Non-invasive arrhythmia risk evaluation in clinical environment

Summary We have applied various methods to extract parameters from high-resolution magnetocardiographic (MCG) and electrocardiographic (ECG) recordings for characterizing the risk of life-threatening arrhythmias. The methods include detection of late fields and late potentials at the end of the QRS, abnormalities in spectral variability and signal fragmentation during the QRS, and variability in the heart rate. In addition, we have developed methods to convert MCG signals measured with any sensor configurations to a common presentation form. The signal processing methods have been implemented on a user-friendly interface which allows fast and easy use in a clinical environment.

Key words Magneto cardiology – arrhythmia risk evaluation – signal-averaged electrocardiography

Introduction

There is a constant clinical interest for non-invasive identification of patients at risk of fatal arrhythmias. Variety of methods have been developed for this purpose. Despite the fact that the negative predictive value of such methods is often high, the positive predictive accuracy has remained only around 30%. As the sensitivity and the usability of the instruments for recording both the high-resolution (HR) magneto- and electrocardiographic (MCG, ECG) signals and multichannel mappings have improved, the need for more sophisticated signal analysis methods has also increased. Automatic algorithms are user-independent and can detect small features in signal morphology. They can also extract specific features from temporally and spatially large data sets.

The main approaches for non-invasive arrhythmia risk stratification can be divided into three categories according to their physiological scope of interest: 1) the activation discontinuities during the ventricular depolarization are studied in late potential and late field analysis meth-
ods, in the so-called ‘Berlin fragmentation analysis method’, and in spectral turbulence analysis; 2) the heterogeneity during the repolarization of the ventricles is studied in QT dispersion analysis; 3) the function of the autonomic nervous system is studied in heart rate variation analysis. All these parts can be used as arrhythmia risk indicators either separately or by combining the independent components of each method.

In this paper, a short overview of the MCG risk analysis methods is given. The focus is on the methods that we have applied for analyzing 5-min ECG and MCG mappings in the BioMag Laboratory of Helsinki University Central Hospital (1). We have also studied methods to convert MCG signals measured with any sensor configurations to a common presentation form, in the viewpoint of multicenter MCG studied in the future.

**Recordings and preprocessing**

**Measurements**

The BioMag Laboratory at Helsinki University Central Hospital is equipped with a state-of-the-art 67-channel HR-MCG recording system, operated in a magnetically shielded room (1). The MCG data are measured via the chest of a supine patient at rest. Simultaneously with MCG, 64 ECG channels can be recorded, including the standard 12-lead ECG and xyz-lead systems.

We have implemented the methods presented in the next chapters into a user-friendly Xwindows interface. As an outcome, the user can produce a two-page report containing the basic results after a patient measurement. The report includes numerical results and figures illustrating each method of the analysis and is suitable for clinical work. The software has already been tested in large patient series for assessing the arrhythmia risk (2, 3).

**Averaging**

To analyze specific parts of the heart function, the continuous ECG/MCG signal has to be triggered to identify the heart beats. Each QRS complex is triggered by finding the time instant where the slope of the signal exceeds the predefined threshold value. After triggering, the signal averaging is often applied to improve the signal-to-noise ratio. The beat invariant features are enhanced in averaging and, thus, smaller details can be analyzed. Although, the invariance of the ECG or MCG morphology is not strictly fulfilled, the averaging is usually acceptable if there is no physiological reason to expect any dissimilarity.

The similarity of the beats included in the average is further increased by rejecting the abnormal or too-noisy beats. We have used a template beat, selected from a few representative beats by an experienced user, to which the successive beats are then compared for similarity. Next the maximum cross-correlation between the template and a triggered beat is used for precise timing. The rejection is performed by using noise criteria, two different distance measurements, and a so-called “tube” criterion, where an envelope of the signal is formed by moving the signal both in time and amplitude direction (Fig. 1) (4).

**MCG signal conversion**

Comparison of MCG data recorded with different multichannel magnetometers is difficult because differing sensor types and locations do not allow measurements from the same locations in respect of the body. In addition, the comparison of the signals recorded in one measurement with different types of sensors is problematic. Multichannel MCG signals exhibit significant differences, both in spatial distribution and in time domain. For example, the amplitudes and even durations of the QRS waveforms may vary considerably between planar and axial gradiometers (5). Therefore, in our analysis the seven axial gradiometers and the 30 planar gra-