QUÃO FIÁVEIS SÃO OS MONITORES ELECTROCARDIOGRÁFICOS? O DILEMA DA SELEÇÃO DE FILTROS

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Palavras-chave:
- Artefactos;
- Electrocardiografia;
- Monitorização Intraoperatória

Resumo

Introdução: A monitorização electrocardiográfica foi há muito considerada como parte integrante da monitorização anestésica *standard* por diferentes sociedades internacionais, o mesmo sucedendo em contexto de Cuidados Intensivos. Contudo, esta tecnologia não é isenta de limitações, e uma confiança excessiva nos traçados obtidos pode levar a erros de diagnóstico. No presente artigo analisamos a influência da seleção de diferentes filtros sobre o traçado final. Embora em rigor não se trate de um assunto novo, os mecanismos envolvidos são habitualmente mais do domínio de técnicos e cientistas do que dos clínicos que utilizam a tecnologia no seu dia-a-dia, em grande parte devido a falta de ênfase no ensino das peculiaridades técnicas dos diferentes equipamentos durante a formação médica.

Material e Métodos: Realizámos uma revisão não sistemática sobre o assunto através de uma pesquisa na PubMed utilizando as expressões "ECG filters" e "ECG artifacts", que foi posteriormente complementada consultando referências dos artigos considerados mais relevantes.

Resultados: O presente artigo aborda os conceitos básicos de representação de um sinal electrocardiográfico no domínio da frequência, abordando artefactos que podem ser removidos ou distorções que podem ser artificialmente introduzidas, e procura exemplificar estes conceitos com exemplos da prática clínica diária.

Discussão e Conclusões: Uma selecção adequada de filtros pode permitir a obtenção de um traçado electrocardiográfico mais perceptível e interpretável, enquanto um conhecimento inadequado das definições utilizadas poderá simular ou mascarar alterações importantes, nomeadamente alterações da repolarização.

HOW TRUSTWORTHY ARE ECG MONITORS? THE FILTER SELECTION DILEMMA

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Keywords:
- *Artifacts;*
- *Electrocardiography;*
- *Monitoring, Intraoperative*

Abstract

Introduction: *Electrocardiographic monitoring has long been established as a standard for basic anesthetic monitoring by international societies, also being routine in intensive care settings. However, there are some caveats to this technology, and overreliance on the monitors' results may lead to misdiagnosis. In this article we analyze the influence of filter selection on the final electrocardiographic (ECG) tracing. Though not a new subject, the precise mechanisms involved are usually more familiar to technicians and basic scientists than to physicians, mainly because of a lack of focus on the technical peculiarities of equipment function during medical education.*

Material and Methods: *We performed a non-systematic review of the subject through a PubMed search for the expressions "ECG filters" and "ECG artifacts", complementing it with references from the articles deemed most relevant.*

Results: *The present article presents the basics of frequency representation of ECG signals, as well as examples of artifacts that can be removed or distortions that can be artificially introduced. Real world examples are used to exemplify these concepts.*

Discussion and Conclusions: *Correct filter selection has the potential to provide a neater, clearer electrocardiographic tracing, whereas lack of knowledge as to the settings being used may either simulate or mask important changes, namely repolarization abnormalities.*

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1. INTRODUCTION

Few machines are as widespread in hospitals and particularly in acute care settings as electrocardiographic (ECG) monitors. Their use is nowadays considered routine in the management of unstable patients,[1] and has the potential to reduce mortality. However, as with any diagnostic method, ECG monitoring is only as good as the person who obtains and interprets the data. In fact, all diagnostic tests have their indications, but also their limitations. Whereas in other settings specific tests are supervised by experts in the field who both conduct the exam and give a final interpretation, certifying the validity and reliability of the results, in ECG monitoring both acquisition and analysis of the data are usually made by the nursing and medical professionals. Lack of attention to detail when placing electrodes and setting up connections may render the tracing uninterpretable. Likewise, lack of attention to customizable features on the monitors can also be a source of important artifacts. These are probably some of the reasons why most experienced physicians distrust monitors to some degree, opting to confirm findings such as repolarization abnormalities with a conventional 12-lead ECG. Still, even the conventional ECG may be corrupted if appropriate care is not taken during acquisition and, interestingly, in many hospitals, especially during certain hours of the day, the 12-lead ECG is only available if acquired by the physician himself, rendering it susceptible to some of the same difficulties pointed out for continuous ECG monitoring. In this case, why should it be considered a more reliable exam than the tracing obtained through monitors? Knowing that both methods rely on the same basic principle (measurement of voltage differences on the body surface), shouldn't the result be the same?

