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Changes of the beat amplitude power after partial left ventriculectomy and coronary artery bypass grafting

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Abstract

Partial left ventriculectomy (PLV) was originally introduced as a new surgical approach by patients with an end stage of cardiac disease. Coronary artery bypass grafting (CABG) is a standard procedures used in cardiac surgery. Multichannel ECG (MECG) measurements and body surface mapping (BSM) were used to analyse the normalised beat amplitude power maps (BAM) that reflect an overall cardiac activity. The resulting BAMs show that the amplitude of cardiac signals decrease for approximately 30% after the PLV and stay in the same level during the postoperative monitoring interval while after CABG no significant changes in BAM have been observed. In addition the electrodes from the body surface area above the left ventricle, where surgery was performed, show significant changes in beat amplitudes.

Keywords: Body surface mapping; Beat amplitude maps; Partial left ventriculectomy; On-pump CABG

1. Introduction

In the last decade the gap between the practical and theoretical approach toward the end stage cardiac disease in general was greater from day to day. At this time the partial left ventriculectomy (PLV) was invented in Brasil [1], in the environment, where the possibilities to treat terminal phase cardiac patients were practically none. Today world-wide more than 1000 patients were operated with this technique and a firm basis of diagnostic, pre- intra- and post-operative measurements (ultrasound, coronarography, body surface mapping (BSM) or even computer simulation of surgery [2] etc.) and established evaluation (International Society for Cardiac Volume Reduction).

PLV, as a new surgical procedure, is gaining more and more importance, however one of the important major problems after the operation is sudden cardiac death. The probable cause could be

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ventricular arrhythmia. The presence and exact location of arrhythmogenic focuses prior to operation is not studied carefully and furthermore it is not known what is happening with them after the PLV. Furthermore, the ventriculectomy is actually similar to ventriculotomy, or different opening techniques of heart chambers used in new minimally invasive surgical procedures [3]. 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 amplitude maps as well as compare them with the measurements after standard surgical aortocoronary revascularization (CABG) [4].

The goal of our work was to determine the eventual changes in body surface potentials, particularly focusing on beat amplitudes, by patients who underwent PLV or CBAG surgery.

2. Material and methods

2.1. Patients

We performed MECG measurements on patients operated for PLV in Hospital Angelina Caron (Curitiba, Brasil). However, the material used for suturing was polyglactin and not polypropilene [5,6]. The preoperative data of patients with successively acquired measurements are shown in Table 1. Some of the measurements were not complete and consequently not included in the study.

In addition we measured 11 patients operated for CABG in University Medical Center Ljubljana—all with normal ejection fraction and dimensions of the left ventricle within the normal range (determined with echocardiography). Informed consent was obtained from each patient included in the study.

2.2. Operation

All the patients for PLV 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 third or fourth postoperative day.

All the patients for CABG were operated on-pump with cardiopulmonary bypass and cardioplegic arrest as described [2].

2.3. Measuring equipment

Body surface potentials were measured with 35 unipolar leads referenced to the Wilson central terminal. We measured potentials from 32 electrodes placed on the thorax and additionally from 3 electrodes placed on both arms and left leg. Input signals were filtered by 50 Hz analogue input filters, sampled by 1000 Hz and fed to 14 bit A/D converter. The right leg electrode (electrode 0) was used for a ground reference and not measured. We used MECG measurement system [7] that is comprised of a small battery-powered acquisition unit and a PC-computer running the application software. The software package of the system is designed to be used by a non-specialist. The raw data can be shown, analysed, and graphically represented as standard ECG plots, isopotential,

Table 1
Preoperative data of the patients operated for Partial Left Ventriculectomy

ID	ESD-E (cm)	EDD-E (cm)	EF-E (%)	EF-A-(Dodge %)	EF-A-(Simpson %)	SV-E (ml)	AGE (years)
PLV-F	6.3	7.1	24	20.73	21.16	65	53
PLV-G	6.7	7.8	30			99.2	56
PLV-B	7.4	8.4	25	13.75	14.08	95	44
PLV-I	6.9	8.2	33			120.2	53
PLV-E	6.8	8.8	42				57
PLV-C				16.99	17.24		9
PLV-A	6.4	7.5	37	8.35	8.02		49

