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# ON THE QUESTION OF ASSESSING THE QUALITY OF ELECTROCARDIAC SIGNAL REGISTRATION

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*The results of recording the same electrocardiogram by different devices are compared, the role of filtration in displaying fragmented QRS complexes is discussed.*

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In recent years, with the shift of patient discussions, examination results, and treatments from ward rounds led by department heads or professors, as well as consultations, to chats, groups, and channels, there has been a growing trend of discussing electrocardiograms (ECGs) presented as photos on smartphones. Typically, these are photographs of ECGs either recorded on paper or displayed on computer screens. It is evident that the process of photographing, despite the high resolution offered by modern smartphones, does not improve the quality of the ECG displayed. Furthermore, it appears that even the original ECGs, whether recorded on paper or electronically, do not always adequately convey the full details of the electrocardiographic signal.

On the other hand, all ECG devices are required to conform to national standards and undergo regular calibration. Thus, it remains unclear why ECGs recorded by different devices, all of which comply with the relevant standards, still exhibit discrepancies, sometimes quite significant. In the era of analog ECG machines, the quality of the recording could be assessed based on the form of the millivolt, which was primarily determined by the method of registration. The highest quality was achieved using photo and recording, which was attributable to the minimal inertia of string and other galvanometers and the absence of direct contact with the moving paper. In contrast, «pen» ECG machines were influenced by the mass of the pen, which determined its inertia, as well as the friction between the pen and the paper. The friction varied depending on whether the ink or thermal printing technique was used. To improve the quality of recordings made with pen-based ECG machines, various methods were applied, such as introducing low-amplitude high-frequency oscillations (50 Hz) to the pen or applying a wax coating on the paper that would melt under the heat of the pen.

At the end of the last century, analog ECG machines were replaced by digital systems, fundamentally changing the process of ECG recording. The enhanced, digitized, and processed ECG signal is now printed by printers devoid of inertia or friction between the «pen» and the paper. In digital ECG machines, pressing the millivolt button commands the printer to produce a signal of known form and amplitude, which typically provides little information about the underlying characteristics of the ECG signal. This digital transformation was accompanied by the widespread use of filters designed to «improve» ECG quality. However, these filters, which are intended to reduce or eliminate power line interference, muscle noise, and baseline fluctuations, primarily create the illusion of improved quality while significantly simplifying the process of ECG registration. These filters inevitably alter the ECG signal to varying degrees across different devices. This issue can be avoided by recording the unfiltered (native) signal in the device's memory, with filters applied during viewing and printing. Unfortunately, even if this option exists, it is seldom utilized.

The issue of ECG signal filtering has been extensively addressed in both the AHA/ACC/HRS guidelines and in Russian guidelines [1, 2]. The AHA/ACC/HRS recommendations stipulate that the ECG signal bandwidth should range from 0.05 to 150 Hz, with the upper frequency limit extended to 250 Hz in pediatric practice. It is clearly stated that the use of other filters, such as increasing the lower frequency limit to 0.5 Hz or reducing the upper limit (for example, to 40 Hz), is unacceptable. Regrettably, compliance with these recommendations is not always strictly enforced for medical device manufacturers. Therefore, the AHA/ACC/HRS guidelines recommend that when «non-optimal» filters are used, they should be «reset» after each ECG recording, ensuring that medical personnel manually reconfigure them, thereby acknowledging the distortion of the ECG signal caused by the filters [1].

How can we compare ECG signal registration results from different devices? It seems that the standard calibration using test signals, which is likely performed with filters turned off, does not provide the desired outcome. An optimal approach might involve a study in which ECG is recorded from the same electrodes on patients using different ECG machines and different signal filtering methods. It is understood that as the number of devices being compared increases, the labor intensity of such a study will also rise, and it will require approval from an ethics committee, informed consent forms, etc. The results obtained would be limited by the specific characteristics of the patients' ECG data.

An alternative possibility is offered by the device created by the NPO «Inkart,» which allows recording the digital ECG signal and then outputting it through a digital-to-analog converter in a «patient format.» This format enables the connection of devices with a standard lead cable to register the ECG in the twelve commonly accepted leads. We present the first experience of using this device to compare the characteristics of ECG recording from different machines.

For the test signal, we selected a fragment of a Holter ECG monitoring recording (Holter ECG) in twelve standard leads from patient A., whose examination and treatment were discussed in the Journal of Arrhythmology [3, 4]. This selection was made due to the presence of various P waves and QRS complexes. To reduce the influence of muscle noise, a signal recorded during nighttime sleep starting from 4 a.m. was used. As a «starting point,» we compared low-amplitude fragmented QRS complexes recorded in lead II when registered by different devices (Fig. 1). It is important to note that the term «low-amplitude» here is used simply to describe fragmented complexes whose amplitude is significantly smaller than that of non-fragmented ones.

