PC-BASED DEVICE FOR ECG MAPPING

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Introduction

Multichannel measurement and topographic imaging of the potential distribution over the chest surface gives additional possibilities of heart diseases diagnostics based on the knowledge of more detailed information about the cardiac electric field. In the paper a PC-based device ProCardio is presented which enables the use of body surface potential mapping (BSPM) techniques for cardiac diagnostics or for model-based imaging of the heart state. Device hardware guarantees safe isolation of the examined patient and optimal quality of recorded ecg data. Its software supports several mapping leads sets, enables continuous checking of electrode contacts and monitoring of ecg signals during the measurement. Desired measuring parameters can be set under program control. After ecg recording and processing, isopotential maps, integral maps and their departures from selected references or surface isochrone maps can be computed and displayed. All data formats are freely accessible by the user and can serve as input for further device-independent evaluation.

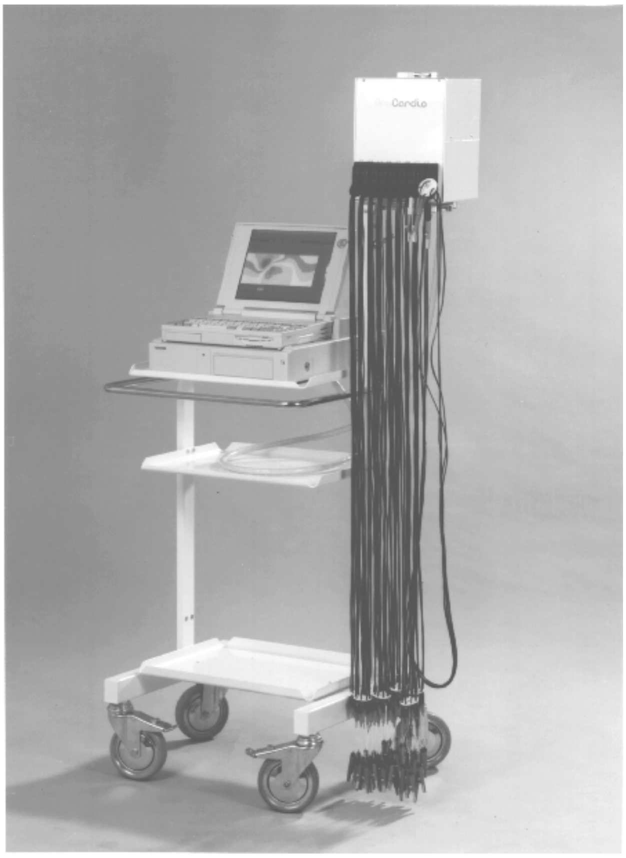

Figure 1: Notebook-based ProCardio mapping device on a carriage.

Method and Results

The ProCardio mapping device is built around a standard desktop or notebook PC computer and its specialized hardware consists of a patient terminal with ecg amplifiers and a data acquisition system connected to the PC main unit. The whole mapping device is portable and can be placed on a small carriage easily transportable by one person as shown in Fig. 1.

The patient terminal guarantees electrical isolation of the patient (4 kV) and can operate several meters from the PC main unit. As a standard, 64 measuring ecg channels are implemented, however, the hardware concept allows up to 256 measuring channels. Signals from limb electrodes are processed in one limb lead module where potentials of the Wilson's central terminal (WCT) and standard limb leads are generated. Signals from unipolar leads are processed in several chest lead modules and lead potentials relative to WCT are generated. The patient terminal conforms with the safety standards and other demands for ecg measuring equipment [1], [2]. Ecg preamplifiers, differential amplifiers and active filters were developed as custom-made hybrid modules in SIP-form. SMD technology is used in all modules.

The input part of the patient terminal amplifies recorded ecg potentials. It consists of lead preamplifiers and differential amplifiers for all channels. The input range of all measuring channels is ±10 mV and their basic gain is 1000. All amplified signals are led to optional programmable active low-pass filters enabling to set the frequency response with 4 different upper cut-off frequencies (0.05 to 100, 250, 500 or 1000 Hz). Eventual bad contact of any electrode is continuously monitored by the hardware and reported as a low-level error signal appearing on the output of the corresponding channel.

