Comparison of magnetocardiography and electrocardiography

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ABSTRACT

Objective: Automated techniques were developed for the measurement of cardiac repolarisation using magnetocardiography.

Methods: This was achieved by collaboration with the Physikalisch-Technische Bundesanstalt (PTB), Berlin, Germany and the Grönemeyer Institute of Microtherapy, Bochum, Germany, to obtain recordings of magnetocardiograms (MCGs) in cardiac patients and healthy subjects. Manual and automated ventricular repolarisation measurements from MCGs were evaluated to determine the clinical relevance of these measurements compared with electrocardiograms (ECGs).

Results: Results showed that MCG and ECG T-wave shapes differed and that manual repolarisation measurement was significantly influenced by T-wave amplitude. Automatic measurements of repolarisation in both MCGs and ECGs differed between techniques. The effects of filtering on the waveforms showed that filtering in some MCG research systems could significantly influence the results, with 20 ms differences common. In addition, MCGs were better able to identify differences in the distribution of cardiac magnetic field strength during repolarisation and depolarisation between normal subjects and cardiac patients. Differences were also determined in ventricular repolarisation between MCGs and ECGs, which cannot be explained by channel/lead numbers or amplitude effects alone.

Conclusion: The techniques developed are essential, because of the many extra MCG channels to analyse, and will encourage the use of MCG facilities. *(Anadolu Kardiyol Derg 2007: 7 Suppl 1; 20-2)*

Key words: magnetocardiography, electrocardiography

Introduction

Heart disease claims the lives of 30% of people in the UK. It is a major concern of the NHS and of health care in general. One of the important, but relatively neglected, areas of concern is cardiac repolarisation. Each time the heart depolarises, producing a heart beat, it needs to recover or repolarise, in readiness for the next heart beat. Abnormalities in repolarisation are potentially fatal.

In clinical practice, dispersion of repolarisation across the heart can provide valuable clinical information. Repolarisation is measured from start of the Q wave to the end of the T wave on the electrocardiogram (ECG). Dispersion of repolarisation in any subject is usually measured as the difference between the longest and shortest QT repolarisation measurement. Greater than normal levels of dispersion are associated with death, especially sudden death in heart failure.

Traditionally, manual QT dispersion measurement has involved assessment and measurement of 12 leads of the ECG. This process is tedious and, as the end of the T-wave is often ill defined, is subject to human error. Reliable automatic measurement of QT dispersion is therefore desirable. Research from the Newcastle Research Group in electrocardiogram analysis has overcome many of the difficulties associated with automated measurement, and one of our papers showed unexpectedly that our automated techniques were more reliable in measuring clinical differences than manual measurement, because they were based on terminal T wave features.

In parallel with our research enormous advances have also been made in magnetocardiography (MCG). Magnetocardiography has the major potential advantage over ECG of allowing the collection of MCG waveforms without any contact with the patient. In addition, the MCG has the potential to give different information, since the waveforms are not influenced in the same way as the ECG by complex conduction pathways outside the heart's boundary.

The aim of our research was to investigate and quantify the differences in repolarisation measurement between ECG and MCG, and to develop useful algorithms for the practical analysis of MCGs.

This was achieved by the collaboration of Newcastle with two other internationally renowned research groups with significant expertise in magnetocardiography; the Physikalisch-Technische Bundesanstalt (PTB), Freie Universitat (Benjamin Franklin Hospital) in Berlin and the Grönemeyer Institute of Microtherapy, University of Witten/Herdecke, Bochum, Germany.

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Methods

Transfer of existing MCG data to Newcastle

The Berlin group measured MCGs using 49 non-contact SQUID gradiometers, obtaining recordings of MCGs in cardiac patients and normal subjects. These data were transferred to Newcastle enabling initial studies and algorithm development. The schematic layout of the 49 simultaneous MCG waveforms from one heartbeat from one subject is shown in Figure 1.

