Heart, Lung and Circulation (2019) **28,** 1472–1483
1443-9506/04/$36.00
https://doi.org/10.1016/j.hlc.2019.03.006

REVIEW

The Footprints of Electrocardiographic Interference: Fact or Artefact

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Received 12 February 2019; accepted 7 March 2019; online published-ahead-of-print 12 April 2019

Corporeal and particularly extra-corporeal interference is a very common problem encountered with both resting electrocardiograph (ECG) tracings and ambulatory recordings. The interference may be either electrical or mechanical and if severe, may affect the interpretation of the tracings. The interference, seen as artefact, can be divided into obvious, subtle or complicated. Obvious artefact may result from poor electrode attachment or body motion, whereas electrical interference is predominantly 50 or 60 Hz alternating current or radiofrequency waves from power lines, electrical equipment, mobile phones, fluorescent lights and electrical diathermy. Careful attention to the application of electrodes and finding the best environment for performing a 12-lead ECG will eradicate most interference. When subtle, the artefact can mimic cardiac arrhythmias, leading to incorrect interpretation of the tracings. There is also a complicated interference group, usually due to implanted cardiac electronic pacing devices and neurostimulators. These create persistent artefact, which may result in repeated unsuccessful attempts at procuring an artefact free tracing. This manuscript will describe the genesis of interference, how an ECG machine or monitor deals with interference and will discuss the common causes of interference. The characteristic patterns will be described and clues provided on how to differentiate subtle artefact from cardiac arrhythmias.

Keywords Electrocardiography • ECG artefact • Pacemaker stimulus artefact

Introduction

An electrocardiographic (ECG) artefact is an inscription on an ECG tracing originating from a non-cardiac source of interference. These artefacts may be electrical or mechanical, corporeal or extracorporeal and may distort the P, QRS or T waves as well as the isoelectric baseline.

The standard ECG or Holter monitor recording requires skin electrodes or sensors to document the cardiac electrical activity associated with depolarisation and repolarisation. These electrodes must convert the ionic current in tissues to an electron current on the skin surface. This transduced signal is then filtered and amplified before being displayed as a visual tracing. For optimal recordings, the skin electrodes must provide a low resistance interface in order to transmit data to the ECG cable and from there to the amplifier/recorder.

Early ECG electrodes were metal plates on the limbs and suction cups on the chest wall, which were bathed in a conducting gel. In recent years, these cumbersome electrodes have been replaced with a plethora of inexpensive disposable designs containing a solid conducting gel interface with embedded silver/silver chloride and a variety of adhesive backings including soft cloth, plastic, breathable tape, paper or foam. They may be simple sticky tabs for ECG recordings and round or oval electrodes with stainless steel or carbon snaps for both ECG recordings and Holter monitoring. More recently, sophisticated multi-electrode patches have been developed for both long-term event or Holter monitoring [1].

Despite the best intentions, interference on ECG and Holter monitor tracings with resulting recording artefact is a common problem, often poorly understood by the

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staff who perform and report these studies. This review will describe the genesis of interference, list the common causes of artefact and how the ECG machine deals with it. The characteristic patterns will be described and clues provided on how to differentiate subtle artefact from cardiac arrhythmias, thus hopefully preventing serious misdiagnosis.

ECG Signal Processing and Filtering

The frequency of signals processed by an ECG machine are measured as the cycle rate or Hertz (Hz), where 1 Hz is equal to 1 cycle per second. The baseline cardiac electrical frequency or sinus rate is about 60 beats per minute (bpm) or 1 Hz and the lowest cardiac rate encountered is 30 bpm or 0.5 Hz. For the construction of an ECG, the signals are decomposed into oscillatory sine waves or harmonics by Fourier analysis and then reconstructed into P, QRS and T waves. Each harmonic has amplitude (mV), frequency and phase (delay before the signal commences).

The ECG skin electrodes record signals from a number of sources although cardiac signals are the most important. Other biological or corporeal signals include skeletal muscle, brain or respiration, whereas extracorporeal signals comprise those at the dermal-electrode interface and external sources. Another source of electrical signals are those generated by implantable electronic devices. Table 1 is a summary of the range of frequencies seen on the ECG tracings both from the heart and other non-cardiac sources.

For ECG recordings, filters are required to remove unwanted interference. These differ between the ''diagnostic mode'' filters for the high fidelity resting 12-lead ECG and the ''monitor mode'' filters for the various types of cardiac monitoring. An ECG machine or monitoring recorder incorporates a range of filters within the analysis software all of which can distort the resultant ECG tracing, either as amplitude or phase. There are at least four types of filters used:

Table 1 Frequencies of cardiac and non-cardiac signals seen on the ECG.

