The absence of high-frequency QRS changes in the presence of standard electrocardiographic QRS changes of old myocardial infarction

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Background This study compares the high-frequency QRS components (HF-QRS) in patients with and without standard electrocardiogram (ECG) changes indicative of old myocardial infarction (MI). Previous studies have indicated that patients with an old MI differ in their HF-QRS compared with healthy subjects. The HF-QRS has been reported to be decreased during acute coronary occlusion and increased after reperfusion. However, there is controversy about the appearance of HF-QRS after the acute phase of MI.

Methods A total of 154 patients were included, 57 with and 97 without QRS changes of old MI on the standard ECG. The patients with old MI were divided into subgroups on the basis of the MI location indicated by the standard ECG. Signal-averaged ECGs from the 12 standard leads were recorded. The root-mean-square values of the HF-QRS were determined within two frequency bands: 150 to 250 Hz and 80 to 300 Hz.

Results There was a large interindividual variation in HF-QRS in patients without MI as well as in those with different MI locations. There were no significant differences between the groups in the summed HF-QRS of all 12 leads or in the pattern of lead distribution of the HF-QRS. Not even the patients with the greatest QRS changes of old MI could be differentiated from those without any changes of old MI on the standard ECG. The results were the same in both analyzed frequency bands.

Conclusions This study shows, contrary to previous studies, that analysis of HF-QRS cannot differentiate between patients with and without old MI. (Am Heart J 2001;141:573-9.)

It is well known that changes of the electromotive forces resulting from an old myocardial infarction (MI) may produce morphologic alterations visible in the QRS complex in the standard electrocardiogram (ECG). Early attempts at investigating the impact of old MI on high-frequency components in the QRS complex were based on counting the number of “notches and slurs” visible on the ECG recorded by equipment with an expanded frequency response at rapid paper speeds. These results indicated an increased number of notches and slurs after an MI.1–5 More sophisticated methods, with use of signal averaging and digital filtering techniques, later made it possible to assess intra-QRS high-frequency energy in a more quantitative and more easily measured way. These techniques have yielded conflicting results regarding an old MI6–11 but have documented a decrease in high-frequency QRS components (HF-QRS) during acute coronary occlusion12–17 and an increase after successful reperfusion.18,19

Several investigators have documented reduced HF-QRS in patients with old MI compared with healthy subjects.6–10 Goldberger et al6 found the HF-QRS, in the frequency range of 80 to 300 Hz, to be significantly lower in leads V2 and V5 in patients with an old anterior MI. In patients with old inferior MI, the HF-QRS was lower in leads II, aVF, and III.6,7 A reduction of the HF-QRS has also been documented by Talwar et al9 in lead III in patients with old inferior MI. The same observations were made by Berkalp et al.10 Reduced HF-QRS was observed in patients with inferior and anterior MI in the X, Y, and Z leads in the frequency range of 150 to 250 Hz. In contrast, Novak et al11 documented HF-QRS, defined as frequencies ≥90 Hz, to be higher in post-MI patients compared with healthy subjects in leads X, Y, and Z.

In previous studies of HF-QRS, several different bandwidths have been used.6–19 The frequency band most commonly used for the assessment of changes in HF-QRS during acute myocardial ischemia has been 150 to 250 Hz.12–17 In some of the studies investigating the
effects of an old MI, the HF-QRS has been determined within a bandwidth of 80 to 300 Hz. In most of these previous studies, only a few leads have been used. With modern computerized ECG recorders it is possible to obtain high-frequency data from all 12 standard leads and also to select the desirable frequency band.

The objective of the current study was to compare the HF-QRS, in the frequency ranges of 150 to 250 Hz and 80 to 300 Hz, in patients with and without QRS changes indicative of old MI on the standard 12-lead ECG.

Methods
Study population
The study population consisted of 219 patients, 117 of whom were admitted to the Department of Clinical Physiology at Lund University Hospital, Sweden, for exercise testing. The remaining 102 patients were admitted to the Charleston Area Medical Center, WV, for elective percutaneous transluminal coronary angioplasty. The study was approved by the local Investigational Review Board, and informed consent was obtained from each patient before enrollment.