ID = number of acquired measurements—patient ID, ESD-E = Echo End Systolic Diameter of the left ventricle, EDD-E = Echo End Diastolic Diameter of the left ventricle, EF-E = Echo Ejection Fraction, EF-A-Dodge = Angio Ejection Fraction (Dodge method), EF-A-Simpson = Angio Ejection Fraction (Simpson method), SV-E = Echo Stroke Volume

isointegral, isoamplitude, isochronal maps [8,9]. For some special purposes used in the study of cardiac conduction paths, it is able to generate also animated maps [10]. Different computer supported algorithms can find beat rate or the duration of other custom selected interval automatically. Their frequency spectra and interval variability can be calculated and analysed [11].

2.4. Measuring protocol

We made a single pre-operative measurement for all patients, four post-operative measurements for each PLV patient from the second till the fifth postoperative day and three postoperative measurements for CABG patients until four postoperative day. The electrode positions were selected according to the E-protocol (see [8,9] for details). This placement is in fact a subset of a much bigger protocol introduced for example in [12]. The E-protocol follows the equidistant principle that enables the direct map presentation of measured signals with no additional extrapolation.

In order to use the same electrode locations for each person during the monitoring period, 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 several subsequent measuring days.

After positioning of the electrodes we started the data acquisition procedure that has collected the data in a period of 60 s. The quality of measured data were checked immediately (baseline, electrode contacts, noise level, etc.) and if acceptable, saved on a computer disk. If the data quality was poor, the problem was solved immediately and the data acquisition procedure restarted with the same measuring protocol.

2.5. Data presentation

At the end of the measuring period the recorded data of each patient have been presented as a set of five (four by CABG) separate measurements on 35 body surface electrodes each 60 s long (60,000 samples from each electrode). Measured data can be examined now either in time or frequency domain or by different types of BSMs.

2.6. Map generation

After the loading of the body surface measurement from a computer file, the signals are examined manually interval-by-interval and the most appropriate interval is selected for further analysis. Eventual extra systoles are skipped or discarded manually. The digital filtering with 50 Hz low pass filter has been applied on the selected interval. The beat rate is calculated and the average beat is devised.

In order to improve the reliability, five user selected beats and the average beat have been analysed. The base line was defined first by positioning of two cursors on the selected beat, see two cursors of short-cross type in Fig. 1. All samples from the selected interval are recalculated for all electrodes according to the specified base line. Then the selected beat (actual or averaged) is utilised on all electrodes (channels) and a particular sample (potential) or sum of samples (integral) is shown on a rectangular isoplot area, called body surface map (BSM) (see Fig. 2). The BSM consists of a mesh with 4 lines and 9 columns. The electrode positions are in the mesh of the row-column crossing points, for example electrode (1,1) is the lower left electrode. The exact measured values are given only on these places while all other map area is filled by interpolated values. The shown

