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MULTICHANNEL ECG MEASUREMENT FOR NONINVASIVE IDENTIFICATION OF HEART REGIONS WITH CHANGED REPOLARIZATION

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Abstract: Multichannel system for ECG measurement and body surface potential mapping is introduced and its application for noninvasive identification of ischemic heart regions with changed repolarization is presented. The system uses up to 128 active electrodes, separate common mode signal sensing and active neutralization of the patient to get optimal signal quality. Microprocessor controlled and battery powered data acquisition module is connected through an optical extension cable to the USB port of a personal computer with Windows based measuring and data analysis software. In 11 patients with myocardial infarction, integral maps of the QRST interval of the ECG signal were measured before and after the percutaneous cardiac intervention. Changes in the maps together with information on a model of the patients' torso volume conductor were used to calculate an equivalent current dipole characterizing the region influenced by the therapy. In this way, the affected ischemic region could be noninvasively identified in 7 patients.

Keywords: body surface potential mapping, noninvasive cardiac diagnostics, dipole model of the cardiac generator

1. INTRODUCTION

Body surface potential (BSP) mapping is a non-invasive electrocardiographic method enabling more precise diagnostics of cardiac diseases based on detailed registration of surface cardiac potentials using high number of sensing electrodes. During the last 4 decades, experience with different mapping lead sets showed that information contents in maps constructed from 24 to 240 leads is greater than that of standard 12-lead ECG. Model studies prove that maps constructed from higher number of leads could substantially improve the diagnostic value of the maps. Moreover, BSP maps together with information on torso structure obtained from MRI, CT or ultrasound systems can be used for advanced inverse diagnostic methods for non-invasive assessment of electrical abnormalities in the cardiac tissue.

Local ischemia of myocardial cells is connected with changed repolarization, namely shortening and decrease of their action potentials. These changes are reflected in changed surface ECG potentials and it is generally accepted and confirmed by advanced model studies that integrals of potentials over the whole ventricular depolarization - repolarization period (QRST interval in ECG) practically depend only on the action potentials and not on the ventricular activation sequence [1]. Measured changes in surface QRST integral maps together with the knowledge of torso geometry and electrical properties thus can be used as input data for a non invasive assessment of heart regions with changed repolarization.

2. PURPOSE

In this paper, a newly developed high resolution ECG mapping system that can be used for advanced BSPM-based cardiac diagnostics is presented and possibility to locate heart regions with changed repolarization using measured difference integral maps and model of the patient torso is demonstrated.

3. METHOD

Body surface potentials were measured from multiple chest leads using a new high resolution BSP mapping device. Nonivasive inverse method based on a dipole model of the cardiac electric generator, realistic model of the chest geometry and electrical properties of inhomogeneous human torso were used to identify local ischemic changes in the myocardium.

3.1. BSP mapping device

To get high quality multi-channel ECG recordings necessary for the inverse solution, a battery powered ECG mapping system ProCardio-8 was developed. It consists of a data acquisition subsystem and a common personal computer used for measurement control, processing of measured data and their analysis and model-based interpretation (Fig. 1).

The multi-channel amplifying and measuring subsystem is placed in a patient terminal box and connected to the USB port of the host personal computer. The patient terminal is powered by a rechargeable Li-ion battery module. Its small geometric dimensions (approx. 15x15x10 cm) and metallic shielding minimize the capacitive coupling with the environment in the examination room.

