The Relationship between Mechanical and Electrical Dyssynchrony

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Abstract

The new QRS electrical depolarization map concept that is based on the processing of high frequencies in the QRS complex was introduced. The QRS electrical depolarization maps were derived from standard 12-lead ECG electrode placement and mechanical initiation maps were obtained using speckle tracking echocardiography of the left ventricle from 6 subjects suffering from left bundle branch block.

The proposed method for assessing electrical depolarization showed to be highly reproducible in various passbands and also a high level of agreement between the shape of electrical depolarization and mechanical activation was demonstrated. The QRS electrical depolarization maps in frequencies ranging between 150-1000Hz could serve as a non-invasive and very easily accessible evaluation of the electrical properties of ventricular depolarization that initiates the mechanical action.

1. Introduction

The myocardial deformation imaging techniques such as speckle-tracking echocardiography (STE) and feature tracking cardiac magnetic resonance are becoming an important diagnostic tool in heart disease [1]. The noninvasive spatial electrical depolarization of the ventricles can be roughly assessed by a 12-lead ECG, but this does not offer a direct link to mechanical activation.

A clinical evaluation of the relationship between the mechanical contraction and electrical depolarization of the ventricular myocardium would be helpful in precise diagnostics and would provide for a more accurate treatment of patients requiring pacemaker therapy [2]. It is not always possible to accurately interpret a standard 12-lead ECG, although for example, precisely assessing the true left bundle branch block (LBBB) is very important as a possible benefit for cardiac resynchronization therapy [3].

The QRS complex consists of frequencies higher than the standard clinically used frequency of 150Hz. The properties of these frequencies can carry vital information about inhomogeneity in the electrical depolarization of the ventricles [4]. The proposed QRS electrical depolarization maps, based on the processing of high frequencies in the QRS complex, offer insight into the temporal-spatial electrical activation of the myocardium.

The aim of this work was to investigate the ability of the newly-proposed QRS electrical depolarization maps to determine the time-course of ventricular electrical activation. Since an evolution of electrical depolarization represents the initiating point for the mechanical action of the myocardium, another aim was to explore whether the QRS electrical depolarization maps in various frequencies ranging from 150-1000Hz could be compared with the mechanical contraction initiation of the left ventricle (LV) myocardium assessed using Speckle Tracking Echocardiography (STE).

2. Methods

To assess electrical and mechanical dyssynchronous activation, a 12-lead ECG (SciSDA14, M&I s r.o., Prague, Czech Republic) and echocardiography (Vivid E9, GE Healthcare, Wauwatosa, WI) were performed in 6 heart failure patients with left bundle branch block (LBBB) that were indicated for CRT.

2.1. Electrical depolarization activation

The 12-lead ECG was recorded using a high dynamic range recording system (sampling frequency 5 kHz, amplitude resolution 26 bits) for 10 min in a supine resting position. The precise R-wave detection and exact categorization of different QRS morphologies was performed using robust multichannel correlation algorithms [5, 6]. The amplitude envelopes were computed by the Hilbert transform in the following frequency ranges: HFQRS (150-250Hz), VHFQRS (250-500Hz) and UHFQRS (500-1000Hz). The signal averaging technique

was applied to improve the signal-to-noise ratio. Signals were low pass filtered (pass band 0-40 Hz) and the resulting 2D matrix represents the time (time relative to the R wave) and spatial (V leads) distribution of electrical activity. An example of an amplitude envelopes is shown in Figure 1 in the upper right panel. Electrical activation maps were then created using amplitude normalization over the V lead envelopes (max. amplitude – red, min. amplitude – blue), arranging an envelopes into rows from V1 to V6 and performing a linear interpolation between the rows (Figure 1 at the bottom). Such a presentation describes the time-spatial distribution of electrical activity (phase 0 of action potentials (AP)) in a graphical form and should correspond to the initiation of mechanical activity. The presented time area is ±120 ms around the R wave.