Figure 1a shows a fragment of the original Holter ECG, uploaded into the device for subsequent output in the «patient format.» Two QRS complexes in lead II were «cut» from the ECG example, included in the report after being converted to PDF format. This and all subsequent recordings are presented with a «tape speed» of 50 mm/s at a scale of 1 mV = 2 cm. All filters, except for the overrange filter (which, with this quality of recording, obviously does not function), are turned off. The first of the two QRS complexes, with an amplitude of about one millivolt, exhibits pronounced fragmentation. The dynamics of this fragmentation when outputting this signal to other devices will be the focus of our evaluation.

Figure 1b shows the same fragment as Figure 1a, output to a «Cardiotech» system monitor, the same one used to record the original signal. The result is not identical to the original. A decrease in the amplitude of the discussed QRS complex and a moderate reduction in its fragmentation are observed. This could be due to both the conversion of the signal from digital to analog and vice versa, as well as the relatively low sampling frequency (256 samples per second). It is evident that for future studies, we will need to select an ECG signal recorded with a higher sampling frequency of 1024 samples per second. By analyzing this signal, the impact of sampling frequency on the final result can be assessed when outputting it to modern ECG machines (see below). It should be emphasized that in future comparisons, we will primarily compare the results of outputting the signal to various devices, not with the original signal, but with its representation in Figure 1b.

The result of exporting the discussed fragment of Holter ECG to a single-channel thermographic analog ECG machine «Salyut» from 1974 is shown in Figure 1c. It is noteworthy that despite maximum amplification (which is smoothly adjustable on this machine), it does not reach the scale of 1 mV = 2 cm. Additionally, the distance between the complexes has noticeably decreased, indicating a reduction in the tape speed. This ECG machine does not have any filters. It should be emphasized that the fragmented QRS complex decreased in amplitude (not only due to scale changes), but almost unchanged in configuration compared to Figure 1b. In our view, this indicates that the old analog ECG machine demonstrates quite respectable recording quality. The change in its amplitude characteristics certainly requires further study.

Figures 1d and 1e show the same ECG fragment recorded on a three-channel digital electrocardiograph Siemens-31S, produced in the early 1990s. The recording with filters turned off (Fig. 1d) shows moderate network interference, likely due to room conditions (the recordings on different machines were made in different rooms) and the grounding of the device itself. The fragmented QRS complex is similar to those previously discussed. When the 35 / 50 Hz filter is applied, the network interference is significantly reduced, but at the same time, the amplitude of the fragmented QRS complex decreases, its initial part changes, and the «notching» on the descending part of the R wave transitions to a «smoothed» appearance. In our opinion, this is a significant change in the ECG signal.

The results of the ECG signal registration of patient A. on a modern digital ECG machine are shown in Figures 2a and 2b. When exporting the recorded signal to machines providing synchronous recordings of twelve standard leads, we did not aim to register the same fragment under different filtering conditions. Figure 2a shows the ECG signal recording with optimal filtering, meeting the recommendations [1]. The fragmented QRS complex in lead II is close to the original, and its amplitude corresponds to that shown in Figures 1c and 1d, exceeding the amplitude in Figure 1b and 1d. With «non-optimal» filters turned on (Fig. 2b), the fragmentation and amplitude of such QRS complexes decrease significantly, with the following pattern observed: the smaller the amplitude of the QRS complex, the greater the reduction. This is clearly seen in lead III.

The result of importing the ECG signal into a widely used domestic computer ECG machine is presented in fragments saved in PDF format. It should be noted that we could not record the ECG with all filters turned off, and the personnel operating this machine confirmed that they never turn off the filters. We had to register fragments with the


***Fig. 1. Results of registering the same ECG signal fragment from patient A by different devices: a - original ECG signal recorded using the Holter monitor «Cardiotechnika», b - ECG signal output in «patient format» and recorded by another Holter monitor «Cardiotechnika», c - the same signal recorded on a single-channel thermoprint analog ECG machine «Salyut» from 1974, d - results of registration on a three-channel digital electrocardiograph Siemens-31S with filters off, e - consequences of signal filtering. Explanations in the text.***