In the patient terminal, active neutralization of noise from the measured patient is used: the leg electrode N is driven by the inverted and amplified common mode signal sensed by the R electrode. Additional reduction of interfering signals is achieved by active compensation of the common node in the floating input part.

The amplified and filtered ecg signals are led into the data acquisition system (DAS). After analog multiplexing, they are fed into a programmable gain amplifier (with gains 1, 2, 4 or 8) which enables to set the total amplification of 1000 to 8000 in each individual channel. Finally the signals are sampled and digitized in a 12 bit A/D converter. The digitized data are stored in an intermediate buffer (FIFO register) and transferred to the computer.

The desired channel sequence and gains for all individual channels can be preprogrammed in the DAS before the recording. This enables flexible configuration of the

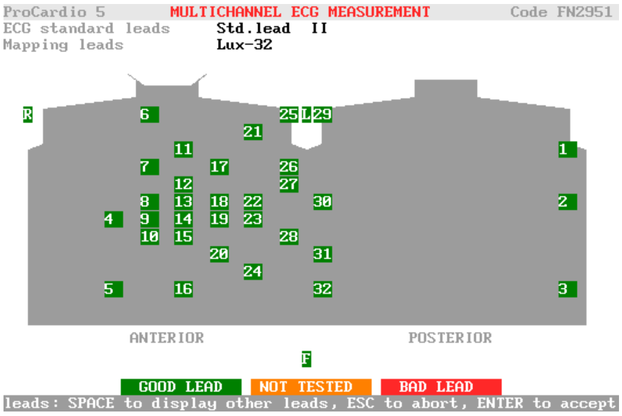

Figure 2: Display during application of electrodes: lead II and 32 mapping leads (Lux-32) are tested.

measuring unit to any combination of ecg leads and patient specific ecg amplitudes.

Modular DOS-based software package of the system enables ecg measurement, processing of measured signals, computation of body surface maps and management of all data. It includes a resident organizer and a number of applications working with consistent set of data files. Desired application is invoked by selection from a task menu. Communication with the user is supported by hierarchical selections and input windows. All programs setting for a particular user can be saved for future use, online help for each screen is included.

With the measuring program, ecg signals from several lead sets can be measured: standard 12 lead ecg, Frank vcg, regular grid of up to 64 mapping leads, limited lead sets for mapping with 24 leads according to Barr [3], 32 leads according to Lux [3] or NEKTAL [5] and 63 leads according to Savard [6]. Additional lead sets may be defined by the user. Signals from two or more lead sets can be measured simultaneously up to the full number of measuring channels in the particular device configuration. Another recording parameters such as sampling frequency (1, 2 or 4 ms), number of samples from each channel (up to 10000) and format of the ecg monitor (1 to 32 selected leads) can be set before measurement. During application of electrodes, status of all leads is checked and reported on display as shown in Fig. 2. After application of electrodes, amplification for each lead is set by the user or automatically to an optimum. During the measurement, signals are continuously monitored on screen and record up to 20 seconds long is saved in a circular buffer. Keyboard input freezes last recorded data, they can be viewed in detail and finally stored on disk.

Ecg signal processing includes selection of proper heart beat, desired type of baseline corrections and signal filtering. Signals are visually checked, times and ecg amplitudes can be measured and important time instants for processing by the mapping programs can be marked as shown in Fig. 3. Measured values of ecg signals or ecg graphs can be printed in several formats.

After signal processing, body surface potential maps, integral maps or isochrone maps are computed. While in regular mapping grids simple bilinear or spline interpolation is used, in limited lead sets the data in full mapping grid are computed first, using reconstruction technique specific for the particular lead set (e.g. statistical or functional approximation).

In displayed maps, left half represents anterior chest, right half posterior chest surface. Maps can be displayed as isopotential lines, colored areas or mixed. Colors, size of the frames and isopotential (isointegral, isochrone)