One can always argue that 12-lead ECG's are able to characterize changes further, using more leads and thus providing a more complete "map" of the heart's electrical activity. In addition, we know that the leads themselves are not always equivalent in both methods, and in ECG monitoring some strategies are sometimes used that obtain "12-lead" tracings from information derived from only five electrodes (EASI method)[2] – as opposed to the conventional ten. However, all things considered, it is perplexing when the 12-lead ECG turns out completely normal whereas the simultaneous tracing on the monitor presents changes on the ST segment or T wave. Interestingly, this happens much more often than previously thought.

Such situations immediately raise quality concerns, and it is easy to think that the monitor is out of order. However, the true problem may actually lie with the user of the equipment, who is perhaps not making the most out of its configurations. A few examples of such situations have already been published in the literature,[3] but confusion remains[4,5] as to the causes underlying these findings.

2. MATERIAL AND METHODS

We performed a non-systematic literature review beginning with a PubMed search for the expressions "ECG artifacts" and "ECG filters". The obtained articles were then analysed and additional references retrieved from their bibliography, so that as complete a picture of the problem could be portrayed. We also included some figures representing real life examples from our daily practice.

3. ECG FILTERING AND SIGNAL BANDWIDTH

Some important differences between a conventional 12-lead ECG and the tracing obtained through continuous ECG monitoring have already been described, but Table 1 helps to compose the picture a bit further. For the purpose of this article, however, we will be focusing on one particularly relevant point: the use of different "filters" in each modality, which is especially pertinent in continuous monitoring devices.* Filtering[6] is a means of manipulating the ECG signal in order to minimize artifacts by separating extrinsic components from the original data. Considering that electrocardiography is susceptible to a multitude of artifacts,[7-8] both from movement and electromagnetic interference, the "filtering" concept appears as rather attractive. Unfortunately, the separation of both is seldom straightforward, and when attempting to remove the unwanted components, part of the signal from true cardiac origin is usually also lost – which in itself can be a source of artifacts.

Table 1 – Differences between the conventional 12-lead ECG and continuous electrocardiographic monitoring.

FEATURE	CONVENTIONAL 12-LEAD ECG	ECG MONITOR
Acquisition time	Short	Long (continuous)
Patient Apnea/Immobility	Short	Not possible continuously
Tracing presentation	Not necessarily real time	As close to real time as possible, continuous
Leads	Conventionally 12, if necessary more	Depends on the monitor; usually 1-3, sometimes more
Electrode positions	10 positions in the typical 12-lead ECG	3 positions, possibly 5 as in the EASI method
Right leg electrode (helps reduce artifact)	Present	Often absent
Customizable filters (as there are also constitutive filters, which cannot be removed, to allow sampling and improve the overall quality of the tracing)	Present, usually not necessary	Present, usually necessary to remove artifacts
Goal	Diagnostic version, "gold standard"	Monitoring version; - suitable for rhythm related diagnosis; - depending on the filters used may not be suitable for diagnosing repolarization abnormalities or voltage related changes

* A constitutive filter is always present in either the conventional 12-lead ECG machine or in ECG monitors, to avoid the aliasing that would occur should the machine sample frequencies exceed the Nyquist limit. In this article, however, we refer particularly to the selectable, additional filters present in both types of machines, which can usually be "disregarded" in the conventional 12-lead ECG if there is good patient cooperation but are often necessary in continuous monitoring.

How can one distinguish artifacts from true cardiac signals?

The foundations for a rational separation between both were unknowingly laid down by a French baron (Jean Baptiste Joseph, baron of Fourier), nearly two hundred years ago in a simple but ground-breaking concept: the Fourier series.[9-10] According to it, any periodic function or waveform may be represented as the sum of simple sinusoidal waves with frequencies that are entire multiples (harmonics) of a fundamental frequency, with appropriate amplitudes and phases. To put it simply, a composite waveform may be “decomposed” into a set of simple sinusoids whose sum equals the original waveform. This concept is part of the theory know as Fourier analysis[11-12] and is illustrated in Fig. 1, where on top we can see the sinusoids that when summed produce the waves depicted below.

