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Quantification of the first-order high-pass filter's influence on the automatic measurements of the electrocardiogram

Jonas Isaksen, Remo Leber, Ramun Schmid, Hans-Jakob Schmid, Gianluca Generali, Roger Abächerli *

SCHILLER AG, Altgasse 68, 6341 Baar, Switzerland

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ABSTRACT

Background and objective: The first-order high-pass filter (AC coupling) has previously been shown to affect the ECG for higher cut-off frequencies. We seek to find a systematic deviation in computer measurements of the electrocardiogram when the AC coupling with a 0.05 Hz first-order high-pass filter is used.
Methods: The standard 12-lead electrocardiogram from 1248 patients and the automated measurements of their DC and AC coupled version were used. We expect a large unipolar QRS-complex to produce a deviation in the opposite direction in the ST-segment.
Results: We found a strong correlation between the QRS integral and the offset throughout the ST-segment. The coefficient for J amplitude deviation was found to be –0.277 μV/(μV·s).
Conclusions: Potential dangerous alterations to the diagnostically important ST-segment were found. Medical professionals and software developers for electrocardiogram interpretation programs should be aware of such high-pass filter effects since they could be misinterpreted as pathophysiology or some pathophysiology could be masked by these effects.

1. Introduction

Case reports have shown that high-pass filtering of an ECG-signal may mask a disease. García-Niebla et al. found that improper high-pass filtering led to a false-positive Brugada syndrome diagnosis in a patient [1]. Ruta et al. experienced the same in 2013 [2]. Other scientists have examined the high-pass filter itself and its relation to the ECG waveform [3–6]. It is well known that the low-frequency content of the electrocardiogram (ECG) is of importance in relation to the interpretation of the ECG and especially the detection of acute myocardial infarction (AMI) [7].

The resting ECG may also be used for gatekeeper purposes, deciding which chest-pain patients go directly to the catheter lab and which go to the emergency room for further evaluation. Therefore, the quality of these ECGs directly influences the level of care for the patient, and the quality of every such recording must be optimal.

1.1. *The AC coupling in electrocardiographs*

The AC coupling in electrocardiographs became necessary when digital recordings were introduced. Due to a limited signal range for the analog-to-digital converters (ADCs), the naturally

* *Corresponding author.* Cardiovascular Research Institute Basel (CRIB), Cardiology, Spitalstrasse 2, University Hospital Basel, SCHILLER AG, Altgasse 68, 6341 Baar, Switzerland; Lucerne University of Applied Sciences and Arts, Technikumstrasse 21, Horw, Switzerland.
E-mail address: roger.abaecherli@usb.ch (R. Abächerli).

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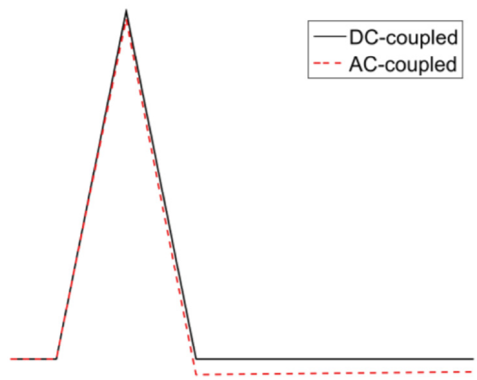

Fig. 1 – The principal effect from high-pass filtering of a large positive, monophasic area corresponding to a large QRS complex. The positive deflections produce negative offsets on the filtered signal after the deflection as shown in this example. A positive offset will be seen for a negative deflection.

occurring offset and baseline wander had to be reduced. The solution was an analog high-pass filter.

In 1966, Berson and Pipberger did extensive research on the topic of first-order analog high-pass filters and their influence on the ECG waveforms. They concluded that high-pass filtering may influence the morphology of ST segment and T wave (see Figs. 1 and 2) when the cut-off frequency of the filter is too high. Based on their research, Berson and Pipberger suggested a maximal cut-off frequency for a first-order high-pass filter of 0.05 Hz [8].

