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Discussion of Estimating Multiple Sources Based on Three-Dimensional Magnetocardiograms Measurement

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Abstract

A SQUID magnetometer system with three-dimensional(3-D) second-order gradiometer was used to measure the magnetocardiograms(MCG) for the normal subject and the patient with myocardial infarction (MI). The multiple sources were estimated using the single current dipole model based on the 3-D MCG measurement. The difference between the normal subject and the patient with MI was discussed in the conduction pathways. It is helpful to discriminate the location and the direction of multiple sources based on combining *Bz* component with *Bx* and *By* components. The 3-D MCG measurement may be more efficient than the 1-D MCG measurement in estimating the multiple sources.

Keyword: SQUID magnetometer, 3-D second-order gradiometer, MCG, equivalent source, multiple sources

1. Introduction

A point-contact SQUID magnetometer was used inside a shielded room to record the magnetocardiograms (MCG) of the subject at first in 1970[1]. The detector was a single point-contact rf biased SQUID and used the Josephson effect. Based on the detector, the multichannel SQUID magnetometer has rapidly been developed and applied in medical research during the past decade[2]. As a non-invasive measurement, its main advantage is to measure the MCG at some different positions of the anterior chest wall simultaneously and be able to obtain much more information about cardiac electric activation than the electrocardiogram(ECG) measurement. However, the magnetic field is almost all perpendicular to the anterior chest wall. There are problems of separating multiple sources overlapping

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time when cardiac tissues are active. In some cases, the magnetic field perpendicular to the anterior chest wall was not helpful in estimating the location and the number of source, owing to the lack of a dipole pattern. However, the magnetic field tangential to the anterior chest wall can provide information about constraint conditions by visual inspection[3]. In the study, we used SQUID magnetometer system with three-dimensional(3-D) second-order gradiometer to measure the MCG for the normal subjects and the patient with myocardial infarction (MI). The multiple sources were estimated using the single current dipole model based on the 3-D MCG measurement. The difference between the normal subject and the patient with MI was discussed in the conduction pathways. We propose to provide new method in estimating multiple sources.

2. SQUID Magnetometer system

The SQUID magnetometer system mainly consisted of 3-D second-order gradiometer, rf-SQUID, flux locked loop(FLL) circuit, data terminal device and an electro-magnetically shielded room[4]. Fig. 1 showed a 3-D second-order coil, which was made of superconducting wire(Nb-Ti-Cu) and was orthogonally wound on a rectangular solid 3×3×6 cm. Its magnetic field output was expressed as follows

$$Bx = B(x,y,z) - 2B(x,y,z+\Delta z) + (x,y,z+2\Delta z) \quad (1)$$

$$By = B(x,y+\Delta y,z+\Delta z) - 2B(x,y,z+\Delta z) + B(x,y-\Delta y,z+\Delta z) \quad (2)$$

$$Bz = B(x+\Delta x,y,z+\Delta z) - 2B(x,y,z+\Delta z) + B(x-\Delta x,y,z+\Delta z) \quad (3)$$

Where position (x, y, z) was the lowest coil place for the Bz component. Δz was a base line (28 mm) of the coil for Bz component. Δx and Δy were a base line (14 mm) of the coil for Bx and By components. In order to obtain the characteristic of 3-D second-order gradiometer, a computer simulation was performed in such a condition, that is, a single current dipole was located in the lower middle of the measurement plane and the distance to the nearest sensor was 3cm, which was 2 cm from the nearest sensor to the measurement plane and 1 cm from the measurement plane to the single current dipole. The current dipole moment was set with 30 nAm and the direction was set from front to back. As shown in Fig. 2, above the location of the current dipole, the perpendicular magnetic field (Bz component) showed a dipole pattern having a maximum field extreme and a minimum field extreme, the tangential magnetic fields (Bx and By components) showed a maximum field extreme or a minimum field extreme when the direction was set from back to front. For application of the 3-D MCG measurement, if a maximum field extreme and a minimum field extreme are obtained in two measurement positions for Bz component, there exists an equivalent source(ES) in the middle of two measurement positions. If a maximum field extreme or a minimum field extreme is obtained in a measurement position for Bx and By components, there exists an ES in the same measurement position.