Cardiac signals:	
Heart rate	0.5 Hz (30 bpm) to 5 Hz (300 bpm)
P wave	0.67 to 5 Hz
QRS	10 to 50 Hz
T wave	1 to 7 Hz
High frequency potentials	100 to 500 Hz
Non-cardiac signals	
Skeletal muscle	5 to 50 Hz
Respiration	0.12 to 0.5 Hz
External electrical	50 or 60 Hz
Other electrical	> 10 Hz
(pacemakers, neurostimulators, magnetic fields)	

- Bandpass filters limit the frequency band. There can be:
  - High-pass filters which remove low frequency signals such as motion artefact (Figure 1). They do not attenuate the signal, but rather cause phase distortion. For full fidelity resting 12-lead ECG recordings, the high-pass filter lies between 0.05 and 0.5 Hz. However, an amplifier with a cut-off of 0.5 Hz frequency may distort T waves and ST segments [2]. Digital technology now permits a variety of methods for increasing cut-off frequency and minimising ST distortion [3,4].
  - Low-pass filters remove high frequency signals such as skeletal myopotentials and external interference. Such filters may reduce the QRS amplitude and have for visual diagnostic accuracy, a cut-off between 50 and 100 Hz, although ECG frequencies higher than 100 Hz, such as late potentials with coronary disease, need to be investigated with equipment up to 500 Hz [3].
- AC (notch) filter removes 50 or 60 Hz line interference.
- Common mode rejection filters via the earth electrode.

For a routine 12-lead ECG or Holter monitor, the frequency settings should have a range of 0.05 to 150 Hz for full fidelity ST segments including epsilon waves. In practice, however, the filter settings are limited to a more narrow range. The filters on modern ECG machines are programmable allowing for a wide range of filter settings. For ECG monitoring through smart phone technology, the transmission of large volumes of data requires the development of new intelligent algorithms necessary to remove or identify the artefact created by movement [5].

Classification of ECG Artefact

For simplicity, interference on the ECG or Holter monitor recording can be classified as Obvious, Subtle or Complicated. Obvious artefact should be readily recognised and thus not lead to confusion in diagnosis. The artefact may or may not interfere with the recorded P, QRS and T waves. Subtle interference is more serious in that it may mimic t he patterns of abnormal ECG tracings, leading to misdiagnosis. Complicated interference, usually from implanted cardiac pacemakers or electrical stimulators have characteristic patterns which should be recognised.

Obvious Artefact

Obvious ECG or Holter monitor interference creates artefact patterns on the tracings which are usually easily recognised. They may be either electrical or mechanical, but cannot always be differentiated as such and the same tracings may show evidence of both forms of interference. As a rule, electrical interference is more common in the 12-lead ECG as the patient is at rest, whereas mechanical interference is more likely in the active Holter monitor patient. Table 2 lists the most common causes of electrical and mechanical interference.

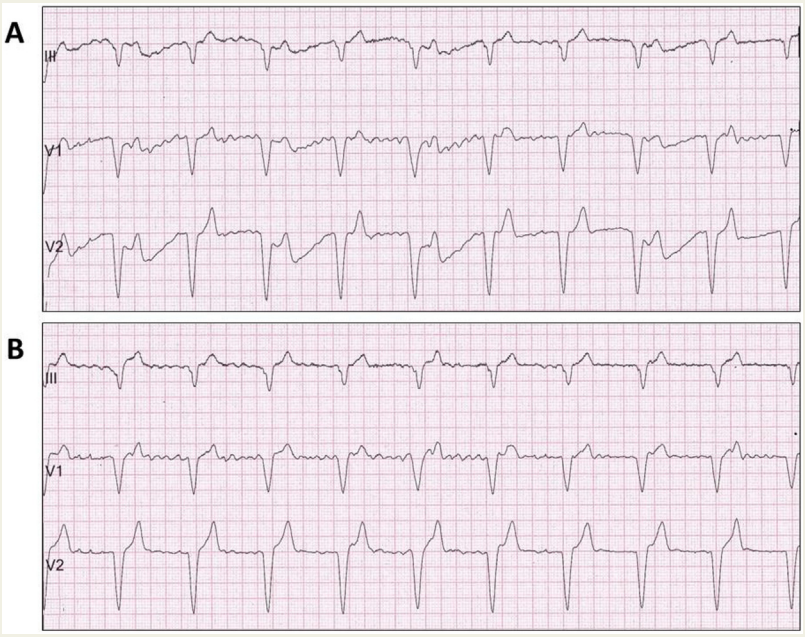

Figure 1 Electrocardiographs (ECGs) leads III, V1, V2 demonstrating the effect of applying a high-pass filter to remove motion artefact during ECG interpretation. (A) No filter. (B) High pass (baseline) filter applied (ECG Management, McKesson Cardiology™ San Francisco, CA, USA).

The most common artefact seen on the 12-lead resting ECG is electrical alternating current (AC) interference. This was the near-universal finding on all the earlier ECGs, so commonly seen in the literature before 1970. AC current is described as either 50 or 60 Hz. In most of the world, AC current is 50 Hz, whereas in the United States (USA) and very few other countries, it is 60 Hz. As far as ECG and Holter monitor interference is concerned, this difference is irrelevant. The interference may be seen on the whole tracing or one or more leads (Figure 2). Modern filters generally deal with AC interference, unless it is significant in which case the recordings may need to be repeated elsewhere. Similarly, radiofrequency (RF) interference such as power lines, adjacent electrical equipment, mobile phones and fluorescent lights may produce interference similar to AC current, but of varying intensity (Figure 3).

Table 2 Causes of interference on the ECG and Holter recordings.

