Short Distance Bipolar Electrocardiographic Leads in Diagnosis of Left Ventricular Hypertrophy

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Abstract

The study evaluates the performance of closely separated (6 cm) bipolar leads in differentiating subjects with left ventricular hypertrophy (LVH) from normal subjects.

The study population consists of 236 healthy subjects, 116 pure LVH patients) and 189 complex LVH patients. A total of 36 vertical, 30 horizontal and 66 diagonal bipolar leads located on the anterior thorax were analyzed. The findings of the study show that the best leads differentiating normals from pure and complex LVH subjects are vertical leads located on lower anterior thorax and mid-thoracic region, respectively. These leads have better performance and are more sensitive than clinically applied Sokolow-Lyon criteria.

As a conclusion the new short distance bipolar leads are efficient in discriminating subjects with LVH from normal subjects based on QRS amplitude.

1. Introduction

Cardiac activity is traditionally recorded with the standard 12-lead ECG system. However, advances in measurement technology and wireless signal transfer have enabled the design of new small and portable ECG measurement devices for a wide range of clinical purposes (1-3). Sensor technology for implantable applications has also been developed to measure biosignals inside the human body (4). The standard 12-lead ECG is an invaluable tool, but new portable, implantable or wearable devices offer novel means of recording ECG signals. However, these ECG devices often utilize bipolar measurement and new lead locations, because they have a smaller number of electrodes and don't always include the Wilson's central terminal (WCT). This sets unique demands for measurement and diagnostics (3, 5).

Left ventricular hypertrophy (LVH), which can be diagnosed by an ECG, is associated with an excess risk of acute coronary events. The commonly used ECG-LVH criteria are based on the traditional 12-lead system and most of them use the sum of R and S amplitudes of different leads as one criterion (6-8). Kornreich et al. have identified the best unipolar leads for diagnosing LVH through a statistical analysis of BSPMs (9, 10), and Oikarinen et al. have assessed the capability of BSPM unipolar leads' QRS area in LVH diagnosis (11). We have lately published a study related to the performance of short bipolar leads in differentiating patients with pure LVH from healthy cases (12). However Kornreich et al. have divided LVH cases in two groups, pure LVH patients and complex LVH patients (13). Thus, our objective here was to apply BSPM data to study the capability of a small bipolar lead to differentiate subjects with different types of LVH from normal subjects.

2. Materials and methods

The study population consists of 236 healthy subjects, 116 pure LVH patients having either pure left-sided valvular disease or sustained hypertension (150/90 mmHg or higher) and 189 complex LVH patients with various cardiac conditions frequently associated with LVH (14). The presence of LVH was diagnosed from ECG-independent information: echocardiography, cardiac catheterization with coronary angiography and ventriculography, radionuclide angiography, chest radiographs or cardiac surgery (13, 14).

The BSPM data contains 120 signals recorded by methods described in earlier studies (15). Briefly, ECG was recorded simultaneously from 117 surface leads and 3 limb leads with Wilson' central terminal as reference, at 500 Hz sample rate. For the present study, bipolar leads were formed by calculating the difference between two unipolar lead signals. The formed bipolar leads on the anterior thorax included 36 vertical, 30 horizontal, 36 diagonal sloping downwards left (dL), and 30 diagonal sloping downwards right (dR) leads. Examples of the bipolar lead locations are illustrated in Figure 1. Different lead orientations were studied as the LVH is known to shift the QRS axis (16). The electrode distances of the constructed bipolar leads were approximately 5 cm vertical, 6 cm horizontal, and 6 cm diagonal, depending on the person's size. The rationale for this electrode spacing was that the BSPM data directly supported this spacing. Further, this electrode spacing represents a possible size for a wearable or implantable ECG device.

