Magnetocardiographic stress test investigations analyzing ventricular repolarization changes

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1 Introduction

Since the early beginning of magnetocardiography (MCG) the question of whether or not SQUID measurements contribute additional information to the understanding of the heart's electrophysiology has been intensely discussed. Starting with observations from MCG studies in a canine model and in man, made by Cohen and coworkers, the myocardial repolarization of the ventricles was investigated in various studies [1, 2, 3, 4]. It was claimed that ventricular repolarization during ischemia induce weak injury currents undetectable in the surface electrocardiogram (ECG).

Interestingly, differences in ventricular repolarization were also seen in healthy subjects during stress testing, when signals from MCG and ECG were compared by the Romani group [5, 6].

In a more comprehensive experimental setting these observations were confirmed by the Berlin group of the Physikalisch Technische Bundesanstalt [7]. Here body surface potential maps (BSPM) were compared to magnetic field maps (MFM) before and during pharmacologically induced stress. Using correlation analysis of temporal field changes and approaches based on multipole expansions of the field and comparing magnetic and current dipole changes during ventricular repolarization, vortex components of the field were suggested as the physical explanation of the observed changes in the MCG during stress.

In the meantime, further studies performed on healthy volunteers have shown magnetic repolarization changes immediately after bicycle exercise which were not found in ECG: the Erlangen group noted a T-wave inversion in the MCG in a large proportion of subjects [8] and investigators in Helsinki found a caudal-right shift in the MFM at the T wave maximum (T max) in 11 out 12 subjects [9]. The amount of ST-T segment changes differed interindividually but, typically, MCG changes exceeded the changes seen in simultaneously recorded ECGs.

As MCG/ECG differences are best explained by the existence of vortex components of the current field, those changes can be investigated by SQUID measurements exclusively, as they are undetectable with the use of the surface ECG alone.

2 Repolarization under stress conditions in coronary artery disease

The first observations of MCG repolarization changes due to stress were made in healthy individuals and therefore were presumably of normal/ physiological origin. With respect to pathological conditions, there have been reports of repolarization differences between patients with and without coronary artery disease (CAD) which became apparent under stress.

Using BSPM, Montague et al [10] were able to show that patients with CAD revealed an increase in negative potential values in the ST integral map after cessation of exercise which was not apparent in healthy subjects. Furthermore, a discrimination between single and multiple vessel disease was possible in CAD patients.

On the other hand there have also been MCG studies demonstrating repolarization effects of stress in CAD patients. Examining ST and T max MFM orientation after cessation of exercise, Hänninen et al. [11] were able to discriminate between subjects with and without single vessel CAD. They also noted differences in the single vessel CAD group with respect to the location of the affected vessel.

Furthermore, the Bochum group has noted changes in the non-dipolar content of QT integral maps and in the spatial QT dispersion during pharmacologically induced stress in patients with CAD which were not found in subjects without CAD [12,13].

These studies indicate that in CAD patients electrophysiological changes during ventricular repolarization occur which become apparent during stress and that these changes are evident in both BSPM and MFM. On the background of the MFM changes which have been associated with vortex currents in healthy volunteers, the question arises as to their presence and articulation under pathological conditions. Several groups are at present investigating the field of MCG stress testing in both healthy subjects and patients. Their results are reported in this proceedings volume [14,15].

3 Theoretical considerations

To date, little work has been published dealing with possible explanations on why stress related changes during the ST-T appear in magnetic, but not electric activity. These proceedings also contain two contributions which attempt to shed some light on this phenomenon [16,17]. Based on various models of the heart and torso which, among other factors, take curved myocardial surfaces into consideration, both papers offer a good point of departure for the theoretical study of repolarization changes due to stress.

4 Discussion

The proposed explanation for the differences between ECG and MCG - experimentally found - is the existence of vortex components of the current field. In future work on this topic, a number a factors must be taken into consideration which may influence the findings and therefore have some bearing on the interpretation of the results. These include the type of stress induction (physical exercise, pharmacological stress), the target heart rate under stress as well as the data acquisition setting (i.e. during or after stress). With respect to data analysis, one may examine the signal at selected instants in the time domain or implement mapping techniques and analyze various time instants or time integrals. The studies available to date vary on many of these aspects. Nonetheless their results seem to point in the same direction.
Summarizing, the concept of recording vortex components of the current field by the use of the MCG is gaining acceptance. The physiological origin of vortex components under stress-test conditions remains unclear. More information will be available by intensely investigating appropriate models as well as by increasing the empirical evidence by performing studies in healthy subjects as well as patients.

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