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Influence of the Main Filter on QRS-amplitude and Duration in Human Electrocardiogram

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Accurate measurement of electrocardiograms (ECG) is critical for effective diagnosis of patient's cardiac functions. Detailed examination of filters' effects on ECG accuracy, reproducibility and robustness covering a wide range of available commercial products can provide valuable information on the relationship between quality and effectiveness of filters, and assessments of patients' cardiac functions. In this study, ECG device with 12 leads and built-in filters used for ECG measurements was assessed on human volunteers. Results showed that with respect to measuring QRS wave duration and R-amplitude variation, there was a 4 % inaccuracy when the main filter was ON and OFF, and R-amplitude variation was most pronounced in the V4 lead. Accordingly, variability of R-amplitude and length of QRS wave can be reduced by the use of appropriate lead, and filter activation during the ECG assessment.

Keywords: Electrocardiogram, filters, QRS-amplitude, QRS-duration.

1. INTRODUCTION

Cardiovascular diseases are one of the leading causes of death worldwide [1]. Print-outs of electrocardiogram (ECG) are one of the most recorded parameters when assessing cardiac functions, which provide cardiologists with valuable information on how to diagnose cardiac diseases. ECG is also widely used in sports to assess cardiac functions and output in athletes [2]. At present the concept of personal health care is often based on wearable sensors and smart mobile devices that have given a new momentum to ECG recording even during fast walking, jogging and running, adding to the increase of the artefact presence [3]. The modern electrocardiograph machines are constructed to contain an electrical circuit – built-in filters, which continue to eliminate or reduce internal and external artefacts [4]. Recorded ECGs can be interpreted correctly by medical experts. Sources of internal artefacts are usually the consequence of muscle activities, respiration, and non-ideal or smoothless contact of the electrodes with the skin (some of those cause the so called baseline wander), whereas all external causes come from all the electrical signals which can be put off through the power-line [5] or other interference signal from ambient atmosphere (magnetic field). The power-line interference is one of the biggest problems in an ECG recording and has been studied for the reduction of noise, such as driven-right-leg circuit [6] or the application of analogue and/or digital notch filters [7]. The disturbances caused by breathing and movement of electrodes lead to distortions of the isoline and ECG signal. The existence of noises and artefacts are the reasons why ECG signal differs from the ideal which is represented in Fig.1.a) (each wave or QRS complex gives data about particular heart activity – depolarization or repolarisation). The most frequent ECG records are in the frequency range from 0.25 Hz up to 35 Hz, but in some exceptional cases can be up to 100 Hz. The frequency spectrum of the EMG signal is very close to the QRS complex [8], therefore ECG signal processing should remove interference and other noises, but at the same time this procedure can result in certain deviation of the signal. The filter centre frequency is usually posted to be from 6.25 Hz to 25 Hz [9]. Effects of different filter electrical configuration and filter cut-off frequency in certain parts of the ECG signal were reported earlier. For example, influence of four types of electrical filters on the R-R measurement error was analysed in [10], because R peak and R-R period is one of the most important parameters of an ECG print-out. The R peak wave, in a great majority of cases, has the largest voltage amplitude among all other waves in the ECG signal [11] and is most frequently investigated [12]

