Analysing Bipolar ECG Implant's Specificity to 12 Segments of Left Ventricle

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Abstract

New heart monitoring devices such as implantable ECG recorders may provide effective ways to monitor specifically certain heart region, e.g. ischemic region. Previously we have developed and presented the region of interest sensitivity ratio (ROISR) parameter to describe how specific a measurement is to the activation arisen the ROI compared to other source regions. Present study demonstrates the applicability of ROISR in analyzing the specificity of an implanted bipolar ECG monitor. Sensitivity distributions of the implanted ECG system at six locations were calculated in a realistic model of a human thorax. These were applied in calculation of ROISRs for 12 different ROIs of the left ventricle. The results indicate that some of the tested locations provide high specificity to an individual ROI but some have high specificity to number of ROIs. The study demonstrates that the ROISR analyzing method is effective when studying the capabilities of ECG implants to measure certain heart areas.

1. Introduction

The measurements of bioelectric signals such as electrocardiograph (ECG) or electroencephalograph (EEG) are conducted with various standard and extended electrode arrangements. In clinical ECG the most commonly applied electrode system is the 12-lead system. Nowadays there exist, at least for research purposes, such systems which have electrodes up to 128 and even more to provide more information of cardiac and neural activity. Still there exist many situations such as emergency EEG or ECG as well as implantable monitors where the number of electrodes is limited. In all these cases it would be beneficial to know where to locate the electrodes to measure the target signals and their source regions as efficiently as possible. One might also desire to concentrate the measurement on a certain area of the cardiac muscle, like in segment of left ventricle, and locate electrodes in such way that the measurement is most specific to the activation arising in this region of interest (ROI). This is especially of interest when using implants in monitoring different cardiac arrhythmias or changes in activation of certain ROI after infarctions.

Modeling of measurements and their sensitivity distributions is one possibility to study the properties of electrode combinations and compare them to each other to find the optimal setup for the case at hand.

There have been only few methods which describe the properties of meausrement with numerical values when studying and analyzing modeled sensitivity distributions. One method is Half-Sensitivity Volume(HSV) concept [1, 2]. It describes what the source volume is where the sensitivity is at least half of the maximum of the lead in question [2]. We have applied HSV in estimating how the implantation of electrodes affects the focus of the sensitivity distribution [3]. However, HSV does not provide information related to the region of interest and neither has it described how well the measurement sensitivity is concentrated in the HSV. Thus we have developed analysis methods to assess different properties of modeled sensitivity distributions of bioelectric measurements [4-6]. In [5, 6] we have introduced and applied the region of interest sensitivity ratio (ROISR) parameter to describe how specific the bipolar bioelectric measurement is to the activation arisen in the region of interest (ROI) compared to other source regions in the volume conductor. In those papers the ROISR was used for EEG analysis. The objective of present study is to demonstrate for first time the developed method in analyzing ECG electrode systems. In this paper we apply the method in analyzing the specificity of implanted bipolar ECG monitor to the 12 segments of left ventricle.

2. Methods

2.1. Sensitivity distributions

The sensitivity distributions of the measurement configurations can be expressed as lead fields defining the relationship between the source (J^i) and the measured lead voltage (V_{LE}) as described in Equation 1 [7]. The lead field (J_{LE}) can be expressed as current density vectors. The measured lead voltage is dependent on the

magnitudes of the lead and source current vectors as well as the angle between these vectors. [7]

$$V_{LE} = \int \frac{1}{\sigma} \bar{J}_{LE} \bullet \bar{J}^{i} dv \ , \quad (1)$$

where V_{LE} is the lead voltage, $\bar{J}_{LE}$ is the lead vector $\left[\frac{1}{cm^2}\right]$, $\bar{J}^{i}$ is the current source density vector $\left[\frac{A}{cm^2}\right]$ and σ is the conductivity of the source location in the volume conductor $\left[\frac{1}{\Omega cm}\right]$

The lead field can be defined by employing volume conductor models of the heart and thorax and by applying the principle of reciprocity. In [7] it is stated that the current field (J_L) in the volume conductor raised by the reciprocal unit current (I_r=1 A) applied to the measurement electrodes provides the source-field relationship for the electrode setting meaning that the current field is the lead field (J_{LE}). The essential benefit of this method is that the lead field of a measurement lead is calculated at all source locations in the volume conductor with a single calculation.