Electrical:
Alternating current (AC) 50 Hz, (USA 60 Hz)
Radiofrequency (RF) - power lines, electrical equipment, mobile phones,
fluorescent lights and electrical diathermy
Static electricity (humidity)
Dry electrodes
Inappropriate filter settings
Loose connections (mixed)
Dislodged electrode / connection (mixed)
Fractured ECG cable (mixed)
Mechanical:
Movement, tremor, shivering
Respiration
Creams and oils
Loose connections (mixed)
Dislodged electrode / connection (mixed)
Fractured ECG cable (mixed)
Mixed = both electrical and mechanical

Abbreviation: ECG, electrocardiograph.

Electrical interference artefact may also occur due to static electricity from humidity or inappropriate filter settings on the ECG machine. Dry electrodes may cause poor skin contact and high impedance, resulting in very low voltages (Figure 4A). This appearance can be confused with reversed limb leads [6]. Issues with the electrodes and cables such as poor contact, loose connections and lead fractures may demonstrate mechanical artefact, although mixed interference patterns may also occur.

An offset potential is another form of electrical interference seen on an ECG or monitor. This is an artefact created by the voltage stored in the electrode. It depends on skin preparation and in particular, the use of silver-silver chloride electodes. Certain older electodes like the early stainless steel plates held their charge like a capacitor rather than allow it to dissipate and are referred to as polarised electrodes. As stated earlier, there is a transfer of current from ions to electrons at the dermal-electrode interface. These ions carry the charge to the leads and from there to the ECG machine. At the dermal-electrode interface, there is an uneven distribution of anions and cations resulting in a resistance or impedance to current flow and this can be offset by silver-silver chloride in the conducting gel. Today, offset potentials only play a minor role unless the interference is massive, such as

Figure 2 Two channel Holter (A) and electrocardiograph (ECG) lead II (B) demonstrating 50/60 HZ AC interference.

Figure 3 Holter monitor (A,B) and ECG leads II (C,D) demonstrating RF interference. Abbreviations: ECGs, electrocardiographs; RF, radiofrequency.

after defibrillation and the ECG recording takes time to return to the baseline.

Mechanical interference causing artefacts is usually seen with Holter monitoring. However, it may also occur with 12-lead resting ECG recordings such as an arm falling off the side of the table, shivering and neurological tremors (Figure 4B). Mechanical artefacts are generally crude. Minor movements may not interfere with the P, QRS and T waves, nor distort the baseline (Figure 5A). On other occasions, there is marked interference with the ECG tracing (Figure 5B). With a fractured cable, there may be intermittent loss of the tracing with a straight baseline, mimicking asystole (Figure 5C).

Not infrequently, artefact is seen on the ECG or Holter monitor tracings which cannot be differentiated into electrical or mechanical. Figure 6 illustrates a range of artefact which theoretically could be either source. Figures. 6A and B show a regular artefact signal at around 5 Hz, suggesting EMI. Figure 6C is also regular, but much slower and could be either electrical or mechanical, although Figure 6D is irregular with fragmented signals above or below the baseline suggesting a mechanical source.

Subtle Artefact

One of the challenges of ECG interpretation is differentiating artefact from true ECG abnormalities. Table 3 is a list of ECG abnormalities and, in particular, cardiac arrhythmias that may bewilder the cardiac technologist and cardiologist and lead to misdiagnosis. In many of the examples to be shown, the ECG was interpreted incorrectly.

The Lost QRS

Although common with early ''analogue'' ECG machines, the loss or modification of a QRS can still be seen occasionally with newer machines even those without paper delivery. Figure 7 is a composite illustration of the range of abnormalities that must be recognised in order not to diagnose atrioventricular (AV) block. Figure 7A, B, C are examples of irregular ECG paper delivery, usually due to intermittent

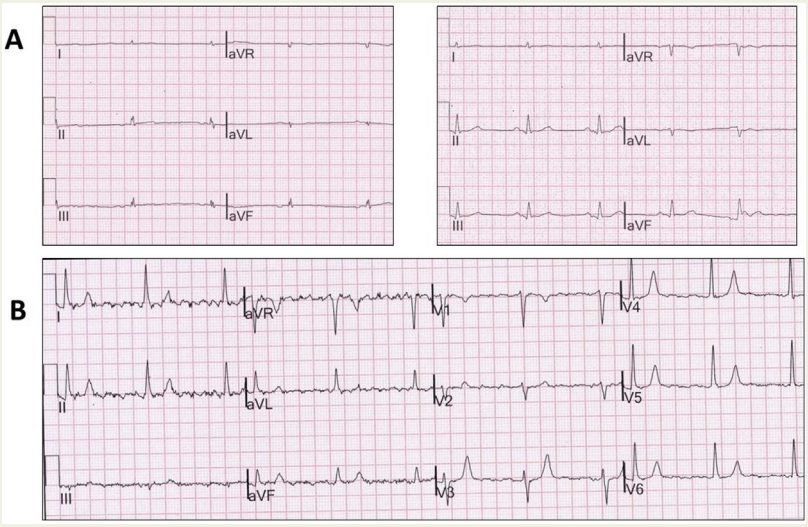

Figure 4 (A) Six (6) lead electrocardiographs (ECGs) with low voltages. Left: Poor lead attachment or dry electrodes. All leads have low voltages. Right: Reversed arm and leg leads. Lead I has very low voltages, whereas leads II, III and aVF are near identical as are aVL and aVF. (B) 12-lead ECG from patient with Parkinson's disease. The sinus P waves are obscured and the appearance, although regular, mimics coarse atrial fibrillation.