None of the patients had clinical or ECG evidence of an acute or recent MI. To reduce any potential confounding factors, patients with the following abnormalities on standard 12-lead ECG recorded by the conventional electrode placement were excluded: intraventricular conduction delay with QRS duration ≥ 120 milliseconds (11 patients), left ventricular hypertrophy by either or both of the Cornell voltage criteria, and the Sokolow-Lyon criteria (25 patients), left anterior fascicular block (7 patients), low voltage (2 patients), or atrial fibrillation (5 patients). In 14 of the patients the standard or high-frequency ECG recording was incomplete (misplaced or missing leads) and these patients were excluded.

The patients were divided into groups on the basis of the presence and location of old MI as indicated by the standard 12-lead ECG, according to the Selvester QRS scoring system. The scoring was performed by two independent investigators blinded to each other and later compared. Any differences were identified and adjudicated.

To be considered as indicating old MI, the ECG had to either (1) meet the Anderson screening criteria set from the complete Selvester QRS scoring system for one or more MI locations (inferior location [Q wave ≥ 40 milliseconds in V6], anterior location [any Q wave, or R wave < 0.1 mV and < 10 milliseconds in V1], or posterior location [R wave ≥ 40 milliseconds in V1]) or (2) achieve ≥ 4 points from nonscreening criteria, with ≥ 2 points of these awarded in other leads than V6 or V1.

The location of the MI was indicated by the presence of either a screening criterion or at least 2 points from nonscreening criteria. Patients who met criteria for both inferior and posterior location were regarded as inferior. The 3 patients with the highest numbers of Selvester QRS points (each scoring point representing 3% of the left ventricle) were in each of the anterior and inferior MI groups identified.

“No MI” was defined as neither any of the Anderson screening criteria in any available cycles nor ≥ 2 points from nonscreening criteria. Patients meeting neither the MI nor the no-MI criteria were considered as indeterminate regarding old MI and excluded from the study (3 patients).

A control group of healthy individuals was selected from the no-MI group because they had no objective signs of ischemic heart disease (4 patients). These patients met all of the following criteria: no previous history of cardiac disease, no therapy with β-blockers or nitrates, normal resting ECG, normal exercise test (peak workload > 90% of predicted, maximal heart rate > 85% of predicted, no chest pain, < 0.1 mV ST depression), and no reversible ischemia visible on myocardial scintigraphy.

Finally, 154 patients (male = 104 and female = 50, ages 21 to 88 years, mean 58 ± 11 years) were eligible for this study. The number of patients with and without old MI was 57 and 97, respectively. The characteristics and distribution of the patients into the various old MI location groups are shown in Table I. There were no significant differences in age or sex between the no MI group and the different MI groups.

ECG acquisition
The ECGs were recorded with equipment provided by Siemens-Elema AB, Solna, Sweden. Limb lead electrodes were placed according to the Mason-Likar electrode configuration, to reduce excessive noise due to skeletal muscle activity. The precordial leads were obtained using the standard electrode placements. The signals were digitized at a sampling rate of 1 kHz, with an amplitude resolution of 0.6 µV.

The ECG recording was acquired continuously for 5 minutes while the patient was resting in the supine position, before exercise testing (Lund patients) or percutaneous transluminal coronary angioplasty (Charleston patients). None of the patients had clinical evidence of acute myocardial ischemia during the ECG recording.

Signal averaging
The 5-minute recording from each patient was signal averaged to minimize the noise level, which is essential for later analysis of the low-amplitude HF-QRS. The recordings were processed offline with software for ECG analysis developed by the Signal Processing Group, Department of Applied Electronics, Lund University, Sweden. For signal averaging, only beats with similar morphologic features were accepted. Each beat was cross-correlated to a “template beat,” representing the predominant morphologic characteristic. In the beat align-
HF-QRS analysis

The 12-lead signal-averaged ECGs were analyzed with a Butterworth filter at the frequency intervals of 150 to 250 Hz and 80 to 300 Hz. The whole signal was first filtered forward and then backward. The objectives of this approach are to provide sharper edges of the bandpass filter and to ensure linear phase of the filtering process and thus minimal distortion (the forward/backward filtering technique should not be confused with so-called bidirectional filtering used for assessment of late potentials).

The HF-QRS in each of the 12 leads was expressed as root-mean-square values in microvolts. This method quantifies the signals by determining the square root of the mean of the squares of each of the voltage samples during the entire QRS duration. The 1-kHz sampling rate provides one voltage sample each millisecond. The QRS onset and offset were automatically determined from the signal-averaged ECG in the standard frequency range before the filtering process.