2.2. Region of interest sensitivity ratio concept

The sensitivity distributions are not widely modeled and thus there are not that many methods to analyze their properties. We have developed parameter called region of interest sensitivity ratio (ROISR) which provides a new measure to analyze the sensitivity distributions of measurement systems by modeling [4]. ROISR defines how well the measurement sensitivity is concentrated in the ROI compared to other source areas in the volume conductor. Equation 2 describes the ROISR as a ratio between the mean sensitivity within the ROI and mean sensitivity outside it. The magnitude of the lead vector at each location of the lead field is applied as sensitivity of the measurement on that location.

$$ROISR = \frac{mean\left(\left\|\bar{J}^{LE}\right\|_{ROI}\right)}{mean\left(\left\|\bar{J}^{LE}\right\|_{nonROI}\right)}, \quad (2)$$

where $\left\|\bar{J}^{LE}\right\|_{ROI}$ are the sensitivities of the source locations in the region of interest and $\left\|\bar{J}^{LE}\right\|_{nonROI}$ are the sensitivities of the source locations in the rest of the source volume

2.3. Model

In this study we modeled the sensitivity distributions of implantable ECG monitor with a finite difference method (FDM) in a realistic model of a human thorax. The FDM allows the implementation of complex anatomic geometries from the image data, and the resulting potentials and currents can be calculated within the whole volume conductor model [8]. FDM model applied here was the 3D male thorax based on the Visible Human Man dataset (VHM) [9, 10]. The segmented dataset represents data on 95 slices where resolution in the slices close to the heart was 1.67 x 1.67 x 4 mm^3 and elsewhere 1.67 x 1.67 x 8 mm^3. Model contains altogether 2.7 million nodes with 2.6 million elements. The model contains over 20 different organ and tissue types with corresponding resistivities [11].

The model of the implant applied here was ~52 x 12 x 7 mm^3 and it has non-conducting body with 5 mm long electrodes in both ends. The implant is illustrated in Figure 1

Figure 1. Horizontal illustration of the implant model. The insulated body in white and electrodes in black.

2.4. Calculations

The lead fields were calculated for cases where the implant was in vertical orientation, at 6 different locations in upper thorax. The depth of implantation in each case was approximately 5 mm from the body surface corresponding to implantation under the skin. Figure 2 illustrates in white the electrode locations in front side of thorax for standard 128 electrode measurements and in black the implantation sites. The vertical orientation is illustrated in gray at location 8. The left ventricle was divided into 12 areas representing possible regions of interests based on the standard 12 segment left ventricular subdivision recommended by the Committee on Nomenclature of Myocardial Wall Segments of the International Society of Computerized Electrocardiography [12]. The division is illustrated in Figure 3. We calculated ROISRs for all the 12 segments in such way that one segment was ROI and other areas in the left ventricle where applied as nonROI source areas. The same procedure was applied for all six implant locations.

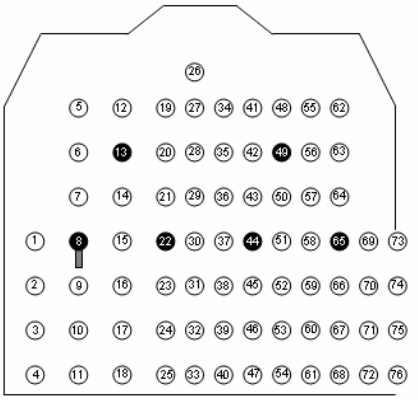

Figure 2. The implant locations in black. As an example also the implant is depicted in the applied vertical orientation at location 8, in gray.

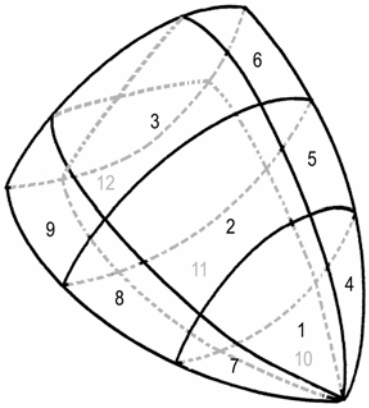

Figure 3. The standard 12-segment left ventricular subdivision. Segments 1-3 anteroseptal, 4-6 anterosuperior, 7-9 inferior and 10-12 posterolateral.