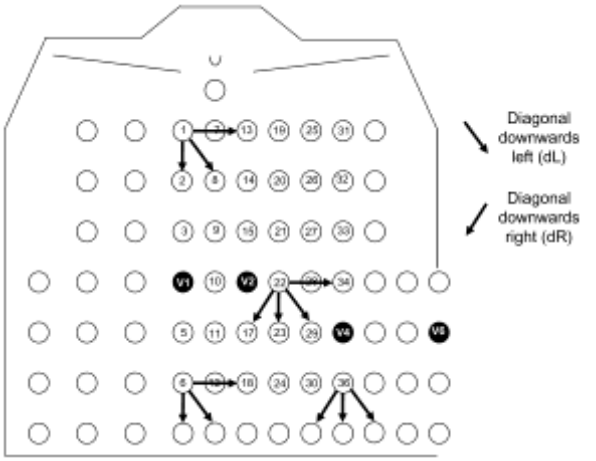
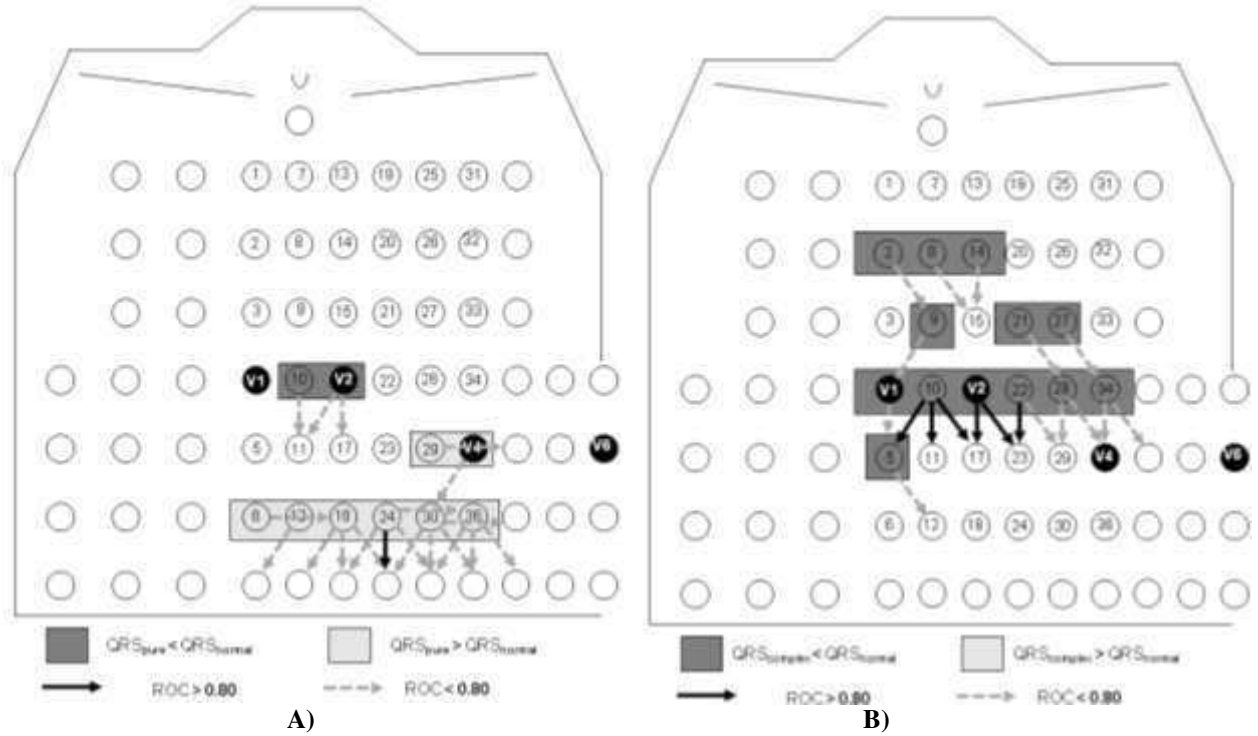


Figure 1. Locations of the constructed bipolar leads oriented vertically, horizontally, diagonally sloping downwards left (dL), and diagonally sloping downwards right (dR) in the Dalhousie lead system

The overall diagnostic performance of the studied bipolar leads was evaluated using receiver operating characteristic (ROC) analysis. The area under the ROC curve represents the probability that a random pair of patients with or without LVH will be correctly diagnosed (17). Statistical data analysis was performed with SPSS version 16.0 software (SPSS Inc., Chicago, IL, USA). The diagnostic variable used in the ROC analysis was QRS amplitude, i.e. maximum peak-to-peak value of the signal during the ventricular activation. For reference, ROC analysis was also performed to standard 12-lead ECG based LVH detection criterion, Sokolow-Lyon voltage (sum of the amplitude of S wave in lead V1 and R wave in lead V5 or V6, which ever higher) (6). In addition, the sensitivity values at 90% specificities and corresponding cut off values were determined for best bipolar leads and for Sokolow-Lyon voltage method.

3. Results

The studied bipolar leads having a good overall performance (ROC area ≥ 0.70) in group comparisons of normal subjects vs. pure LVH subjects and normal subjects vs. complex LVH subjects are presented in Figure 2. A total of 6 leads provided a very good overall diagnostic capacity (ROC area > 0.80), when comparing normal subjects vs. subjects with complex LVH. A single lead provided very good performance in case of pure LVH. Generally, the ROC areas were higher when differentiating complex LVH subjects from pure LVH subjects from normal subjects. Figure 2 also shows that the QRS amplitudes in bipolar leads are lower in complex



A) B)

Figure 2. Best precordial bipolar leads for differentiating LVH subjects from normal subjects. These leads provided a good overall diagnostic capacity in differentiating pure LVH (A) and complex LVH (B) subjects (ROC area ≥ 0.7) from normal subjects. Leads presented with solid black arrow have ROC > 0.80. In bipolar leads marked with dark gray the QRS amplitudes of LVH cases were lower than amplitudes of healthy cases.

