Noninvasive Diagnosis of Partial Atrial Standstill Using Magnetocardiograms

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A 59-year-old woman with partial atrial standstill was studied using magnetocardiograms (MCGs), which revealed through QRS-T subtraction and time-frequency analysis that there was a high-frequency (6Hz) magnetic source at the low atrial septum. MCGs are useful for noninvasively evaluating the clinical course of patients with atrial fibrillation. (Circ J 2002; 66: 1178–1180)

Key Words: Atrial fibrillation; Magnetocardiograms; Partial atrial standstill; Time-frequency analysis

It is difficult to noninvasively distinguish atrial standstill (AS) from atrial fibrillation (Af). In the clinical course of chronic Af, the voltage of f waves sometimes decreases, indicating atrial dilation and dysfunction, and usually an electrophysiological study (EPS) is needed to distinguish AS from Af with diminished f waves.1,2 Although magnetocardiograms (MCGs) are theoretically sensitive to microvolt electrophysiological phenomena,3 a MCG study of AS has yet been reported. The aim of our study was to use MCGs to noninvasively investigate the atrial activity of patients diagnosed as having AS by standard surface electrocardiograms (ECGs).

The raw data of MCGs includes noise and because methods of analyzing atrial arrhythmias have not been established, there have been few MCG studies of atrial arrhythmias.4 To extract the atrial components, we reduced the ventricular components through QRS-T subtraction and reduced the noise through time–frequency analysis. We believe this is the first report of a case of partial AS analyzed by MCGs.

Case Report

A 59-year-old woman with constrictive cardiomyopathy was admitted for a recurrent episode of congestive heart failure in 1999. She had an 18-year history of Af. The 12-lead ECG had recorded f waves (0.3 mV) in 1982, but in 1999 (Fig 1a) her baseline ECG revealed a narrow QRS rhythm at a rate of 64 beats/min without f waves. Echocardiography showed atrial dilatation and no active contraction in either atrium, so we performed an EPS to evaluate the atrial activation. The signals were filtered between 30 and 400Hz and recorded at a speed of 100 mm/s and a gain of 0.05–0.25 mV/cm. In the EPS, atrial electrograms were recorded at 2 sites: the low septum of the right atrium, and the lateral to the mitral valve annulus. Electrograms could not be recorded at the free wall of the right atrium. From the results of the EPS, the patient was diagnosed as having partial AS.

Magnetocardiograms

Measurement We measured the cardiac magnetic field at the anterior chest using a 64-channel superconducting quantum interference device (SQUID) system with the following sensor arrangement: 8x8 rows, an interval of 2.5 cm, a measuring area of 17.5x17.5 cm, and a 0.1–100 Hz band-
pass filter (Hitachi Ltd, Japan). The ECG lead II recording was done simultaneously. The magnetic strength of the normal components was recorded for 2 min at 1-ms intervals.

**Raw Data**  The MCGs revealed ventricular depolarization and repolarization waves corresponding to the QRS complex and ST-T interval on the ECG (Fig 2a, partial AS). The magnetic strengths of the depolarization and repolarization waves were 30 and 8 pico tesla (pT), respectively. Irregular components (1.5 pT) were detected in the R-R intervals.

**Time–Frequency Analysis**  Because we could not directly demonstrate that the random pattern was atrial activity, we made a 2-step algorithm for analyzing atrial activation. First, we abstracted the atrial components from the raw data (=atrial and ventricular components + noise). We then subtracted the QRS-T signal-averaged waveforms from the raw data and hypothesized that they comprised the atrial components and noise. We then did a time–frequency analysis to reduce the noise. We signal-averaged the ventricular waves for 2 min (heart rate: 71 beats/min, R-R intervals: 0.85±0.13 s). The R peak in lead II was triggered, and ventricular waveforms with an interval of 700 ms (100 ms before R and 600 ms after R) were signal averaged. We then subtracted the signal-averaged waveforms from 10 s of sampling data (Fig 2b). Next, we did a time–frequency analysis of the subtracted waveforms. A high-frequency (6Hz) component was detected in the patient, but not in a normal subject with a normal sinus rhythm (35-year-old man, heart rate: 60 beats/min, atrial components: 2 pT) (Fig 2c). In a time–frequency analysis using ECGs, the high-frequency components were not evident (Fig 2d).

**Isomagnetic Field Map**  To investigate the location of the high-frequency components, we made an isomagnetic field map of the tangential components of the cardiac magnetic fields by using Bxy = √((dBz/dBx)² + (dBz/dBy)²) (Bxy: calculated tangential components, Bz: measured normal components). Although the magnetic strength immediately above a magnetic source (=an electrical source) is zero, translating positive to negative, in normal components, it is maximal in tangential components. In the isomagnetic field map, peaks (red area, 0.02 pT/cm) were found at the low atrial septum (Fig 3) and this magnetic source was recognized reproducibly at any 10-ms interval of the simultaneous 2 min of recorded data.

**Discussion**  MCGs have the advantage of being a noninvasive, non-contact mapping system that does not require body-surface electrodes compared with body-surface potential maps. Another advantage is that the data in MCGs are vector markers using absolute scales, whereas the data in ECGs are scalar markers using relative scales. These advantages have been explored in MCG studies of Wolff-Parkinson-White syndrome, and ischemic heart disease. The accuracy of MCGs is affected by the distance between the magnetic source and the SQUID sensor, by body motion associated with respiration and the heartbeat, and by the models used to analyze the data. The sampling data is therefore usually signal-averaged, but this is inapplicable to AF, atrial flutter and atrial tachycardia because they are complicated arrhythmias with irregular atrioventricular conduction. We have already reported that MCGs can distinguish atrial flutter caused by macro reentry from atrial tachycardia caused by other mechanisms (automaticity or micro reentry), and in the present study we have developed a new algorithm for analyzing atrial activation in patients with AS and AF by using QRS-T subtraction and time–frequency analysis. As a result, atrial activation in a patient...
with partial AS has been analyzed by MCG and the results of this study clearly show that MCGs are indeed sensitive to microvolt electrophysiological phenomena relevant to clinical medicine.

It also showed the limitations of MCGs. In the EPS, atrial activation was recorded at the atrial septum and the mitral valve annulus, but on the MCG, activation was only detected at the atrial septum. The strength of the magnetic field detected at the anterior chest decreases with the distance between the magnetic source and the SQUID sensors, and the atrial activation at the mitral valve annulus was posterior to the study site, which is one of the reasons why it was not detected. Complete QRS-T subtraction may also mean that weak atrial components are analyzed. In this study, the MCG revealed atrial activation during partial AS that was not detected by surface ECGs. Further studies are needed to determine the locations and numbers of atrial activations.

A 64-channel MCG system can record all channels simultaneously with an interval of 1 ms and we performed a time–frequency analysis of a 10-s record of the data. High-resolution mapping of the spatial and temporal components was used for short-time analysis. In a patient with a lower heart rate, a longer time might be needed.\(^1\)

Recent studies of ion channels\(^1\) and radiofrequency catheter ablation\(^3\) have demonstrated that there are multiple factors in the initiation and persistence of AF. AS is thought to be a deteriorated stage of chronic AF, but the clinical course of AF is not clear. ECGs are not sensitive enough to diagnose AS, and repeated EPSs are impractical for following the clinical course. This study indicates that MCGs are useful in evaluating the clinical course of patients with AF.

Acknowledgments

We would like to thank Dr. Yuichi Noguchi, Mr. Toshio Ebashi, and Mr. Kazuhiko Akamatsu of the Tsukuba Medical Center Hospital, Ibaraki, Japan for their cooperation.

References