Therefore, instead of a single waveform of considerable complexity (like the ECG tracing), we now have an array of simple sinusoids, each characterized by a specific frequency, amplitude and initial phase, which can be represented graphically as a whole by means of a spectrum.

While this may seem overly technical, the beauty of it is that we know that some frequencies in the spectrum are more likely to have a cardiac origin, whereas others most likely represent artifacts that will make up a noisy signal and render the interpretation more difficult. Filtering can remove these unwanted parts of the spectrum, so that (ideally) only sinusoids of cardiac origin persist. These remaining sinusoids can then be summed up again to reconstitute what one expects to be the true ECG signal, artifact-free.

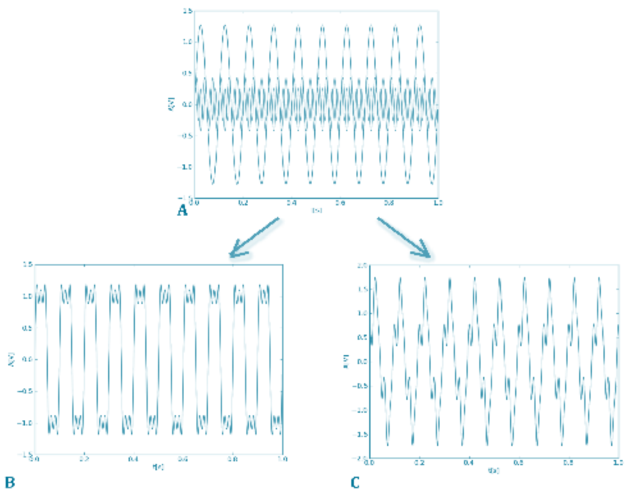

Figure 1 – A complex waveform may be represented as the sum of simple sinusoids, with adequate frequencies, amplitudes and phases. In figure A we can identify such sinusoids, whose sum produces the waveform in figure B. If the very same sinusoids are summed with a different phase relation to each other, a different waveform is produced, as happens in figure C.

In fact, and for the sake of completeness, it should be mentioned that ECG machines and monitors do not really use the Fourier series, but rather an algorithm known as the fast Fourier transform (FFT), which efficiently computes the discrete Fourier transform (DFT). The DFT is the most important discrete transform, used for Fourier Analysis and in digital signal processing. It is a discrete time version (opposed to continuous time) of the Fourier series. Also, the ECG signal is not truly periodical but rather quasi-periodic, which leads to additional tools like wavelets.[13]

Moreover, the formal treatment of ECG signals, because of their non-deterministic behavior, requires that we consider them non-stationary or locally quasi-stationary signals, leading to more complex set of tools.[14] Still, the basic principles remain valid, concerning the issue at hand.

4. LOWER FREQUENCY LIMIT OF THE ECG SIGNAL AND ITS MANIPULATION (USING HIGH-PASS FILTERS)

We already know that any periodic signal can be decomposed into a set of sinusoids with frequencies of entire multiples of a fundamental frequency (with appropriate amplitudes and phases). The fundamental frequency is defined as the lowest frequency in the set of frequencies constituting a periodic waveform. If we approximately consider the ECG a periodic signal, then its lowest frequency will be the one corresponding to a single occurrence per cardiac cycle. In other words, if we analyze an ECG with a heart rate of 60 beats per minute (bpm), we will have one cycle per second, which corresponds to a fundamental frequency of 1 Hz. Consequently, all the information in the signal spectrum comprising frequencies below 1 Hz is not truly of cardiac origin, constituting noise, that can be filtered out by using a high-pass filter.[15] If the heart rate were 120 bpm, the fundamental frequency would be 120/60=2 Hz, and all information below 2 Hz could theoretically be removed thus decreasing noise. However, when one projects an ECG machine, it is important to make it appropriate for use in as many people as possible, not just on those with a specific heart rate at a specific moment in time. Therefore, the rationale behind the development of these diagnostic tools was to find a cut-off frequency corresponding to a low enough heart rate to make it unlikely that a patient could actually present it. The cut-off of 0.5 Hz was thus idealized (corresponding to a heart rate of 30 bpm), though some prefer to use 0.67 Hz (corresponding to a heart rate of 40 bpm).[16] The systematic filtering out of signals below this threshold would thus be an important step towards reducing noise and artifacts.