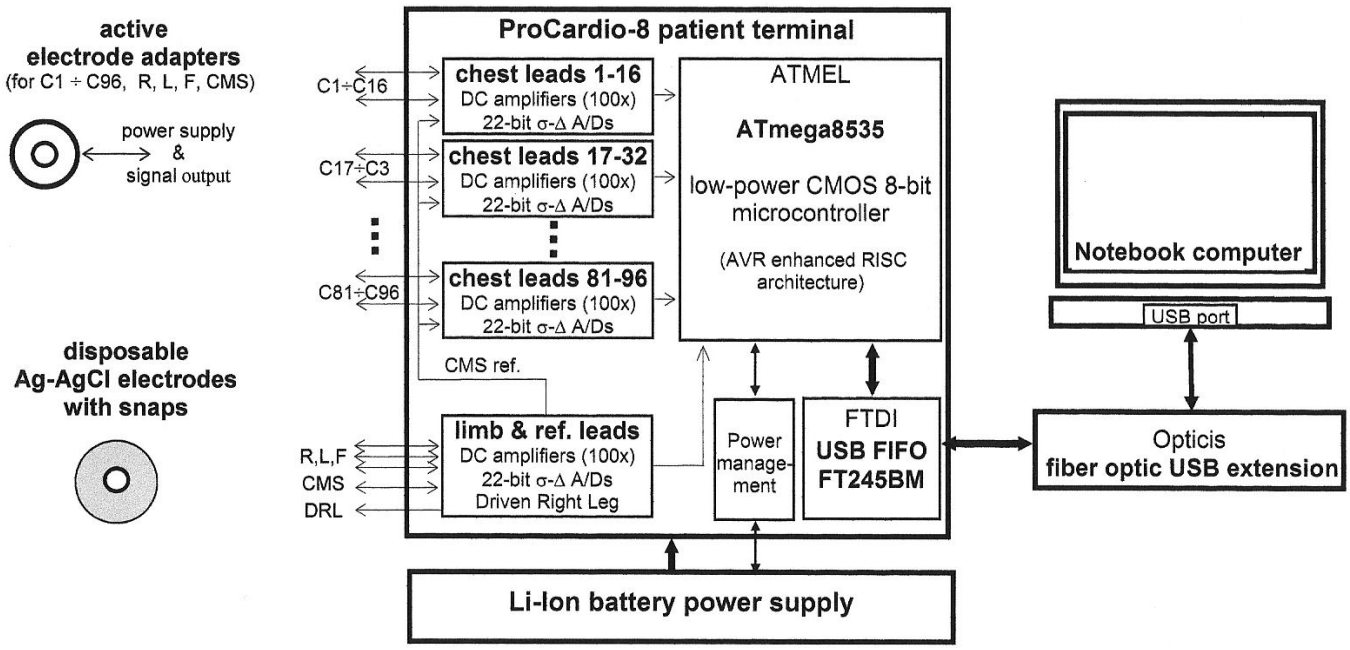

Fig. 1. Block scheme of the ProCardio-8 system

The data acquisition system can be configured to record ECG signals simultaneously from up to 256 leads. The system is modular; one board contains 16 input channels with two 24-pin Centronix connectors. Currently 100 channels are implemented and the mapping system enables to record signals from 96 chest leads and optional limb leads.

ECG signals are sensed by disposable Ag-AgCl electrodes with active adapters connected to the electrode snaps (Fig.2). Low output impedance of the active electrodes reduces the possible disturbing signals induced in the electrode cables.

Fig. 2. Active electrode formed by a disposable Ag-AgCl electrode and active adapter with a snap connection and a special multi-wire cable

To minimize the common mode signal, active neutralization of the patient using a DRL (driven right leg) electrode is employed and all signals are measured relative to a common mode sense electrode CMS that that can be attached to such a place on the patient body that the overall noise in ECG signal is minimal. Besides reducing the common mode voltage, the current limiting resistor in the DRL also protects the patient against defects in the amplifiers. In the worst case that one of the active electrodes would break down and would become shorted to the power supply voltage, function of the DRL results in a maximum error current of 50 µA which complies with the value specified for the IEC-60l CF type isolation used in Europe (by changing the value of the resistor, maximum of 10 µA can be achieved to comply with the US standard).

We have integrated an additional patient protection in the ProCardio 8 data acquisition module which disables the power supply when some error is detected by the DRL circuit and the error current reaches approx. 80% of the maximal allowed value.

Each measuring channel is equipped by a DC-coupled ECG amplifier with a fixed gain of 100 and a 22-bit σ-Δ A/D converter. Sampling frequency can be selected in the range between 500 and 2000 Hz. The data acquisition system is controlled by a low-power 8-bit RISC microcontroller Atmel ATmega8535 based on the AVR enhanced RISC architecture. Controller streams the serial data from selected channels to the host PC. Selection of measured channels and proper formatting of digitized data with several possible byte lengths is controlled by commands received from the host computer.

Communication with the host PC over an USB FIFO circuit (FT245R from FTDI) provides easy data transfer to or from the host with data rates of up to 1 MB/s.

To further minimize the coupling between the patient terminal and the host PC and to guarantee patient safety a fiber optic USB extension cable is inserted between the

patient terminal and the USB port of the host PC. The optical fiber link combined with battery power supply of the patient terminal provides complete patient safety with leakage currents well below the permitted limits (l μA).

The patient terminal is powered by a rechargeable Li-Ion battery module. Due to the advanced power management controlled by the by the on-board microcontroller the system can work the whole working day before the battery has to be recharged.

Modular ProCardio-8 application software is running under Windows/XP. Real-time ECG data acquisition program enables to set the working mode of the data acquisition subsystem, to check the electrode contacts and to read and store the stream of measured data. ECG signals from selected channels can be simultaneously monitored on the PC screen. Real-time data acquisition is followed by off-line ECG processing, body surface potential mapping and diagnostic evaluation of the measured data by modular application software written mostly in MathLab.