Table 1. ROC areas, sensitivities and cut off points at 90 % specificities for the best bipolar leads and for Sokolow-Lyon criteria. Group comparisons were normal subjects vs. pure LVH and normal vs. complex LVH. Note that the diagnostic criteria for complex LVH are reversed.

Method	ROC	Sensitivity at 90% specificity	Cut off point (μV) at 90% specificity
Sokolow-Lyon (pure)	0.73	42 %	> 4255
Best bipolar (vertical lead 24) (normal vs. pure)	0.81	59 %	>765
Sokolow-Lyon (complex)	0.67	39 %	< 1766
Best bipolar (vertical lead 16) (normal vs. comp)	0.85	65 %	< 816

LVH cases than in corresponding normal cases.

For comparing the performance of the new bipolar leads with that of an existing LVH criterion, the corresponding ROC areas, sensitivity values at 90 % specificities, and cut off values are listed in Table 1. The best bipolar leads differentiating pure and complex LVH from normal subjects provide notably better sensitivities than Sokolow-Lyon for 90 % specificities. It is worth noticing that QRS amplitude criteria of best bipolar leads are different for discriminating the pure LVH and complex LVH groups from normals.

4. Discussion

This study evaluated the performance of bipolar ECG leads with short interelectrode distance in population with different type LVH. A total of 36 vertical, 30 horizontal and 66 diagonal bipolar leads located on the anterior thorax were assessed with ROC analysis. One major finding was that the there exist two areas of bipolar leads providing a good overall diagnostic performance. One region is located near the precordial electrodes of standard leads V1-V3 and the other on lower anterior thorax. The optimal leads for differentiating complex and pure LVH subjects from normal subjects are located in different areas as shown in Figure 2.

For reference, the ROC areas provided by clinical Sokolow-Lyon voltage method were also determined. The ROC area of Sokolow-Lyon method was 0.73 and 0.67 for pure and complex LVH cases, respectively.

An interesting observation was that the amplitude detected by the some of the new precordial bipolar leads was lower in LVH groups compared to normal subjects. Generally it is the opposite, as LVH is associated with high QRS voltages in the unipolar leads, especially V1, V2, V5 and V6. It is interesting that the pure LVH group had higher amplitudes in bipolar leads located at lower thoracic region and lower amplitudes in leads located at mid thorax. The complex group had also lower amplitudes in leads located at upper thorax. The reason for the lower amplitudes in the new precordial bipolar leads could be that the thickening of tbhe left ventricular wall enhances all body surface potentials in the precordial area, thus decreasing the potential difference between two closely lying bipolar lead electrodes. Hence, the amplitude difference between the transversal level of V2 and the transversal level of V4 decreases in LVH cases. Another possible reason is that the shifting of the QRS axis related to LVH shortens the projection detected by the bipolar leads, thus inducing smaller amplitudes. It is known that LVH causes the QRS frontal axis to shift slightly leftward and the QRS transversal axis to shift markedly posterior (16).

In clinical diagnostics R and/or S amplitudes are applied to criteria of LVH. It has been reported that the voltage based LVH criteria have high specificity but low sensitivity (18, 19). The differentiation done with BSPM data has been recognized to provide better performance and higher sensitivity (15). Our results suggest that new small precordial bipolar leads could provide advanced tools for LVH diagnostics. These new leads cannot replace the standard 12-lead system. However, with short electrode distance they provide compelling advantages in applications utilizing wearable or implantable long term measurements. Though further study is needed for more specific diagnostic purposes, these results indicate that the new precordial bipolar leads are able to discriminate normal subjects from subjects with pure or complex LVH.

There are some limitations to our study. In our dataset the male and female patients are not separated, so we cannot state how the effects of lead orientations differ between genders. It should also be noted that although large voltage differences were noticed between normal subjects and patients with pure or complex LVH, there is also large inter-individual variability.

5. Conclusions

This study indicates that precordial bipolar ECG leads with a short interelectrode distance (~6 cm) are able to discriminate subjects with LVH from normal subjects. The best performance was obtained with vertical and diagonal bipolar leads located on precordial and lower anterior thorax. These bipolar leads provided even very good overall diagnostic capacity in differentiating LVH subjects from normal subjects, when using the QRS

amplitude as a variable. These leads also provide higher sensitivities than traditional Sokolow-Lyon method.

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