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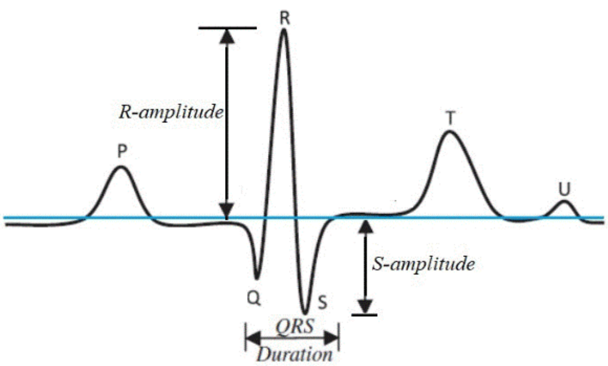
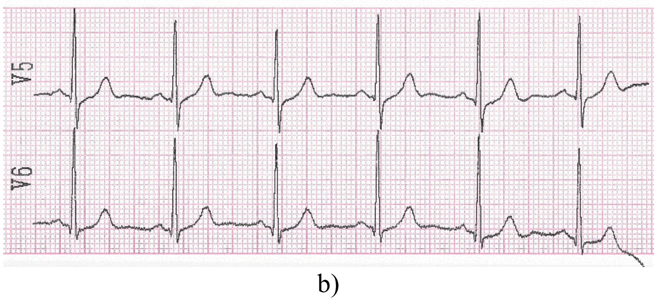
for the efficient diagnosis of heart rhythm irregularity [13]. R-wave detection was used for nonlinear median filter as reported in [14]. Furthermore, authors elaborated the effects of 0.67 Hz high-pass filter on spatial QRS-T angle in [15]. A new algorithm for QRS detection in ECG was presented in [16], based on the two stage median filter and enhancement of the characteristic peaks in the ECG signal. The method was tested using open access MIT/BIH (Massachusetts Institute of Technology/Beth Israel Hospital) and European ST-T and QT databases, which were often used in many other references in the field. *A. Fedotov* reported in [17] that band-pass filter (in the range of 8 – 20 Hz) and the Hilbert transform are efficient in the process of QRS complex detection. AC and DC coupling, unfiltered, were analysed in [18], and authors found a correlation between QRS interval and ST-amplitude. The same authors concluded in [19], that 0.05 Hz filter has an effect on the ECG in cases of large QRS area. The reliable approach for identifying the QRS complex for eight prematures (23-25 weeks) was presented in [20]. The above-mentioned papers usually used databases that were devoted mainly to the engineering community. However, there is an urgent need for engineers in the field to provide useful information about the influence of different filter(s) in ECG devices on the recorded signal for clinicians.

In this work, we present a study concerning the influence of the main filter present in broadly available ECG devices worldwide, for testing the quality of the recorded ECG signal. Contrary to using available databases in the past, all important segments of one ECG print-out (interval or amplitude) were recorded (Fig.1.b)) or calculated based on clinical testing of nine randomly chosen subjects.



a)



b)

Fig.1. a) Typical shape of ECG signal with some characteristic intervals and amplitudes; b) An example of recorded signals for leads V5 and V6, in our study.

2. SUBJECTS & METHODS

Subjects. Nine adults ranging in weight from 55 to 86 kg participated in this study. They are labelled for the purpose of this work as Subject ID12 to Subject ID20 and their ages were in the range 49-78 years. The informed consent was signed by all participants.

Equipment. A commercial EMA 322 ECG electrocardiograph from the EMA company [21], with power supply ~ 220 V, 50 Hz, 60 VA, was used in this study because of its cost-efficiency, portability and real-time continuous recording. The paper speed was set to 25 mm/second for this study. This ECG device has a low pass filter (tremor filter) with cut-off frequency equal to 30 Hz. This filter can be manually switched on or off on the front panel of the device. When the main filter is OFF, the upper frequency of the recorded ECG is 100 Hz. The ECG signal has been digitised at a rate of 250 samples per second, using 10 bit A/D conversion. The filter for 50 Hz powerline interference elimination has been implemented into the device by computing the interface amplitude and subtracting these data from the original signal. The applied method reduced requirements towards amplifiers, shielding, earthing, electrode quality, and consequently easier and faster patient processing can be achieved [22].

Procedure. First recording of ECG was performed with the main filter switched off and immediately followed by ECG recording with this filter switched on. Records from all leads were printed and saved: (i) unipolar D1-D3, (ii) bipolar AVR, AVL, AVF, and (iii) precordial V1-V6. The following parameters: heart rate, R-amplitude, S-amplitude, QRS-duration were derived from paper recordings, following standard procedure in our institution. These paper records were digitized and then an image-processing method was implemented for estimation and accurate calculation of important parameters (analysed magnitudes and time intervals).

