MAGNETOCARDIOGRAPHY-An Effective Tool for Heart Scan

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Abstract-With the dramatic rise in heart disease among the people, there is a dire need to develop a method with high accuracy and precision. Patients with chest pain undergo extensive tests like stress test, contrast or radio tracer injection, radiation or catheterization. The above mentioned tests involve a lot of risk and do not produce immediate result. Magnetocardiography (MCG) is an effective tool to detect the electrophysiological activity of the myocardium which is rapid as well as risk free. The MCG recording system uses sensors called SQUIDs which enhances the accuracy by measuring the weak magnetic fields of the cardiac cycle. It has almost been 50 years since the first magnetocardiogram was recorded. Yet, due to lack of clinical trials, MCG is not used on regular basis. This review paper summarises its image acquisition process, advantages, applications, comparison with various tests and its future scope.

Keywords- Magnetocardiography, Electrocardiography, Sensitivity, Specificity, Tests Comparison

I. INTRODUCTION

Magnetocardiography (MCG) is a risk free, non-invasive technique that measures the magnetic field strength above thorax and the electrical signals of the heart. Special sensors are used to detect these signals called SQUIDs (Superconducting QUantum Interference Devices) which require liquid helium for cooling. The magnetic field generated by currents flowing in the heart are of the order 10-10 to 10-12Tesla [1], which is much weaker than the earth's magnetic field. Since the detectors are extremely sensitive, SQUIDs can detect the electrical signals of heart with ease and are the only tool available to detect MCG recordings. They are the only sensors with adequate sensitivity to measure the biomagnetic fields [2]. Biomagnetic activity of the heart can be detected in different phases of the cardiac cycle- P wave, QRS complex and T wave.

Balue and McFee recorded the first Magnetocardiogram in 1963[1]. They used two coils. Each coil had million turns of thin copper wires around a ferromagnetic core which was kept at room temperature. Major loophole was considered during the recording of Magnetocardiogram. To improve the results, the measurements were done in remote rural site away from the urban area because the magnetic field generated by electrical signals of heart are much weaker than the urban noise.

Looking back at the milestones of MCG, pre-clinical research studies were conducted in Germany, USA, Finland, Japan and Italy in 1980s. The first multichannel system was developed in 1988[3]. In mid 1990s inexpensive, small, unshielded MCG systems, which can directly work in the clinical settings were developed in Moscow (Russia) and Kiew (Ukraine). Because this system was more practical in the use of clinical routine, it was later developed in Germany and USA.

To add, Siemens Medical Engineering developed a 37-channel Krenikon system in 1990 which allowed simultaneous recording of chest without the need for repositioning the sensor. Krenikon is the first commercial multichannel system used for biomagnetic investigations [3]. The first successful measurement of the magnetic signals related to foetal cardiac activity was described long back in 1974.

II. ELECTROPHYSIOLOGY OF HEART

Both Electrocardiogram (ECG) and MCG have common physiological origin [2]. Due to temporary permeability of the ions in the membrane, cardiac muscles undergo de- and repolarisation. This causes changes in the cell membrane and the intra and extra cellular volume currents. Volume currents changes in the potential on the body surface which detects the changes in the electrical potential. The heart is electrically excited from the apex to the base. This current activity is represented in the form of equivalent current dipole. The spatial dispersion of the current dipole is calculated by Biot-Savart Law.

Surrounding anatomical structures, tissues and body fluids do not hamper the MCG recordings. Since these body tissues and fat layers or bones act as spatial low pass filter. Hence MCG recordings are more accurate than ECG recordings.

III. CLINICAL APPLICATIONS

Magnetocardiography is used to detect:

- The genetically transmitted arrythmogenic diseases such as Brugada syndrome [4].
- The arrythmogenic substrates of atrial arrythmias such as Atrial Fibrillation (AF) [5]

- Detection of ST shift (rest and stress MCG) and risk stratification in Ischemic Heart Disease (IHD)/ myocardial infarction/ coronary artery disease [6]
- Distinguishing the interatrial conduction pathways [7].
- Fetal arrythmia diagnosis [8]
- Prolongation of QT interval and dispersion [8, 9]
- Localization of cardiac arrhythmias such as ventricular tachycardia, premature ectopic beats, supra ventricular arrhythmias [9]
- Monitoring rejection after heart transplantation [9]
- Detection and quantification of left ventricular hypertrophy [9, 10]
- Localization of accessary pathways or pre-excitation sites in Wolff-Parkinson White syndrome[9, 10]
- Three-dimensional localization of ventricular pre-excitation sites [11]
- Detection of myocardial ischemia (rest and stress MCG) and viability [1]
- Assessment of the evolution of the myocarditis [2]
- Early diagnosis of arrhytmogenic right ventricular dysplasia[1] evaluation of percutaneous coronary
- intervention results [1,2]
- Identification of viable myocardium after myocardial infarction [1]