Figure 5 (A) Electrocardiograph (ECG) lead II demonstrating mechanical artefact, which does not distort the baseline, nor interfere significantly with the QRS complexes. (B) Two channel Holter monitor recording, demonstrating major interference involving the baseline and QRS complexes. (C) ECG lead II demonstrating intermittent loss of electrical activity due to a fractured cable, resulting in a straight baseline, mimicking asystole.

''sticky'' rollers, giving an uneven speed. There may be slowing with an apparent prolongation of the PR interval and a widened QRS (Figure 7A), whereas at other times, there is a short PR interval (Figure 7B) and an absent or very narrow QRS with an obvious T wave (Figure 7A, B, C). There is a subtle change in the P-P or P-T intervals, confirming uneven paper delivery. In comparison, Figure 7D demonstrates an absent QRS and T wave due to Wenckebach second degree AV block. On this occasion, the clue is the change in the PR interval with the longest PR interval before the absent QRS/T waves and the shortest immediately following it [7].

In many early model single channel ECG machines, there was an ''Insto'' switch, which when activated would trigger a 400 ms blanking period, following the detection of artefact. At the time, most pacemaker leads were unipolar and single chamber ventricular. The prominent stimulus artefact was interpreted as artefact resulting in bizarre appearances on the ECG recording, mimicking high threshold exit block (Figure 8A). On rare occasions, similar appearances can be seen even today on ECG tracings (Figure 8B).

Mimics an Atrial Tachyarrhythmia

This is the most common misdiagnosis associated with artefact. Figure 9A demonstrates a regular rhythm with a mechanical artefact such as shivering or rigors [8]. The clue is the second last complex confirming sinus rhythm. This

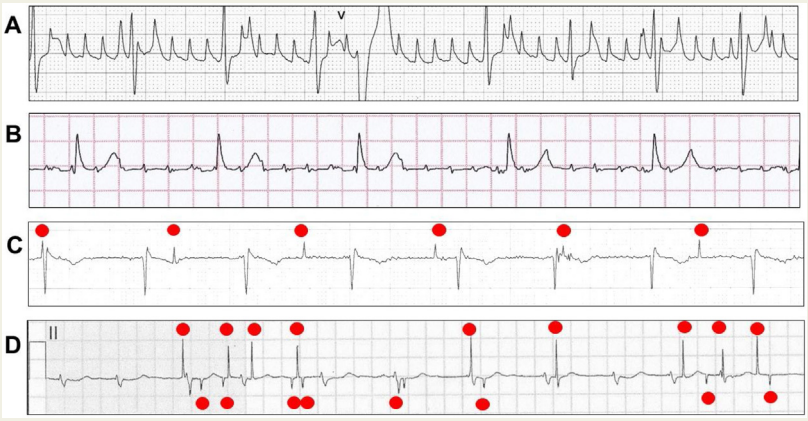

Figure 6 Holter monitor recordings (A,C) and electrocardiograph (ECG) leads II (B,D) demonstrating either electrical or mechanical interference. (A,B) The interference is regular at about 300 ppm and suggests EMI. (C) The interference is regular, but much slower (red circles) and could be either electrical or mechanical. (D) The interference is irregular with fragmented signals of different voltages (red circles) above and below the baseline, suggesting a mechanical source.

Table 3 Subtle ECG artefact which may lead to misdiagnosis.

The lost QRS
Mimics an atrial tachyarrhythmia
Mimics a ventricular tachyarrhythmia
Mimics ventricular ectopics
Mimics asystole
Mimics limb lead malposition
Mimics myocardial ischaemia and infarction
Mimics cardiac pacing

Abbreviation: ECG, electrocardiograph.

ECG was misinterpreted as atrial flutter with high degree AV block. Figure 9B demonstrates an irregular rhythm misinterpreted as atrial fibrillation, but as the vertical arrows suggest the rhythm is sinus rhythm with atrial ectopics. Figure 9C is another example of irregular ECG paper delivery due to sticky rollers and was misinterpreted as an atrial triplet, despite the RT intervals being very short.

Mimics a Ventricular Tachyarrhythmia

This is potentially the most serious of the misdiagnoses associated with ECG artefact. These artefacts are much more common with Holter or bedside/telemetric ECG monitoring and careful inspection of the tracings are required to exclude a potentially serious ventricular tachyarrhythmia. The diagnosis of interference is usually obvious with the resting 12-lead ECG as the artefact will not usually occur in all leads.

As the artefact overlies the native rhythm, there are two helpful signs to identify the native QRS as it progresses though the artefact. The first, is demonstrated in Figure 10A which closely mimics ventricular tachycardia or flutter. The regular red dots signify the underlying native R waves and because they are seen as sharp spines above the artefact are referred to as the ''spike sign''. The second, also shown by the red dots in Figure 10B, are the regular ''notch sign'' within the artefact, which represent the native QRS complexes [9].

Figure 10C demonstrates that not all reported artefact is artefact. There is a short run of a supraventricular tachyarrhythmia with progressive aberrant ventricular conduction and first appearances would be consistent with artefact, which was reported as such. A more serious misdiagnosis is shown in Figure 11A. The appearances on the Holter monitor ECG, suggested Torsade de Pointes, but once again the red dots identify the timed spikes and notches confirming artefact. In Figure 11B, an actual ECG of Torsade de Pointes is shown highlighting the similarities of the two appearances.

