Body surface mapping of cardiac activity after partial left ventriculectomy

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Abstract

MECG measurements were performed using 35 electrodes in 10 patients operated with partial left ventriculectomy (PLV). Body surface ECG signals were recorded and five measurements were done: prior to PLV, second, third, fourth and fifth postoperative day. This work was concentrated on the following mapping methods: average isopotential ST segment maps (STM), QRS interval isointegral maps (QRM) and isochronal activation maps (IAM). STMs of the patients show a great positive area (elevation) over the anterior aspect of the heart and a great negative area (depression) over the lateral and posterior aspect of the heart before the operation. After the operation, the ST elevation over the anterior, lateral and posterior aspect of the heart was reduced. A substantial positive value over the excised area of the heart was present also on the end of the postoperative monitoring interval. Minimal and maximal values of the QRMs were smaller and also show some kind of normalisation. The area of the left ventricle, where PLV was performed, was carefully analysed for any changes of activation time for different heart regions. IAMs indicate that the start of the first activation was quite stable and in accordance with the position of the QRMs minimum.

Keywords: Body surface mapping; Isopotential maps; Isointegral maps; Isochronal maps; Partial left ventriculectomy

1. Introduction

Partial left ventriculectomy (PLV) was invented in Brasil [1], in the environment, where the possibilities for modern treatment of terminal phase cardiac patients were limited.

In the beginning, PLV as a new surgical procedure was generally accepted worldwide, also in the countries where cardiac transplantation and artificial heart (in it’s various developmental stages) were available.

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However, after the first enthusiasm, the moment of truth emerged, as suddenly as the PLV procedure itself and the surgeons and cardiologists were became aware of the fact that dilative cardiomiopathy practically is not as easy to cure as in theory. In fact, the gap between the practical and theoretical approach toward the end stage cardiac disease in general was greater from day to day.

Established in its early phase International Society for Cardiac Volume Reduction did not prove to be efficient in reducing this gap and the important major problems of the operation were not resolved, however, at least they were recognized.

One of the major problems after this operation is sudden cardiac death. The probable cause could be ventricular arrhythmia. The presence and exact location of arrhythmogenic focuses prior to operation is not studied carefully and furthermore it is not known exactly what is happening with them after the PLV.

It would be of importance to study post-surgical cardiac electrophysiologic changes which might be useful in identifying patients at risk to sudden death or increased arrhythmia susceptibility. We wanted to demonstrate, with the use of the MECG measurements prior and after the PLV, the changes in isopotential, isointegral, normalised amplitude, and isochronal maps.

The measurement procedure and the map definitions were described elsewhere [2]. The aim of this article was to show the results of the measurements on patients after PLV with maps and graphs. The personalised analysis for each patient and for all five measurement was done (maps and graphs) including the presentation on a separate graph for all the measured patients (seven patients) in order to see some common characteristics. However, the size of article space these maps are taking is rather big, so we decided to present the whole analysis set just for one patient—the rest can be seen and downloaded for study from [3]—for raw measured data please contact (borut.gersak@maat.si). In Discussion, the results are compared and some common characteristics are devised.

2. Material and methods

2.1. Patients

We performed MECG measurements on patients operated for PLV in Hospital Angelina Caron (Curitiba, Brasil), as described in [4].

2.2. Operation

All the patients were operated in Hospital Angelina Caron. The technique of the operation was the same as described previously for PLV [1]. Immediately after the operation they were transferred into the ICU, where they stayed till the 3rd or 4th postoperative day.

2.3. Equipment

Body surface potentials were measured with 35 unipolar leads referenced to the Wilson central terminal as described [2].
2.4. Measuring protocol

We made a single pre-operative and four post-operative measurements for each patient from the 2nd till the 5th postoperative day. Two protocols for electrode positioning were used: L- and E-protocols. L-protocol is based on the maximal given information criteria proposed in [5]. E-protocol follows the equidistant principle which enables the direct map representation of measured signals with no additional extrapolation. The reason we used two different protocols was to make the collected data exchangeable for different parties interested to study the raw data. MECG signals were recorded for 1 min for each protocol. Both measurements were performed successively each for 60 s starting with L-protocol. All the electrodes shown in Fig. 1 were positioned at the beginning of the measurements. The electrodes were numbered from 0 to 35 (0 = ground reference on the right leg—not measured, 1 = right arm, 2 = left arm, 3 = left leg). The electrode positions denoted by X were placed in advance for E-protocol and left free for the time of the first measurement based on L-protocol.

