the current density distribution, power density distribution on the top surface of a thin rectangular prism, power density distribution on the top surface a rectangular prism having three times thickness of 2(b), and power density distribution on the top surface of a rectangular prism having seven times thickness of 2(b), respectively.

The results in Fig. 2 suggest that the power density distribution corresponds well to the conducting path only if the conducting path is located near to the top surface. However, it is possible to identify a grobal conducting path even if the target conducting path is somewhat far from the measurement surface.

D. Application to the human heart diagnosis

Figures 3(a), 3(b), 3(c) and 3(d) show the surface power density distributions of the normal heart, right bundle branch block (RBBB), left bundle branch block (LBBB) and Wolf-Perkinson-White (WPW) syndromes, respectively. One of the differences compared the results of FEM simulation (Fig.1 or 2) with practical human heart data (Fig.3) is that the positive as well as negative power density distributions can be observed in the practical human heart. This is because the practical human heart has the electromotive force part as described in the Section <a>. Obviously, distinguished difference among the power density distributions of normal and distinct syndromes.

Thus, we have succeeded in realizing a method of human heart diagnosis.



(a) (b) (c) (d)

Fig. 3 Surface power density distributions of practical human hearts. (a),(b),(c) and (d) show the surface power density distributions of the normal, RBBB, LBBB and WPW syndromes, respectively. The difference compared the results in Fig.1 or 2 is that the positive as well as negative power density distributions can be observed in the practical human heart.

Ⅲ.CONCLUSION

As shown above, we have proposed a new method of human heart diagnosis based on the hibrid MCG and ECG approach. One of the merits of our approach needs not solving the inverse problem searching for the current dipoles so that the unique results are always available.[3,4] Finally, we express our heartly thanks to Prof. Nakaya of the Medical school in Tokushima University who has provided the MCG and ECG data for this paper.

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