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Research Article

Use of High-Pass and Low-Pass Electrocardiographic Filters in an International Cardiological Community and Possible Clinical Effects -

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ABSTRACT

Background: High-pass and low-pass filters applied to 12-lead Electrocardiograms (ECG) are fundamental to avoid artifacts, but an inappropriate use may lead to misdiagnosis. Our goal is to evaluate cutoff points for these filters used as routine by cardiology professionals from different countries, and to determine to what extent they adjust to the established guidelines.

Methods: We designed a descriptive study where 12-lead ECGs were included, both from adults and teenagers, distributed between August 2016 and February 2017 within the Ibero-American Forum on Arrhythmias on the Internet (FIAI) through the instant messaging apps WhatsApp and Telegram.

Results: 48% of ECGs had at least one of the two filter cutoff points printed. The bandwidth recommended by different scientific societies (≤ 0.05 Hz and ≥ 150 Hz) was present in 2%. The most frequent low frequency cutoff value was 0.5 Hz (47%) and the high frequency one was between 25 Hz and 40 Hz (74%). As to the last consensus guidelines, we registered that 32% of ECGs met the low frequency cutoff point and just 5% the high frequency cutoff point.

Conclusions: There is a high ratio of tracings lacking printed information on the filter used, and those that do have it, use inappropriate cutoff points in a high percentage, which may have significant diagnostic consequences.

Keywords: Electrocardiography; Low-Pass Filter; High-Pass Filter; Artifacts

INTRODUCTION

For a proper electrocardiographic recording, it is not only necessary to prepare the patient adequately, or to place the electrodes correctly, but for the professional conducting the Electrocardiogram (ECG) to know and apply the right technical parameters to obtain a recording with the maximum quality possible to evaluate it subsequently. Among them, the filters applied to 12-lead ECGs are essential when reducing or preventing unwanted signals in the form of noise or interferences. Between the artifacts to be avoided, we find those produced by muscle activity, the ones caused by breathing or by small movements by the patient, as well as those coming from alternating current. To avoid these artifacts, high-pass and low-pass filters are added to electrocardiograph devices. By applying the cutoff points of both filters properly, we will preserve as much as possible the cardiac signal without modifications or distortions, preventing erroneous electrocardiographic diagnoses [1,2]. The guidelines for the standardization and interpretation of ECG, published already a decade ago by the American Heart Association, the American College of Cardiology and the Heart Rhythm Society (AHA/ACC/HRS), advise using a cutoff point of 0.05 Hz for the high-pass filter and 150 Hz for the low-pass filter in adults, being extended to 250 Hz in children [3].

The aim of this study was to evaluate the cutoff points used as a routine by cardiology professionals from different countries, and to determine to what extent they meet the established guidelines.

METHODS

We carried out a study with a descriptive design, where 12-lead ECGs were included consecutively, from both adults and teenagers, distributed from August 2016 to February 2017 within the Ibero-American Forum on Arrhythmias on the Internet (FIAI), by the comprehensive instant messaging system used by this organization (through the WhatsApp and Telegram apps) [4]. The FIAI is a wide group of cardiology professionals from different countries that, since year 1998, operates as a platform for the exchange of opinions and consultations about electrocardiology, through different virtual channels; instant messaging is one of such communication channels that has been operational since mid-2016.

For the term of the study, ECGs with full tracings were selected. From these tracings, it was analyzed whether they contained information on the filters used (textual or numerical), and if so, whether they had the corresponding cutoff points (numerical values).

The data obtained were organized and analyzed by worksheet using the Microsoft Excel software. All the percentages were rounded off so as to use only whole numbers. The analysis of cutoff points for bandwidths was conducted taking into account the guidelines by the AHA/ACC/HRS from year 2007 [3].

RESULTS

The results of the study are divided into four fundamental axes: 1) general results; 2) results on bandwidth; 3) results on high-pass filters; 4) results on low-pass filters.