The dimensioning of the lower frequency limit has to take into consideration that ECG signals from patients with abnormal rhythms may have a non-periodic behavior. As an example, cases like some ventricular dysrhythmias may induce frequencies lower than the fundamental frequency.[17]

Another particular aspect that should to be taken into account is that real-world filters are non-ideal,[18] and because of that some tolerance is required on the filter limits. In fact, most analogic and digital filters in common use have a non-linear phase response, which means they cause a phase shift in the sinusoids passing the filter, which behave differently according to their frequency.[6]

That means that the different sinusoids composing the signal lose their original phase relation to one another within the filter, some being delayed more than others. When these sinusoids are “summed” up again to reconstitute the original signal, the sum yields a necessarily different result, and the tracing is no longer the same. Fig. 1 illustrates this phenomenon: both B and C are composed by the sum of the same sinusoids (shown in A), but with different phase relations.

This happens everyday when we select a filter like “ESU filter”, and in real life ECG’s, this phase shift can be translated into artifactual distortion of the ST segment or T wave.[6, 19]

Trying to circumvent this conundrum, guidelines like those issued by the American Heart Association (AHA)[19] and the American National Standards Institute (ANSI)[20] state that the bandwidth (i.e., the set of frequencies in the spectrogram) of a diagnostic ECG should begin at 0.05 Hz, because this lower threshold makes it so that the frequencies of interest undergo a negligible phase shift in the filter and thus avoids clinically important distortion of the tracing. This is the filter usually referred to as “diagnostic” in some ECG monitors. Should a filter with linear phase response be used, however, this limit could be relaxed to 0.67 Hz as linear phase response means the filter does not cause phase shift.[15,19]

Though solving part of the problem, the truth is that lowering the cut-off from 0,5 to 0,05Hz equates to incorporating information from events occurring between 3 and 30 times per minute (3/min = 3/60s = 0.05/s = 0.05 Hz; 30/min = 30/60s = 0.5/s = 0.5 Hz), which is clearly below the fundamental frequency and thus not of cardiac origin, possibly contributing to the creation of artifacts. In clinical practice, the most common interference incorporated into the signal is that originating from respiratory movements. While in the conventional ECG it is possible to ask the patient to hold his/her breath momentarily as the acquisition is being made, in continuous monitoring such is clearly not the solution, and the final result can be contaminated by a rhythmic oscillation of the baseline (wandering baseline artifact),[9] as shown in Fig. 2.

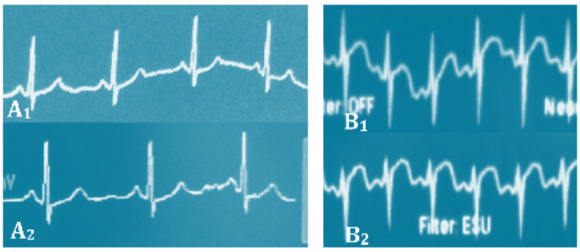

Figure 2 – Wandering baseline artifact. ECG tracings A1 and A2 were obtained from the same patient using a GE Healthcare B30 monitor. In Figure A1 the selected filter is “FiltST” (bandwidth 0.05-30 Hz) and there is clear wandering baseline artifact due to breathing. Applying the “Monitor” filter (bandwidth 0.5-30 Hz – figure A2) eliminates information between 0.05 and 0.5 Hz and consequently that artifact, produced by low frequency information.

ECG tracings B1 and B2 were obtained from a different patient with a Siemens SC 9000XL monitor. Figure B1 was acquired with the “OFF” filter (bandwidth 0.05-40 Hz), there being a notorious wandering baseline artifact. In figure B2, after correction with the “ESU” filter (bandwidth 0.5-20 Hz) there is no longer significant baseline wander (with the residual change due to a fast respiratory rate in this newborn, above 30 cycles per minute, thus above the cut-off value of 0.5 Hz). There is however ST segment elevation that was not seen in B1 (see text). Also note that the QRS amplitude is now reduced, which is particularly visible in the R wave, due to the upper limit reduction from 40 to 20 Hz.