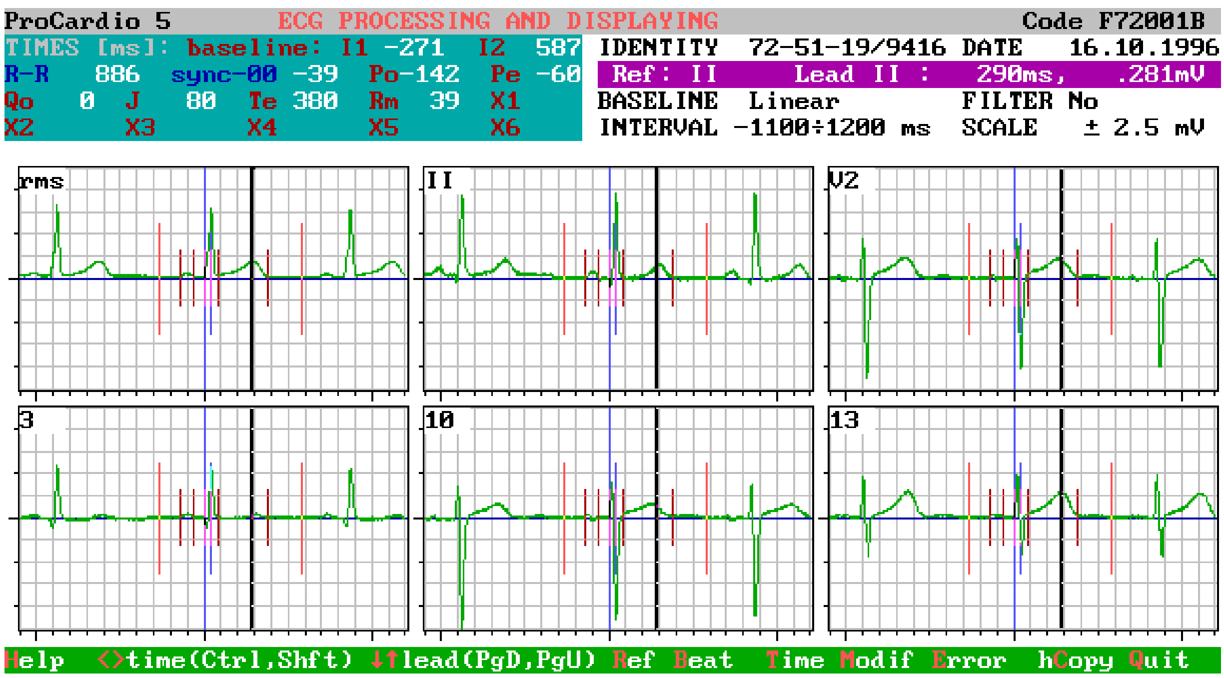

Figure. 3: Example of the display during ecg processing. Marked times are displayed in the left upper part. Time and potential at cursor position in selected lead are measured and displayed in the right upper area.