IV. ADVANTAGES

- Magnetocardiography is non-invasive i.e. It does not require electrode attachment as required in ECG nor are injections required. This further has an additional advantage. The artifacts associated with the fluctuating skin electrode contact potential which may affect the data is absent. The technique is non-invasive. Hence the pre preparation time like to apply a conducting gel in ECG is not required and patients with burns can also undergo this test [1].
- Measurements of magnetic field in MCG are absolute and do not require any reference.MCG is suitable for the detection of vortex also called circular currents in a plane parallel to the skin surface [2]
- MCG is insensitive to tissue interference. A variation in the electrical conductivity of the intervening tissues between the current source and sensor does not hamper the test. The presence of electrically insulating layer vernix caseosa does not hamper the detection of foetal MCG whereas recording foetal ECG during gestation period is difficult.
- Operation does not interfere with pacemaker function. Pacemakers are safe in the presence of MCG equipment.
- It is highly sensitive; it accurately detects tangential currents suitable for detection of abnormal activation.
- The examination is fast. It takes less than 10 minutes.
- Unlike ECG, to detect arrhythmia, exercise stress and breath holds are not required.
- Resting Magnetocardiographic imaging provides immediate results with very high positive predictive value for obstructive CAD that exceeds or meets the performance of SPECT [12].
- Considering the safety aspects, MCG is safe since radiation is not required.
- There is no age limit of the patient undergoing the MCG test. Even children can take this test.
- No biohazard wastes are produced.

V. DISADVANTAGES

The test disadvantages are categorized either as instrument drawback or data drawback. They are as follow:

- The test requires high capital cost due to its specific requirements like SQUIDs, magnetically shielded room and liquid helium infrastructure. The system operation and maintenance cost is also high since the operator needs to maintain a low noise environment and liquid helium is used.
- The machine is not portable unlike ECG machine.
- Since the MCG signals are extremely weak, it is necessary to take extra care during the design of the hardware to ensure that the measured MCG signals are not distorted [1].
- To demonstrate or test the instrument, realistic torso models are required.
- To analyse the data a special operator is required. A person with sound knowledge in cardiovascular physiology and cardiac electrophysiology is required.
- It is sensitive to pacemakers and metal objects like jewelry and currency notes, which are usually printed with a magnetic ink. Pacemakers create electrical signals that interfere with the MCG measurement; therefore, patients with pacemakers are not advised to take an MCG exam.

VI. IMAGE ACQUISITION

The MCG signals originating from a human subject are detected by an array of axial gradiometers [2]. Built- in laser pointers are used to adjust the patient's position on the MCG bed. The position is directed towards the 'suprasternal notch'. The role of an operator or a technician is to lower the column containing the sensitive magnetic field probes. This is done so that the probes are close to but not touching the patient's chest. The data is recorded sequentially at four pre-defined positions for 90 seconds at each position. Therefore the total time it takes for imaging is six minutes. Nine MCG traces and one MCG trace is recorded continuously during measurement and is displayed on the virtual oscilloscope. Four consecutive scans achieved from a 20cm x 20cm area above torso gives 36 traces of MCG data. The ECG trace is used as a time reference to average these 36 traces of MCG data acquired. The time averaged MCG trace from 36 positions is displayed on a 6 x 6 grid [1].The interspacing of the sensors is 4cm in a 3x3 grid configuration.

Interpolation and assignment of colour to the strength and direction of the magnetic field to the 36 positions of the MCG data yields magnetic field maps. These maps display the electric activity of the heart during the entire cardiac cycle as noticed from outside of the body. After data acquisition, raw, unfiltered MCG data are stored.

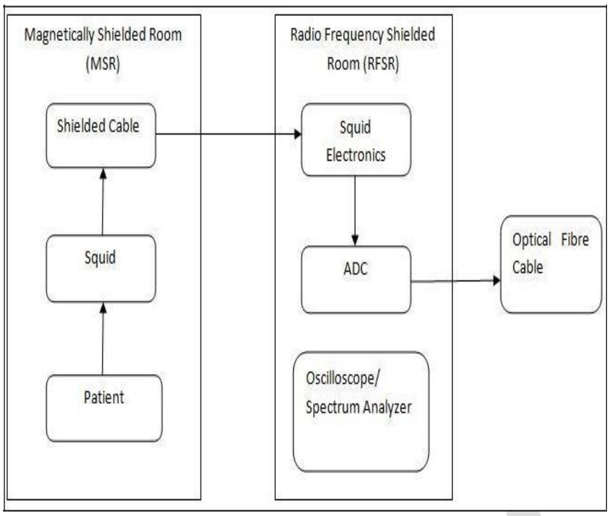

Fig 1. Flow chart of the Image Acquisition Process.