Of course that when one encounters such a tracing in the monitor and cannot ask the patient to hold his breath, the most simple action would be to raise the cut-off of the high-pass filter to a frequency higher than that of breathing, i.e., to filter out all frequencies below a higher threshold, as mentioned. This would effectively provide a much straighter tracing and can easily be made in most ECG monitors in current use. However, the aforementioned price of artifactual distortion of the ST segment or T wave, often simulating ischemia, must be taken into account. This brings us to a fundamental point in this review: in terms of monitoring, what tracing would we prefer? One that wanders in and out of the screen, or one that is straighter and thus more amenable to rhythm analysis? Clearly, the second. However, when we make such a compromise using the appropriate filters, we must acknowledge not only what we gain – a straighter tracing – but also what we lose – the possibility to correctly represent the ST-T segment. If changes appear simulating ischemia, it is important to reapply a diagnostic filter (0.05 Hz with a non-linear response filter) to confirm whether those changes remain or disappear – thus confirming of infirming their artifactual nature. Fig. 3 reproduces tracings from patients where the application of different filters produced repolarization abnormalities either initially minor or originally not present at all.

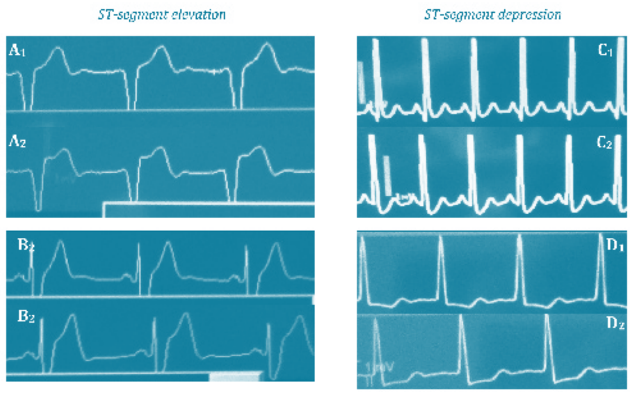

Figure 3 – ECG tracings from different patients, illustrating the effect of raising the lower frequency cut-off of the ECG signal from 0.05 Hz (A1, B1, C1 and D1) to 0.5 Hz (A2, B2, C2 and D2) with non-linear phase filters. In all of these examples there is clear change in the ST-segment, with the new filter selection either causing or exacerbating ST-elevation (figures A and B, on the left) or ST depression (Figures C and D, on the right). Also note that in figure C2 there are no Q waves, which were present in C1. That is due to the concurrent removal of high-frequency information (filter in C1 0.05-40 Hz; filter in C2 0.5-20 Hz).

Interestingly, we have also found that raising the lower cut-off from 0.05 Hz to 0.5 Hz could tamper with the T-P segment, a finding we had not previously found mentioned in the literature and that is illustrated in Fig. 4.

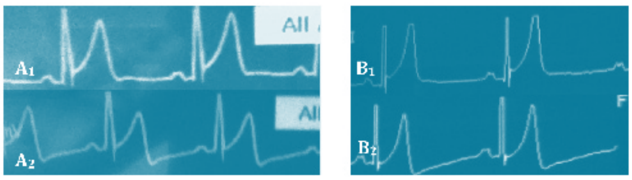

Figure 4 – Artifactual T-P segment distortion secondary to the use of a more restrictive filter.. A1 and A2 are tracings from the same patient, obtained with a Siemens 9000XL Monitor. A1 – “Off” filter (bandwidth 0.05 – 40 Hz). A2 – “Monitor” filter (0.5 – 40 Hz). B1 and B2 are from a different patient, monitored with a GE Healthcare B30 Monitor. B1 – “Diagnostic” filter (bandwidth 0,05Hz - 150Hz). B2 – “Monitor” filter (bandwidth 0.5 - 30Hz). Although this distortion of the T-P segment does not simulate disease, it is a testimony to the potential for signal distortion due to the use of non-linear filters.