When the first measurement (L-protocol) was done the electrode cables were repositioned on the positions shown in Fig. 2 and some electrode positions used for the first measurement were left free for the second measurement. Then the second measurement (E-protocol) was performed. In order to use the same electrode locations in all the five measurements, it was of importance to mark their positions with pen, because the electrodes were removed when the patient has gone to the operating room. On the second postoperative day the electrodes were carefully placed again avoiding the contact with the surgical wound. For some of the patients, the electrodes stayed in their positions for the measurements in several subsequent days.

After positioning of the electrodes we started the data acquisition procedure as described in [2]. The raw data of each patient were represented as two sets (E- and L-protocols) of five separate measurements on 35 body surface electrodes with the duration of 60 s (60,000 samples on each electrode) for a particular measurement.
After the finishing with the L-protocol measurement some electrode cables were systematically repositioned for the next measurement done according to the E-protocol (see the upper part of this figure). The arrows denote the necessary cable movements e.g. the cable from electrode 7 is moved to the position X which represents the electrode 7 in E-protocol, the cable from electrode 8 is moved to the next position X where represents the electrode 8 in E-protocol, etc. The electrodes placed and numbered according to E-protocol are shown in the lower part of this figure. Some electrode positions marked with Y were used in the L-protocol and left free during the E-protocol.

After applied analysis, data have been presented as: ST40 isopotential maps (STM), QRS isointegral maps (QRM) and isochronal activation time maps (IAM). In this work, the E-protocol measurements only have been analysed and shown. We used the body surface maps to study the electrical cardiac signals in the patients prior and after the PLV—the generation of the maps is described in detail in [2]. The selected pairs of maps X and Y were compared to quantify the similarities between them. The correlation coefficient ($CC_{xy}$) and the root-mean-square ($RMS_{xy}$) of maps differences have been calculated as in [4].

3. Results

In order to show all possible aspects of results, and because the number of patients was too small for reliable statistical analysis, personalised analysis of all patients was proposed in this study. All maps have been acquired in the same way for all patients. First, the appropriate interval of 5 s was
chosen, then the digital filtering with 50 Hz low pass filter has been applied for five consecutive beats, and all mentioned maps have been devised. Finally, the average beat was calculated from these five beats and sixth set of maps has been devised for the selected patient. The corresponding maps of each measurement have been cross-correlated in order to prove the reliability of the mapping process. Typically, the map cross-correlation among the mentioned five beats and the average beat were greater than $CC = 0.98 \pm 0.02$ for the same measurement. The above process has been repeated for all measurements and for all patients. Totally 168 maps (four maps for five beats and for seven patients plus four maps for the averaged beat for all patients equals $4 \times 5 \times 7 + 4 \times 1 \times 7$) maps have been generated on this way. The special analysing software had to be developed for the shown analysis. Corresponding numerical values are shown with graphs in Figs. 4 and 5.

The results are visualised by the maps of the average beats and by the numerical values shown in graphs. In order to cover different signals, the scaling in some maps and graphs is changed, but always the appropriate scale information is given either by a palette bar for maps or by axis values for graphs.

For each patient, however, in this article presented just for the patient 5-F, $CC_{xy}$ and the $RMS_{xy}$ [4] are shown for the pairs composed of the measurement before operation, denoted by index 0, and all consecutive measurements: 2 days after operation—index 2, 3 days after operation—index 3, 4 days after operation—index 4, and 5 days after operation—index 5. For example $CC_{03}$ represents the correlation between the measurement before operation and the measurement 3 days after operation. Separate graphs are shown for pairs composed of successive days, for example $CC_{34}$ represents the correlation between the measurements taken in the 3rd and 4th day after operation. The same is valid also for the RMS.

**Minimal and maximal values** are shown for all maps in separate graphs for all patients. Numbers on the $X$-axis denote: 0—the measurement taken before operation; 2–5—the 2nd, 3rd, 4th and 5th day after operation, respectively.