VII. MAGNETIC FIELD MAPS

MCG data is acquired at a frequency of 1 kHz. Hence there are 1000 maps for every cardiac cycle. The dynamics of interventricular septal depolarization is achieved from the sequence of 18 maps. Consecutive maps are evenly spaced by a time interval of 2 msec [14].

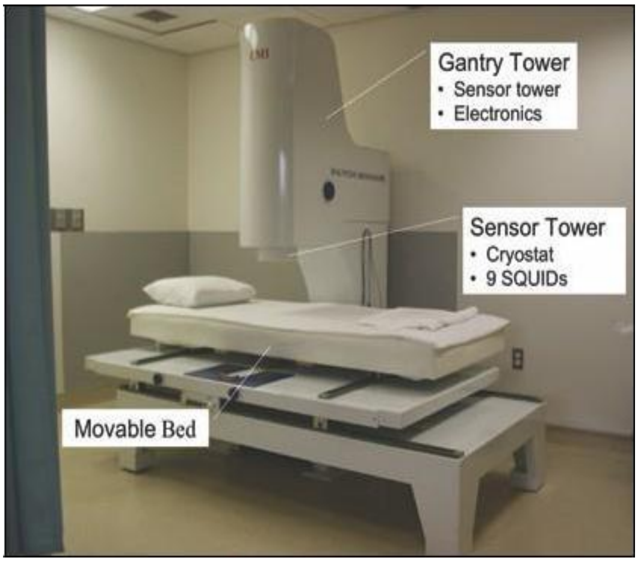

Fig 2. Magnetically Shielded Room [14]

VIII. DATA PROCESSING

First, the raw MCG data traces are processed manually to assure proper positioning and to delete any major magnetic influences. To process and interpret the acquired MCG data, an automated MCG analysis programme is used. This software takes around five (5) minutes to analyse the data. The method, Effective Magnetic Dipole Vector (EMDV) analysis, is based on an automated analysis of ventricular repolarisation. The electrical activity during repolarisation gives rise to effective magnetic vectors. The dynamic motion of the magnetic vectors describes the displacement of the electrical source. The software calculates 40 magnetic vectors at equally spaced time intervals around the peak of the T-wave (pre- and post-peak repolarisation). The detection of repolarisation abnormalities is directly related to the direction and dynamic motion of the magnetic vector around the peak of the T-wave [14].

IX. MCG AND ECG TEST

While comparing the two tests, their similarities and dissimilarities are taken into consideration.

Both the tests are risk free and detect the same morphological aspect (P-wave, QRS complex, and T waves) in the temporal dependence of the cardiac cycle.

With limited similarities, these tests are unique in their own way.

Moreover MCG is a multichannel system and not six surface lead system like ECG. The results here can be superimposed on magnetic resonance images for three-dimensional reconstruction of current density distribution. ECG is sensitive to both radially and tangentially oriented current

dipoles, while the MCG is more sensitive to the tangentially oriented current dipole.

X. COMPARISON OF MAGNETOCARDIOGRAPHY WITH OTHER TESTS FOR CORONARY ARTERY DISEASE

Table 1 Comparison of Magnetocardiography with ECG for patients with coronary artery disease.

Parameter	Magnetocardiography	Electrocardiography
Exposure to radiation	No radiation required	No radiation required.
Disadvantage of frequent monitoring	Expensive, sensitive to metal objects and pacemaker.	The U.S. Preventative Services Task Force do not recommend ECG as a routine screening procedure in patients without symptoms and those at low risk for coronary heart disease, because overuse of the procedure is more likely to supply incorrect supporting evidence for a nonexistent problem than to detect a true problem.
Capability to detect disease:		
• **Sensitivity**	Higher accuracy than ECG [13] 97.6%	26.2%
• **Specificity**	Specificity was almost same. [13] 82.8%	82.8%

Table 2 Comparison of Magnetocardiography with Echocardiography for patients with coronary artery disease

Parameter	Magnetocardiography	Echocardiography
Exposure to radiation	No radiation required	Works on Doppler sound effect hence no radiation required.
Disadvantage of frequent monitoring	Expensive sensitive to metal objects and pacemaker.	A common example of overuse of echocardiography when not indicated is the use of routine testing in response to a patient diagnosis of mild valvular heart disease. In this case, patients are often asymptomatic for years before the onset of deterioration and the resultsof the echocardiogram would not result in a change in care without other change in clinical status.
Capability to detect disease:		
• **Sensitivity**	More sensitive than echocardiography.[14] 86.9%	34.8%
• **Specificity**	More than echocardiography.[14] 93.5%	68.8%

Table 3 Comparison of Magnetocardiography with PET scan for patients with coronary artery disease.