We will start with the general results of the study. From the 332 ECGs analyzed, we selected 222 complete tracings (110 ECGs were discarded because their images were not complete or did not meet the quality conditions necessary to perform a correct analysis of the filters used). From these, 139 recordings (63%) had references to the filters used (in a textual or numerical way). From the latter, 106 tracings (48%) had the cutoff points printed; 90 ECGs had the two cutoff points printed, and 16 ECGs had only one of the two. The 222 ECGs included in the study were contributed by 62 professionals in the field of cardiology (physicians, technicians or nurses) from 13 countries (mostly from South America) and 43 cities (Table 1).

As to the second cutoff point (results on bandwidth), first we should clarify that for the analysis we used the recordings where both cutoff points were included (90 ECGs). We observed that the combination most frequently used was 0.5-25 Hz (26%). In our study, the bandwidth recommended by the AHA/ACC/HRS in 2007 (≤ 0.05 Hz and ≥ 150 Hz) was present in 2% (Table 2).

Next, we continue with the third point (results on high-pass filters). We clarify that for the analysis, we used the recordings where the cutoff value was specified (93 ECGs). We observed that the most frequent low frequency cutoff value was 0.5 Hz (47% of the analyzed ECGs). About the cutoff point recommended by the AHA/ACC/HRS in 2007 (≤ 0.05 Hz), we registered that 32% of ECGs adjusted to this recommendation (Table 3).

Finally, we have to present the fourth point (results on the low-pass filters), by commenting that for the analysis, we used the recordings where the cutoff point was specified (103 ECGs). Here,

we observed that the low-pass cutoff points were frequently between 25 Hz and 40 Hz (74% of analyzed ECGs), with 25 Hz being the most prevalent cutoff point (35% of analyzed ECGs). About the high frequency cutoff points recommended by AHA/ACC/HRS in 2007 (≥ 150 Hz), we observed that 5% of the evaluated tracings met those values (Table 3).

DISCUSSION

A decade after the last AHA/ACC/HRS guidelines on technical ECG issues, we present this descriptive study where we verified: 1) the lack of printed information on ECGs on the filter cutoff points used when performing them (only 48% of the tracings had some of the two cutoff points printed); 2) a widespread use of cutoff points not recommended, with 0.5 Hz being the low frequency cutoff point most widely used; while the most used high frequency points are in a range of 25-40 Hz.

In agreement with the results from our study, Kligfield and Okin published in 2007, a paper where they concluded that an inappropriate use of electrocardiographic filters was highly prevalent within the medical community studied (physicians referring patients to surgery in a New York hospital) [5]. The authors verified that the cutoff frequency most widely used for the high-pass filter was 0.5 Hz, while the low-pass was 40 Hz. In our analysis, the most prevalent cutoff point for the high-pass filter was 0.5 Hz, while the cutoff point most frequently used for the low-pass filter was lower (25 Hz against 40 Hz). Although the number of analyzed ECGs in this study was greater than in ours (370 against 222), this one has the value of having added ECGs from different centers and countries. Further, in our study we have taken as reference the new guidelines for the interpretation of ECG, where the cutoff point for the low-pass filter is modified (from 100 Hz to 150 Hz). Beyond all this, it is interesting to observe how ten years after this study, the prevalence of an incorrect use of filters is still remarkably high.

In our study, 47% of the tracings presented a high-pass filter cutoff point of 0.5 Hz; a value that in some given circumstances may generate problems when the ECG is assessed in real time (manually) [6]. Particularly, the use of traditional analogic filters with a cutoff frequency not recommended, may lead to significant ST segment and T wave alterations [7]. This situation is particularly important in non-linear phases, which occur when the contained frequency and the wave width change suddenly, as it occurs at the end of the QRS complex and the onset of the ST segment. The current guidelines establish a low frequency filter cutoff point of 0.05 Hz, which may extend up to 0.67 Hz, or less if we use linear filters with zero distortion phase [3]. To avoid potentially important distortions from the clinical point of view, it is necessary to use a linear phase filter or a low frequency filter set at 0.05 Hz. The bidirectional filter is the most common linear phase filter, and it acts on the signal in the initial direction and then in the reverse direction.

