CASE REPORT

Filtering electrocardiogram: Music, math, and ST-elevation myocardial infarction

Elektrokardiyogram filtreleri: Müzik, matematik ve ST-yükselmeli miyokart enfarktüsü

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Summary– Clinicians should have a basic understanding of the working principle of the instruments they use to avoid potential pitfalls caused by post-processing of the acquired biological signals. An electrocardiogram (ECG) is no exception; many different errors can arise during the acquisition or the processing of the ECG data, which may result in dangerous misdiagnoses. We present a case where the use of an inappropriate high-pass filter led to a false diagnosis of ST-elevation myocardial infarction. In addition, this report discusses the basic mechanisms of this frequently overlooked phenomenon and methods to avoid it.

Özet– Klinisyenler, biyolojik sinyallerin işlenmesi sırasında oluşabilecek potansiyel hatalardan kaçınabilmek için, kullandıkları cihazların temel çalışma prensipleri konusunda bir miktar fikir sahibi olmalıdır. Elektrokardiyogram (EKG) da buna dahildir; EKG sinyalinin kaydı ve işlenmesi sırasında pek çok tehlikeli yanlış tanıya yol açabilecek hatalar meydana gelebilir. Biz burada uygunsuz yüksek-geçiş filtresinin yanlış ST-yükselmeli miyokart enfarktüsü tanısına yol açtığı bir olgu sunuyoruz. Ayrıca sıklıkla göz ardı edilen bu durumun temel mekanizmalarını ve bu durumdan nasıl kaçınılacağını da tartışıyoruz.

Most biological signals, including an electrocardiogram (ECG), require processing to eliminate the interference from other sources. Although the frequently used ECG filters can eliminate some of the undesirable noise, but these may add new ones that can cause potential diagnostic errors. In this case report, we present a case where the use of a high-pass filter led to a false diagnosis of ST-elevation myocardial infarction (STEMI).

CASE REPORT

A 29-year-old male, admitted to gastroenterology ward for Crohn's disease, was consulted for his ECG and a family history of premature heart disease. Despite having no active complaints, his ECG showed striking anterior ST-segment elevation, and the clinicians were suspicious of an acute coronary occlusion (Figure 1, right panel). The patient was transferred to the coronary angiography unit, where a repeat ECG with a different device (Cardico 1215, Suzuken-Kenz Co., Nagoya, Japan) was completely normal (Figure 1, middle panel). The attending physician first assumed an electromechanical association artifact to be the possibility, but a carefully repeated ECG with the first device (iMac 12, Wuhan Zoncare Bio-medical Electronics Co., Hubei, China) reproduced the same finding. Changing the settings of the device resulted in diminished ST-elevation (Figure 1, left panel). The ST-elevation was judged to be artifactual, which is supported by a normal ECG and negative serial troponins. Patient was discharged uneventfully. The history and ECG findings are presented after taking an informed consent from the patient.

DISCUSSION

This case illustrates that, despite being previously well-described, high-pass filters are not a widely appreciated cause of pseudo-STEMI.[1] It underlines that the clinicians should be aware of and quickly re-

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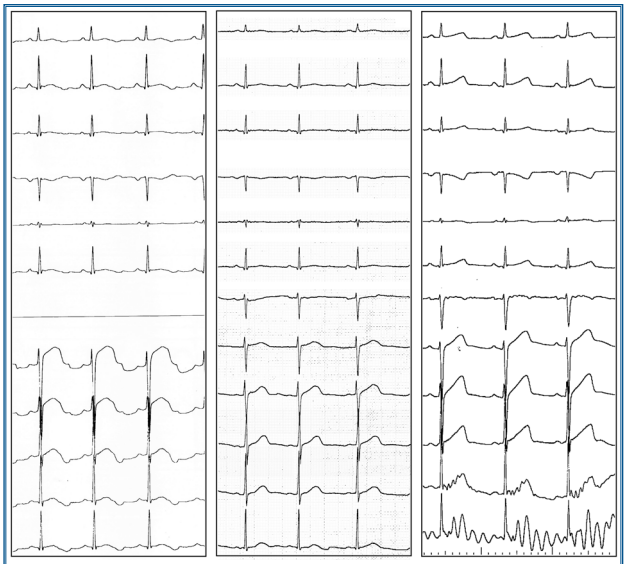

Figure 1. Sequential recordings from the same patient. Left panel, the electrocardiogram (ECG) recorded in manual mode with a high-pass filter set to 0.6 Hz shows significant ST-segment elevation. Middle panel, ECG taken with a different device, in automatic mode and high-pass filter set to 0.05 Hz, is completely normal. Right panel, ECG acquired with the same device in the first recording, recorded in manual mode with a high-pass filter set to 0.05 Hz. ST elevation still exists, but it is less now.

view the potential sources of error, especially in patients with a very low pretest likelihood of STEMI. In this case, the attending physician first thought of an electromechanical association artifact,[2] caused by the arterial pulsations,[3] but in this condition, the amplitude of the artifactual deflection in chest leads is expected to be one-third of that in the standard limb leads.[4] Additionally, the waveform was reproduced by a carefully recorded second ECG with the same device settings (not shown). The wavy progression of general tracing, with the most prominent ST-elevations accompanying the deeper S waves, is a clue for the artifactual origin. Another very subtle clue in the third ECG is the artifactual deflections in V5 and V6. Although they seem to be simple movement artifacts at first glance, their consistency in the successive beats, and their fixed frequency corresponding to exact multiples of the heart rate (seems to be the seventh harmonic of the fundamental frequency in V6, see below), hint that they may be the remnants of higher harmonics of Fourier transformation and indicate the error-proneness of the filter system of this particular model. To understand this concept a bit clearer, the mechanism of ECG filtering should be briefly reviewed, which can be done more easily with the help of a musical analogy.