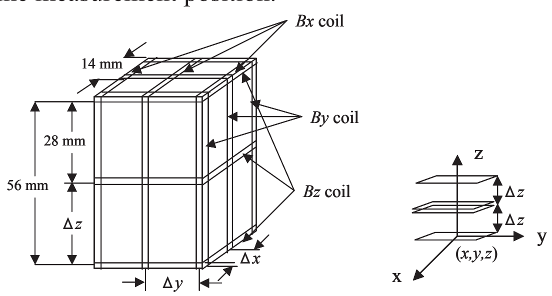

Fig. 1. A 3-D second-order coil.

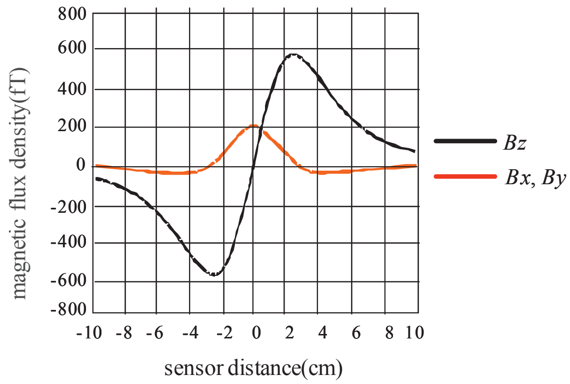

Fig. 2. Characteristic of 3-D second-order gradiometer.

3. MCG measurement

The MCG measurement was carried for 4 male normal subjects (average age 23) and 1 male patient with anterior MI (age 81) with the measurement system in a magnetic shielded room (MSR). The system noise level measured in the MSR was about 12 fT/(Hz)$^{1/2}$ for *Bx*, *By* components and 15 fT/(Hz)$^{1/2}$ for *Bz* component at 10 Hz[3]. The MCG signal was amplified by the amplifier at high gain 32 dB, and passed through the analog bandpass filter of 0.5 to 300 Hz. The filtered MCG signal was digitized with 1000 Hz sampling frequency. While the output of the data was recorded on the computer hard disk, the ECG signal in the lead II was also recorded on the computer hard disk simultaneously as a timing reference for averaging the MCG signal. Fig. 3 showed the measurement grids (*X*=4cm, *Y*=4cm) of the MCG signal. The measurement positions of 42 points indicated by the circles on the anterior chest wall were set up according to the Saarinen's method[5]. In the 3-D coordinate system, *Bx* component is tangential to the anterior chest wall and is indicated from right to left. *By* component is tangential to the anterior chest wall and is indicated from the head to the foot. *Bz* component is perpendicular to the anterior chest wall and is indicated from the front to the back.

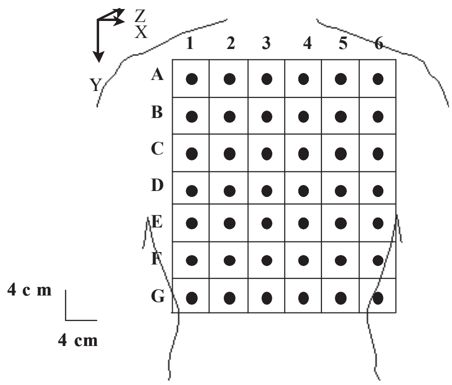

Fig. 3. MCG measurement grids according to the Saarinen's method.

