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Construction of Intracardiac Vectorcardiogram from Implantable Cardioverter-Defibrillator Intracardiac Electrograms

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Abstract

We constructed an intracardiac vectorcardiogram from 3 configurations of intracardiac cardioverter defibrillator (ICD) electrograms (EGMs). Six distinctive 3 Lead combination were selected out of five leads: Can to right ventricular coil (RVC); RVC to superior vena cava coil (SVC); Atrial lead tip (A-tip) to right ventricular (RV)-ring; Can to RV-ring; RV-tip to RVC, in a patient with dual chamber ICD. Surface spatial QRS-T angle (119.8°) was similar to intracardiac spatial QRS-T angle derived from ICD EGMs combination A (101.3°), B (96.1°), C (92.8°), D (95.2°), E (99.0°), F (96.2°) and median (101.5°). Future validation of the novel method is needed.

Graphical Abstract

Keywords

Implantable cardioverter defibrillator; Vectorcardiography; Intracardiac electrogram

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The implantable cardioverter defibrillator (ICD) is a life-saving device. Analysis of intracardiac electrograms (EGMs) is a vital part of ICD function [1-4]. Vectorcardiogram (VCG) characterizes movement of the heart vector over the cardiac cycle and was proven to be more informative than projection of the heart vector on a limited number of leads axes. We developed a novel method to construct and analyze intracardiac VCG (iVCG) from ICD EGMs.

ICD EGMs and surface 12 lead electrocardiogram (ECG) were recorded simultaneously, for a 30 second duration, in a patient with an implanted dual chamber ICD (Medtronic Inc., Minneapolis, MN)[5]. Recording was performed in intrinsic sinus rhythm and AAI pacing mode immediately after device implantation. This recording was then repeated after 1 week of verified atrial and ventricular pacing in DDD mode with a short AV delay to achieve complete ventricular capture from the device. All the recordings were performed supine. ICD EGMs and surface ECG were digitized respectively with sampling rates of 256 Hz and 500 Hz. Bi-plane X-ray images were obtained after ICD implantation. Patient data were collected at the Beth Israel Deaconess Medical Center (BIDMC). The novel iVCG reconstruction method was developed, and data analysis was performed at the Oregon Health and Science University (OHSU).

Inverse Dower transform was applied to acquire orthogonal XYZ ECG from 12 lead ECG recordings. Respiration effects were removed by moving, rotating, and rescaling VCG [6]. Median beat was analyzed. Beats were aligned by the QRS onset. The following ICD EGMs were available for analysis: (1) Can to right ventricular coil (RVC); (2) RVC to superior vena cava coil (SVC); (3) Atrial lead tip (A-tip) to right ventricular (RV)-ring; (4) Can to RV-ring; (5) RV-tip to RVC; (6) RV-tip to RV-ring. Near field EGM RV-tip to RV-ring was excluded from the study due to its low resolution volume[7], while the remaining 5 EGMs were used to construct three different configurations of three-dimensional (but not orthogonal) coordinates: : A) Can to RVC, A-tip to RV-ring and RV-tip to RVC. B) Can to RVC, Can to RV-ring and RV-tip to RVC. C) RVC to SV, A-tip to RV-ring and RV-tip to RVC (D) A-tip to RV-ring, Can to RV-ring and RV-tip to RVC, (E) Can to RVC, RVC to SVC and RV-tip to RVC, (F) RVC to SVC, Can to RV-ring and RV-tip to RVC. ICD leads were located using the bi-plane X-ray images (Figure 1). The lead locations were used to acquire the EGM signal vectors used to orthogonalize the EGMs as following:

$$V1 = \frac{(VB - VA)}{\|VB - VA\|}, \quad V2 = \frac{V1 \times (VA - VC)}{\|V1 \times (VA - VC)\|}, \quad V3 = V3 \times V1 \quad (1-3)$$

$$S_{xO} = SA \cdot V1, \quad S_{yO} = SB \cdot V2, \quad S_{zO} = SC \cdot V3 \quad (4-6)$$

where VA, VB and VC are the vectors representing direction for signals SA, SB and SC: Subsequently, S_{xO} , S_{yO} and S_{zO} are orthogonalized EGMs, resulted from SA, SB, and SC, which were further used to reconstruct iVCGs. Finally, the median was taken from entire 6 employed combinations' orthogonal signals. The median iVCG was reconstructed. Median iVCG hold the closest morphological representation to VCG (Figure 2).

