REVIEW ARTICLE

Main artifacts in electrocardiography

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Electrocardiographic artifacts are defined as electrocardiographic alterations, not related to cardiac electrical activity. As a result of artifacts, the components of the electrocardiogram (ECG) such as the baseline and waves can be distorted. Motion artifacts are due to shaking with rhythmic movement. Examples of motion artifacts include tremors with no evident cause, Parkinson's disease, cerebellar or intention tremor, anxiety, hyperthyroidism, multiple sclerosis, and drugs such as amphetamines, xanthines, lithium, benzodiazepines, or shivering (due to hypothermia, fever (rigor due to shaking), cardiopulmonary resuscitation by chest compression (oscillations of great amplitude) and patients who move their limbs during the test, causing sudden irregularities in the ECG baseline that may resemble premature contractions or interfere with ECG wave shapes, or other supraventricular and ventricular arrhythmias. When the skeletal muscles experience shaking, the ECG is "bombarded" by apparently random electrical activity.

KEYWORDS

artifacts, electrode misplacement, incorrect electrode interchange, tremor artifacts

1 | INTRODUCTION

An irregular electrocardiogram (ECG) baseline may resemble atrial fibrillation (AF) (Finsterer, Stöllberger, & Gatterer, 2003) or atrial flutter (Baranchuk & Kang, 2009; Barrett, Kelly, Halley, & Sugrue, 2007; Hwang, Chen, Sung, & Lee, 2014; Nam, Best, Greaves, & Dayananda, 2016; Prabhavathi, Ravindranath, Moorthy, & Manjunath, 2009), and a slow regular rhythm may suggest the possibility of AF with complete AV block or junctional escape rhythm. However, on a more thorough inspection, P waves are visible.

The presence of other electrical devices in the room where the ECG is being conducted may cause recordings with electrical interference. In such cases, any device that may interfere with the ECG signal should be turned off: these include cell phones within 25 cm of the ECG sensor module, electrical beds, surgical and fluorescent lamps.

The artifacts produced by alternating current cause a "darkened reinforcement" in the ECG baseline, often making an analysis of rhythm difficult. This is due to lack of filters for alternating current systems or a poor operation of the device.

2 | ARTIFACT EXAMPLES

To assess the cause of this artifact, the ECG should be checked to see the ECG is connected to a properly grounded outlet, the ECG should be recorded using the battery as the power source (Figure 1). It is important to identify this artifact, since artifacts may lead to performing unnecessary tests with additional costs and therapeutic interventions. For this reason, continuous education of technicians who record ECGs is essential.

2.1 | Electrocardiographic artifacts observed in Parkinson's disease and parkinsonian syndromes (due to rest tremor)

In Parkinson's disease and parkinsonian syndromes, continuous muscle twitching can be mistaken for atrial flutter (pseudo-atrial flutter) due to gross and constant irregularities with a 300 bpm rate. In such cases, electrodes should be placed at the upper part of the arms and legs (Figures 2 and 3).

To eliminate limb tremors due to Parkinson's disease, the electrodes should be placed at the roots of the limbs, which attenuates

FIGURE 1 Artifact during hypothermia. In this ECG strip in lead II, there is marked sinus bradycardia (HR 39 bpm), and QRS complex widening due to Osborn waves. In addition, there is a baseline artifact caused by muscle tremor due to hypothermia

or abolishes the tremors and the myopotentials. Parkinsonian tremor may cause very wide complexes resembling VT. In a patient with a wide tachycardia complex and tremors, an artifact related to tremors should be considered (Sawhney & Campbell, 2014). A careful analysis of the ECG may exclude artifacts related to pseudo-ventricular tachycardia (Llinas & Henderson, 1999; Riaz, Gardezi, & O'Reilly, 2010). The proper interpretation of ECGs and a correlation with clinical history are keys.

2.2 | Differentiation of ventricular tachycardia artifacts

Some ECGs may resemble specific arrhythmias, such as VT (Ortega-Carnicer, 2005) and atrial flutter (Handwerker & Raptopoulos, 2007) or atrial fibrillation. It is important to make a correct diagnosis because a mistaken diagnosis may lead to an unnecessary use of medications and procedures in a patient. The characteristics that help to differentiate VT from an artifact include:

1. Absence of hemodynamic impairment during the event;
2. Presence of normal beats in any lead;
3. An unstable baseline in the ECG before or after the event or both.
4. Association with body movement.