It is important to highlight that using cutoff points not recommended, both for high-pass filters and for low-pass filters, may cause a mistaken interpretation of ECG and thus, lead to deleterious clinical effects (possible false positives and false negatives) [5,8-12] (Table 4). In figure 1, two examples of electrocardiographic tracings with different cutoff points for the analyzed filters, and their corresponding results are shown.

According to our experience, the main cause of the incorrect use of electrocardiographic filters is the lack of professional training in relation to this topic. For this reason, we believe that the development of educational programs is essential, placing emphasis on the technical aspects of electrocardiography. To prevent the ECG alterations caused by using filters poorly and their possible clinical effects, we adhere to the guidelines from different specialists on the topic. As a first step, we should be familiar with the electrocardiograph device used and verify its settings before making a new tracing. Second, it is important to minimize the use of high-pass and low-pass filters; to achieve this without obtaining a recording with artifacts,

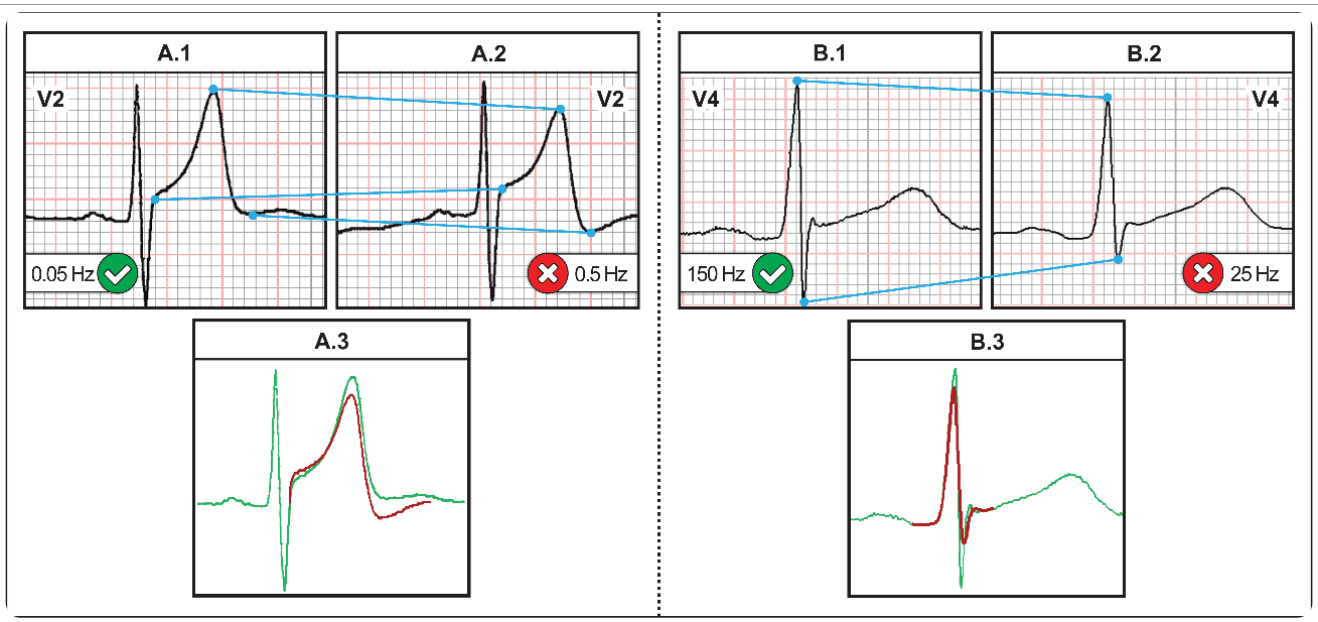

Figure 1: Panels A: Effect of high-pass filters; check how ventricular repolarization is altered when nonstandard filter is applied at 0.5 Hz (panel A.2) in comparison to the recommended filter at 0.05 Hz (panel A.1); panel A.3 shows both tracings superimposed.
Panels B: Effect of low-pass filter; check how R wave and S wave voltages are reduced when nonstandard filter is applied at 25 Hz (panel B.2), in comparison to the recommended filter at 150 Hz (panel B.1); panel B.3 shows both tracings superimposed.