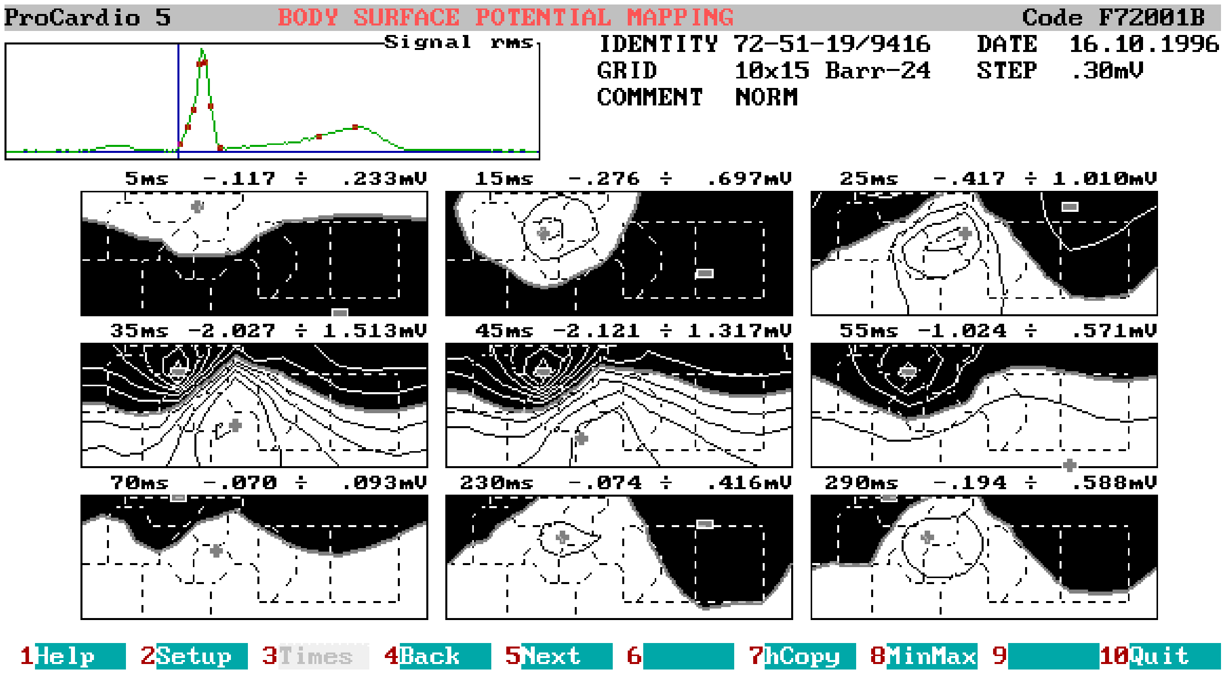

Figure 4: Series of body surface potential maps. Markers of projections of ventricular segments according to Selvester are shown, mapped time instants are marked in the rms signal. Time instant and potential extreme are shown above each map.

step can be changed by the user. Markers of torso, electrode positions, mapping grid and/or projection of ventricular segments according to Selvester can be included. Reference or rms lead can be displayed together with the maps to show the mapped instant or interval. Numerical mapped values can be displayed and map animation on screen is also possible. All maps can be printed in numeric or graphic form in several formats. Body surface potential maps are computed within desired time intervals (up to 12). Fixed number of maps or time step within each interval can be given. An example of potential maps sequence is shown in Fig. 4.

Up to 16 different integral maps can be computed for one patient. Desired integration intervals are selected by the

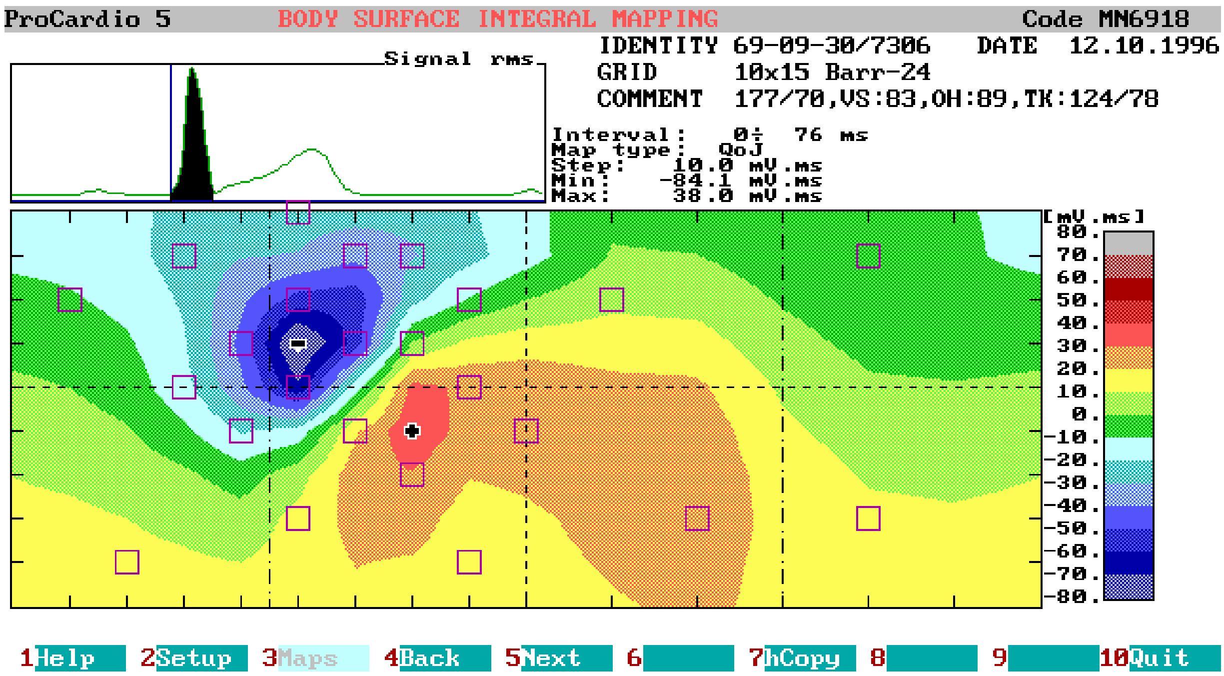

Figure 5: Integral map of the QRS complex in a normal patient. Map is displayed in color, integration interval is shown in rms signal above the map. Electrode positions (24 leads according to Barr), torso markers (transversal plane, sternum, left midaxillary line and spine) and grid line positions are marked.