It is interesting to realize that not all patients' ECG signals behave the same way when filtered, some exhibiting the pseudo-repolarization abnormalities already mentioned whereas others appear to evidence no adverse effects on the tracing. That should not cause awkwardness, though, as the sinusoid composition of an ECG signal is so unique from person to person that it is already being used as a means of biometric identification.[23-24]

5. UPPER FREQUENCY LIMIT OF THE ECG SIGNAL AND ITS MANIPULATION (USING LOW-PASS FILTERS)

Having dealt with low frequency components, we will now focus on the upper limit of the ECG bandwidth. The AHA recommends that a diagnostic ECG should include frequencies up to 150 Hz in adults (0.05-150 Hz), whereas in children this limit should be raised to 250 Hz.[19] All frequencies above these boundaries can and should be filtered out (using a low-pass filter), thus reducing noise.

While this is respected by some of the filters present in monitors, within the broad limits of up to 150 Hz there is still plenty of room for significant interference, namely:

- Electromagnetic interference from the power line, 50 Hz in Europe, 60 Hz in the USA, which is often incompletely filtered out by the constitutive notch filters of the monitors;
- Electromagnetic interference from infusion pumps, cell phones or other electrical equipment;
- Interference from electrosurgical units (ESU) used intraoperatively;
- Muscular contraction (either from voluntary movement or from shivering) (Fig. 5, patient A).

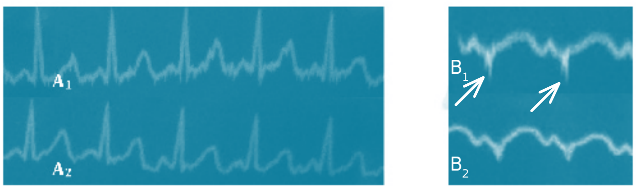

Figure 5 – Effects of filtering high-frequency signals. Tracing A is obtained from a patient with shivering using a Siemens SC 7000 monitor. In figure A1 the "Monitor" filter was used (bandwidth 0.5 – 40 Hz), whereas in A2 we selected the "ESU" filter (bandwidth 0.5 – 20 Hz). Reducing the upper limit of the bandwith from 40 Hz to 20 Hz allowed much of the high-frequency interference from muscular contraction (shivering) to be removed from the tracing, improving it.

However, in some circumstances that action can be detrimental. On tracing B, for example, obtained from a different patient with a Siemens 9000XL monitor, we can see that switching from the "OFF" filter (bandwidth 0.05-40Hz) to the "ESU" filter (bandwidth 0.5-20 Hz) the distinctive notched pattern of the downward curve following the P wave (arrows) (which correspond to a high frequency component) was lost (filtered out), there appearing only a QS pattern in B_2.

In fact, it should be noted that interference can permeate much of the signal spectrum, as emphasized by Fig. 6.

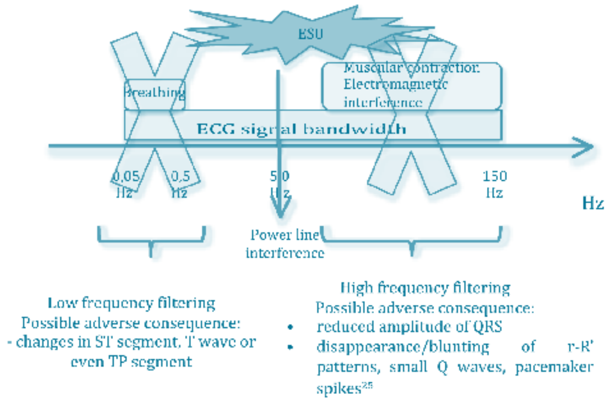

Figure 6 - Representation of sources of noise in the ECG diagnostic bandwidth (0.05-150 Hz in adults). The main source of low frequency interference (left of the picture) is from breathing, and can be eliminated by filtering out the low-frequency components between 0.05 and 0.5 Hz. High frequency interference usually derives from muscular contraction (eg, shivering), but can also be due to power line interference (50 Hz in Europe, 60 Hz in the USA) incompletely eliminated by the constitutive notch filter, or from electronic equipment nearby. A low pass filter with an appropriate cut-off frequency can eliminate these. Electrosurgical Unit (ESU) interference, through its interaction with human tissues, usually provokes a diffuse interference spanning through much of the normal bandwidth and as such is usually incompletely eliminated.

