Frequency Analysis of Premature Ventricular Contraction Using 3-D MCG Measurements

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Abstract— We carried out three-dimensional (3-D) vector measurements of the magnetocardiogram (MCG) on a subject with premature ventricular contraction (PVC) and ten normal subjects using a 39-channel SQUID system. This SQUID magnetometer can detect magnetic field components perpendicular to the chest wall (B_z) and tangential to the chest wall (B_x, B_y) simultaneously. We used principal component analysis in order to compare the normal sinus rhythm of the PVC patient with the sinus rhythm of ten normal subjects. The results showed that the frequencies in the MCG waveforms of the PVC subject were dominated by lower frequencies (less than 10 Hz) than in normal MCGs, and the frequency distribution of B_x was different from those characteristic of B_z and B_y .

Index Terms— three-dimensional vector measurement, magnetocardiogram, premature ventricular contraction, frequency analysis, principle component analysis

I. INTRODUCTION

Premature ventricular contraction (PVC) is one of sudden death factors, it is important to explain this detailed mechanism. Whereas biomagnetic field measurement is widely used the magnetic field perpendicular to the body surface. There are a few reports concerning with a 3-D vector measurement [1]–[5]. We have developed a 39-channel SQUID system consisting of thirteen 3-D second-order gradiometers (12 measurement positions (4×3) and a noise measurement) for vector measurement of the MCG. This SQUID magnetometer can detect magnetic field components perpendicular to the chest wall (B_z) and tangential to the chest wall (B_x, B_y) simultaneously [6], [7]. We carried out three-dimensional vector measurements of magnetocardiogram (MCG) on a subject with PVC and ten

normal subjects. We used principal component analysis in order to compare the normal sinus rhythm of the PVC patient with the sinus rhythm of ten normal subjects.

II. METHOD

Fig. 1 shows the configuration of a 3-D second-order gradiometer and locations of the measurement positions on a subject's chest. MCG and ECG (lead II) of a PVC and ten normal subjects were measured by this system. There were twenty-four measurement positions (2 scanning, fixed circle in Fig. 1) on the chest wall and a band-pass filter was used in the range of 0.1 to 80 Hz. All magnetic data were averaged for fifty measurements at each position. The reference signal for averaging was R-wave of ECG. Waveforms obtained from each position were calculated by the fast Fourier transform (FFT) for each magnetic field component, then a covariance (equation 1) and its matrix (equation 2) were calculated from these twenty-four frequency characteristics ($B_i(\omega_m)$), where M is analyzed maximum frequency, i and j are measurement positions, $\bar{B}_i$ is mean value of B_i , p is total number of measurement positions. This matrix was analyzed by principal component analysis (PCA) with equation 3, where λ is eigenvalue, I is unit matrix. Finally, the score ($Z_k(\omega_m)$) defines as equation 4 and score proportion ($F_k(\omega_m)$) defines as equation 5, where l_k is eigenvector, k is k -th principal component.

$$\sigma_{ij} = \frac{1}{M} \sum_{m=1}^M (B_i(\omega_m) - \bar{B}_i)(B_j(\omega_m) - \bar{B}_j) \quad (1)$$

$$\Sigma = \begin{bmatrix} \sigma_{11} & \sigma_{12} & \cdots & \sigma_{1p} \\ \sigma_{21} & \sigma_{22} & \cdots & \sigma_{2p} \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_{p1} & \sigma_{p2} & \cdots & \sigma_{pp} \end{bmatrix} \quad (2)$$

$$|\Sigma - \lambda I| = 0 \quad (3)$$

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$$Z_k(\omega_m) = \sum_{i=1}^p [l_{ki} \times (B_i(\omega_m) - \bar{B}_i)] \quad (4)$$

$$F_k(\omega_m) = \frac{Z_k(\omega_m)}{\sum_{m=1}^M Z_k(\omega_m)} \times 100 \quad [\%] \quad (5)$$

Fig.1 Coordinate system and a 3-D second-order gradiometer and measurement positions on a subject's chest.

Fig.2 The Bz component of the MCG of PVC subject measured at C4

III. RESULTS AND DISCUSSIONS

Fig.2 shows an example of the MCG waveform (Bz) recorded from the PVC subject at position C4 in Fig.4(a). To find PVC factor induced by ectopic excitement, the MCG of the PVC subject was classified into four types;

PVC2: Premature Ventricular Contraction, PVC(NSR): normal sinus rhythm, PVC1: heartbeat preceding PVC, PVC3: heartbeat following PVC.