Physician misdiagnosis of artefact as ventricular tachycardia is potentially serious, particularly if it leads to a recommendation for an implantatable cardioverter-defibrillator (ICD) [10]. It is of more significance, if the artefact occurs during bedside or telemetric ECG monitoring in an emergency room, coronary care or intensive care where the patient is generally unwell and being monitored for syncope, palpitations or chest pain [11]. In a study where 766 physicians were surveyed with an ECG example of artefact simulating a wide complex tachycardia with timed spikes and notches, 94% of internists, 58% of cardiologists and 38% of electrophysiologists diagnosed ventricular tachycardia and most recommended an electrophysiology study [12].

Mimics Ventricular Ectopics

Figure 12A is an example of artefact mimicking an interpolated ventricular ectopic, labelled 1. The artefact continues through the Holter tracing and the complex labelled 2 is actually a ventricular ectopic with a compensatory pause. The bottom tracing has less artefact and confirms the diagnosis.

Mimics Asystole

Figure 5C is an example of a fractured ECG cable, suggesting sinus arrest and asystole. The machine was used on two patients that day with similar findings. Figure 12B also

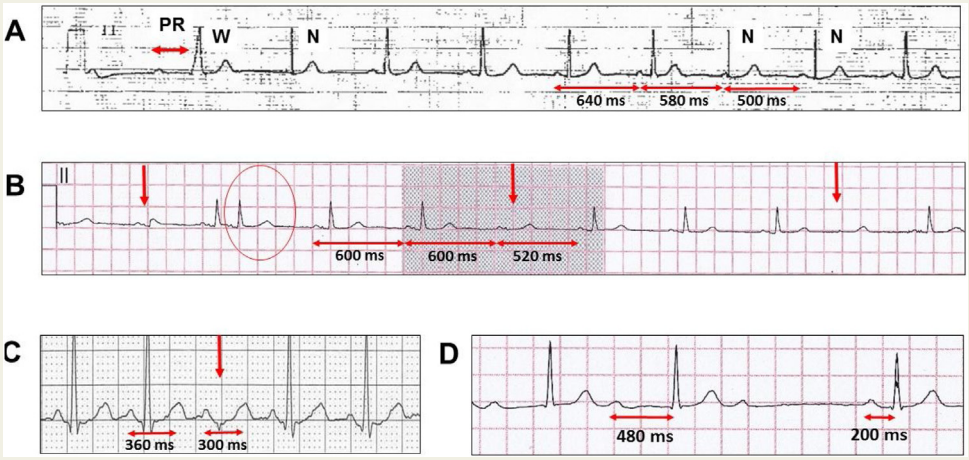

Figure 7 ECGs lead II illustrating a range of abnormalities mimicking AV block. (A) Irregular ECG paper delivery due to intermittent ''sticky" rollers, giving an uneven speed (red horizontal arrows with P-P measurements). There is an apparent prolongation of the PR interval (red horizontal arrow) and a widened QRS (W). There are short PR intervals and very narrow QRS complexes (N). (B) Irregular ECG paper delivery due to intermittent ''sticky" rollers, giving an uneven speed (red horizontal arrows with p-p measurements). There are absent QRS complexes (red vertical arrows), but T waves are present confirming artefact. The open red oval is a normal QRS after a very short R to R interval. (C) Abbreviated QRS (red vertical arrows) with narrowing of the P-T interval (red horizontal arrows) due to sticky rollers. (D) Absent.
QRS/T wave due to Wenckebach second degree AV block. There is shortening of the PR interval after the pause (red horizontal arrows) confirming the diagnosis. Abbreviations: ECG, electrocardiograph; RF, radiofrequency; AV, atrioventricular.

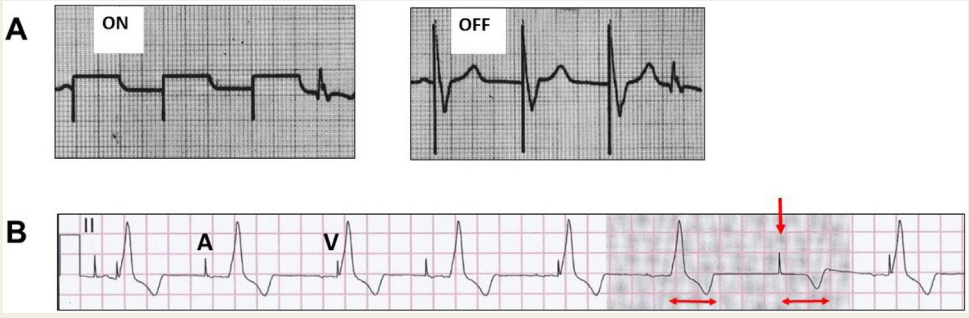

Figure 8 Electrocardiographs (ECGs) lead II illustrating absent QRS complexes. (A) Single channel ECG machine of a patient with a unipolar single chamber ventricular pacemaker (VVI). Left: ''Insto" switch is ON resulting in complete filtering of the QRS/T wave after detection of the large stimulus artefact. Right: The ''insto" switch is turned OFF and paced QRS/T waves are now seen. (b) Dual chamber pacemaker with varying size of the atrial and ventricular stimulus artefacts. Following a tall ventricular stimulus artefact, there is no QRS suggesting that the ECG machine has filtered out the QRS complex. This is not ventricular exit block as there is a T wave following.

suggests asystole, but in this example there are smaller QRS complexes at the beginning and end of the asystole on the Holter recording suggesting that the monitoring electrode had temporarily become detached from the skin increasing the dermal resistance with attenuation and loss of QRS complexes. A similar but consistent appearance is shown in Figure 4A due to dry electrodes.