3.2. Assessment of ischemic heart regions

The method for assessment of local ischemic regions is based on evaluation of changes in QRST integrals caused by local ischemia and measured in many surface ECG leads. These changes can be interpreted as being caused by additional sources originating in the ischemic heart region due to changed action potentials during the repolarization phase. If the heart region is small, these sources can be represented by a single equivalent current dipole (ECD) located at the centre of the region. To estimate the location of the region a fixed dipole model located at one of *n* selected positions within the ventricular myocardium was used. For each of these positions, equivalent dipole was inversely estimated:

$$\boldsymbol{M}_i = \boldsymbol{T}_i^{+}\,\boldsymbol{\Phi} \qquad \text{for } i=1, 2, \ldots n \qquad (1)$$

where $\boldsymbol{M}_i$ is estimated integral of the dipole moment of a dipole located at the *i*-th position in the myocardium, $\boldsymbol{\Phi}$ are differences in QRST integrals of surface potentials measured in *m* surface points, and $\boldsymbol{T}_i^{+}$ is a pseudo-inverse of the transfer matrix between the *i*-th dipole and potentials in m surface points. Matrix $\boldsymbol{T}_i$ depends only on the geometry and electrical properties of the torso. Minimal rms error between measured differences in QRST integrals and integrals produced by dipoles estimated at each of the *i* positions was used as a criterion for finding the best ECD representing the changes in QRST integrals.

3.3. Measured data

Possibility to assess the heart region with changed repolarization was tested on patients after myocardial infarction (MI) that underwent percutaneous cardiac intervention (PCI) on one of the main coronary arteries. It was hypothesized that some ischemic regions around the infracted tissue will disappear after the treatment due to the tissue revascularization.

11 patients after MI (age 45–69, 8 men, 3 women) that underwent successful PCI of a single coronary vessel: 8 LAD (left anterior descending artery), 1 RCx (right circumflex artery) and 2 RCA (right coronary artery) were examined and surface QRST integral maps before and after the PCI were computed from 32 ECG leads according to Lux (Fig.3).

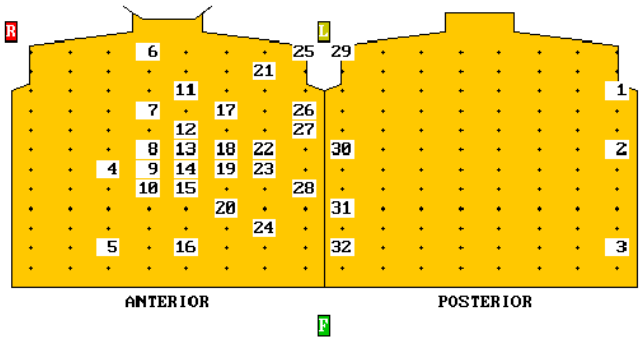

Fig. 3. Positions of 32 measured leads according to Lux were used in the study. Left part of the panel represents anterior torso, right part represents the back. For practical reasons no electrodes on the back were used.

Values in maps were linearly corrected for QT interval length if it varied more than 5% between the measurements. Inhomogeneous torso model with lungs and both realistic and analytical heart model was used for all patients to calculate an ECD representing the region with changed repolarization (Fig. 4). Ventricular volume was divided to 28 segments and possible positions of the ECD were placed in their gravity centers.

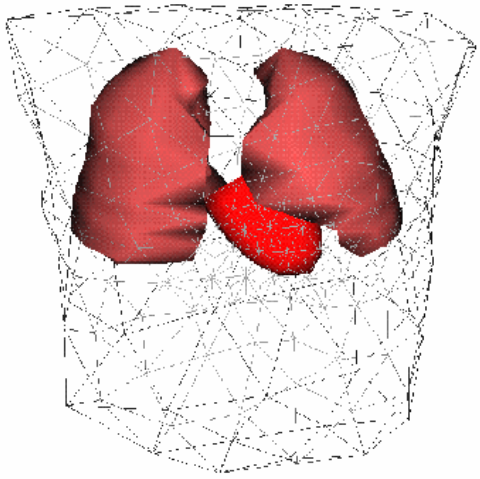

Fig. 4. Inhomogeneous torso with lungs and analytical heart model used in the study.