1.2. *Tests and requirements for high-pass filters*

Berson and Pipberger's suggestion was adopted in the 1967 AHA recommendations and kept in the 1975 version [9,10]. In 1990, a special report from the AHA [11] suggested a rectangular pulse test to limit high-pass filters such that the distortions to the ST segment would be similar to those of a single-pole 0.05 Hz high-pass filter. The exact suggestions for a test were the following:

- "A 1 mV-sec impulse should not produce a displacement greater than 0.3 mV after the impulse."
- "For a 1 mV-sec impulse input, the slope of the response outside the region of the impulse should nowhere exceed 1 mV/sec."

This test was adjusted and accepted in the 1991 AAMI/ANSI standards for diagnostic ECG devices [12], so that the pulse now was a 0.3 mV·s pulse (3 mV·0.1 s). The offset requirement became 0.1 mV and the slope requirement became 0.3 mV/s. Both current American and international standards [12,13] have the pulse test in exactly this form. The current specifications therefore directly date back to research made in 1966.

1.3. *Distortions from the AC coupling*

In 1966, it was clearly stated that the 0.05 Hz filter was a compromise that "the electrocardiographer has to live with", and that "ideally, records with a DC-response should be used".

With the modern opportunities of the digital DC-coupled ECG recorder [14] and computer measurements, we wish to quantify the distortions to the ST segment caused by the AC–coupling with a 0.05 Hz first-order high-pass filter.

2. Methods

2.1. *Hypothesis*

We wish to quantify the influence of the filtering on all parts of the ECG, including the P-wave, QRS-complex, ST segment and T-wave (Fig. 2).

Our hypothesis is that a positive QRS integral creates an ST depression while a negative QRS integral creates an ST elevation (see Fig. 1), and that there exists a somewhat linear dependency between the QRS integral and the offset produced. The model thus becomes $y = \alpha x + \beta$, where y is the offset produced, x is the QRS integral and $\beta = 0$ is the intercept. A value of $\beta \neq 0$ would indicate an inherent deviation caused by the filtering that cannot be attributed to the QRS integral. The offsets at different distances from the QRS complex have different coefficients, α. Based on initial simulations, for the 0.05 Hz first-order high-pass filter, we expect a −0.31 μV offset in J amplitude per unit area in μV·s for an isolated beat. A ± 25 μV offset would then be expected for QRS integrals that are absolutely greater than 81 μV·s. In practice, these numbers are influenced by the heart rate, by differences in QRS morphologies from one beat to another, and by the relaxation status of the filter (the effect is greater for beats occurring before the filter has adapted to the signal). For a heart rate of 71 bpm (beats per minute, found to be the mean heart rate in this dataset), we expect the linear coefficient, α, to be $-0.277\,\frac{\mu V}{\mu V \cdot s}$, based on simulations with rectangular pulses with constant rate and 100 ms duration (Fig. 3). A 25 μV deviation would then be expected for a QRS

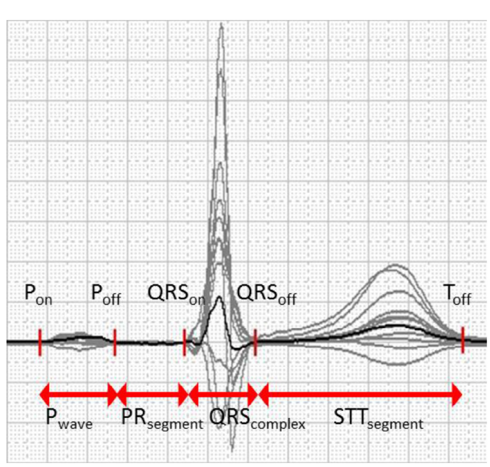

Fig. 2 – 12-lead ECG (butterfly plot) shown with markers (top) and segment names (bottom). The J-point is equal to the QRS_{off}.