Statistical analysis. The calculated values of magnitudes and time intervals from ECG records were entered as input data in GraphPad Prism software (GraphPad Prism, USA) and other parameters (heart rate, QRS-duration, R- and S-amplitude) were analysed using the statistical tool of this software. Parametric/non-parametric t-test or One-Way ANOVA were carried out as appropriate. Confidence level of 95 % was selected in the performed analysis.

3. RESULTS AND DISCUSSION

We applied ECG as a most often non-invasive technique for monitoring the health of patients and results for nine of them are presented in this section. The complete set of 12 curves was recorded with various standard positions of electrodes – 3 unipolar, 3 bipolar, and 6 precordial. The importance of R-wave has been explained, and it is usually used as a reference for many other analyses. Fig.2. shows the difference in R-amplitude with and without the main filter for some characteristic signals which have R-amplitude more pronounced – D1, V4-V6. Linear regression is also displayed in the graphs.

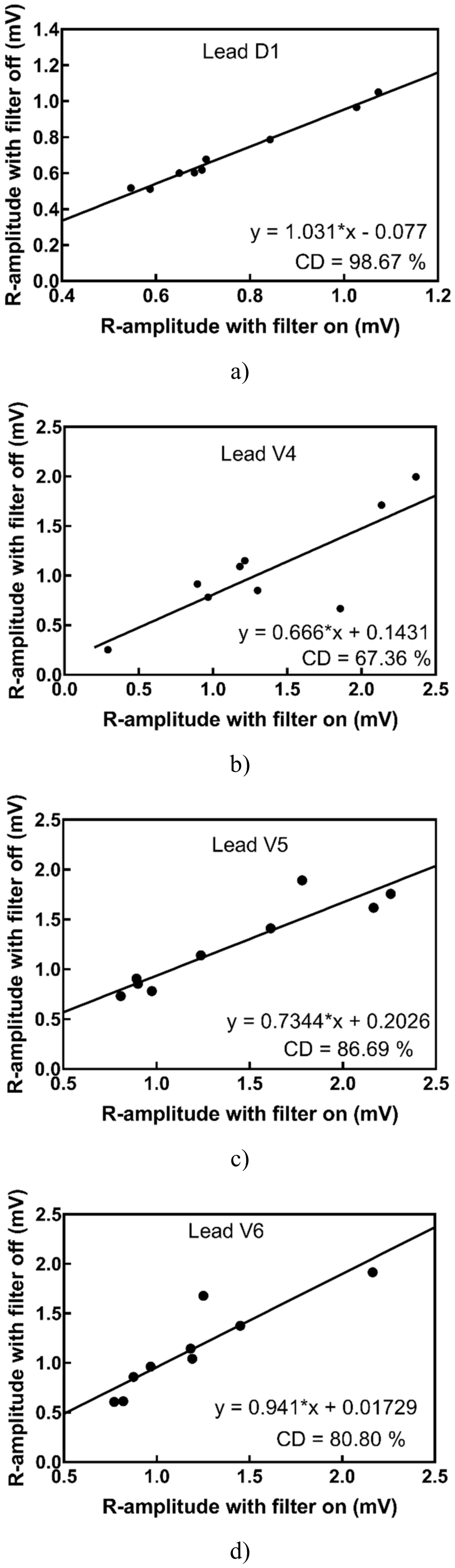


Fig.2. Dependence between R-wave amplitude with the main filter switched off and on, for a) D1 lead, b) V4 lead, c) V5 lead, d) V6 lead.