Table 1: General data on the analyzed ECGs.

Country	Number of ECGs	Number of professionals	Number of cities
Argentina	95	36	20
Brazil	55	4	4
Paraguay	14	1	1
Peru	14	5	4
Spain	10	1	1
Guyana	8	1	1
Colombia	6	5	5
Uruguay	6	4	2
Venezuela	5	1	1
Mexico	4	1	1
Bolivia	2	1	1
Lebanon	2	1	1
France	1	1	1
Total	**222**	**62**	**43**

There were 222 ECGs analyzed, contributed by 62 professionals from 43 cities and 13 countries.

Table 2: Bandwidths recorded.

Bandwidth (Hz)	Number of ECGs (n = 90)
0.01 - 20	2 (2%)
0.01 - 100	11 (12%)
0.05 - 25	4 (4%)
0.05 - 35	7 (8%)
0.05 - 40	4 (4%)
0.05 - 150 *	2 (2%)
0.1 - 25	2 (2%)
0.15 - 100	2 (2%)
0.5 - 25	23 (26%)
0.5 - 35	10 (11%)
0.5 - 40	6 (7%)
0.5 - 150	2 (2%)
0.67 - 25	5 (6%)
Others	10 (11%)

* Bandwidths that meet the AHA/ACC/HRS 2007 guidelines.

Table 3: Cutoff points for the high-pass and low-pass filters recorded.

Filter (Hz)	Number of ECGs
High-pass filter	**93 (100%)**
0.01*	13 (14%)
0.05*	17 (18%)
0.08	2 (2%)
0.1	3 (3%)
0.15	5 (5%)
0.16	1 (1%)
0.25	2 (2%)
0.5	44 (47%)
0.67	5 (5%)
1	1 (1%)
Low-pass filter	**103 (100%)**
20	5 (5%)
25	36 (35%)
30	1 (1%)
35	27 (26%)
40	12 (12%)
75	2 (2%)
100	15 (15%)
150*	5 (5%)

*Cutoff points that meet the AHA/ACC/HRS 2007 guidelines

Table 4: Consequences of an inappropriate use of high-pass and low-pass filters.

Type of filter	ECG modifications with an inappropriate use	Diagnostic effects
High-pass	Alterations in ventricular repolarization (ST-T)	It mimics acute coronary syndrome [8]
		It mimics Brugada syndrome [9]
Low-pass	Decrease in QRS width	Less diagnostic value for ventricular hypertrophy [5]
	Increase in Q waves duration	It mimics old infarction [5]
	Decrease of pacemaker spike width	It mimics left bundle branch block or idioventricular rhythm [10]
	Attenuation, removal or modification of J waves	The pattern of early repolarization disappears or its expression changes [11]
	Attenuation or removal of Epsilon waves	Less diagnostic value of arrhythmogenic RV dysplasia [12]

it is important to control the different aspects of the patient and the technique (comfortable environment, relaxed patient, proper electrode placement and contact, etc.). In the latter, if we have to use cutoff points not recommended, we have to take it into account when interpreting the ECG [2,13].

We want to disclose, as a limitation to the study, the lack of information on the technologies used in high-pass filters (conventional filters or digital filters that attenuate distortions), which prevented us from making an accurate analysis on the observance of the last AHA/ACC/HRS guidelines from year 2007, in regard to this issue. Moreover, we only analyzed ECGs from adults and teenagers, so the results are not applicable to the population of pediatric cardiology professionals.

CONCLUSION

In conclusion, according to our results, we know:

1) That there is a high ratio of tracings using inappropriate cutoff points that, occasionally, may lead to significant diagnostic consequences.

2) That there is a high ratio of tracings missing printed information on the cutoff points used.

We think it is necessary to disseminate the optimal filter cutoff points and the possible effects in case of not using them, within electrocardiography training programs.

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