For example, the mapped results for the patient 5-F are shown in Fig. 3. represents in part (a) the $CC$ between all maps before surgery and all consecutive 4 days and in part (b) the $CC$ between two consecutive days. Fig. 4 represents also the RMS with the same protocol. Fig. 5 represents the maximal and minimal values for all five measurements. Minimal IAM value is by definition equal to 0, what represents the earliest activation. Some interesting comments are added in captions after each figure. In the same way all consecutive results for all patients are organised.

After the personalised analysis, $CC, RMS$ and minimal/maximal values are shown for all patients on separate graphs in order to compare different patient responses. Finally, the **average amplitude** discussed in [4] and **average beatrate** are shown on separate graphs for all patients and for all measurements.

Please note the figures are represented as STM (Fig. 6), QRM (Fig. 7) and IAM maps (Fig. 8). Beat amplitude maps (BAM) are discussed in [4] and average beatrate here (Fig. 9).

### 4. Discussion

We recognised that the body surface mapping system as described here can be usable method for analysing the differences in the cardiac impulses propagation and their time variability. This is a non-invasive method that could be used in order to confirm the susceptibility to fatal arrhythmia
Fig. 3. A set of maps (STM, QRM, BAM, IAM) for patient 5-F: (a) 1 day before operation, (b) 2nd day after operation, (c) 3rd day after operation, (d) 4th day after operation and (e) 5th day after operation. It is possible to see the substantial change in all maps for (a) and (b), then the maps converge to a new stable state. The electrode (9,4) in IAM (lower right part of (c) shows an unexpected great value and is probably an artefact generated by the computer algorithm.
especially [6–8] in the patients after PLV. The excised area of the left ventricle after PLV is showing the ischemic patterns shown in STM, giving the possibility to generate the fatal conduction changes of the reentry type (VT and VF).

By all patients, the STM are showing the striking difference between prior and after the operation. All the STM of the candidates for PLV are showing the same pattern before the operation: large
positive area (ST elevation) over the anterior aspect of the heart and great negative area (ST depression) over the lateral and posterior aspect of the heart. All these patients had normal coronary angiography data. The normal population data map does not show these effects. After the operation the STM also showed the same pattern for all the patients: a normalisation of ST elevation over the anterior, lateral and posterior aspect of the heart, still leaving a large positive area on the heart, where the excision and the suture line was supposed to be. The excision goes down from the junction between the middle and distal third of the LAD artery, between the anterior and posterior papillary muscle toward the mitral valve and the base of the heart. This area is typically circumferential on the STM and is showing a decrease of ST elevation over the time from the 2nd to the 5th postoperative day.

The QRM are showing the diVerence between measurements prior and after the operation. All the QRM of the candidates for PLV are showing the same pattern before the operation: large positive area over the anterior aspect of the heart and great negative area over the lateral and posterior aspect of the heart.

The IAM show in general the small prolongation of the heart activity in the different heart regions.

5. Summary

To demonstrate cardiac electrophysiologic changes in patients where partial left ventriculectomy (PLV) was performed multichannel ECG (MECG) measurements and body surface mapping (BSM) were used. All these patients had normal coronary angiography data. PLV was originally introduced 2 years ago as a new surgical approach by patients with an end stage of cardiac disease. MECG measurements were performed using 35 electrodes with two different electrode positioning (L- and
Fig. 4. (a) Correlation coefficients for the set of maps from Fig. 3 (STM, QRM, IAM) for patient 5-F. Comparisons with the pre-operative measurement (a), and comparisons between two successive days, (b) Index 0 denotes the measurement taken before operation, indices 2, 3, 4, 5 mean the 2nd, 3rd, 4th and 5th day after operation, respectively. For example: $CC_{03}$ represents the correlation between a map before operation and a map taken 3 days after operation, and similarly $CC_{34}$ represents the correlation between the measurements taken in the 3rd and 4th day after operation. Note that $CC_{02}$, $CC_{03}$, $CC_{04}$ and $CC_{05}$ for the STM have negative values that means that the maps after operation show completely different situation. The results in (b) show that the most important change occurs soon after surgery (see $CC_{02}$), then the situation converges to a new stable state, (c) Root mean square for the set of maps from Fig. 3 (STM, QRM, IAM) for patient 5-F. Comparisons with the pre-operative measurement (a) and comparisons between two successive days and (d) Index 0 denotes the measurement taken before operation, indices 2, 3, 4, 5 mean the 2nd, 3rd, 4th and 5th day after operation, respectively. For example: $RMS_{03}$ represents the correlation between a map before operation and a map taken three days after operation, and similarly $RMS_{34}$ represents the correlation between the measurements taken in the 3rd and 4th day after operation. It is possible to see from (d) that all maps become very similar after the 2nd post-operative day.