Huang et al. (2006) describe three signs that may help to differentiate VT from pseudo-VT. The presence of any of these elements suggest pseudo-VT:

FIGURE 2 Pseudo-atrial flutter due to parkinsonian tremors. In this tracing, the baseline waves could be interpreted as "F" waves of atrial flutter with a sawtooth pattern

FIGURE 3 Elimination of parkinsonian tremor placing electrodes properly in the limbs. This ECG corresponds to the same patient as in the Figure 2, the electrodes of the arms and legs were placed correctly, preventing the artifact of pseudo-atrial flutter (Vereckei, 2004)

FIGURE 4 Typical ECG of LA/RA reversal. Note negative P, QRS and T waves in I, QS pattern in II, III, and aVF followed by inverted T wave that can simulate inferior myocardial infarction. The clues for the correct diagnosis are the normal progression of QRS complexes in the precordial leads and all negative waves in lead I

ISinus sign: one of the frontal leads (I, II, and III) may present normal sinus rhythm with P, QRS, and T waves.

II Spike sign: presence of small regular or irregular peaks between wide QRS complexes.

IIINotch sign: overlapping notches in the artifact, appearing to be a wide QRS complex, coinciding with the duration of the cycle in which the sinus rhythm was recorded.

2.3 | Mistaken placement of electrodes

It has been estimated that errors in the placement of electrodes occur in 0.4% to 4% of ECGs performed (Kors & van Herpen, 2001). Incorrect connections of electrodes during ECG recordings may resemble rhythm or conduction alterations, myocardial ischemia or infarction. They also cause shifts in P waves and the QRS axis, and they may mimic ectopic atrial rhythms, fascicular block or dextrocardia; the latter occurring with left arm-right arm reversal. When only precordial electrodes are reversed, or just those of the limbs, excluding the neutral lead, the shapes of waves are inverted or do not change, and the interval duration is not modified. The mistake can be recognized by the presence of unusual P-QRS patterns, for example, negative P-QRS in I or II, positive in aVR, P-QRS complexes in an opposite direction to leads I and V₆, etc. Computerized algorithms have been developed to detect recurrent placement of electrodes, such as those based on artificial neuronal networks, or correlation between original and rebuilt leads (Batchvarov, Malik, & Camm, 2007).

2.3.1 | Accidental left arm-right arm reversal (LA/RA)

In this case, negative P, QRS and T waves are recorded in lead I, compatible with dextrocardia but the precordial leads maintain the normal progression of QRS complexes, thus eliminating the possibility of dextrocardia (Figure 4).

Other elements that allow a diagnosis of LA/RA reversal are:

1. The presence of positive P and R waves in aVR.
2. The electrical axis of QRS with possible extreme shift to the right, i.e., located in the right upper quadrant between -90° and $\pm 180^\circ$, north-east quadrant, or “no man’s land.”

2.3.2 | Differential diagnosis with dextrocardia

In dextrocardia, lead I has inverted P, QRS, and T waves. Lead II: represents the usual III lead and vice versa. aVR and aVL are reversed and prominent negative deflections are observed in aVL instead of in aVR. aVF is not affected. The P axis (S_{âP}) is to the right and inferior at approximately $+140^\circ$. The P wave is negative in aVL and I, positive in III and aVR.

Unlike the accidental mistaken RA/LA reversal, the precordial leads: from V₁ through V₆, unlike the accidental mistaken RA/LA reversal, have QRS complexes with R/r wave of progressively decreasing width: there is reverse progression of the r wave in the precordial leads from V₁ through V₆ (decreasing). V₁ is the equivalent to the usual normal V₂ and vice versa (Figures 5–7).