It is important to note that removing interference by aggressive filtering also eliminates part of the original ECG information (see text), thus possibly adversely affecting the final tracing.

The "X"'s represent filtering out of the involved frequencies, and we summarize some of its consequences.

If interference is identified as placing an unacceptable burden on the tracing, preventing proper visualization, then it simply has to be removed – even if at the cost of sacrificing an important part of information originating from the heart itself. Once again, the most important aspect is that we know the consequences of such action, as we will once again be distorting the original signal and corrupting the tracing – but at least there will be a tracing. It is all a matter of choice and cost/benefit analysis. The example in Fig. 7 is paradigmatic.

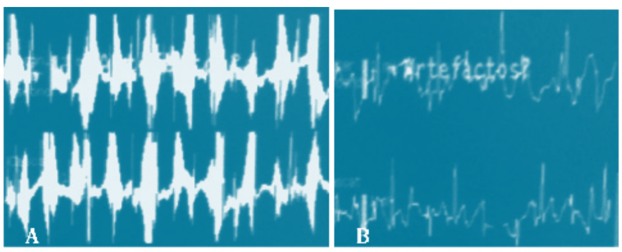

Figure 7 – ECG tracing obtained during and MRI exam with monitor GE Healthcare B30. A – tracing with "Diagnostic" filter (bandwidth 0.05-150 Hz). B – tracing with "Monitor" filter (bandwidth 0.5-30Hz). As we can see, decreasing the upper limit of the frequency from 150 Hz to 30 Hz eliminates a substantial part (though not all) of the high-frequency interference from the MRI machine, and it becomes possible to see some QRS complexes.

As we can see, the ECG signal is completely "flooded" by electromagnetic interference from the MRI machine. The application of more aggressive filters, while not providing a "clean tracing", makes it perceptible, with clear R waves and organized electrical activity that was simply not seen before. The tradeoff is that after applying these filters one cannot make diagnosis based on voltage (for example using amplitude criteria to diagnose left ventricular hypertrophy), and high frequency information like pacemaker spikes,[25] rR' patterns or small Q waves may be completely obscured by the removal of every information above 20Hz as depicted in Fig. 5 (patient B).

The same happens when we apply filters to remove interference from electrosurgical units intraoperatively, which usually have an important high frequency component spanning through a significant portion of the so-called diagnostic ECG bandwidth.[2]

In Fig. 2 we have already observed changes in the QRS amplitude associated with high-frequency filtering. Fig. 6 summarizes these findings.

Select your filter

Unfortunately there is little uniformity between monitors, who not only provide different filter options but also name similar filters differently, as seen on table 2.* Still, it is usually easy to understand which of them are more aggressive and which are more diagnostic. In every case, though, a quick look at the monitor's manual should clear any doubts as to the resulting signal bandwidth after applying each available filter.

It is important to note that most modern monitors will allow at least one option with a lower frequency cutoff of 0.05 Hz so as to avoid ST – T changes (usually the filter option "off" or "diagnostic", according to the manufacturer and model).

Table 2 – Filter specifications for some commonly used monitors.

MAKE AND MODEL	FILTER DESIGNATION	FILTER BANDWIDTH
Drager Infinity Delta and Kappa	Off	Monitor: 0.05 - 40 Hz Impressora: 0.05 - 125 Hz
	Monitoring	0.5 - 40 Hz
	ESU	0.5 - 16 Hz
Drager Infinity Gamma XL	Europe	0.5Hz - 28Hz
	USA	0.5Hz - 40Hz
GE Healthcare B30 patient monitor	Monitor	0.5 - 30/40 Hz
	ST	0.05 - 30/40 Hz
	Diagnostic	0.05 - 150 Hz
Siemens SC 7000 Siemens 9000XL	Off	0,05 Hz - 40 Hz
	Monitor	0,5 Hz - 40 Hz
	ESU	0,5 Hz - 20 Hz
Welch Allyn Atlas TM Monitor	"monitor mode"	0.5 - 40 Hz
	"extended mode"	0.05 - 100 Hz

Also note that because a filter specifies a bandwidth, selecting a new filter alters both the upper and lower ends of the allowed spectrum simultaneously (they are called band-pass filters, which can be seen as the combination of a high-pass and a low-pass filter). Therefore, there is potential for change in the tracing due to interference with both high- and low-frequency components.