4. Estimating multiple sources

We used the single current dipole model to estimate the multiple sources based on the 3-D MCG[6][7]. Fig. 4 showed the isofield contour maps and the arrow maps obtained at four time instants(①,②,③, ④) during the QRS wave of a normal subject. Fig. 5 showed the isofield contour maps and the arrow maps obtained at the same four time instants during the QRS wave of a patient with MI. For the isofield contour map, the plot showed line of constant magnetic field on the anterior chest wall. The white sections presented the positive magnetic field. The black sections presented the negative magnetic field. The boundary line of the black and the white presented the zero magnetic field. For the arrow map, the plot showed distribution and direction of current inside the heart. The size of arrow was proportional to the largeness of current. First, we have observed Fig. 4 using the characteristic of 3-D second-order gradiometer. At time instant ①, the two field extremes of *Bz* component appeared at measurement positions C4 and E5, which were the maximum field extreme of 1.11 pT and the minimum field extreme of –1.23 pT respectively. An ES was estimated at the middle of the measurement position C4 and E5. For *By* component the minimum field extreme of –0.10 pT appeared at the measurement position D4. An ES was estimated at the measurement position D4. Its current flow was toward the left direction, which was strong comparing *Bx* component at the same position. At time instant ②, the one maximum field extreme of *Bz* component appeared at the measurement positions D3. This was not a dipole pattern. But by referring to the isofield contour map of *Bx* component, we could found the minimum field extreme of –0.31 pT appeared at the measurement position E4. Therefore, an ES was estimated at the measurement position E4. Its current flow was toward the down direction, which was strong comparing *By* component at the same measurement position. At time instant ③, the one maximum field extreme of *Bz* component appeared at the measurement positions E3. This was not a dipole pattern either. But by referring to the isofield contour map of *Bx* component, we could also found the minimum field extreme of –0.79 pT appeared at the measurement position E4. Therefore, an ES was estimated at the measurement position E4. Its current flow was toward the down direction, which was strong comparing *By* component at the same position. At time instant ④, the patterns of *Bx*, *By*, *Bz* components were almost the same as those appeared at time instant ③. Second, we have observed Fig. 5 using the characteristic of 3-D second-order gradiometer. At time instant ①, the one minimum field extreme of *Bz* component appeared at the measurement position B3. This was not a dipole pattern. But by referring to the isofield contour map of *Bx* component, we could found the maximum field extreme of 0.49 pT appeared at the measurement position C4. Therefore, an ES was estimated at the measurement position C4. Its current flow was toward the up direction, which was strong comparing *By* component at the same measurement position. At time instant ②, the patterns of *Bx*, *By*, *Bz* components were almost the same as those appeared at time instant ①. At time instant ③, the three field extremes of *Bz* component appeared at the measurement position B3, F3 and E5 respectively, this was not a dipole pattern either. But by referring to the isofield contour maps of *Bx* and *By* components, we could also found the maximum field extreme of 0.41 pT of *Bx* component appeared at the measurement position C5 and the maximum field extreme of 0.45 pT of *By* component appeared at the measurement position C4. An ES was estimated at the measurement position C5 for *Bx* component. Its current flow was toward the up direction. An ES was estimated at the measurement position C4 for *By* component. Its current flow was toward the right direction. At time instant ④, the two field extremes of *Bz* component appeared at the measurement positions E5 and E3, which were the maximum field extreme of 3.38 pT and the minimum field extreme of -2.75 pT respectively. An ES was estimated at the middle of the measurement position E5 and E3. For *Bx* component the maximum field extreme of 0.36 pT appeared at the measurement position F4. An ES was estimated at the measurement position F4. Its current flow was toward the up direction.

5. Discussion

We finished the isofield contour maps and the arrow maps obtained at the same four time instants(①, ②,③,④) during the QRS wave for other normal subjects. We found these patterns were almost the same for all normal subjects. However, it was clear that the patient with MI was different from the normal subject. It was proved that the conduction pathways were uniform or the directions of activation are constant in the normal myocardium, but the conduction pathways were various or the directions of activation change in the ischaemic parts. Let us observe Fig. 4 and Fig. 5 again to understand the difference mentioned above. At time instant ③, the current flow were from the upper left to the upper right near the measurement position D3 for *Bz* component of the normal subject, however, the current flow were perturbation near the measurement position D3 for *Bz* component of the patient with MI. We have obtained some useful information based on the isofield contour maps of the 3-D MCG although estimating multiple sources are complex and difficult in practice. The mapping of the MCG is a promising method in estimating the source localization of cardiac electric activation.

6. Conclusion

In the study, we used the SQUID magnetometer system with 3-D second-order gradiometer to measure the MCG for the normal subjects and the patient with MI. We estimated the multiple sources using the single current dipole model based on the 3-D MCG. The results show that much and useful information can be obtained by combining *Bz* component with *Bx* and *By* components. The 3-D MCG measurement may be more efficient than the 1-D MCG measurement in estimating the multiple sources. However, there are still some problems to be remained in the study. The characteristic of 3-D second-order gradiometer will be discussed in next step based on two current dipoles and three current dipoles.