FIGURE 5 Typical example of dextrocardia. We observe S_{âP} at the right and below, pointing at approximately $+120^\circ$ (III); negative P wave in aVL and I, positive in III; inverse progression of R wave in precordial leads V₂ through V₅. This is the important key to differentiate it from LA/RA reversal

FIGURE 6 ECG-VCG correlation in the horizontal plane in a case of dextrocardia. Negative P wave in V_5 – V_6 , the initial 10 ms vector is heading forward and to the left; QRS loop of clockwise rotation and predominantly located in the right posterior quadrant; reverse progression of R wave in precordial leads V_1 through V_6 (decreasing) and negative T wave in V_5 – V_6

FIGURE 7 Left arm/left leg (LA/LL) electrode reversal. (a) Greater P wave width in I in relation to II. This is abnormal. (b) Normal position of LA/LL lead. In this case, the PII/PI width ratio >1 . This is normal

In reversal of the LA/LL electrodes, Einthoven's triangle rotates 180° vertically around an axis formed by aVR with the following effects on ECG: Lead III becomes inverted, leads I and II switch places, leads aVL and aVF switch places and aVR remains unchanged.

The P wave has a larger voltage in I than II (exchanged amplitude of P waves: this should raise the suspicion of accidental LA/LL lead reversal, and has a 90% accuracy if the patient is in sinus rhythm (Abdollah & Milliken, 1997; Velagapudi, Turagam, Ritter, & Dohrmann, 2017). However, Heden (2001) found a 90% sensitivity and 38% specificity for this abnormality.

LA/LL reversal has the potential to create a pseudo-inferior wall infarct pattern on the ECG. LA/LL reversal also causes inverted P waves in III. This is an important clue to determine the presence of a lead reversal. Frequently this error will lead to a near isoelectric line in leads I, II, or III; which might be the only sign of LA/LL lead reversal in routine clinical practice.

The usual cause for this accidental LA/LL leads reversal is due to the leads not being inserted in the proper place in the cable junction box after cleaning (Figure 8).

- aVL and aVF are reversed.

The changes in precordial leads are null or minimal. There would be changes in amplitude or voltage if the “exchanged” electrode was the indifferent one, the one in the right leg).

A surprising historical fact is that the initial description of P voltage sign in $I > II$ ($PI > PII$) and P with a positive final portion (minus-plus

FIGURE 8 ECG Junction box (ECG lead wires side). The technician inadvertently changes the leads from their correct position (color-blind or complacent technicians), leading to this lead reversal mistake

FIGURE 9 Schematic example of RA/LL reversal (a), LA/RL reversal (b) and bilateral arm-leg reversal (c). (a) Einthoven's triangle rotates 180° around the axis formed by aVL. (b) Einthoven's triangle collapses to very thin "slice" with the RA electrode at its apex. (c) Einthoven's triangle collapses to a very thin slice with the LL electrode at its apex

P-wave in III) was made by Goldberger in 1942 (Goldberger, 1942a,b), who was the creator of limb leads aVR, aVL, and aVF. Originally there were only three leads: I, II, and III.

2.3.3 | Right arm/left leg (RA/LL) electrode reversal

The RA/LL electrode reversal may cause pseudo-inferior myocardial infarction. However, unlike inferior infarction in sinus rhythm, P waves in leads aVF and II are also inverted. Lead II, I, and III become inverted, leads I and III switch places, leads aVR and aVF switch places, and lead aVL is unchanged (Figure 9a).

2.3.4 | Truncal or nonstandard limb leads placement

This may cause pseudo-inferior or inferolateral myocardial infarction pattern, or disappearance of inferior or inferolateral infarction pattern (Sevilla et al., 1989) or QRS electrical axis deviation to the right (Bond et al., 2016).

2.3.5 | Accidental reversal of right leg and right arm electrodes (RL/RA)

Diagnosis of RL/RA reversal should be suspected when a very small voltage is recorded (<0.1 mV) in limb lead II. RL/RA lead reversal has the following ECG features: lead I becomes an inverted lead III, lead II records a flat line, lead III is unchanged, lead aVL approximates an inverted lead III, and leads aVR and aVF become identical.