Fig.3 shows the results of PCA comparing the normal sinus rhythm of the PVC patient (PVC(NSR)) with the sinus rhythm of ten normal subjects. The frequency distribution of score proportion of the PVC(NSR) was dominated by lower frequencies (less than 10 Hz) than in normal MCGs, and the frequency distribution of score proportion of Bx was different from those characteristic of Bz and By. Table 1 shows the correlation coefficient(γ) of the frequency distribution of the score proportion between the perpendicular component and tangential component for each subject. We found that γ of the normal sinus rhythm of PVC patient was different from that of normal subjects (Bz-Bx: $\gamma=0.51$).

Fig.4 shows the results of PCA about four types of PVC (NSR,1,2,3) heartbeats. Table 2 shows the correlation coefficient(γ) of the frequency distributions of score proportion between PVC(NSR) and PVC1, PVC2, PVC3 for premature ventricular contraction. The frequency distributions (Bz, By) of score proportion of PVC(NSR) showed a similar pattern as that of PVC1(Bz: $\gamma=0.99$, By: $\gamma=0.99$) and PVC3(Bz: $\gamma=0.98$, By: $\gamma=0.98$). On the other hand, the frequency distribution (Bx) of score proportion of PVC(NSR) was similar to PVC3(Bx: $\gamma=0.99$), but it differed from that of PVC1(Bx: $\gamma=0.72$).

Table 1 Correlation coefficient of the frequency distributions of the score proportion between the perpendicular component and tangential component for each subject.

	Normal	PVC(NSR)
Bz-Bx	0.93	0.51
Bz-By	0.95	0.98

Fig.3 Results of principal component analysis for PVC(NSR) and normal subjects.

Fig.4 Results of principle component analysis for PVC.

Table 2 Correlation coefficient of the frequency distributions of the score proportion between PVC(NSR) and PVC1,2,3 for premature ventricular contraction.

	Bz	Bx	By
PVC(NSR)-PVC1	0.99	0.72	0.99
PVC(NSR)-PVC2	-0.08	0.51	-0.08
PVC(NSR)-PVC3	0.98	0.99	0.98

IV. CONCLUSION

We carried out three-dimensional vector measurements of magnetocardiogram on a subject with premature ventricular contraction and ten normal subjects. We used principal component analysis in order to compare the normal sinus rhythm of the PVC patient with the sinus rhythm of ten normal subjects. The results showed that the frequency distribution of score proportion of the PVC(NSR) was dominated by lower frequencies (less than 10 Hz) than in normal MCGs, and the frequency distribution of score proportion of Bx was different from those distributions of Bz and By. The frequency distribution of score proportion of PVC(NSR:normal sinus rhythm) was similar to PVC3(heartbeat following PVC), but it differed from that of PVC1(heartbeat preceding PVC). The study shows promise in detecting components in the normal sinus rhythm in PVC subject, not seen in normal subjects.

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REFERENCES

- [1] A. Rosen, G.T. Inouye : " A study of the vector magnetocardiographic waveform", IEEE Trans. Biomed. Engng. BME-22, 167-174 (1975)
- [2] J.P. Wikswo, W.M. Fairbank : " Application of superconducting magnetometers to the measurement of the vector magnetocardiogram", IEEE Trans. Magnetics, MAG-13, 354-357 (1977)
- [3] J.A.V. Malmivuo, J.P. Wikswo: "A new practical lead system for vector magnetocardiography.", Proc. IEEE, 65, 809-811 (1977)
- [4] M. Seppanen, T. Katila, T. Tuomisto, T. Varpula : " Measurement of biomagnetic fields using multichannel superconducting magnetometer techniques", IL NUOVO CIMENTO, Vol.2, 166-174 (1983)
- [5] K. Shirao, H. Furukawa, M. Katayama: "Measurements and characteristics of vector magnetocardiography", Biomagnetism 87, Tokyo Denki Univ. Press, Tokyo, 294-297 (1987)
- [6] Y. Uchikawa, K. Kobayashi, M. Kotani : "Application to discrimination of multi-sources to somatosensory evoked field using 3-dimensional second-order gradiometer.", Biomagnetism: Fundamental Research and Clinical Applications, Elsevier Science, IOS Press, 389-393 (1995)
- [7] K. Kobayashi, Y. Uchikawa : "Estimation of multiple sources using a three-dimensional vector measurement of a magnetoencephalogram", Journal of Applied Physics, Vol.83, No.11, Part 2, 6462-6464 (1998)