The summed HF-QRS of all 12 leads in each patient was calculated as a measure of the “total” HF-QRS. In each group of patients, the mean HF-QRS was determined for each individual lead. The same analysis was performed in both analyzed frequency bands (150 to 250 Hz and 80-300 Hz).

The noise level was calculated in each lead in the 150 to 250 Hz frequency band and expressed as a root-mean-square value in an interval of 100 milliseconds, starting 100 milliseconds after the QRS offset. All patients had a noise level ≤0.75 μV in all leads, so no patient was excluded because of a high noise level.

Statistical analysis

Data are expressed as the mean ± 1 SD unless otherwise specified. Comparisons of HF-QRS and age between the different groups of patients were performed with a Student t test. The Fischer exact test was used to examine differences in proportions of sex in the patients groups. Statistical significance was defined as P < .05.

Results

In all patient groups there was a large interindividual variation in the summed HF-QRS of all 12 leads in the 150 to 250 Hz frequency band (Table II). In patients with no MI the sum ranged between 12.9 and 73.8 μV, mean 33.8 ± 10.1 μV. Considering all patients with an old MI, the sum ranged between 17.3 and 87.2 μV, mean 34.7 ± 12.7 μV. The results were similar for the MI subgroups (anterior, inferior, and posterior MI). The small differences observed among the different groups were all nonsignificant (P ranging from .57 to .88).

There was a large interindividual variation in the HF-QRS also in each individual lead in all patient groups. The HF-QRS was in general high in the anterior leads V2-V4 and in the inferior leads II, aVF, and III. The root-mean-square values of the HF-QRS in each individual lead in the no MI group are presented in Table III. Patients with old MIs showed the same pattern of lead distribution of their HF-QRS as the no MI group. The same was true regardless of location of the MI. The small differences among the groups were all nonsignificant (P ranging from .08 to .94). The distribution of the mean HF-QRS among the 12 leads in each patient group (in the 150-250 Hz frequency band) is presented in Figure 1.

The HF-QRS in each individual patient in the anterior and inferior MI groups compared with patients with no MI is presented in Figures 2 and 3. Only the anteriorly oriented leads V2 and V3, and the inferiorly oriented leads II and III, are presented, respectively, in accordance with the location of the MI in each group. The patterns observed in these leads were also observed for the other 10 leads in each group. The 3 patients in the anterior and inferior MI groups with the highest Selvester QRS scores (8, 8, and 9 points in the anterior and 8, 8, and 10 points in the inferior MI group) showed similar distributions of the magnitude of their HF-QRS as patients with lower scores. This was true also for the 4 patients in the healthy control group.
In the 80 to 300 Hz frequency band, the HF-QRS was, in general, approximately 3-fold higher compared with the 150 to 250 Hz frequency band because of the contribution of low frequencies. The summed HF-QRS in the 80 to 300 Hz frequency band for each patient group is presented in Table II. The small differences between the groups in the summed HF-QRS were also nonsignificant in this frequency band (\( P \) ranging from .49 to .95).

The distribution of the HF-QRS among the 12 leads was similar in both analyzed frequency bands. There was no significant difference in the mean HF-QRS in any lead between the patient groups in the 80 to 300 Hz frequency band (\( P \) ranging from .053 to .95).

**Discussion**

The current study suggests, in contrast to several previous reports, that there is no significant difference in the magnitude of HF-QRS in patients with old MI compared with those without MI. Also, there were no significant differences between patients with an MI in different locations. With use of data from the 12 standard leads, no significant differences in the summed HF-QRS or in the mean HF-QRS in each individual lead were found between the groups. Not even the patients with the largest MIs, as estimated by Selvester QRS scoring, or those in the healthy control group could be separated from the remainder of the study population. The same nonsignificant results were found for both analyzed frequency bands, 150 to 250 Hz and 80 to 300 Hz.

**Comparison with previous studies**

The results in the current study contrast with the findings of several others.\(^6\)\(^\text{-}^\text{11}\) Goldberger et al\(^6\)\(^,\)\(^7\) found a reduction of the HF-QRS in the leads II, aVF, and III in patients with old inferior MI compared with healthy subjects. The same was true for patients with anterior MI in leads V\(_2\) and V\(_5\).\(^6\) In contrast, Novak et al\(^11\) documented the HF-QRS values to be higher in patients with old MI than in healthy subjects.