2.3.6 | Accidental reversal Left Arm/Right Leg (LA/RL)

With LA/RL(N(neutral)) electrodes reversal, the LA/LL electrodes record almost identical voltages, with difference between them (i.e., lead III = zero). By Einthoven's law, perpendicular to aVR is ≈lead III. In this exchange of electrodes, the perpendicular to aVR becomes ≈lead II. The displacement of the neutral electrode renders leads aVL and

aVF mathematically identical, such that they appear exactly alike (but different to the baseline ECG). LA/RL(N) lead reversal has the following ECG characteristics: Lead I becomes identical to lead II, lead II is unchanged, III has a flat line (zero potential), aVR approximately to an inverted II, aVL and aVF become identical and the precordial voltages may also be distorted, because the neutral electrode has been moved (Figure 9b).

2.3.7 | Arms and legs reversal or bilateral arm-leg reversal (LA/L and RA/L)

If the electrodes on each arm are switched with their corresponding leg electrode (LA with LL, RA with RL), the RA and LA electrodes (now sitting on adjacent feet) record almost identical voltages, which makes the difference between them negligible (lead I = zero). Leads II, III, and aVF become identical (equivalent to inverted lead III), as they are all now measuring the voltage difference between the left arm and the legs. The displacement of the neutral electrode renders leads aVL and aVR mathematically identical, such that they appear exactly alike (but different to the baseline ECG) (Figure 9c, Table 1).

2.3.8 | Normal and incorrect placement of precordial leads

A correct placement of precordial leads is basic for a proper performance of a tracing. (Kligfield et al., 2007; Rautaharju, Park, Rautaharju, & Crow, 1998).

Clues to recognize this type of misplacement of electrodes:

1. The bipolar inferior leads II or III and the bipolar lateral lead I show (almost) a straight line because they measure the potential difference between the two inferior limbs. This difference is minimal.
2. The other two bipolar leads of the limbs look identical, or one of them is an inverted image of the other.

Reversed and inverted limb leads	Major and minor footprints	Relative frequency
Accidental left arm-right arm reversal (LA/RA)	Lead I inverted; lead II and III reversed; lead aVR and aVL reversed; lead I isoelectric; imitates a nonsinus atrial rhythm with high anterolateral myocardial infarction; positive P wave and R waves in aVR; eventually QRS axis between -90° and $\pm 180^\circ$. Normal precordial progression (differential diagnosis with dextrocardia)	Very common
Reversed arm with leg leads	II, III, and aVF identical; aVR/aVL identical	Common
Right arm-right leg reversal (RA/RL)	Leads I and III mirror image; lead I and aVL identical; lead aVL and aVF identical; lead I inverted P wave	Intermediate
Left arm-right leg reversal (LA/RL)	Leads I-II identical; leads aVL and aVF identical. Exchanging the RA and LL leads creates what seems to be an inferior wall myocardial infarction and a nonsinus atrial rhythm in normal patients. (Peberdy & Ornato, 1993)	Less common
Right arm-left leg reversal (RA/LL)	Lead II inverted; leads aVR and aVL reversal. Can mimic as high lateral myocardial infarction (Karur, Patra, Shankarappa, Agrawal, & Nanjappa, 2013)	Rare
Left arm-left leg reversal (LA/LL)	Greater P wave width in I in relation to II	Rare

A summary of the footprints of ECG lead malposition should be readily available for those who perform ECGs, those who interpret the tracings and those responsible for clinical care (Mond, Garcia, & Visagathilagar, 2016).

- Two of the leads of the unipolar limbs also look identical, while the third one looks like one of the bipolar limbs or their inverted image (Batchvarov et al., 2007).

2.4 | Misplacement and interchange of precordial electrodes

The six precordial leads are called “V” leads, and numbered V_1 through V_6 . A standardized procedure for locating and documenting ECG chest electrode positions is paramount for a correct tracing (Figure 10). A frequent mistake when performing an ECG is a positioning of the right precordial leads (V_1 , V_2 , V_3); too high or too low, i.e., above the 4th intercostal space observed in 50% of tracings or inferior and left shift in 30%–50% of the cases in leads V_4 through V_6 , which indicates that these lateral precordial leads are commonly placed outside their respective anatomical sites (Wenger & Kligfield, 1996).