Parameter	Magnetocardiography	PET scan
Exposure to radiation	No radiation required	Yes, since the system detects pairs of gamma rays emitted indirectly by a positron-emitting radionuclide
Disadvantage of frequent monitoring	Expensive sensitive to metal objects and pacemaker.	Being exposed to radiation cancer
Capability to detect disease: • **Sensitivity** • **Specificity**	 More than pet scan[15] More than pet scan[15]	 Less sensitive and specific than MCG[15]

Table 4 Comparison of Magnetocardiography with SPECT scan for patients with coronary artery disease

Parameter	Magnetocardiography	SPECT scan
Exposure to radiation	No radiation required	Yes, since this technique requires delivery of a gamma-emitting radioisotope into the patient, normally through injection into the bloodstream.
Disadvantage of frequent monitoring	Expensive sensitive to metal objects and pacemaker.	Being exposed to radiation cancer
Capability to detect disease: • **Sensitivity** • **Specificity**	 78.6% 75%	More sensitive[12] 98.4% Less specific [14] 12.5%

Table 5 Comparison of Magnetocardiography with Angiography for coronary artery disease.

Parameter	Magnetocardiography	Angiography
Exposure to radiation	No radiation required	Yes. It is done by injecting a radio-opaque contrast into the blood vessel and imaging using X-ray based techniques such as fluoroscopy.
Disadvantage of frequent monitoring	Expensive sensitive to metal objects and pacemaker.	Complications can include bleeding or bruising at the site where the contrast is injected, blood vessel damage on the route to the heart from the catheter and allergic reaction to the contrast.
Capability to detect disease: • **Sensitivity** • **Specificity**	 Less than Angiography[14] 87.1% More than Angiography[14] 85.7%	 90.3% 68.6%

XI. DISCUSSION

A combination of electric and magnetic measurements (i.e., ECG and MCG) gives a better diagnostic performance than either method alone with the same number of diagnostic parameters, because the number of independent measurements doubles. With the advent and exposure of Magnetocardiography and its findings, MCG tests are acknowledged by the cardiologists. MCG test are practiced over SPECT and ECG tests. MCG mapping has the potential to generate a three dimensional image and provide useful information required to carry out a cardiac surgery.

Research has been going on to use the MCG system to detect the functional activities of the cortical area by measuring the magnetic field associated with neuronal currents, which is known as magnetoencephalography (MEG) [16].

Clinical care of cardiovascular disease is time consuming and hence costly. Thus, there is a need for fast, reliable, effective and pocket friendly method to tackle heart disease. Magnetocardiography adequately fits into this category.

The shape of the chest is complex and there are in homogeneities due to the presence of lungs and blood vessels [16], which weighs down the accuracy of biomagnetic localization site. They can even influence the MCG measurements. Also the equivalent current dipole (ECD) model used for data processing makes an assumption. It assumes that the whole human body can be represented as a homogeneous volume conductor because the myocardial fibres are referred as the electrical current dipoles. The assumption is made since it is not possible to resolve the current distribution on a small scale. This assumption allows an easier mathematical approach for the interpretation of magnetic signals generated by the heart [3]. Thus computerized models representing realistic volume conductor have been designed. Moreover to improve the accuracy of MCG recordings, we have to create torso models using magnetic resonance imaging (MRI). MRI data are essential for the construction of individualized volume conductors which reflect the real body shape of the subject undergoing the examination [2]. Magnetic resonance imaging is useful to improve the spatial accuracy of the mcg data reconstruction.

Looking at the current scenario, where the WHO estimates that 3% of rural and 7% of urban population which is roughly 50 million suffers from coronary artery disease, cardiovascular diseases have been a major concern to all Indians. The percentage of people having heart disease had increased from 1-2 to 3-5 % in rural India and from 2-3 to 10-11 % in urban India as per statistics provided by A Enas, Director, CADI (Coronary Artery Disease among Asian Indians). Due to the limited number of clinical studies, researchers have not come up with a definite conclusion about the clinical application of Magnetocardiography. Since the cost of the entire system and infrastructure is high, research on Magnetocardiography has been limited. If MCG tests are commercialised then the detection of cardiovascular diseases will be easy and would no more be threatening. It would benefit both the patients and the doctors. And would also save the patient's time and energy. It would also save the doctor's operative time since operator/technician is needed. With high doctor to patient ratio in India which is currently 1:1000 lesser than what WHO has prescribed, Magnetocardiography would be a boon.

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