There is no obvious reason for the different results. The criteria used for defining old MI could not possibly affect the main results of the studies. The study population and the number of leads in the current study were considerably larger than in other studies.\(^6\)\(^\text{-}\)\(^\text{11}\) Comparing the specific leads analyzed in previous studies, the results are still different from those reported. A possible explanation for the different results could be that healthy individuals have constituted the no-MI group in previous studies.\(^6\)\(^\text{-}\)\(^\text{11}\) The study population in the current study, both the no-MI and MI groups, consisted of patients with known or suspected ischemic heart disease. Because it has been shown that acute myocardial ischemia decreases the HF-QRS,\(^12\)\(^\text{-}\)\(^\text{17}\) it is possible that
The HF-QRS (150-250 Hz frequency band) in each individual patient without old MI and with old anterior MI. The circles within the no MI group indicate those 4 patients who had no signs of ischemic heart disease. The circles within the anterior MI group indicate the 3 patients with the largest infarct sizes (as indicated by the highest Selvester QRS scores). **Upper panel, Lead V2; lower panel, lead V3.**

The HF-QRS (150-250 Hz frequency band) in each individual patient without old MI and with old inferior MI. The circles within the no MI group indicate those 4 patients who had no signs of ischemic heart disease. The circles within the inferior MI group indicate the 3 patients with the largest infarct sizes (as indicated by the highest Selvester QRS scores). **Upper panel, Lead II; lower panel, lead III.**

chronic ischemic heart disease, even in the absence of either acute ischemia or old MI, is capable of altering the HF-QRS. The results obtained from the patients in the healthy control group contradict this hypothesis. These patients could be differentiated neither from the remainder of the no MI group nor from the MI group. However, this subgroup contained a small number of patients and it is therefore difficult to reach definite conclusions about the HF-QRS in healthy individuals compared with patients with ischemic heart disease.

It has been reported that successful reperfusion therapy results in an increase in HF-QRS, indicating that potentially reversible ischemia is capable of reducing these signals. However, standard QRS changes are typically used for diagnosis and even sizing of established MIs. Such changes commonly evolve although reperfusion therapy success is documented. It is not known whether the QRS changes on the standard ECG are accompanied by HF-QRS values below, above, or within the patient’s preinfarction levels. Because it is difficult to obtain such comparison of HF-QRS in individual patients before and after their MIs, we have to study groups of patients with and without old MIs. A change in HF-QRS after an MI in an individual patient could be within the large interindividual variation in HF-QRS found in the current study.

**Physiologic background**

The physiologic and pathophysiologic mechanisms underlying the HF-QRS are not fully understood. Abboud et al conclude from simulation experiments that ischemia-induced changes in HF-QRS can be attributed to a slowing of conduction velocity in the region of ischemia. The possible explanations given to the previous reported decrease in high-frequency signals in post-MI patients are an overall loss of electromotive force or a slowing of conduction associated with myocardial necrosis.

When an MI is established, there is no electrical activity in and therefore no conduction through the infarcted cells. There might be an overall prolonged activation time of the myocardium resulting from periinfarction block, but this is due to detour of conduction.
around, rather than slow conduction through, the infarcted area. If reduced HF-QRS is present only when there is slow conduction through a profoundly ischemic region of the myocardium, the myocardial scar remaining from infarction would not be expected to affect these QRS components.

Limitations of the study
The diagnostic classification into the different MI groups relies entirely on the standard 12-lead ECG. Even if the patients with potential confounding factors and those who were considered as indeterminate regarding old MI were excluded from the study, it would have been preferable to also have non-ECG evidence of the diagnosis.

The QRS complex of the unfiltered ECG was used to obtain the fiducial point for the signal averaging. Any trigger jitter in the fiducial point acts as a low-pass filter and thereby attenuates the high-frequency components.15 The determination of QRS onset and offset is another critical step in the analysis of HF-QRS. An incorrect QRS delineation affects the calculation of the root-mean-square value. It has been shown that this source of error can be reduced by using the standard QRS for the delineation of QRS onset and offset as was done in the current study.31

Conclusions
In summary, the current study shows that analysis of HF-QRS cannot differentiate between patients with and without an old MI. Thus there is contrast between the presence of standard QRS changes but absence of high-frequency changes of old MI. In an individual patient, it is still possible that an old MI might alter the HF-QRS. This change, if present, might be concealed in the large interindividual variation when investigating groups of patients.

References
25. Selvester RH, Wagner JO, Rubin HB. Quantification of myocardial...