Mimics Limb Lead Malposition

This was demonstrated in Figure 4A.

Mimics Myocardial Ischaemia and Infarction

An unsteady wavering baseline often due to respiration artexfact, may be confused with ST segment depression, particularly by computerised ECG interpretive algorithms (Figure 13A) [13]. The tracing should be repeated during held respiration. Reversal of the right arm and leg leads, when performing a resting 12-lead ECG will result in an isoelectric lead II, but as lead III is the reverse image of lead I, there is occasionally the appearance of an old inferior infarct [6,14]. Of more importance is the diagnosis of an acute myocardial infarction with marked ST and T wave elevation in the 12-lead resting ECG. This is a rare appearance due to placement of the ECG electrodes over arteries and in particular, the radial arteries [15]. Because of the delay in pulse transmission, the actual ST elevation commences at the end of the ST segment, thus differentiating it from true ST elevation. This

Figure 9 Electrocardiograph (ECG) tracings with artefact mimicking atrial arrhythmias. (A) Regular rhythm with mechanical interference, possibly shivering, mimicking atrial flutter. Toward the end of the tracing, the artefact subsides, confirming sinus rhythm (red vertical arrow). There is no change in the QRS repetition rate at the end of the artefact. (B) Irregular rhythm with the red vertical arrows indicating P waves. The rhythm is sinus with atrial ectopics. This ECG was reported as atrial fibrillation. (C) Irregular ECG paper delivery due to sticky rollers. The ECG was interpreted as an atrial triplet (red vertical arrows), despite the RT intervals being very short.

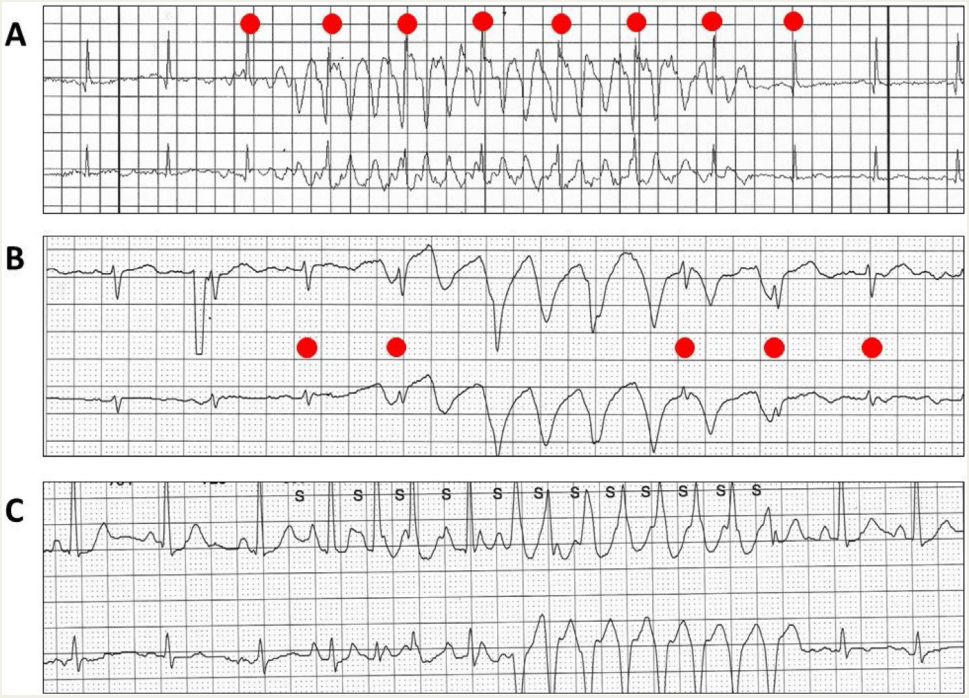

Figure 10 Two channel Holter monitor recordings. (A) Electrocardiograph (ECG) artefact mimicking ventricular tachycardia. The regular red dots signify the underlying native R waves (sinus rhythm) and because they are seen as sharp spines above the artefact are referred to as the ''spike sign''. (B) ECG artefact mimicking ventricular tachycardia The red dots indicate the ''notch sign'', which represent the native QRS complexes. (C) Run of a supraventricular tachyarrhythmia with progressive aberrant ventricular conduction, which was mistakenly reported as artefact.