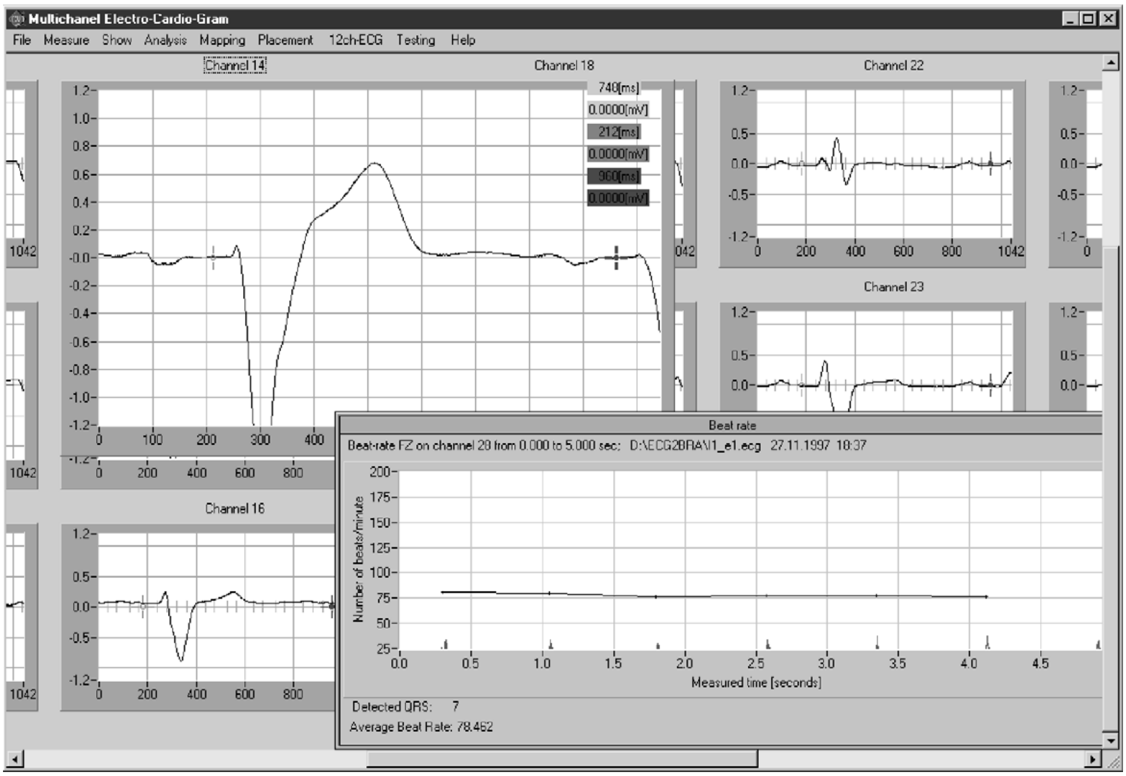

Fig. 1. Intermediate results of the average beat calculation. Seven beats have been taken into account. Average beat rate is calculated and equals 78.5/sec. The resulting averaged signal is saved in the computer memory for further analysis and shown as a graph. Shown signals are taken from the preoperative measurements of the patient PLV-I.