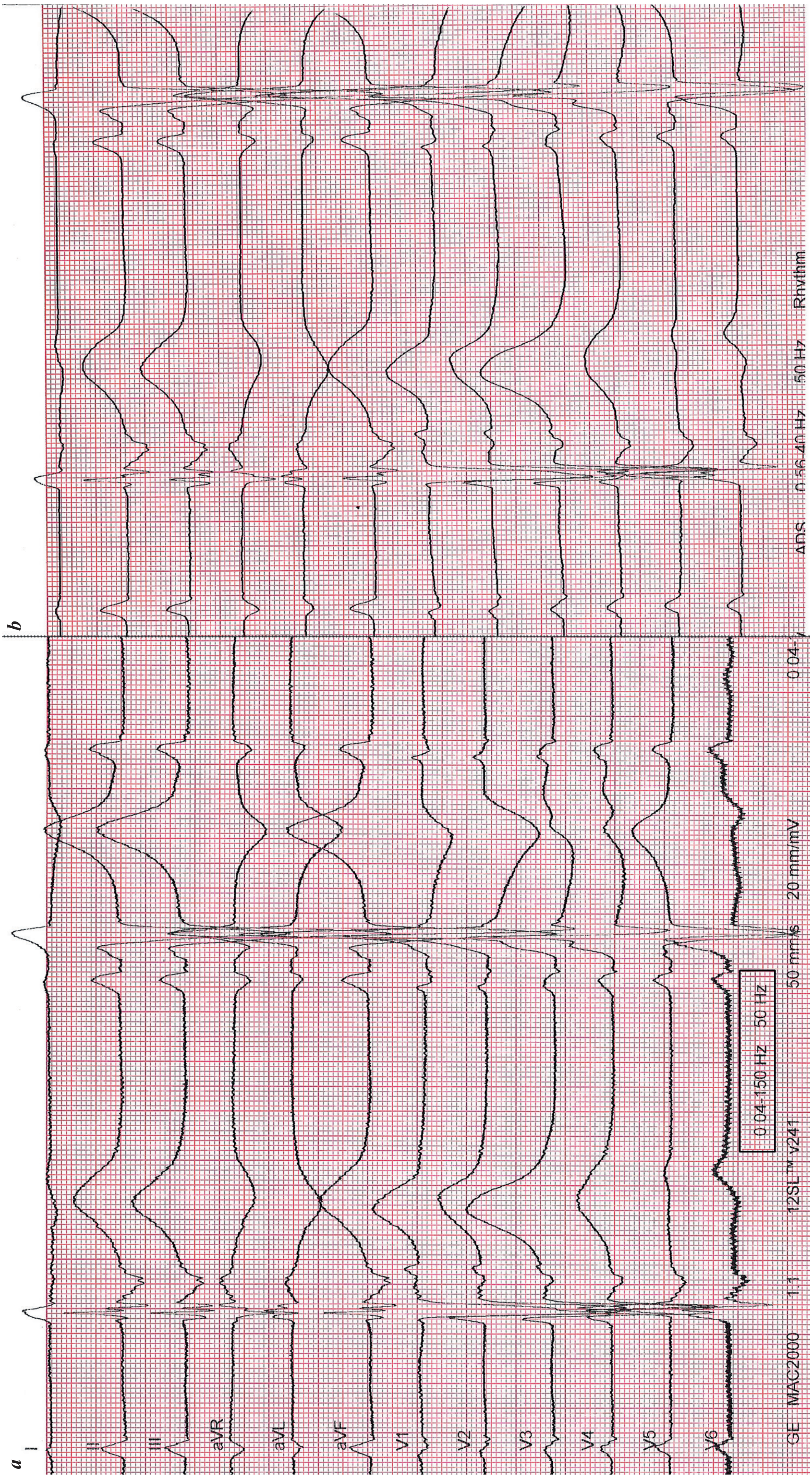


***Fig. 2. Results of ECG signal registration from patient A on a modern digital ECG machine: a - with «optimal» filtering with a passband of 0.05-150 Hz, b - when using other filters. Explanations in the text.***