Assessing electrical depolarization dyssynchrony (the line that represents electrical activation over the V leads) is not unequivocal in relation to mechanical initiation. The acquired activation in the single lead represents the time evolution of the activity of all myocardial cells in the lead corresponding area. The times corresponding to the maximum amplitude of the envelope (A_max) and 20% resp. 50% of the signal integral (I_20% resp. I_50%) were chosen. The 10 min measurement was divided and separately analyzed for the purpose of the reproducibility assessment of electrical activation maps. Electrical depolarization dyssynchrony was assessed as the difference the between earliest and latest activation between the V leads. (DYS in Figure 1.)

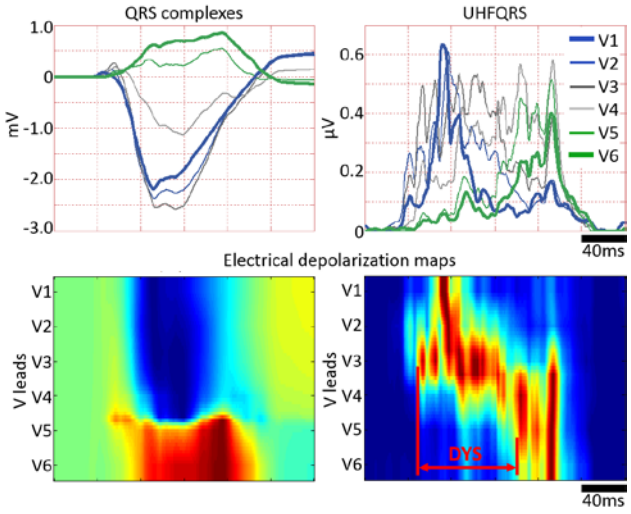

Figure 1. An example of an electrical depolarization activation analysis in an LBBB subject. The QRS complexes from all V leads (the left upper panel) and the UHFQRS envelopes in the 500-1000Hz passband (the right upper panel). The UHFQRS electrical activation map provides information about the time-spatial distribution of electrical activity over the V leads (the right bottom panel).

2.2. Mechanical activity initiation

Two-dimensional speckle tracking echocardiography (STE), as a robust technique for quantitatively assessing LV function [1], was chosen to assess the mechanical dyssynchronous initiation of the LV. STE describes the mechanical deformation of the myocardium over the whole heartbeat cycle including the depolarization – repolarization phase of the beat. For comparison with electrical depolarization, only the time corresponding window with the area of the QRS complex was used (Figure 2). Activation time was measured from the color-coded strain rate map for each of the six segments (from the basal septum to the basal lateral wall), which should correspond to the V leads. The first occurrence of yellow in any given segment was used as the start of mechanical initiation. Two ventricular contractions per subject were analyzed using STE. The reproducibility of the dyssynchronous shape of STE activation maps was tested using a correlation analysis. The mechanical dyssynchronous activation of the ventricular myocardium was assessed as the difference between the earliest and latest activation obtained from STE maps (the DYS in Figure 2.).

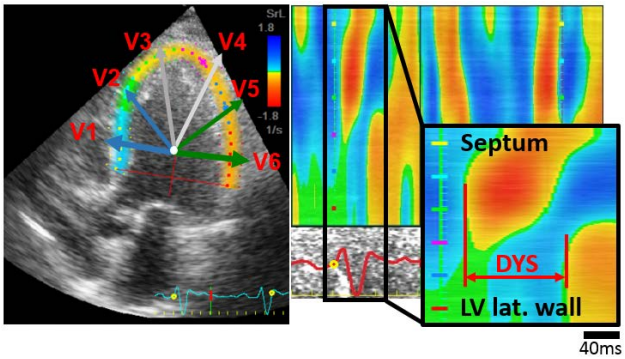

Figure 2. An example of the STE strain rate analysis of the LV in an LBBB subject. The LV is divided into six segments approximately corresponding to the surface V leads (the left part). Mechanical activity initiation represents the region of interest for comparison with electrical depolarization activation (the right part).

2.3. A comparison of the electrical depolarization and mechanical activation of the ventricular myocardium

The subject's myocardial depolarization was considered to be identical during a calm resting state in a supine position regardless of the fact that the ECG and echo-measurements were not taken at the same time. The ECG recording was made just prior to the echocardiographic procedure. The agreement between mechanical activation and different definitions of electrical activation was tested.