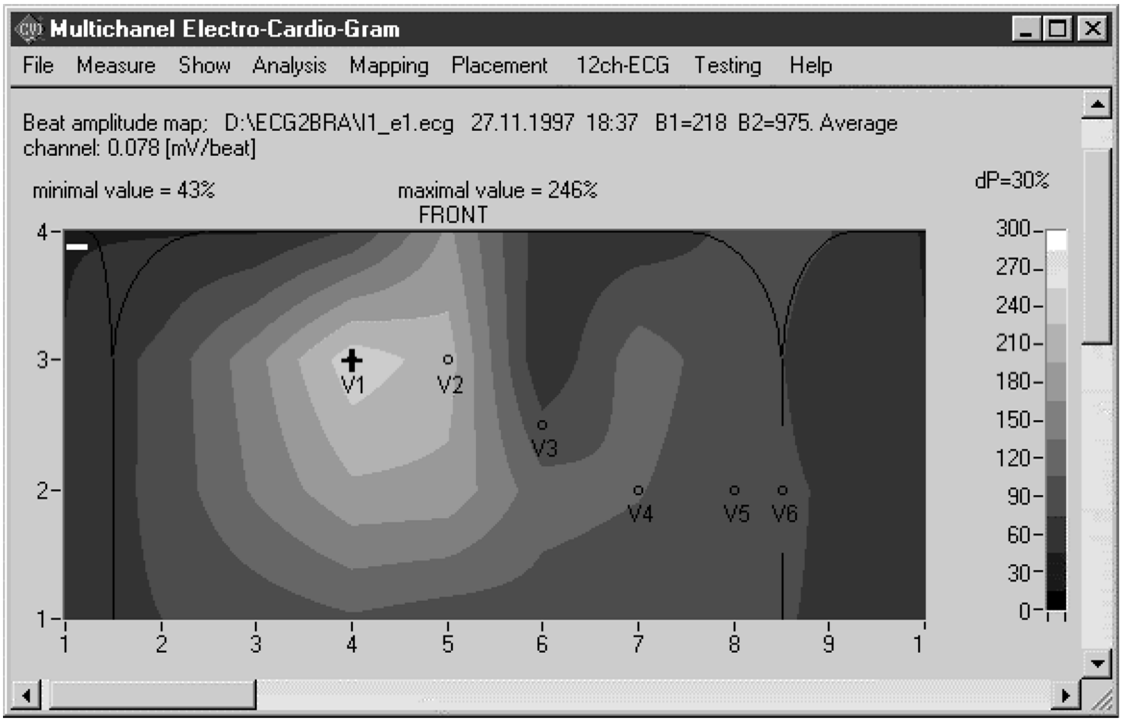

Fig. 2. An example of the BSM from the preoperative measurement of patient PLV-I, for the period defined by cursors from Figure 1. Rectangular area presents unfolded surface of human torso from sternal notch (5, 4) toward umbilicus (5, 1) by 4 lines of electrodes, numbered from 1 to 4, placed in nine columns, numbered form 1 to 9. The first left column 1 is the same as the last right column 1 for easier readability. Schematic FRONT and part of BACK part of the body is shown with left and right axillary mid. V1-V6 are shown as the reference points.

range is given on the right range bar and is represented by different colours or different levels of grey. The maximal and minimal values of the particular map are given in the first line above the map. Their position is denoted by + and − signs. The map type, file data, time, and other specific values, needed for the map reproduction are given in the two lines above the map. An example of the beat amplitude map (BAM) interpreting the amplitude distribution of MECG signals relative to the average channel amplitude is shown in Fig. 2. In this particular case the calculated average amplitude is 0.078 [mV/beat]. Each difference of grey is equal to 30% of the average channel as shown on the right bar. Maximal signals are near V1 on position (4,3), the extreme of the minimal signal is not present.

2.7. Normalised beat amplitude maps

The normalized beat amplitude maps (BAM) were generated by a custom designed computer program as described earlier [7,8]. The average channel beat amplitude BA_{AVG} is the total beat amplitude divided by the number of channels. The total beat amplitude is a sum of all channel beat amplitudes, where the channel beat amplitude is the sum of absolute values of sampled potentials s_j,

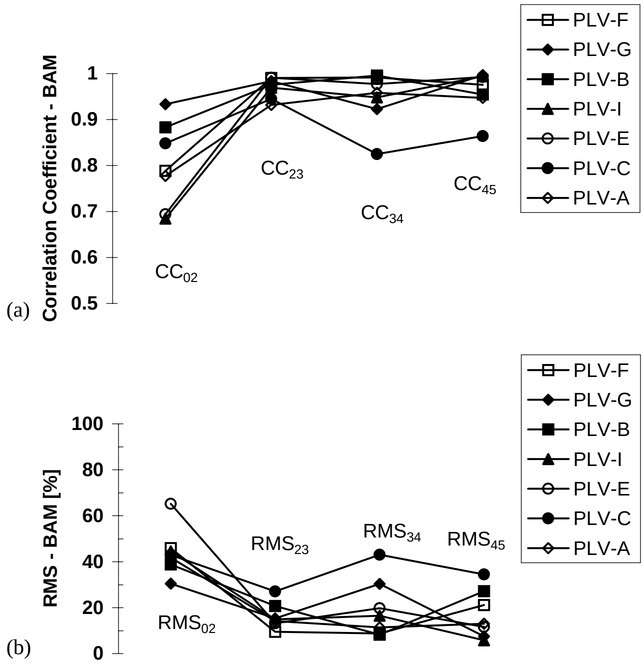

Fig. 3. Comparison of a) CC, b) RMS of BAMs for all seven PLV patients. Index 0 denotes the measurement taken before operation, indices 2,3,4,5 mean the second, third, fourth and fifth day after operation, respectively. C_{23} represents, for example, the correlation coefficient between BAM maps from the second and third day.