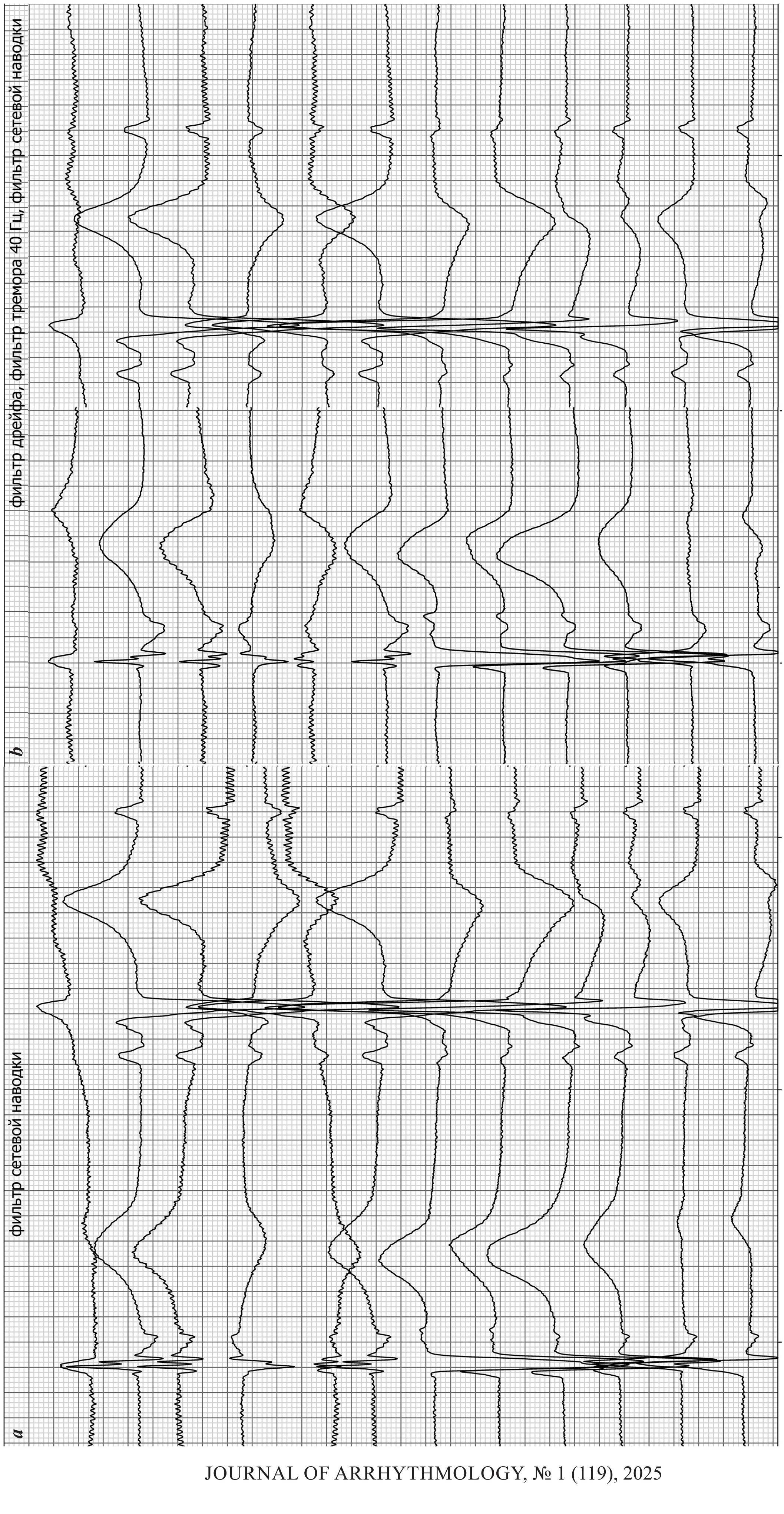


***Fig. 3. Results of ECG signal registration from patient A on a widely used domestic computer electrocardiograph: a - using only the network noise filter, b - with various filters in use. Explanations in the text.***

network interference filter turned on. Its operation deserves further study, as the amplitude of the remaining network interference varies significantly over time. The amplitude of the QRS complex in lead II with the network filter turned on (Fig. 3a) corresponds to that of the original complex (Fig. 1a), which is likely due to the high sampling frequency, allowing the complete depiction of the waves. The machine transmits the fragmentation of the QRS complex well, but for reasons not fully understood, there is a marked decrease in the amplitude of the retrogradely conducted P waves following the fragmented QRS complex. This phenomenon certainly requires confirmation in other similar complexes and further study. After all filters are turned on (Figure 3b), the amplitude of the fragmented QRS complexes significantly decreases, their configuration changes, and the shape of the T waves also changes.

## CONCLUSION

The comparison of the registration features of the same ECG signal by different devices demonstrated significant differences, which were primarily attributed to the nature of the filters used. In the framework of this pilot study, we only examined the possibility of such a comparison, focusing solely on the high-frequency components of the ECG (specifically the QRS complexes with pronounced fragmentation). It is evident that the nature of the registration of other ECG elements, including by other devices, requires further separate study.

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