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Emerg Med Clin N Am 24 (2006) 227–235

EMERGENCY
MEDICINE
CLINICS OF
NORTH AMERICA

Electrode Misconnection, Misplacement, and Artifact

Richard A. Harrigan, MD

Department of Emergency Medicine, Temple University School of Medicine, Jones Hall, Room 1005, Park Avenue and Ontario Street, Philadelphia, PA 19140, USA

The emergency physician (EP) examines the electrocardiogram (ECG) looking for evidence of normalcy and for signs of ischemia, dysrhythmia, and many other variations of normal, such as are described in this issue. An under appreciated cause of ECG abnormality is electrode misconnection and misplacement. This occurs when the ECG electrode is mistakenly connected to the wrong part of the body (electrode misconnection, as can occur most commonly with the limb electrodes, I, II, III, aVR, aVL, and aVF) or is placed improperly on the body (electrode misplacement, such as can occur most easily with the precordial electrodes, V1–V6). Knowledge of the common patterns of electrode misconnection and misplacement lead to the ready recognition of this phenomenon in everyday practice.

Using recordings from four limb electrodes (RA or right arm, LA or left arm, RL or right leg, and LL or left leg), six frontal plane electrocardiographic tracings, or leads, are generated. An understanding of limb electrode misconnection begins with a review of the derivation of the three limb leads (I, II, and III) and the three augmented leads (aVR, aVL, and aVF) (Fig. 1). In the horizontal plane, six precordial electrodes (V1–V6) yield six electrocardiographic leads (V1–V6); although they too can be misconnected, the pitfalls of right/left and arm/leg reversal do not apply here. Recording problems with the precordial electrodes more significantly are caused by improper positioning of the individual electrodes on the body surface because of anatomic variation. Common examples of limb electrode reversal and precordial electrode misconnection and misplacement are described.

E-mail address: richard.harrigan@tuhs.temple.edu

0733-8627/06/$ - see front matter
doi:10.1016/j.emc.2005.08.015

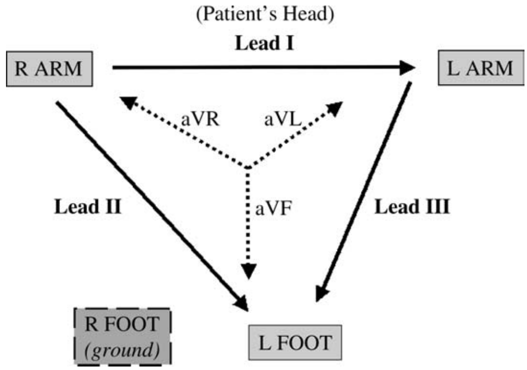

Fig. 1. The standard limb and augmented leads on the 12-lead ECG. Solid arrows represent leads I (RA→LA), II (RA→LL), and III (LA→LL), where RA = right arm, LA = left arm, and LL = left leg. *Dotted arrows* depict leads aVR, aVL, and aVF. *Arrowheads* are located at the positive pole of each of these vectors. The right leg serves as a ground electrode, and as such is not directly reflected in any of the six standard and augmented lead tracings.

Limb electrode misconnection

There are myriad possible ways to misconnect the four limb electrodes when recording the 12-lead ECG; commonly, such errors result from reversal of right/left or arm/leg. Common limb electrode reversals therefore include the following: RA/LA, RL/LL, RA/RL, and LA/LL. More bizarre reversals involving reversal of right/left and arm/leg also yield predictable changes, but are intuitively less likely to occur, because they require, by definition, two operator errors. Only the four common limb electrode reversals thus are discussed in detail, followed by those less common misconnections (RA/LL and LA/RL).

Arm electrode reversal (RA/LA)

Fortuitously, this is the most common limb electrode misconnection and one of the easiest to detect [1–4]. Because the RA and LA electrodes are reversed, lead I is reversed, resulting in an upside-down representation of the patient's normal lead I tracing (Fig. 2; and see Fig. 1). Lead I thus features, in most cases, an inverted P-QRS-T, yielding most saliently a rightward QRS axis deviation (given the predominant QRS vector is negative in lead I and positive in lead aVF) or an extreme QRS axis deviation (predominant QRS vector is negative in leads I and aVF). Furthermore, an inverted P wave in lead I is distinctly abnormal and should prompt the EP to consider limb electrode misconnection, dextrocardia, congenital heart disease, junctional rhythm, or ectopic atrial rhythm. Reversal of the arm electrodes means reversal of the waveforms seen in leads aVR and aVL—thus the EP may see a normal appearing, or upright, P-QRS-T in lead aVR. This too is distinctly unusual, because the major vector of cardiac depolarization