for the selected beat designated in Fig. 2 by two cursors and for the particular channel i. Eventually, instead of a complete beat an user can select some other interval of interests. The normalised beat amplitude map is then in fact the normalised channel beat amplitude

$$\mathrm{BAM} = \frac{100}{BA_{\mathrm{AVG}}} \sum_{j=1}^{k} |\mathbf{s}_j|,$$

expressed in percentage, where k equals to the number of samples in the interval of interest, and $|\mathbf{s}_j|$ denotes a vector of absolute values of sampled potentials from all channels. BAM is useful for the study of the signal amplitudes distribution and their spatial changes. The average channel beat amplitude reflects in fact the electrical power of MECG signals.

2.8. Comparison criteria

We compared two maps to quantify the similarities between them. The Correlation Coefficient (CC) and the root-mean-square (RMS) of map differences have been used in the analysis of our results [13]. Additionally, explicit values and positions of maximal and minimal amplitudes have been monitored.

3. Results

Prior the final analysis a set of six BAM maps has been devised for each measurement from the five user-selected beats and their average beat. The corresponding maps have been correlated in order to prove the reliability of the measuring and mapping process. Typically, the correlation among the mentioned five beats and the average beat were greater than $CC = 0.98 \pm 0.02$. The above process has been repeated for all measurements and for all patients. Then the CC and RMS of BSM were calculated for all patients. Results are presented graphically for two groups—PLV (Figs. 3–5) and CBAG (Figs. 6–8).

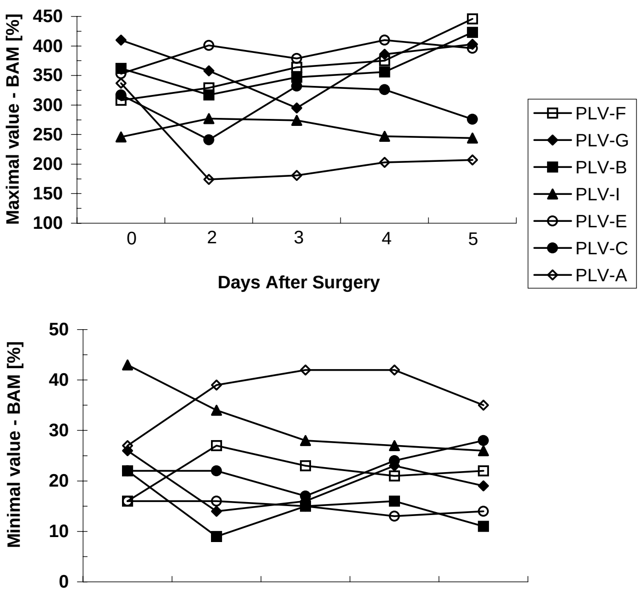

Fig. 4. Comparison of maximal and minimal values from BAMs of seven PLV patients. Labels on the X-axis denote: 0 - the measurement taken before operation; 2,3,4,5 - the second, third, fourth and fifth day after operation, respectively.

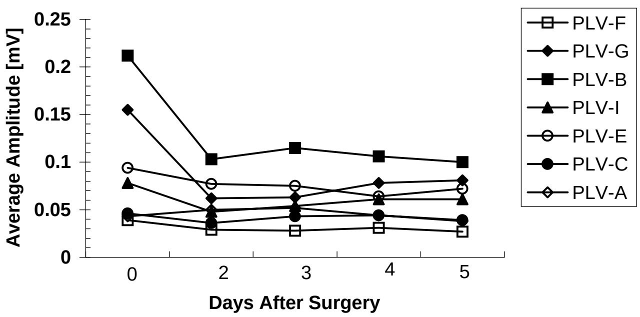

Fig. 5. Average Body Surface Potential for all measurements and for all PLV patients. The average was calculated from a selected R-R beat for all samples from all channels. Labels on the X-axis have the same meaning as in Figure 4.