4. RESULTS

In all 11 studied patients there were noticeable changes in QRST integral maps after the PCI. In 8 of them the measured difference integral maps could be reasonably represented by maps generated by single current dipole. In 6 cases the relative rms error between the measured and approximated difference integral map was < 35%, in another 2 patients it was < 56%. In remaining 3 patients rms error of

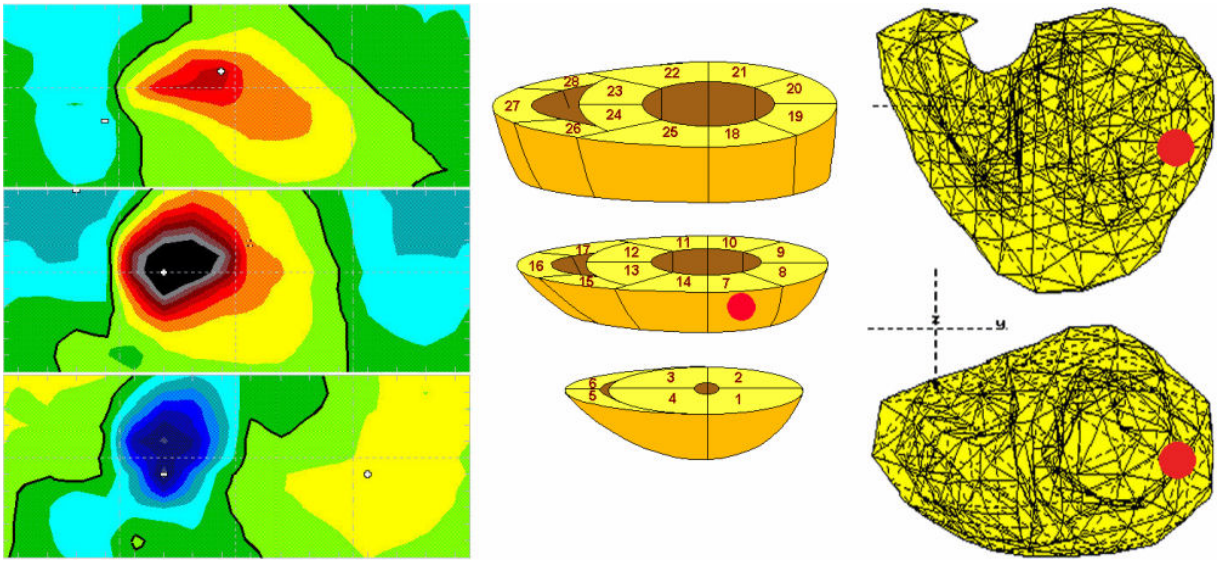

Fig. 5. Left: QRST integral maps in a MI patient (N693, female, 69 years old, 95% stenosis of RIA) before and after the PCI on LAD (top, center) and difference integral map (bottom). Left part of each map represents values of QRST integrals on the anterior chest, right part values on the back. Step in maps is 12 mV.ms, zero isointergral line is marked. Center and right: Analytical and realistic heart model with marked position of the calculated equivalent current dipole representing the repolarization changes caused by PCI (in heart segment 7 and 8, respectively).

the approximation was higher and they were excluded from further analysis. QT interval was corrected to compensate for the changed heart rate between the measurements in 6 of the 8 analyzed patients.

Despite the use of a common torso model, in 7 of 8 analyzed patients the positions of estimated ECD matched the region supplied by the treated vessel or at least they were located as expected at anterior or postero-lateral wall of the left ventricle. Dipole moments were directed inwards the ventricle and suggested changes near the endocardial wall. In 1 patient after PCI on RCA the ECD was probably incorrectly located in mid anterior left ventricular wall.

In Fig. 5 there is an example of measured integral maps before and after the PCI on the left anterior descending artery (LAD) and corresponding difference integral map. Estimated ECD location on the anterior left ventricular wall as identified using both, analytical and realistic heart model is shown in the central and right panel.

5. DISCUSSION

Our experience with departure integral maps (comparing patient integral map with a mean integral map of a normal group) showed that the pathological changes are relatively small when compared with normal inter-individual fluctuations and can hardly be detected by departures from mean normal integral maps [2].

Therefore the possibility to identify small heart regions with changed repolarization using model-based interpretation of differences in QRST integral maps was extensively tested on simulated data [3]. The simulations showed that changes in QRST integral maps caused by small ischemic lesions were greater than observed intra-individual variability what in principle allows their identification. Small ischemic lesions could be localized with a mean error of 11±8 mm, for larger transmural lesions the error reached 43 mm what suggests that more sophisticated model should be used for extensive or multiple ischemic regions. ECD localization from 32 ECG leads provided slightly worse results than from 62 or 192 leads. Hence more than 32 leads should be used in future if possible.

6. CONCLUSIONS

Acceptable localization of an equivalent current dipole representing the revascularized region in 7 of 11 MI patients after PCI suggest that ECG mapping and model-based interpretation of difference QRST integral maps could be a useful tool helping to identify small heart regions with changed repolarization.

ACKNOWLEDGMENTS

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