In Fig. 2, for example, it is easy to find not only interference with the lower frequencies, with resulting artifactual distortion, but also with the upper frequency limit, with a clear reduction in QRS amplitude.

One final aspect of utmost importance is the recognition that to be able to choose an appropriate digital filter on the monitor one must make sure that an aggressive analogue filter has not already been used directly between the electrodes and the analogue-to-digital conversion unit, as seen on Fig. 8. If such a filter is in place, the signal is filtered at its origin, even before digitalization, and any further processing would be made on an already corrupted signal, thus without the possibility to preserve the diagnostic bandwidth regardless of the monitor settings. In such a case, every filter applied, no matter how aggressive, would have no effect on the tracing provided that the analog filter was more or at least as restrictive in its band-pass as the digital one.

In other words: we can neither filter nor preserve components that were already filtered out before reaching the monitor.

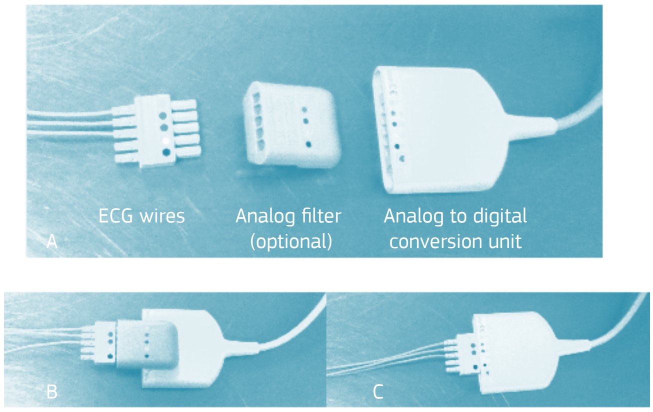

Figure 8 – Assembly of the ECG wires, optional analog filter and analog to digital (A/D) conversion unit. **A** – we can see the three components disconected. **B** – The analog filter is in use, positioned between the ECG wires and the A/D conversion unit. **C** – The assembly without the optional analog filter. This option allows us to select the most appropriate filtering options on the monitor.

6. CONCLUSION

With the present article we aimed at raising awareness onto a particular aspect of great importance to all of us who deal with acute patients in need of electrocardiographic monitoring: the proper application of ECG filters. Because continuous electrocardiographic monitoring is far more prone to artifacts, that cannot be solved by simply asking for the patient's cooperation, than the conventional 12-lead ECG, the use of different filters is welcome, often transforming tracings completely corrupted by artifact into perceptible ones. It stands to reason, then, that filters can and should be used in appropriate circumstances, but that those who use them must be aware of the consequences of that use, so as to avoid being misled by artifacts.

* Please note that Table 2 is not intended to describe every monitor available on the market, but rather reflect data from monitors we personally deal with daily, as well as some others whose filter specifications are available online.

The monitor's settings determine whether the tracing is truly diagnostic, or rather restricted to rhythm analysis. Also, when changes suggesting ischaemia appear, changing to an appropriate filter can give us an impression of whether it is an artifact or rather a true change deserving further investigation (as a complement to the semiology, of course). However, pseudonormalization of tracings with ST segment deviation or T wave inversion can appear surreptitiously with aggressive filtering options, thus denying the physician an early sign of significant importance. To avoid these situations, it is our belief – and proposition - that physicians should consider introducing a filter setting routine in their equipment checklists before each patient is monitored.

We would like to challenge the readers to experiment different filter settings by themselves on their patients. There are bound to be some surprises when they realize what happens – just as we were surprised to see the extent of their influence in such a common, everyday procedure.

Finally, we must stress that the old medical saying holds true: when faced with an ECG tracing that does not correlate with the clinical findings and until a conventional 12-lead ECG is available: "treat your patient, not the ECG". After reading this article, we hope the reader can have a better understanding of some of the rationale behind this saying.

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Conflicts of interest

None to declare.

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