E-protocols). Body surface ECG signals were recorded for 1 min for each protocol. Ten patients operated with PLV were monitored. The same electrode positions were used for all the five measurements: prior to PLV, 2nd, 3rd, 4th and 5th postoperative day. The MECG software were used to evaluate, to store and to analyse the measured ECG signals. The acquired data were analysed by isointegral, isochronal and animated BSMs. The analysis was done on a set of selected typical beats and on averaged beats. This work was concentrated on the following mapping methods: average isopotential ST segment maps (STM), QRS interval isointegral maps (QRM) and isochronal activation maps (IAM). STMs of the patients show a great positive area (elevation) over the anterior aspect of the heart and a great negative area (depression) over the lateral and posterior aspect of the heart before the operation. After the operation, the ST elevation over the anterior, lateral and posterior aspect of the heart was reduced. A substantial positive value over the excised area of the heart was present also on the end of the postoperative monitoring interval. Minimal and maximal values
Fig. 5. Maximal (a) and minimal (b) values for the set of maps from Fig. 3 (STM, QRM, IAM) for patient 5-F. Please note that by definition minimal value for IAM map cannot be less than zero. Numbers on the X-axis denote: 0—the measurement taken before operation; 2, 3, 4, 5—the 2nd, 3rd, 4th and 5th day after operation, respectively. Maximal values for STM increase, while the minimal values of STM decreases substantially.

Fig. 6. Comparison of (a) CC, (b) RMS, and (c) maximal/minimal values for STM maps of all seven patients. Index 0 denotes the measurement taken before operation, indices 2, 3, 4, 5 mean the 2nd, 3rd, 4th and 5th day after operation, respectively. Numbers on the X-axis denote: 0—the measurement taken before operation; 2, 3, 4, 5—the 2nd, 3rd, 4th and 5th day after operation, respectively.

of the QRM were smaller and also show some kind of normalisation. The area of the left ventricle, where PLV was performed, was carefully analysed for any changes of activation time for different heart regions. IAMs indicate that the start of the first activation was quite stable and in accordance with the position of the QRM minimum. It was demonstrated that with the BSM, as described here, it is possible to detect all the most important changes in the cardiac activity for patients where PLV was performed. The BSM is a non-invasive method, which could perhaps be used to study the patients after the PLV to see if they are likely to develop a fatal arrhythmia. Because of very small data base of similar measurements the personalised analysis has been performed in the shown study.
Fig. 7. Comparison of (a) CC, (b) RMS, and (c) maximal/minimal values for QRM maps of all seven patients. Index 0 denotes the measurement taken before operation, indices 2, 3, 4, 5 mean the 2nd, 3rd, 4th and 5th day after operation, respectively. Numbers on the X-axis denote: 0—the measurement taken before operation; 2, 3, 4, 5—the 2nd, 3rd, 4th and 5th day after operation, respectively.

Fig. 8. Comparison of (a) CC, (b) RMS, and (c) maximal/minimal values for IAM maps of all seven patients. Please note that the minimal values for IAM are equal to zero. Index 0 denotes the measurement taken before operation, indices 2, 3, 4, 5 mean the 2nd, 3rd, 4th and 5th day after operation, respectively. Numbers on the X-axis denote: 0—the measurement taken before operation; 2, 3, 4, 5—the 2nd, 3rd, 4th and 5th day after operation, respectively.
Fig. 9. Average beatrate for all measurements and for all patients. Numbers on the X-axis denote: 0—the measurement taken before operation; 2, 3, 4, 5—the 2nd, 3rd, 4th and 5th day after operation, respectively.

In order to involve statistical analysis, it would be necessary to build the PLV operation BSM data bank with the involvement of different centres worldwide, where PLV operations are performed.

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References


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