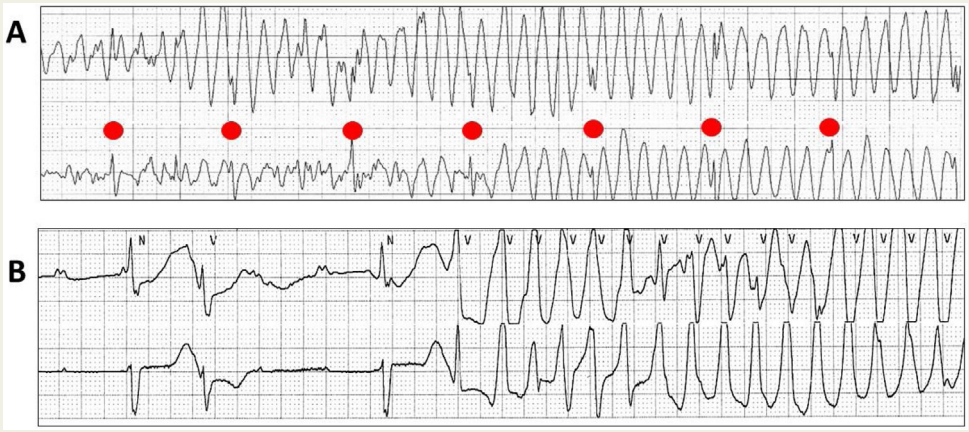

Figure 11 (A) Two channel Holter recording with the tracing strongly suggesting Torsade de Pointes. The regular red dots identify the spikes and notches, confirming artefact. (B) Electrocardiograph (ECG) tracing of Torsade de Pointes in a patient with an acute inferior infarction, complete heart block, prolonged QT interval and R on T. The tracing highlights the similarities of the true ventricular tacharrhythmia with the artefact.

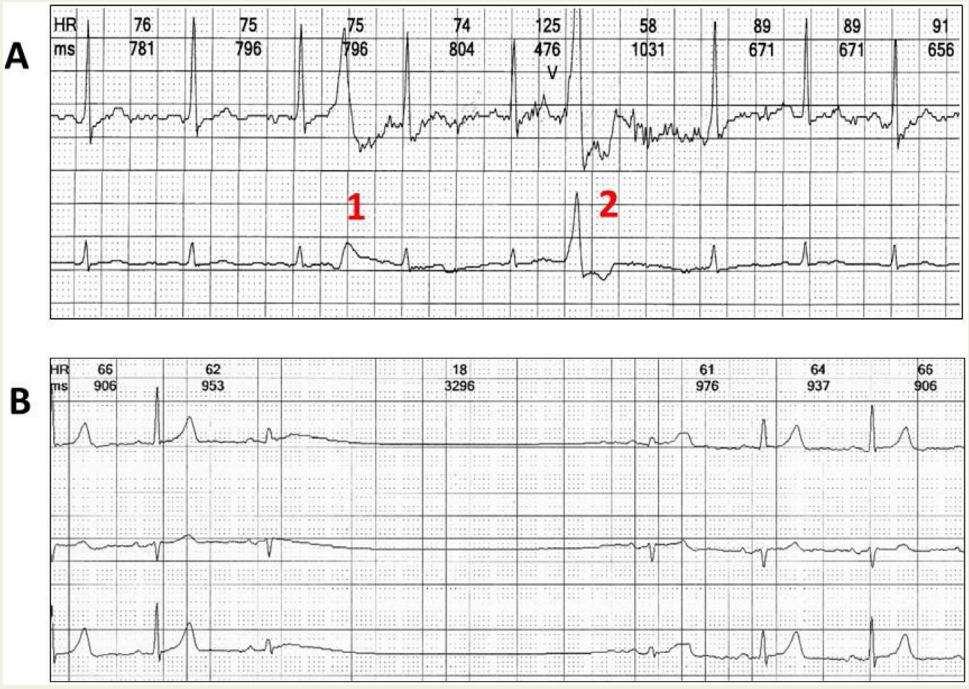

Figure 12 Two and three channel Holter recordings. (A) Interference producing artefact, mimicking a ventricular ectopic (1). The R-R intervals do not change. There is a ventricular ectopic within the artefact (2) identified by the compensatory pause. (B) The rhythm suggests asystole, but there are smaller QRS complexes at the beginning and end of the asystole suggesting that a monitoring lead had temporarily become detached from the skin with attenuation and loss of QRS complexes.

artefact is very hard to reproduce because of the quality of the filters used today as shown in Figure. 1.

Mimics Cardiac Pacing

The presence of single or repeated small spike artefacts on the ECG tracing, frequently leads to confusion as to whether these are pacemaker stimulus artefacts (Figure 6C,D). In Figure 13B, the first artefact occurs prior to an atrial ectopic and the second immediately prior to a sinus beat. The ECG was misinterpreted as atrial undersensing with a premature atrial paced beat and a compensatory pause, terminated by atrial pacing. This is not confirmed by the timing sequences.

Complicated Artefact

This specialised group, which usually results from the implantation of pulse generators can result in unexplained

Figure 13 (A) Electrocardiograph (ECG) lead II with an unsteady wavering baseline, mimicking ST depression. (B) ECG lead II with intermittent single small spike artefacts. The first artefact occurs prior to an atrial ectopic (1) and the second immediately prior to a sinus beat (2). Both mimic atrial pacing, but this is not confirmed by the timing sequences of the spikes.

Figure 14 Electrocardiograph (ECG) recordings from patients with single channel ventricular pacemakers (VVI) demonstrating rare appearances interpreted as artefact. (A) Runaway pacemaker. The pacemaker repetition rate is intermittent, very fast and appears to generate a QRS complex. Where there is a break from pacing, a native QRS is present (red vertical arrow). (B) The artefact is ECG machine generated with the manual 1mv calibration button stuck after being pressed. (C) Failure of the output circuit resulting in a short circuit with direct connection between the battery and the heart.

bizarre artefacts on the ECG, which if not recognised may lead to unnecessary repeated ECGs. Within this group are a number of rare appearances demonstrated in Figure 14.