Table 1. ROISRs for 12 different ROI segments with 6 different implant locations and vertical allignment.If the ROISR is >1 then the measurement is in average more specific to measure sources within ROI than sources outside it.

	Vertical orientation											
	Number of ROI Segment											
	Anteroseptal			Anterosuperior			Inferior			Posterolateral		
Location	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
8	0.83	0.69	0.68	0.86	0.89	0.86	1.29	1.15	0.91	1.34	1.46	1.34
13	0.84	0.80	0.74	1.13	1.44	1.47	0.82	0.79	0.77	0.87	0.99	1.41
22	1.13	0.64	0.49	2.45	1.22	0.66	1.23	0.69	0.45	2.38	1.17	0.64
44	1.69	0.70	0.41	**3.19**	0.98	0.49	1.47	0.64	0.35	**2.39**	0.91	0.48
49	1.08	1.01	0.84	1.66	2.16	1.37	0.76	0.62	0.48	0.81	0.78	0.79
65	**2.37**	0.92	0.47	**3.74**	0.99	0.43	1.32	0.58	0.32	1.76	0.60	0.37

3. Results

Table 1 presents the ROISRs for the six implant locations when one of the 12 segments is ROI and other source areas in the left ventricle are nonROI areas. The higher the ROISR is the more concentrated the measurement is on the selected ROI and more likely the changes in activation are seen in the measured signal.

For example, one may be interested to measure and monitor changes in the activation of segment 4 and thus the measurement is needed to be specific to this region. From Table 1 we can observe that location 65 has highest ROISR for segment 4. In average this measurement site is 3.74 times more sensitive to the changes in activation of the sources in 4th segment than to the changes in activation of other source locations in the left ventricle.

Other possible way to apply the results is to predict where the changes in signal are originated. As an example if there are changes occurring in the measured signal when implant is located at location 44 the ROISR could tell how probable it is that changes are originating in each segment. In this case the highest ROISR 3.19 is in segment 4 and the second highest 2.39 is in segment 10. In this case if there are changes in measured signal they would most probably be generated in area of segments 4 or 10.

From Table 1 it can be observed that the ROISR values correspond with the common knowledge of the bioelectric measurements and their sensitivity distributions. In these cases they should be most sensitive to the segments which are closest to the measurement points and this can be seen e.g. in location 65 which is closest to the segments 1,4,7, and 10 .

4. Discussion

In the present study we demonstrate the use of the developed parameter ROISR in analyzing the sensitivity distributions of implantable ECG measurements. Previously we have simulated the connection between the ROISRs and signal-to-noise ratios of EEG evoked potential measurements and the results of these

simulations strongly encourage us to believe that SNR of bioelectric measurement can be predicted with ROISR. This would also be applicable in ECG cases where we are interested in electric activation of a particular area of the heart muscle and if the activation in ROI is considered as signal and other activation in the muscle as noise.

In the present study the ROISR was calculated based on lead field magnitude - the direction of cardiac activation is not considered. Based on our simulation studies with EEG it is evident that more reliable results of specificity will be achieved when the directions of sources are taken into account. In the future studies it will be considered if the directions of cardiac activation of different muscle regions should be taken into account and is this necessity when the specificities are calculated. If there is no need for direction of activity it would make the method even more applicable.

The prediction of signals measured with implantable devices is hard and methods to study without in vivo measurements are needed while clinical experiments are expensive and time consuming. The modeling and the analyzing method presented here provides an excellent tool when the properties of sensitivity distributions of implantable devices are studied. The methods can be applied as a test bench for instance when positioning or electrode combinations of implant are studied. In clinical use when monitoring e.g. ischemic regions of heart the presented method can be applied to position the electrodes and implant in such a location that it is most specific and sensitive to measure correct diseased area.

The results presented here are still preliminary and more like demonstrative. It is not absolutely evident that the method is applicable in clinical practice and there is still need for studies where ROISR and modeling is compared to real life signals and the true connection will be shown. In [5] it is given a promising results when the method is compared to real EEG measurements.

Although the model and segmentation of left ventricle to 12-segments are quite coarse the study shows that there are locations for implant which are more specific to measure individual segment and locations where the implant is sensitive for number of segments.

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