Acknowledgements

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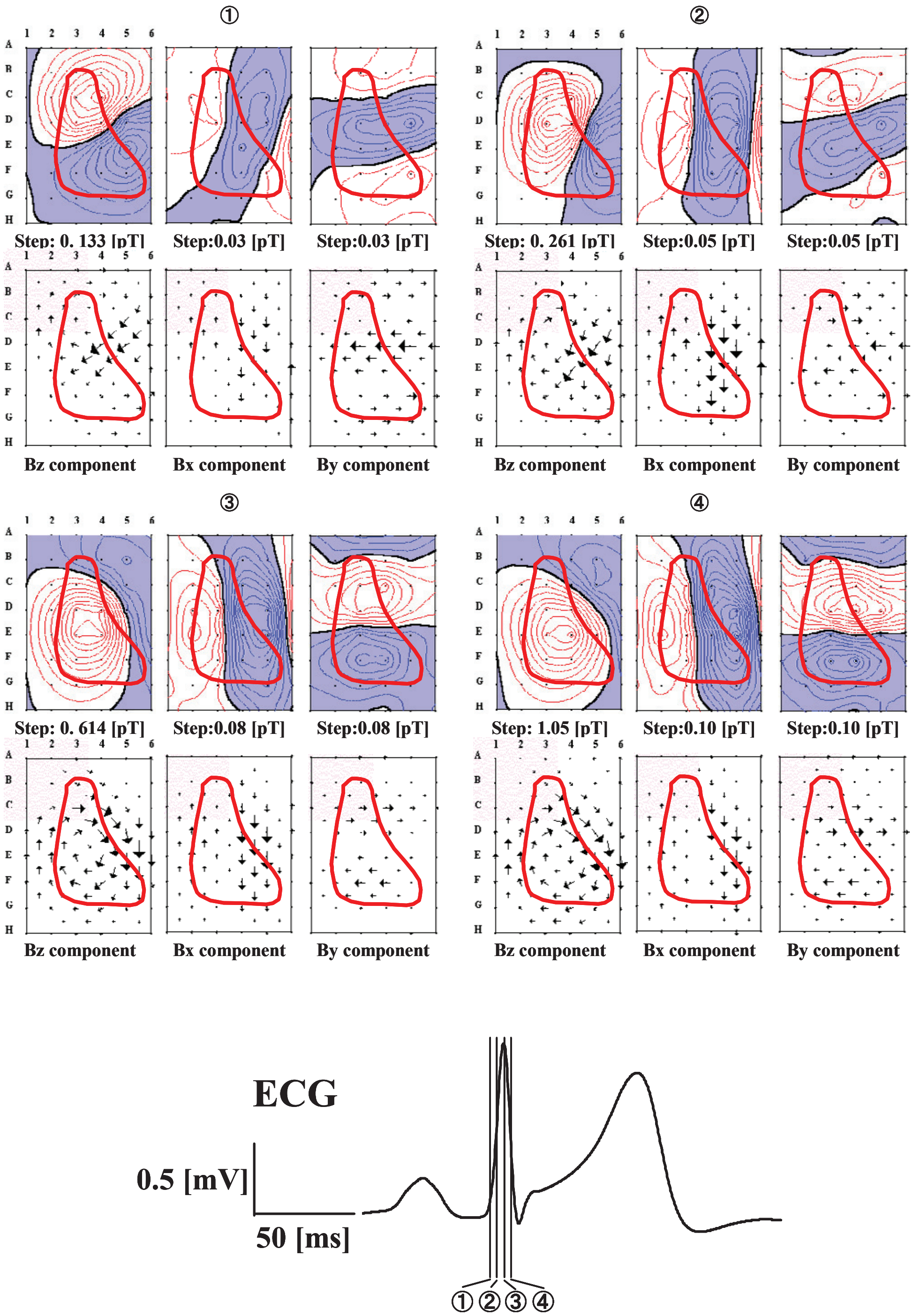

Fig. 4. Isofield contour maps and arrow maps at four time instants for a normal subject.

