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Literature Review on Recent Magnetocardiography and Impedance-Magnetocardiography Technologies

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Abstract

We have developed magnetocardiography (MCG) and impedance magnetocardiography (I-MCG) for detecting heart disease by using dc-SQUID technology. The MCG system, using low-Tc SQUID, is being applied commercially for diagnosing heart disease. Using the low-Tc MCG system, many clinical studies on detection of abnormality have been performed. Furthermore, we have developed a portable MCG system using high-Tc SQUID. For detecting changes in kinetic impedance in the heart, an I-MCG system has been demonstrated. The I-MCG system could detect the mechanical movement of the heart. In this report, we review current clinical applications of magnetocardiography and impedance magnetocardiography.

Keywords : Magnetoconductance, SQUID, MCG, impedance

I. Introduction

In regards to magnetic measurement, there is little interference from organs such as born organ and lungs. Magnetocardiography (MCG) has the potential to detect heart disease, because the magnetic signal sensed by the MCG includes high-spatial-resolution information [1, 2]. MCG is a noninvasive, risk-free, and contact-less technique [3]. Taking up these advantages, many clinical studies on the clinical applications of MCG have been published [3, 4].

We first measured an impedance magnetocardiogram (I-MCG), namely, a record of magnetic-field changes that are dependent on an AC current (with constant amplitude) applied to a subject.

In this paper, we describe clinical applications of the magnetocardiogphy and a new technology, namely, impedance magnetocardiography.

II. Magnetocardiography System using Low-Tc SQUID

Many LTS-MCG systems for studying the mechanism of heart disease by cardiomagnetic imaging have been developed [5]. Korea Research Institute of Standards and Science (KRISS) [6], SQUID AG [7], Physikalisch-Technische Bundesanstalt (PTB) [8], Helsinki University [9], Iwate University [10], and Hitachi Ltd [11]. are some examples. Figure 1 shows a photo of a commercially available MCG system produced by Hitachi High-Technologies Corporation in 2003 [11]. Mapping of MCG data is performed with a superconducting quantum interference device (SQUID) above the patient's body. The M1CG waveform obtained is very similar to an electrocardiogram (ECG) signal, because the source of the field is the same ionic current. To easily obtain a current distribution with high spatial resolution, we developed a method for calculating the current vector (Ix and Iy) from the derivatives of the normal component (Bz) of the MCG signals, namely, Ix =dBz/dy and Iy =-dBz/dx [12]. The derivative vector calculated from the normal component of a magnetic field has a pattern of peaks immediately above the electrically activated region. Furthermore, to enable current distribution to be understood visually, the magnitude of the current arrows, $I = (Ix^2+Iy^2)^{1/2}$, is plotted as a contour map. Using our original current-arrow map (CAM) method, we can directly obtain current distribution over the heart.

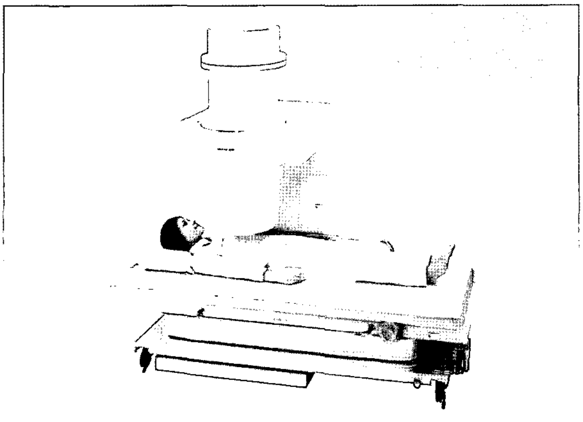


Fig. 1. Magnetocardiography, MC-6400 (Hitachi-High technologies).

III. Clinical Applications of Magnetocardiography

Aiming to make a database of MCGs of normal subjects, we have started standardization of time intervals [45]. Although the standardization of MCG waveforms is not yet completed, we expect that the three main clinical applications of MCGs are as follows (listed in Table 1).

Table 1. List of clinical applications of magnetocardiography.

Application field	Contents with benefits
Medical examinations	Screening of cardiac disease High throughput High sensitivity Few restrictions
Monitoring of growing fetal heart	Noninvasive measurement Non-stress test Completely safe
Evaluation of cardiac treatment	Prognosis Efficacy of catheter treatments or bypasses

(1) Determination of arrhythmia focus

Before surgery or drugs are used to treat arrhythmias, the arrhythmic focus has to be determined so that plans for treatment can be prepared. Although physicians usually use ECG data to investigate arrhythmias, it cannot provide an accurate focal position because ECG signals incur a great deal of interference from conductivity differences between tissues such as lungs and bone. The arrhythmia focus can be determined by several methods [22, 35-39]. Furthermore, we used an electrical image of CAM to investigate the electrical mechanisms responsible for arrhythmias associated with sudden death, such as the long QT syndrome [13] and Brugada syndrome (Fig. 2) [21][34], and we were the first to detect an abnormal current distribution on the right-ventricular outflow tract (RVOT). It is summarized that MCG provides a new strategy to diagnose and treat arrhythmias.