Due to the presence of asymmetrical QRS and T loops on iVCGs and lower sampling frequency on ICD EGMs the mean (but not “peak”) spatial QRS-T angle was measured as previously described [8]. The spatial T peak vector magnitude was measured [9].

Intracardiac spatial QRS-T angle was largely in agreement with surface QRS-T angle and did not change after 1 week of pacing (Table 1). T vector magnitude increased after 1 week of pacing, which is likely a manifestation of cardiac memory [5]. Post-myocardial infarction inferior scar was presented on iVCG as a prominent sharp and rapid change in direction of middle to late part of QRS loop and was more easily seen on iVCG, as compared to surface VCG (Figure 2). The results were highly consistent for both QRS-T angle and T vector magnitude through different EGMs combinations. Further studies are needed to validate the method presented here. Future potential applications of the method include: improvement in rhythm discrimination (supraventricular vs. ventricular arrhythmias), prediction of ventricular arrhythmias, detection of acute ischemia, and detection of acute/intermittent ventricular conduction abnormalities.

Acknowledgments

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Highlights

- Intracardiac VCG was constructed out of intracardiac EGMs
- Intracardiac QRS-T angle was similar to the surface VCG QRS-T angle
- Intracardiac QRS-T angle in several configurations of intracardiac EGMs was similar

Figure1.
Localization of ICD leads and EGMs' vectors using biplane X-ray images. AP = anteroposterior, L = Lateral.

Figure2.
Surface 12-lead ECG, and median beat intracardiac EGMs in AAI pacing mode.
Constructed surface VCG and Median-intracardiac-VCG.

Table1

Comparison of surface VCG and iVCG parameters

	Spatial QRS-T angle, °				Spatial T vector amplitude, mV				Spatial QRS-T Angle
	Baseline		Day 7		Baseline		Day 7		
	ISR	AAI	ISR	AAI	ISR	AAI	IRS	AAI	
sVCG	118.3	122.9	117.2	120.9	0.27	0.30	0.27	0.30	119.8
iVCG A	99.2	103.2	105.2	97.8	1.6	1.6	4.0	3.9	101.3
iVCG B	102.0	99.1	92.3	91.0	1.8	1.7	4.2	3.9	96.1
iVCG C	86.9	110.2	87.5	86.5	1.6	1.6	4.1	4.1	92.8
iVCG D	89.1	105.9	90.1	95.6	1.5	1.5	4.4	4.4	95.2
iVCG E	88.6	108.6	95.4	103.2	1.5	1.3	3.9	3.9	99.0
iVCG F	89.1	93.81	90.0	111.7	1.5	1.4	4.0	3.5	96.2
iVCG M	99.0	92.6	99.2	115.3	0.8	0.7	2.9	2.8	101.5

sVCG=surface VCG. iVCG A= intracardiac VCG A: Can to RVC, A-tip to RV-ring, RV-tip to RVC. iVCG B: Can to RVC, Can to RV-ring, RV-tip to RVC. iVCG C: RVC to SVC, A-tip to RV-ring, RV-tip to RVC. iVCG D: A-tip to RV-ring, Can to RV-ring, RV-tip to RVC. iVCG E: Can to RVC, RVC to SVC, RV-tip to RVC. iVCG F: RVC to SVC, Can to RV-ring, RV-tip to RVC. iVCG M= Median iVCG. ISR=intrinsic sinus rhythm