Collection of simultaneous MCG and ECG data

The collection of simultaneous MCG and ECG signals required special procedures to ensure that the ECG recording technique did not interfere with the MCG data. In Berlin, recordings were made at the Benjamin Franklin Hospital. After the project started, collaboration was offered by the Department of Biomagnetism, Research and Development Centre for Microtherapy, Bochum, and this enabled a greater number of recordings to be obtained than originally proposed. In total, 61 simultaneous recordings were collected from a wide range of cardiac conditions and normal subjects (Fig. 2).

Results

Initial assessment of MCG by manual measurement

Preliminary multichannel analysis of MCGs from normal subjects showed that MCG T-wave shapes differed from ECG T-wave shapes and that manual repolarisarion measurement was significantly influenced by T-wave amplitude. Next, repolarisation time was measured manually in 25 subjects. Results showed that errors in MCGs were similar to ECGs, with 30 ms differences between cardiologists. This compares with 40 ms for normal repolarisation dispersion.

Determine appropriate filtering and baseline identification techniques

Preliminary analysis of multichannel MCGs from normal subjects showed that repolarisation time in MCGs was significantly affected by standard frequency filtering at 40 Hz low pass and 0.5 Hz high pass often used by international MCG researchers (1). Analysis with MCGs from 23 subjects with a range of different frequency filters (4 low pass, 1 notch, 3 high pass filters) confirmed these findings and showed that filtering in some MCG research systems significantly effects the result, with 20 ms differences in repolarisation time common (2).

Quantitative comparison of different automated analysis techniques

Preliminary analysis of an automatic technique which used modeling of the terminal T wave section to determine the end point was applied to MCG waveforms of normal subjects and compared with manual measurement. Results showed that automatic repolarisation intervals were shorter than manual measurement (3).

Four automatic measurement algorithms for measuring T-wave end were applied to multichannel MCG and 3-lead ECG recordings of 23 subjects. Results were compared with manual measurement and showed that although automatic detection of the repolarisation interval in MCGs saves time and also removes subjectivity introduced by different manual analysts, automatic repolarisation interval measurements in the MCG and ECG differed markedly between techniques, by 52 ms in MCG and 64 ms in ECG (4). Additional analysis of the results showed that the variability of automatic repolarisation interval measurements in the MCG was significantly less than that of the ECG. Manually determined QT interval was on average 15 ms longer in the MCG than ECG, suggesting increased shape changes in MCG T-wave signals, compared with ECG (5).

Following the development and quantification of the automatic algorithms for T-wave end detection the spatial distribution of cardiac magnetic field strength during ventricular depolarisation (R-wave) and repolarisation (T-wave) was measured automatically

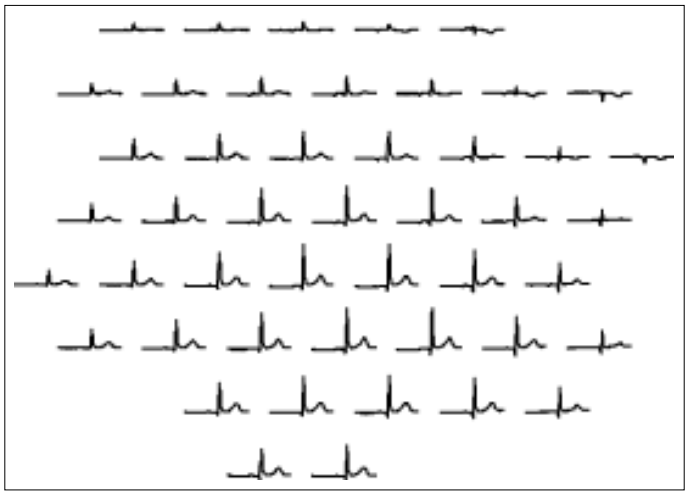

Figure 1. Example of 49 simultaneous non-contact MCG waveforms, arranged in a lattice on a plane covering an approximate circular area of diameter 21 cm