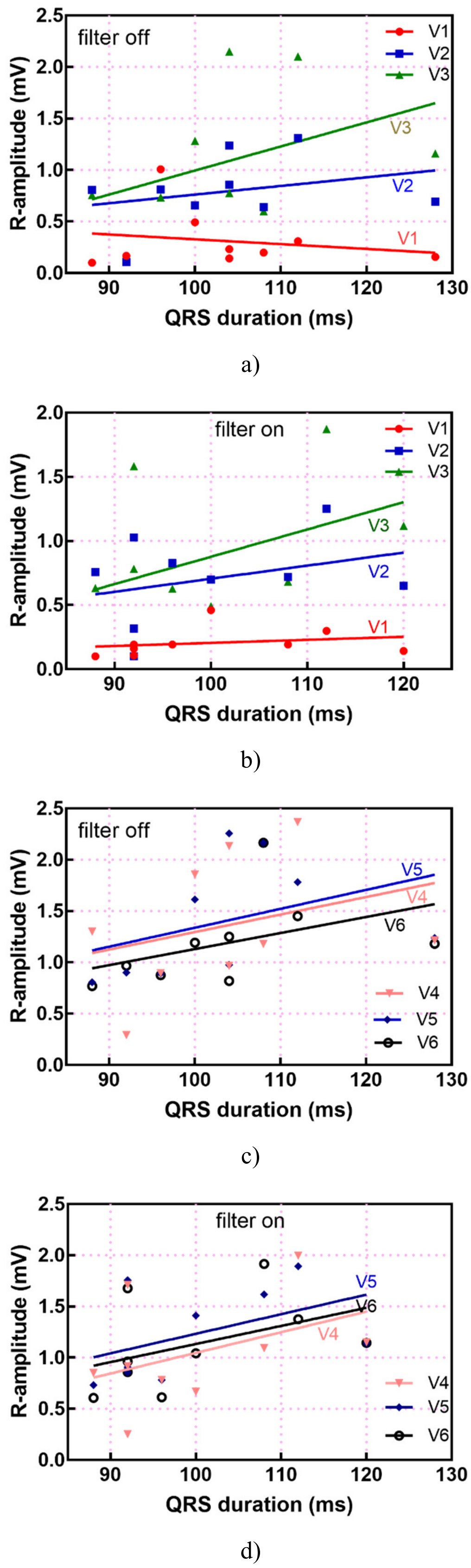


Fig.3. R-wave amplitude as a function of QRS duration for ECG device a) filter off, V1-V3, b) filter on, V1-V3, c) filter off, V4-V6, d) filter on, V4-V6.

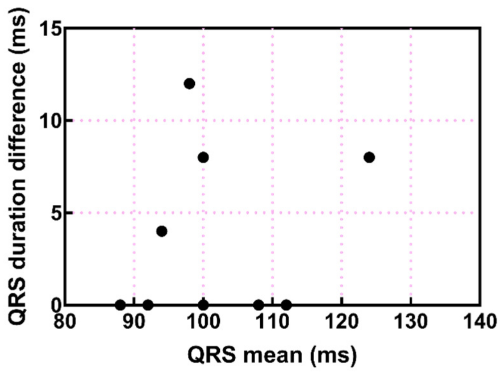
It can be seen from Fig.2. that the best linear correlation is for leads D1 and V6. Apart from the equation of linear regression, insets in Fig.2. show also R2 or the coefficient of determination (CD), which illustrates goodness of fit. The influence of switching on the filter is more noticeable for leads V4 and V5. The reason for this lies in the phenomenon of chest expansion due to respiration, and the fact that leads D1 and V6 have the least excursion distance vs. leads V4 and V5 with the biggest lead excursion route.