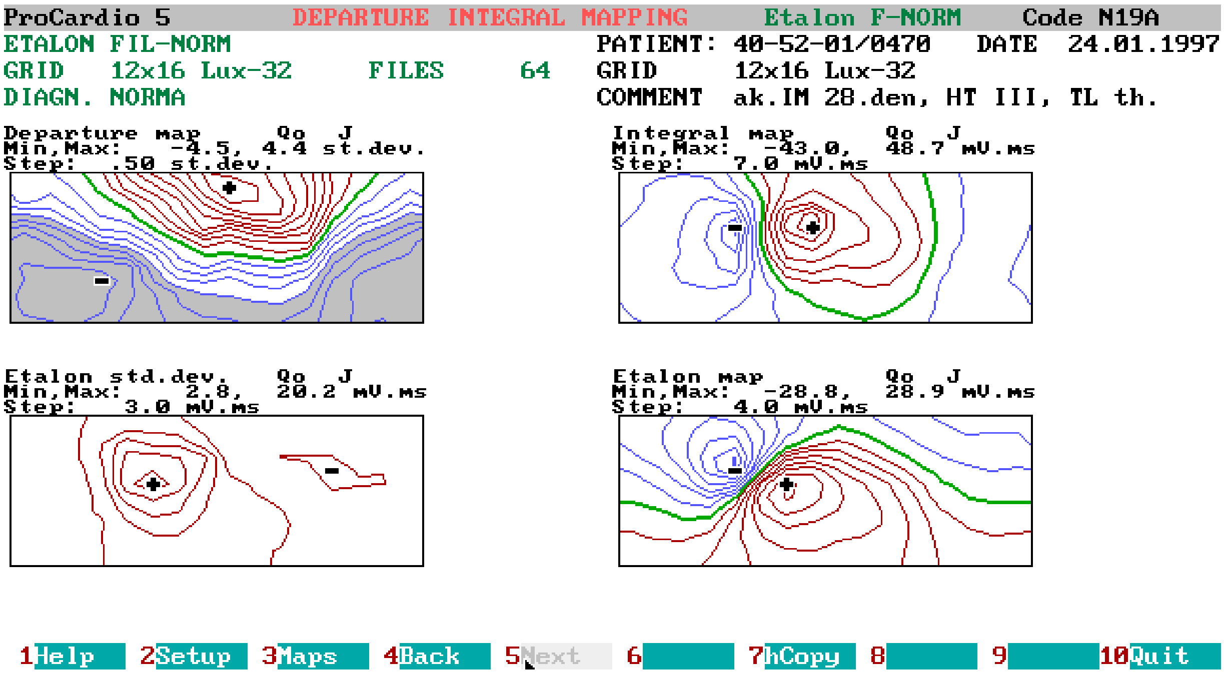

Figure 6: Departure integral map (upper left) of the QRS interval in inferior MI. Integral maps of the patient and reference (mean of 64 normal subjects) and standard deviations of the reference map are also shown. Areas with departures greater than 2 standard deviations are shaded in the departure map.

user. They are defined by previously marked standard times or directly in milliseconds relative to selected time origin. An example of integral map display is shown in Fig. 5.

In departure integral mapping, mean integral maps of normals or selected pathologies are computed and maps of individual patient's departure indexes are evaluated. An example of possible display format is shown in Fig. 6.

In isochrone mapping, selected time intervals or instants measured in all leads are mapped, e.g. QT intervals or times when ecg signals reach extremal values, selected threshold or minimal derivation. Options for map display are similar as in potential mapping.

Discussion

It has been shown by many authors that body surface potential mapping can be a valuable tool for noninvasive estimation of the position and size of myocardial infarction or identification of arrhythmia sources. Several ProCardio devices are successfully used for these purposes in experimental clinic [7]. Independently, obtained maps are used for research of non-invasive model-based assessment of the heart state [8]. The system is being continuously developed and additional map evaluation will be included in the future.

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