3. Results

Table 1. The reproducibility of the shape of electrical dyssynchronous myocardial depolarization based on times corresponding to the maximum amplitude of envelope (A_max) and 20% and 50% of the signal integral (I_20% and I_50%) in three different frequency ranges. The values are represented as a mean Pearson's correlation coefficient ± SD over the subjects.

Passband [Hz]	A_max	I_20%	I_50%
HF	0.99±0.03	0.99±0.01	0.99±0.01
VHF	0.97±0.05	0.97±0.06	0.99±0.01
UHF	0.91±0.13	0.93±0.1	0.99±0.01

The correlation between the two shapes of mechanical initiation assessed by STE was 0.96±0.06 (the mean Pearson's correlation coefficient ± SD over the subjects).

Table 2 shows the significant correlation between the shape of mechanical activity initiation and the electrical depolarization activation of the myocardium over the subjects. The best agreement is seem in the I_20% parameter in the UHF passband. A_max parameter, which defines the time when the maximum number of myocardial cells per time unit are initiated, has a lower correlation with mechanical initiation.

Table 2. Correlation between the shapes of mechanical and electrical myocardial activation. The values are represented as a mean Pearson's correlation coefficient ± SD over the subjects.

Passband [Hz]	A_max	I_20%	I_50%
HF	0.75±0.09	0.84±0.17	0.86±0.02
VHF	0.74±0.15	0.85±0.07	0.82±0.09
UHF	0.77±0.15	0.91±0.04	0.87±0.08

Table 3. Reproducibility of the dyssynchrony. The values are represented as a mean ± SD over all subjects.

Passband [Hz]	Mech. dyssynchrony change [ms]	El. dyssynchrony change [ms]		
		A_max	I_20%	I_50%
HF	22±24	5±7	5±4	4±3
VHF		5±5	8±11	5±4
UHF		10±17	4±4	2±3

4. Discussion

Since it is not clear what amount of electrically depolarized myocardium initiates the mechanical action that is detectable by the STE method, three different parameters (A_max, I_20% and I_50%), quantifying electrical depolarization computed in three different passbands were chosen for the comparison. The high level of reproducibility of the shape of electrical activity, presented by the correlation coefficient, is demonstrated in Table 1. The amplitude of the QRS components and the signal-to-noise ratio (SNR) decrease together with an increase of the frequency range. This physiological fact affects the differences in Table 1. While the reproducibility is almost maximal in the HF passband, it slightly decreases with an increasing frequency range.