Abbreviations:
ECG *Electrocardiogram*
STEMI *ST-elevation myocardial infarction*

The musical note A has a frequency of 440 Hz, but we all know that A note of a piano differs from that of a violin. This is because all musical instruments have different acoustics owing to differing shape of their sound boxes and materials. Therefore, no instrument produces a pure sine wave at a certain frequency (for example, 440 Hz for A); instead, many different sine waves bounce back from different parts of their sound box and are packed up into a single complex waveform. Thus, each musical instrument has a different A note waveform, in which the 440 Hz sine wave (fundamental frequency) is distorted by the addition of several higher frequencies specific to that musical instrument. The human ear, or, more correctly, the cochlea in it, has tiny cilia, which gradually get smaller from the outside to the inside of its spiral shape, every one of which specifically resonates with a certain frequency according to their length. Thus, the cochlea in a sense decodes this complex waveform into its ingredient frequencies, which can be then interpreted by the brain. This process is very similar to a function in mathematics, known as Fourier transform. According to the Fourier transform theory, any complex waveform can be broken into mathematically expressible sine waves, and then easily processed.

Most biological signals must be processed for eliminating the noise coming from other sources, which contaminates the real signal by adding extra frequencies to it. The ECG is no different. Using Fourier transform, the ECG machine decomposes the recorded signal into multiples of fundamental frequency (heart rate) called harmonics, filters some low (direct current potentials occur at the tissue–electrode interface, the baseline wanders due to respiratory movements) and high frequencies (muscle artifacts and power line interference), and then reconstructs a clearer signal using the remaining sine waves. Usually, the sum of the first 50 harmonics is enough to reconstruct the ECG almost perfectly, but the amplitude and the phase (starting point of the sine wave) of each harmonic needs to be adjusted to recreate the original signal.

The filter that eliminates the low frequencies, also called high-pass filter, can generally be set to 0.05

to 0.5 Hz. Because the heart rate (the fundamental frequency of the signal) is generally between 40 and 120 beats per minute (0.66-2 Hz) and the harmonics are multiples of this (for example, for 60 bpm or 1 Hz, second harmonics is 2 Hz, third harmonics is 3 Hz, and so on), a filter set to 0.05 Hz (or 3 bpm) is not expected to influence any genuine heart-made signal. However, as the ECG machine needs to adjust the amplitude and the phase of each harmonic to recreate the original waveform, it shifts especially some of the first 7-8 harmonics back and forth. Moreover, the higher the cut-off, the more prominent the phase shifts are. When the high-pass filter is set to 0.5 Hz, this may cause bumping of native ECG waves and isoelectric segments, and especially cause ST-segment deviation discordant to QRS complex.

The American Heart Association guidelines[1] explicitly warn that high-pass filters with a cut-off frequency of 0.5 Hz may distort ST-segment, whereas 0.05 Hz high-pass filters do not modify it. Unfortunately, a real-life study showed that 75% of the routine ECGs seem not to pay attention to these recommendations.[5] Although ECG manufacturers use different types of filters, many use a post-processing technology utilizing bidirectional filter that allows the correction of these phase shifts for limiting ST distortion. Therefore, ST distortion is especially important in the manual mode (real-time record) compared with the auto mode (computer processed) in which the aforementioned technology has no time to correct the distortion. This should especially be considered when tracings from external defibrillators, bedside monitors, Holter recorders, or routine real-time ECGs, with a high-pass filter set to 0.5 Hz, are being interpreted. This case is another example of how important the device settings are, yet how overlooked they are at the same time.

The high-pass filter is a well-described, but frequently underappreciated, cause of artifactual ST-segment elevation. The analysis of the ST-segment should only be carried out with a low high-pass filter set to 0.05 Hz, especially when real-time mode is utilized. This report suggests using a low high-pass filter set to 0.05 Hz in all situations to avoid confusion.

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REFERENCES

1. Kligfield P, Gettes LS, Bailey JJ, Childers R, Deal BJ, Hancock EW, et al. Recommendations for the standardization and interpretation of the electrocardiogram: Part I: the electrocardiogram and its technology: a scientific statement from the American Heart Association Electrocardiography and Arrhythmias Committee, Council on Clinical Cardiology; the American College of Cardiology Foundation; and the Heart Rhythm Society. Circulation 2007;115:1306-24. [Crossref]
2. Aslanger E, Yalin K. Electromechanical association: a subtle electrocardiogram artifact. J Electrocardiol 2012;45:15-7. [Crossref]
3. Aslanger E. An unusual electrocardiogram artifact in a patient with near syncope. J Electrocardiol 2010;43:686-8. [Crossref]
4. Aslanger E, Bjerregaard P. Mystery of "bizarre electrocardiogram" solved. J Electrocardiol 2011;44:810-1. [Crossref]
5. Kligfield P, Okin PM. Prevalence and clinical implications of improper filter settings in routine electrocardiography. Am J Cardiol 2007;99:711-3. [Crossref]

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Anahtar Kelimeler: Akut koroner sendrom; artefaktlar; elektrokardiyogram; ST-yükselmeli miyokart enfartküsü