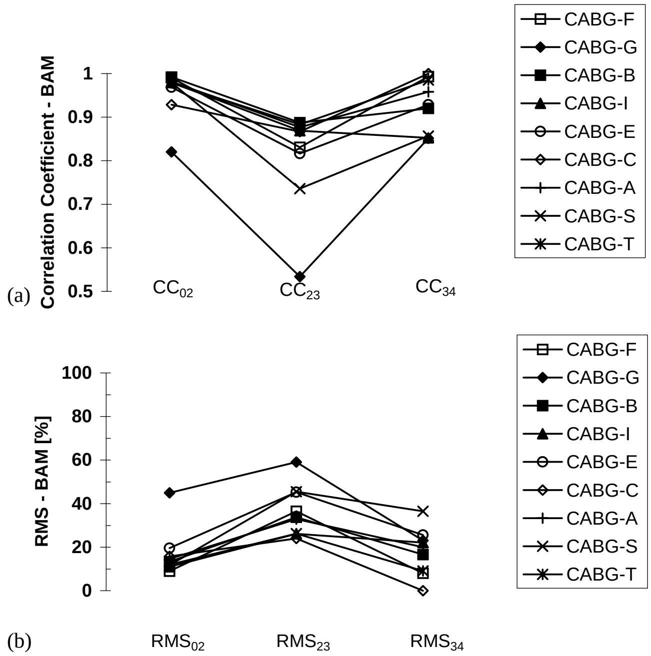

Fig. 6. Comparison of a) CC, b) RMS of BAMs for nine on-pump CABG patients. Index 0 denotes the measurement taken before operation; indices 2,3,4 mean the second, third, and fourth day after operation, respectively. C_{23} represents, for example, the correlation coefficient between BAM maps from the second and third day.

The CC and RMS are shown for the pairs of BAM from two consecutive days. The meaning of indices is as follows: before operation—index 0, two days after operation—index 2, three days after operation—index 3, four days after operation—index 4, and five days after operation—index 5. For example, CC_{02} represents the correlation between BAMs before operation and two days after operation, or CC_{34} represents the correlation between BAMs obtained from the measurements taken in the third and fourth day after operation. The same is valid also for the RMS.

The minimal and maximal values of the amplitudes are shown for all maps in separate graphs and for all patients. Labels on the X-axis denote: 0—the measurement taken before operation; 2,3,4,5—the second, third, fourth and fifth day after operation, respectively.

Finally, the Average Amplitudes are shown on separate graphs for all patients and for all measurements.

3.1. PLV patients

In Fig. 3, numerical values are shown with graphs. In part (a) the CC between pairs of beat amplitude maps of PLV patients before surgery and all consecutive four days after surgery, and in part (b) the same for the RMS.

The maximal and minimal values from BAMs of PLV patients are given in Fig. 4. Note that the BAM values can only be positive because they are normalised and expressed as percentage.

The average beat amplitude for PLV patients is given in Fig. 5.