Fig.3. shows R-wave amplitude as a function of QRS duration for a situation when the main filter on the ECG device was switched off (Fig.3.a) and Fig.3.c)) and switched on (Fig.3.b) and Fig.3.d)). In half of the analysed subjects QRS duration was the same in the case of the filter OFF and ON, whereas in other cases this QRS width was larger in the case of the situation of filter OFF compared with filter ON. In average, R-amplitude for all subjects for all precordial leads was 1.021 mV when filters were OFF, whereas this average amplitude for filters ON had the value 0.866 mV. Additionally, a linear regression has been applied (lines depicted in Fig.3.) in order to display a typical relationship between R-amplitude and QRS-duration, for V1-V3 filter OFF and ON (Fig.3.a) and Fig.3.b)) and for V4-V6 filter OFF and ON (Fig.3.c) and Fig.3.d)). It can be noticed that the difference between R-amplitude for V1-V3 is higher than for V4-V6, which is the consequence of the places of the electrode positioning, but also the range of R-amplitude. This range of R-amplitude is higher for V1-V3, in our cases in the range from 0.2 V to 1.6 V in linear regression lines when the filter is OFF, and from 0.2 V to 1.35 V when the filter is ON. Contrary, this range of R-amplitude for V4-V6 is from 0.8 V to 1.8 V for linear regression lines when the filter is OFF, whereas this range is from 0.75 V to 1.6 V for the filter ON. It is obvious from these data that the variation range of R-amplitude is lower when the filter is switched on.

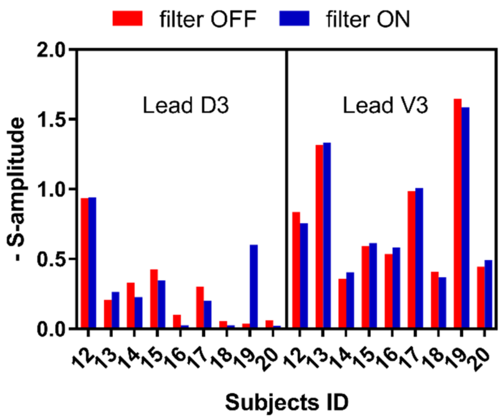
Our finding of the relationship of R-wave amplitude as a function of QRS duration as a filter dependant variable is of particular importance considering the main filter (noise + linear filter), because such finding could affect therapeutic decision making in clinical setting while considering proarrythmic potential in late potential analysis (SAECG) and ruling in and out some medications.

It can be seen that difference between QRS duration when the filter OFF and ON is maximum 12 ms. These results are comparable with ones reported in [23], where two different electrocardiographs were used and performances compared. Moreover, we obtained that QRS duration was 100.0 ± 3.65 ms for the filter ON and 103.6 ± 3.97 ms for the filter OFF. For comparison, in reference [24], authors showed results for QRS duration of 96 ± 10 ms for men, in automated turn on of ECG (Philips) filters. Additionally, we analysed the ST interval. When the filter was in the ON position, we obtained ST mean value of 406.2 ± 22.04 ms, whereas when the filter was OFF this value was 389.8 ± 9.87 ms. These data are similar to the results presented in literature [25], where authors reported ST value of 396 ± 39 ms. Such findings are of particular importance for novel diagnostic criteria for the acute myocardial infarction (also for the silent or the overt coronary disease presence) because they rely on these ST segment appearances - in particular: NSTEMI guidelines from 2015 (European Society of Cardiology). Therefore, presence of a filter may affect diagnostic accuracy as well [26].

The important part of QRS complex is also amplitude of S-wave. This amplitude is presented in Fig.4.b), for all participating subjects with the filter on the ECG switched OFF and ON, as an example on leads D3 and V3. It can be seen that amplitude of S-wave is the highest on the V3 lead. The average difference between the filter switched OFF and ON was 2.11 % in case of lead D3 and 0.23 % for recorded ECG signal from lead V3.



a)



b)

Fig.4. a) Bland-Altman Plot for QRS duration, b) S-amplitude for all subjects for leads D3 and V3.

4. CONCLUSIONS

It can be concluded that QRS duration has a difference around 4 % for situation of the filter ON and OFF. Variation of R-amplitude for these two cases is the most pronounced for the V4 lead. Although we have reported results on a relatively small number of participants, results presented in this study provide useful guidelines for clinicians in the field of ECG and important support to them in order to correctly interpret the recorded signals. Since modern wearable ECG sensors and smart mobile devices provide diagnostic potential for remote insight in sports medicine, it is of particular importance to prevent sudden cardiac death by fighting the barrier set by the main filter and a further challenge for engineering community to solve.

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