The ECG from Figure 14A is from a patient with a single chamber ventricular pacemaker. The ECG artefact repetition rate is very fast and appears to generate a QRS complex. At times the artefacts, which are pacemaker stimuls artefacts, cease and a native QRS is present. This is the appearance of a runaway pacemaker, which was not uncommon with the zinc-mercury pacemaker power source [16], which could fail suddenly and the primitive circuits allowed rapid cardiac pacing, often with exit block. The phenomenon can still occur today with a failing lithium anode battery and may lead to potentially lethal ventricular arrhythmias [17]. Figure 14B is also an ECG from a single chamber ventricular pacemaker. The patient was referred with the diagnosis of a runaway pacemaker, but was well and the artefact could not be reproduced. The artefact was generated from the ECG machine 1 mV calibration button stuck after being pressed. Figure 14C is a more serious artefact with the patient very unwell and not pacing. The artefact is due to failure of the pulse generator output circuit resulting in a short circuit with direct connection between the pulse generator power source and the heart.

Implanted cardiac pacemakers may generate rapid stimulus artefacts for measuring impedance changes. Minute ventilation (Boston Scientific, St Paul, MN, USA) and closed loop stimulation (Biotronik, Berlin, Germany) are highly physiologic pacemaker sensors used with rate adaptive cardiac pacing. They both require the generation of rapid sub-threshold currents, either transthoracic [18] or intracardiac [19], which may be detected on the ECG as artefact (Figure 15). Implanted non-cardiac neurostimulators may be used for deep brain stimulation particularly with Parkinson's disease or as a spinal cord stimulator for pain management and incontinence. These devices generate continual rapid stimulations which can be

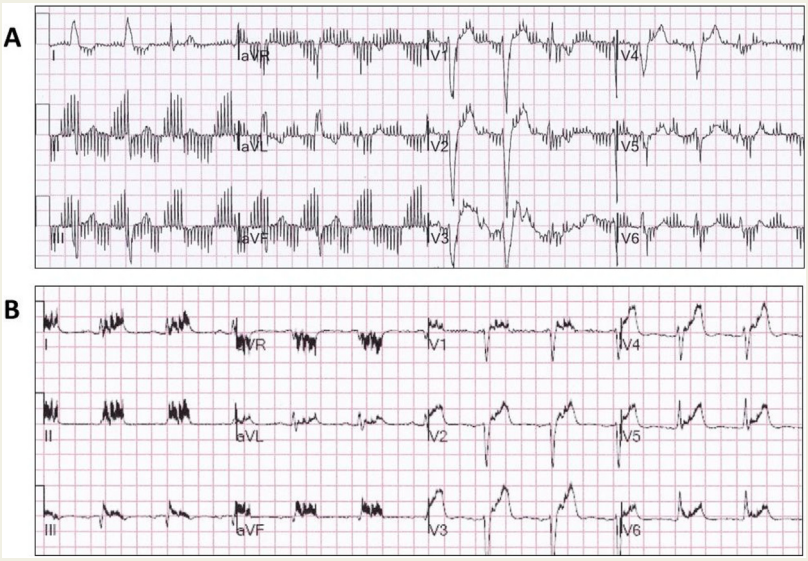

Figure 15 12-lead resting electrocardiographs (ECGs) with persistent artefact from rate adaptive pacemaker sensors. (A) Minute ventilation sensor; single chamber ventricular pacing. The sensor measures changes in transthoracic impedance which reflect changes in minute ventilation. A very small subthreshold current is delivered across the chest wall every 40 ms, resulting in marked artefact throughout the cardiac cycle (Boston Scientific, St Paul, MN, USA). (B) Closed loop stimulation; sinus rhythm and ventricular sensing. The sensor delivers 16 bipolar subthreshold impulses commencing 50 ms after the onset of the sensed (or paced) QRS. The intracardiac impedance measurements reflect changes in the cardiac contraction dynamics (Biotronik, Berlin, Germany).

Figure 16 12-lead resting electrocardiographs (ECGs) with persistent artefact from neurostimulators. (A) Deep brain stimulator for Parkinson's disease. There is artefact in all 12 leads. (B) Sacral stimulator. Because the electrodes are at sacral level, there is little or no artefact in lead I.

detected on the ECG and are virtually identical to the artefact seen with the minute ventilation pacemaker (Figure 16). Because lead 1 is at arm level, the 12-lead ECG gives a clue as to the site of the implant. With a deep brain stimulator, lead 1 is closer to the implanted generator and has marked artefact, whereas sacral stimulators have virtually no artefact in lead 1, as the generator is at pelvis level.

Conclusions

Electrocardiograph artefact is a common problem both with the resting 12-lead ECG tracings and ambulatory recordings. It may be electrical or mechanical and can interfere with the interpretation of the tracing. Although most artefact is gross and obvious, subtle artefact can mimic cardiac arrhythmias,

whereas complicated artefact may result in repeated unsuccesful attempts at procuring an artefact free tracing.

Disclosures

Associate Professor Harry G Mond is medical director of Cardioscan Pty Ltd.

No external financial support.

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