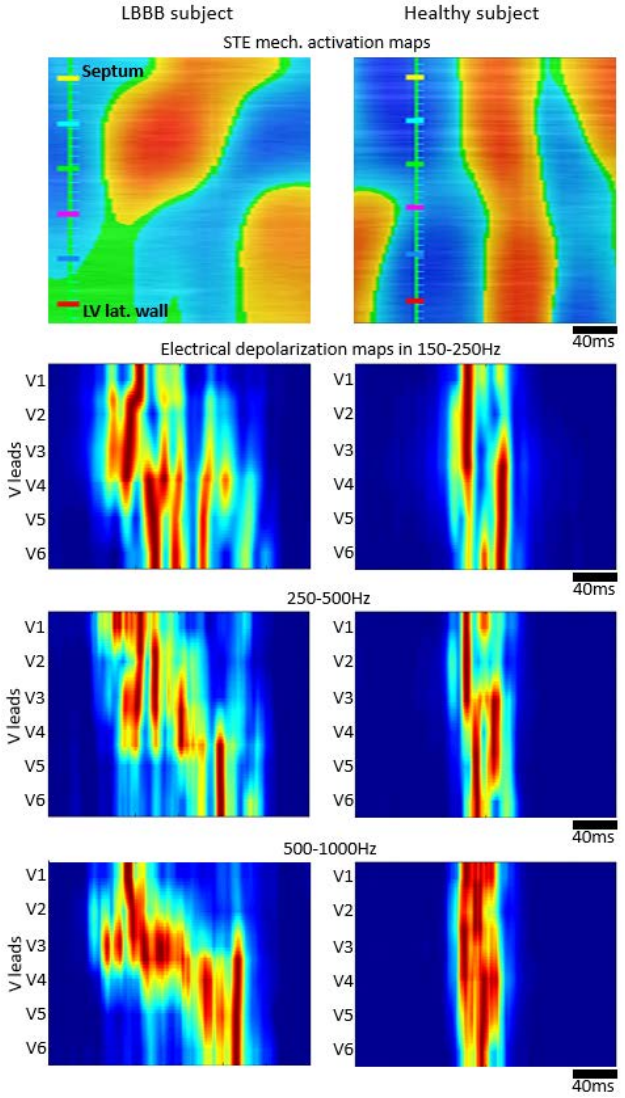

Figure 3. An example of STE mechanical activation maps and electrical depolarization maps (in various frequency ranges) in LBBB and healthy subjects. While in a healthy heart, the electrical and mechanical activation of the myocardium begins (almost) synchronously in all parts of the LV, activation of the LV lateral wall resp. V5-6 is clearly delayed behind the septum in an LBBB subject.

A significant correlation exists between the shapes of mechanical and electrical activity (Table 2.). The best agreement in the UHF passband represents signals corresponding to the fastest changes of AP, i.e. phase 0, without any influence by the slower changes of AP. The best agreement in I_20% should correspond to the point in

time when 20% of the myocardial cells, matching the given leads, are activated with a consequent mechanical activation determined by STE.

Figure 3 demonstrates the shapes of mechanical activation maps with electrical depolarization maps in three different passbands in LBBB and healthy subjects. The electrical and mechanical activation of a healthy myocardium begins (almost) synchronously in all parts of the LV, unlike the activation of the LV lateral wall resp. V5-6, which is clearly delayed behind the septum in an LBBB subject. The graphical differences between the passbands are apparent, but the agreement between the mechanical and electrical shapes of activation are greatest in the UHF passband.

Electrical depolarization maps enable the assessment of the dyssynchrony between the earliest and latest myocardial activation the same way as in the STE analysis (the DYS parameter in Figures 1 and 2). The reproducibility of the STE dyssynchrony assessment seems to be lower in comparison to electrical depolarization maps.

5. Limitations

The study was performed on a very limited number of subjects and thus serves more as an introduction of a new concept for easily derived temporal-spatial information about ventricular depolarization from a surface 12-lead ECG.

Although the STE is a clinically acceptable method, it is not a perfect match for making a comparison with electrical depolarization activation analysis. The temporal resolution is about 10-15 times lower than electrical depolarization maps. Reliable and reproducible dyssynchrony results can be obtained only in subjects with high dyssynchrony (LBBB patients). An STE examination requires a skilled operator and very high quality echocardiographic imaging and cannot be successfully performed on every patient.

The amount of electrical activation that initiates the mechanical myocardial activity detectable by the STE method is not clearly known.

The spatial correspondence between the V leads and the actual position of the heart in a thorax (as indicated in Figure 2 left) is more likely a schematic. Also, electrical depolarization maps are generated by the electrical signal from both ventricles. The electrical depolarization of the septum and the right ventricle mainly escalate in V1-V3 electrodes. For the purpose of making a comparison with an STE analysis of the LV, the influence of the right ventricle's electrical activation was not considered, but could affect the results.

6. Conclusion

A comparison between electrical depolarization activation maps and the mechanical initiation of the ventricular myocardium by STE demonstrated a similar shape of myocardial activation and confirmed the feasibility of the method.

Electrical activation maps will never replace assessing the mechanical properties of the myocardium, because the electrical part is the only small portion (isovolumetric contraction) of the whole ventricular cycle. But the information derived with almost no effort in addition to a standard 12-lead ECG can serve as a robust marker of electrical depolarization disturbances with no need of any special interpretation abilities.

Nevertheless, this is the first kind of easy and non-invasive evaluation of the electrical and mechanical activation of the left ventricle based on nothing more than a standard ECG setup and echocardiography.

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