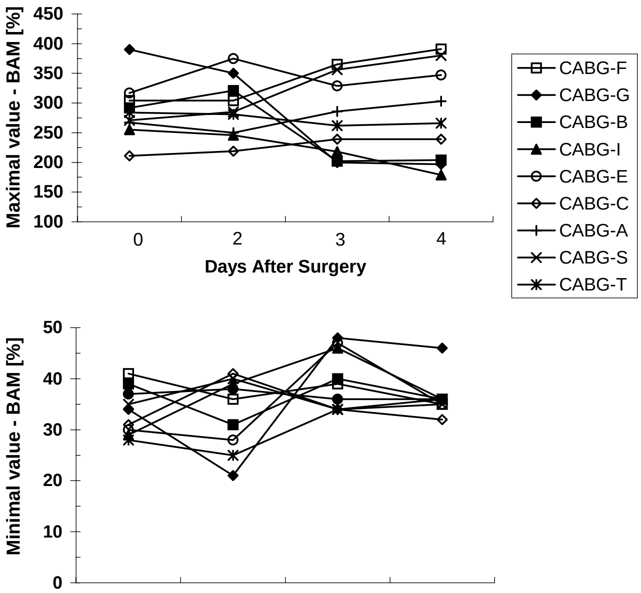

Fig. 7. Comparison of maximal and minimal values from BAMs of nine on-pump CABG patients. Labels on the X-axis denote: 0 - the measurement taken before operation; 2,3,4 - the second, third, and fourth day after operation, respectively.

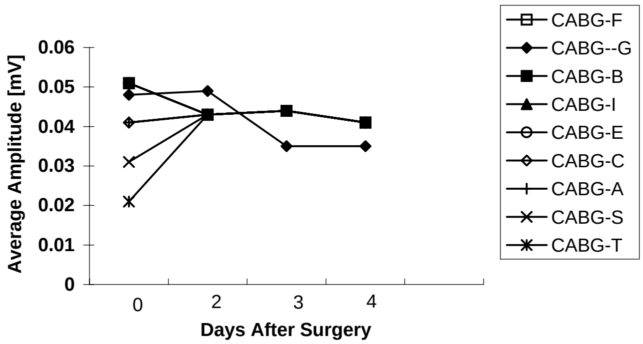

Fig. 8. Average Body Surface Potential for all measurements and for all on-pump CABG patients. Labels on the X-axis have the same meaning as in Figure 7.

3.2. *On-pump CABG patients*

In Fig. 6 part (a) the CC between pairs of beat amplitude maps of CABG patients before surgery and all consecutive three days after surgery, and in part (b) the same for the RMS.

The maximal and minimal values from BAMs of CABG patients are given in Fig. 7. Note that the BAM values can only be positive because they are normalised and expressed as percentage.

The average beat amplitude for CABG patients is given in Fig. 8.

4. Conclusion

The analysed BAMs show that the amplitude of cardiac signals decrease for approximately 30% after the PLV and stay in the same level during the five-day postoperative monitoring interval. In addition the area of the left ventricle, where PLV was performed, show significant changes in the level of beat amplitudes. In contrast, by CABG there are no significant changes in the average amplitudes.

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 the patients where PLV or CABG was performed. The BSM is a non-invasive method, which could perhaps be used to study the patients after the cardiac surgery to see if there are indications for fatal arrhythmias. It was shown that the BSM can be used to determine the changes of cardiac activity by the patients operated for PLV or CABG.

5. Summary

We demonstrated cardiac electrophysiologic changes in patients where partial left ventriculectomy (PLV) and on-pump coronary artery bypass grafting (CABG) were performed, using multichannel ECG (MECG) measurements and body surface mapping (BSM). PLV was originally introduced as a new surgical approach by patients with an end stage of cardiac disease. On-pump CABG is a standard procedures used in cardiac surgery. MECG measurements were performed using 35 electrodes positioned on the body surface and recorded for one minute. Seven patients operated with partial left ventriculectomy (PLV) and nine patients operated by on-pump CABG were monitored. The same electrode positions were used for all the five measurements: one day before operation, and second, third, fourth and fifth postoperative day. The MECG software was used to evaluate, to store and to analyse the measured ECG signals. This work is concentrated on the analysis of the normalised beat amplitude maps (BAM).

The analysed BAMs show that the amplitude of cardiac signals decrease for approximately 30% after the PLV and stay in the same level during the five-day postoperative monitoring interval. In addition the area of the left ventricle, where PLV was performed, show significant changes in the level of beat amplitudes. In contrast, by CABG there are no significant changes in the average amplitudes. We suspect that with the BSM, as described here, it is possible to detect all the most important changes in the cardiac activity for patients where cardiac surgery was performed. The BSM is a non-invasive method, which could perhaps be used to study the patients after the cardiac surgery to see if there are some indications for fatal arrhythmias.

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