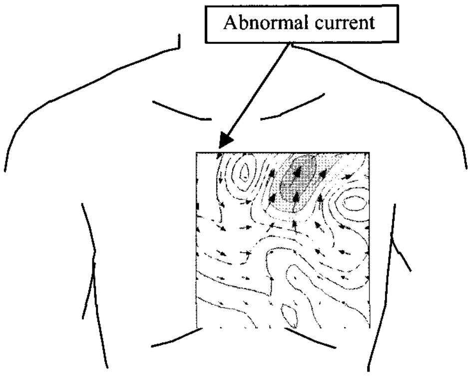


Fig. 2. Brugada-syndrome pattern in an MCG.

(2) Early detection of myocardial infarction

Myocardial infarction often causes sudden death. Early detection is therefore very important. To detect an infarction, single-photon-emission computed tomography (SPECT) with stress is frequently used. With this method, a radioisotope (RI) is injected into a vein, and the increase in blood flow in the ischemic area is visualized. On the downside, SPECT is invasive and, therefore, uncomfortable for the patient. We applied our MCG visualization technique to the early stages of ischemic disease and could accurately detect it non-invasively [14−15, 23, 42−43].

To detect angina pectoris (AP) by using a light-exercise test, we have developed a current ratio map (Fig. 3). We performed the master double test like a step climbing. Two sets of MCG data (taken after 1 min. and after 5 min. of exercise) for calculation of the map as shown in Fig. 3(a). By using the data, we can calculate the current ratio map for detecting the ischemia like that shown in Figure 3(b). By using the peak in the current ratio map, we calculate the sensitivity of detecting the ischemia. As a result, the MCG sensitivity was 82% and the ECG is 47%.

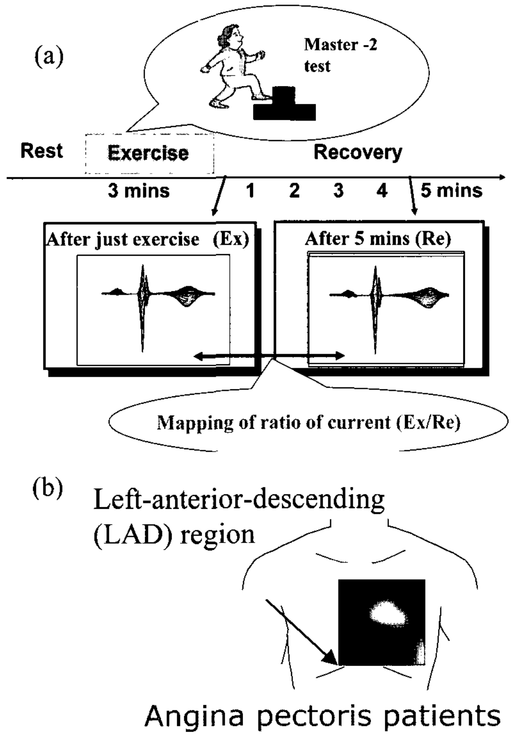


Fig. 3. Early detection of angina pectoris by using a current-ratio map.

(3) Assessment of delivery control in a fetus with arrhythmia

The mechanical movement of the fetal heart can be monitored with ultrasound. However, electrophysiological information about the fetal heart cannot be detected with ECG on the maternal body, because of large interference caused by fetal skin (due to its high resistance). Accordingly, we applied our MCG system to detect fetal arrhythmias [24−26], and we were the first to measure long QT syndrome [16−18] and WPW syndrome [19−20] (Fig. 4). Furthermore, as their arrhythmias had an abnormal current distribution, we estimated the arrhythmic focus from that distribution. The arrhythmic focus enabled us to time the baby's delivery and schedule drug treatment for the neonates. These results show that MCG system has the potential to accurately detect fetal arrhythmias.

As shown in Fig. 5, we estimated the fetal dipole moment during the gestation weeks [31−32]. Using the dipole moment, we determined fetal current strength, and a fetal hypertrophy can be detected, from which a fetal hypertrophy was detected [33]. Furthermore, a pickup coil can be designed by using the strength [31].

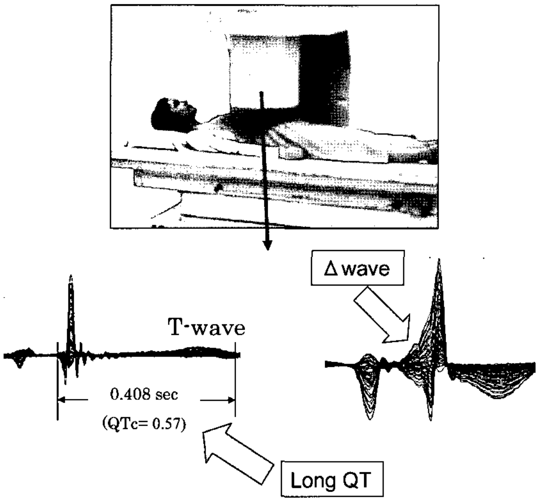


Fig. 4. Typical fetal arrhythmic waveforms (long-QT syndrome and Wolff-Parkinson-White syndrome).