MCG- magnetocardiogram

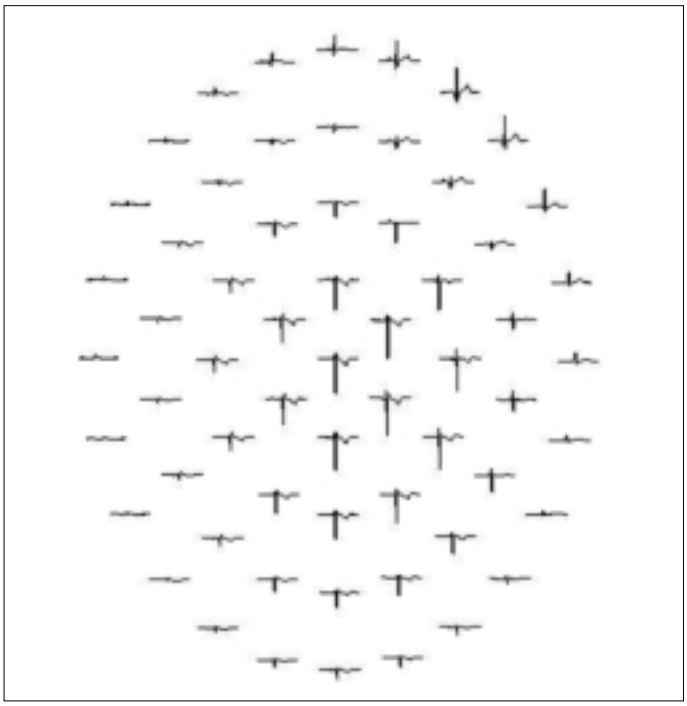

Figure 2. Example of 61 simultaneous non-contact MCG waveforms obtained by the Bochum magnetometer for one heartbeat for one subject

MCG- magnetocardiogram

in both normal and patient groups. The MCG was able to identify differences in the distribution of magnetic field strength, with a shift in the T-wave relative to the R-wave, even without T-wave inversion. These results should enable the improvement of theoretical models for the explanation of the cardiac depolarization and repolarization process (6, 7).

Quantitative comparison of MCG and ECG recordings

Preliminary analysis of the first subjects studied showed differences in dispersion of ventricular repolarisation time between ECG and MCG, with MCG greater than ECG. We also showed that averaging, which is commonly used to reduce MCG noise, significantly influenced ventricular dispersion in both MCG and ECG waveforms (8).

Further analysis of the full dataset of simultaneous MCG and ECG recordings showed significant differences in the dispersion of ventricular repolarisation between ECG and MCG in both healthy and diseased groups, influencing repolarisation distribution at the body surface in the MCG which cannot be explained purely by amplitude effects (9). Dispersion in the ECG is known to be primarily amplitude dependent. As in the preliminary analysis, MCG dispersion was significantly different and greater than ECG dispersion. With automatic measurements both MCG and ECG were able to discriminate between normal and patient groups, with MCG having the greatest discriminating power, with mean differences of 24 ms compared with 8 ms for ECG. Manual repolarisation interval measurement was unable to distinguish between normal and diseased subjects in both ECG and MCG. These results are being submitted for peer reviewed publication. The most important results from our study confirmed significantly greater dispersion with MCG as expected by our original hypothesis.

Discussion

Specific problem areas effecting the repolarisation interval measurement of MCGs arise from the biphasic shape of the end of the T-wave. In order to improve automatic analysis of these waveforms automatic algorithms were generated to reduce measurement uncertainty and variability in these signals. These algorithms were implemented for the dispersion of ventricular repolarisation analysis described above. Measurement uncertainty was reduced by automatically rejecting predefined conditions. The number of channels required to give a consistent estimate of dispersion was also investigated, but approximately 25 channels was the minimum number necessary to identify the differences detected in this study.

Conclusion

The techniques developed are practical, and will encourage the use of MCG facilities, leading to the sales of such equipment in the UK and elsewhere. We realise that this is likely to be some years away, but we expect to be involved in developments as our MCG computer analysis techniques will be valuable to companies working in this area.

In addition, local cardiologists at our Regional Cardiothoracic Centre in Newcastle are keen to have a facility based on our research results. As well as improving understanding of repolarisation (the goal of our research), it will aid diagnosis and give practical assistance with therapy for many cardiac conditions as well as abnormalities of repolarisation (10, 11).

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