A mistaken placement of the right precordial leads may cause a greater negative component of P or totally negative P (García-Niebla, Rodríguez-Morales, Valle-Racero, & de Luna, 2012) and triphasic pattern of the rSr' type, with narrow r' in V_1 of pseudo-incomplete right bundle branch block, poor progression of R or increased voltage of R from V_1 to V_3 . Consequently, we should suspect an inappropriately high placement of right precordial leads in a patient with no

heart disease, by the presence of negative P wave only in V_1 , mainly if accompanied by rSr' morphology. Also, the recording in V_2 of a final negative component of the P wave often accompanied by a biphasic P wave in V_1 with usual predominance of the negative component is also a strong indication of high placement of these leads, and may cause inappropriate progression of the R wave.

The low placement of the right electrodes in the 5th intercostal space usually is unnoticed, but at increased voltage of R, approximately 0.1 mV in V_1 – V_2 for each inferior intercostal space will be observed (García-Niebla et al., 2012).

Exchanging the V_1 electrode with V_3 , red and green, respectively, may lead to R wave in $V_1 > V_2$ – V_3 (Figure 12).

Eventually, the precordial electrode reversal may be confused with right ventricular hypertrophy (RVH). The following main criteria can be applied to confirm the diagnosis of RVH: R wave of V_1 and $V_2 > 7$ mm; S wave of $V_1 < 2$ mm (0.2 mV); ventricular activation time greater than 40 ms in V_1 ; positive T wave in V_1 from 3 days of life up to 6 years of age, when the R/S ratio in this lead is greater than 1; negative “primary” (symmetrical) T waves in V_1 and V_2 in severe cases; R wave of $V_1 + S$ wave of V_5 and/or $V_6 \geq 10.5$ mm (Sokolow-Lyon index for the RV); and V_5 and V_6 ratio: R/S ratio in V_5 and $V_6 \geq 1$ (Figure 11).

Using conductive gel in excessive amounts leads to the so-called “large precordial lead,” resulting in “monotonous” QRSs in precordial leads (Figure 12).

TABLE 1 Summary for recognition of electrocardiographic lead misplacements: Limb lead reversal, major and minors footprints and relative frequency

FIGURE 10 Correct positioning of the precordial electrodes in the frontal projection (a) and supine position (b). The left arm should be a little apart from the chest to place electrodes V_5 and V_6 . V_1 : in the 4th intercostal space, in the right sternal border; V_2 : in the 4th intercostal space, in the left sternal border; V_3 : halfway between electrodes V_4 and V_2 ; V_4 : in the 5th left intercostal space, in the midclavicular line (downward from the half of the clavicle point); V_5 : in the same level as electrode V_4 , the anterior axillary line (downward from the anterior axillary fold); and V_6 : in the same level as electrodes V_4 and V_5 , in the midaxillary line (downward from the middle point of the armpit)

FIGURE 11 Precordial electrode reversal. V_1 and V_3 accidental electrode reversal, R of V_1 of greater voltage than R of V_2 – V_3 . Decreasing progression of R from V_1 to V_3

FIGURE 12 Excessive use of conductive gel on the precordial leads. The use of excessive conductive gel continuously throughout the precordium results in an ECG tracing with equal QRS complexes across the precordial leads, which corresponds to the mean of the electrical potentials in these leads

3 | CONCLUSION

Electrocardiography artifacts are frequent and may be readily identified in most cases. They include external and internal interference such as poor grounding of the device, interference by devices within the room such as cell phones within 25 cm of the ECG sensor module,

electrical beds, surgical and fluorescent lamps, chest compression and decompression movements during CPR, artifacts produced by alternating current affecting the ECG baseline and mistaken placement in the cable junction box. With regard to patient related, muscle twitching is most prominent—causes of which include: shivering due to hypothermia, inappropriate cleansing of the skin, excess of precordial

conductive gel, and mistaken placement of both limb and precordial leads. It is essential to perform periodic evaluations of the technicians in charge of performing the tracings with the aim of decreasing the all types of artifacts.

DISCLOSURE

The authors do not have any conflict of interest regarding this work.

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