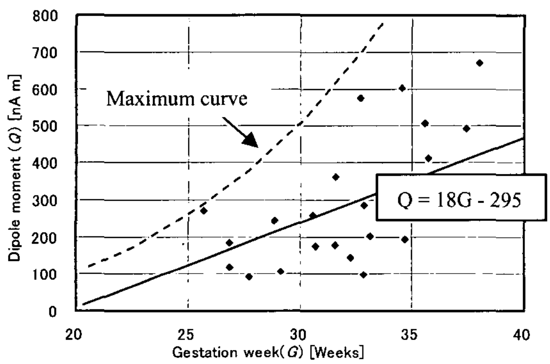


Fig. 5. Fetal dipole moment during the gestation weeks.

IV. Magnetocardiography System using High-Tc SQUID

We have also constructed a prototype 51-ch-MCG system using high-Tc SQUID, which has not yet been commercialized, to check its system performance (see Fig. 6) [41, 44]. This compact system with 70 $fT \cdot Hz^{-1/2}$ (average system noise) could visualize a current distribution in ischemia patients by using a signal-averaging technique.

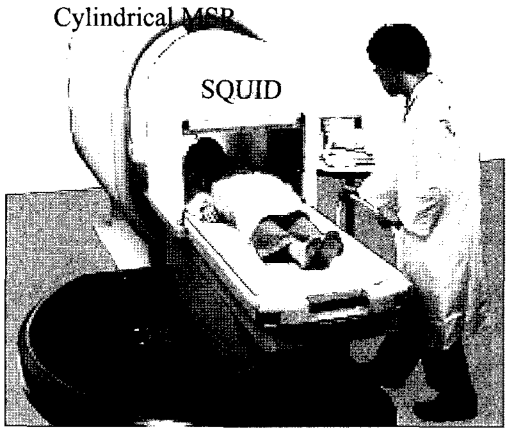
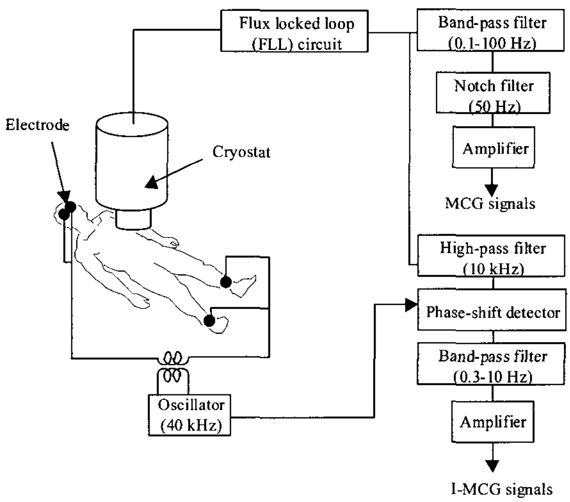


Fig. 6. Prototype 51ch-HTS MCG system.



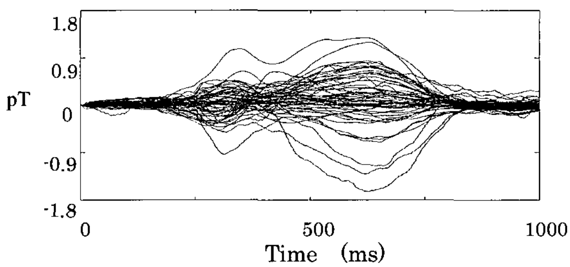


Fig. 7. Measurement of impedance magnetocardiogram.

V. Impedance Magnetocardiography

We recorded an impedance magnetocardiogram (I-MCG), which depends on a conductivity change under an induced current [27−28] (see Fig. 7). This new I-MCG technique can be used to detect blood circulation in the heart.

We have also developed a low-Tc I-MCG system with a room-temperature pickup coil [29] as a simpler means for measuring I-MCG signals. The noise level of this system for a 10-kHz current is 90 fT $Hz^{-1/2}$ (Fig. 8). We have developed the first I-MCG system that combines a high-Tc SQUID with a room-temperature pickup coil [30]. The I-MCG technique has been confirmed by another group [40].

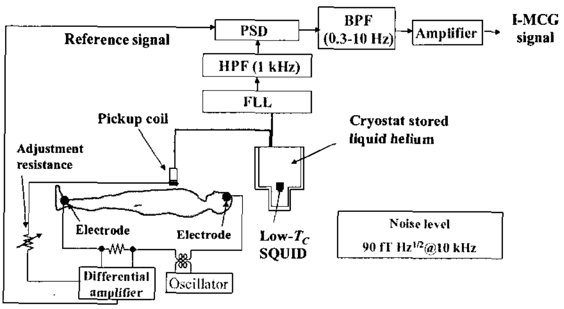


Fig. 8. Impedance-magnetocardiography system using normal pickup coil.

VI. Summary

We have developed magnetocardiography and impedance-magnetocardiography for visualizing electrophysiological images, which have been applied to clinical diagnosis. Much clinical significance has been reported using the technique. The significant clinical findings will lead to new strategies based on MCG and I-MCG for diagnosing heart disease.

Acknowledgments

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