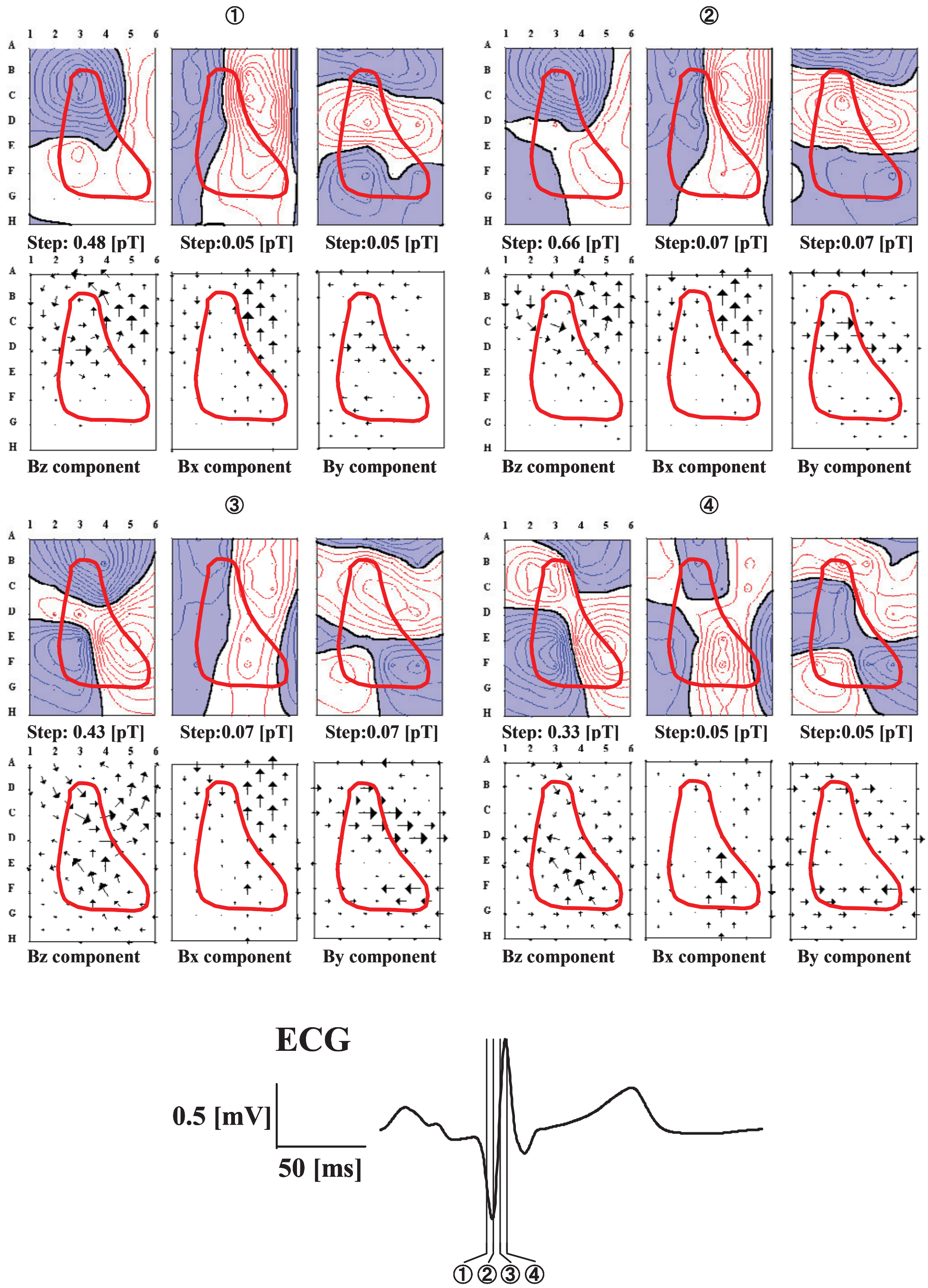

Fig. 5. Isofield contour maps and arrow maps at four time instants for a patient with MI.