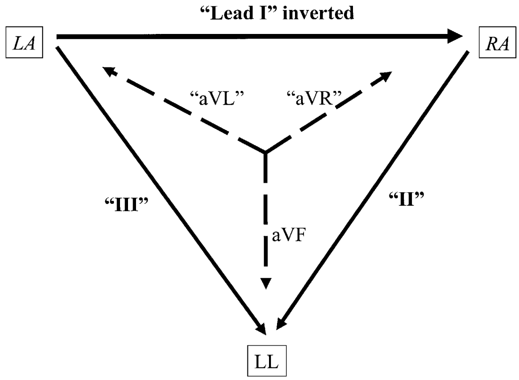

Fig. 2. Schematic of RA/LA electrode reversal. Reversal of the arm electrodes (shown in italics) affects leads I, II, and III, and leads aVR and aVL. Affected leads are shown in quotation marks in this and subsequent schematic Figs. and are shown as they appear on the tracing, ie, in the lead II position on the tracing, lead III actually appears (and vice versa).

usually is directed leftward and inferiorly, or away from, the positive pole of lead aVR, which is oriented rightward and superiorly (see Fig. 1). One final clue to arm electrode reversal is to compare the major QRS vector of leads I and V6. Both are normally directed in roughly the same direction, because both reflect vector activity toward the left side of the heart. Disparity between these two leads' predominant QRS deflection should prompt the EP to consider limb electrode reversal (Fig. 3).

Electrode reversals involving the right leg

The right leg electrode (see Fig. 1) serves as a ground and as such does not contribute directly to any individual lead [5,6]. There is virtually no potential difference between the two leg electrodes, thus inadvertent leg electrode reversal (RL/LL) results in no distinguishable change in the 12-lead ECG. Moving the right leg electrode to a location other than the left leg causes a disturbance in the amplitude and the morphology of the complexes seen in the limb leads [3]. Electrode reversals involving other misconnections of the right leg electrode (RA/RL and LA/RL) can be considered together because of a telltale change attributable to reversals involving the right leg: the key to recognizing these misconnections is recalling that they result in one of the standard leads (I, II, or III) displaying nearly a flat line [5,6]. The location of the flat line depends on the lead misconnection and hinges on the fact that the ECG views the right leg electrode as a ground with no potential difference between the right and left legs [3]. In RA/RL reversal, the lead II vector, usually RA→LL, is now *RL*→LL, and thus a flat line appears in lead II (Figs. 4 and 5). Similarly, LA/RL reversal results in a flat line along the lead III vector, which is now bounded by *RL* and LL electrodes, rather than the normal LA and LL electrodes (Fig. 6).

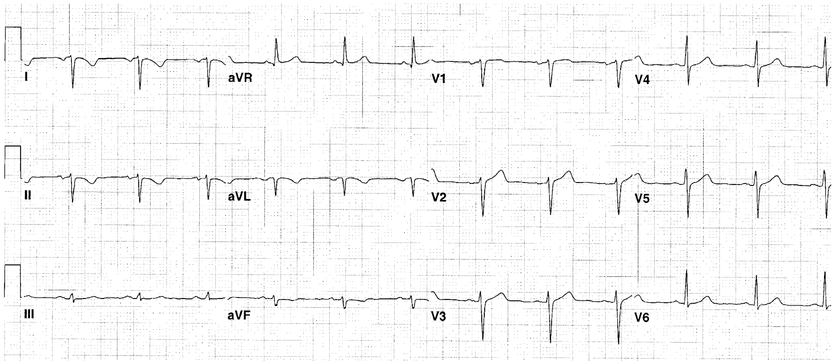

Fig. 3. RA/LA electrode reversal. Note the characteristic changes in this most common lead reversal. Lead I features an upside-down P-QRS-T, and the major vector of its QRS complex is uncharacteristically opposite to that seen in lead V6. The waveforms in lead aVR appear normal and are actually those that appear in aVL when the electrodes are placed properly. Leads II and III also are reversed, which in this tracing yields a principally negative vector in lead II; this is also unusual.

Left arm/left leg electrode reversal

Misconnection of the left-sided electrodes (LA and LL) is the most difficult limb electrode reversal to detect [3,7]. An ECG with LA/LL electrode misconnection usually appears normal and may not be suspected until compared with an old ECG. Making matters worse, the variability between old and new tracings may be ascribed to underlying patient disease, such as cardiac ischemia, if LA/LL electrode reversal is not considered. What makes LA/LL electrode reversal so difficult to detect is that the changes that ensue

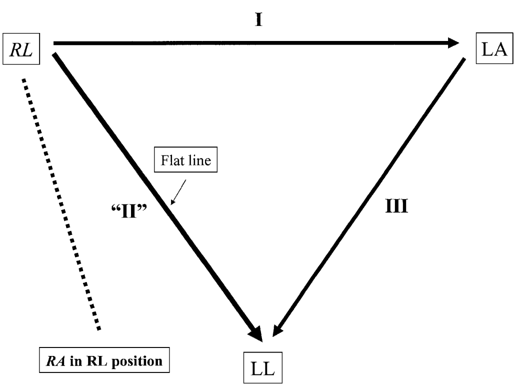

Fig. 4. Schematic of RA/RL electrode reversal. Reversal of the right-sided electrodes (shown in italics) allows lead II (linking the RA and LL normally, but now linking RL and LL because of the misconnection) to demonstrate the lack of potential difference between the leg electrodes. Lead II thus features a flat line.

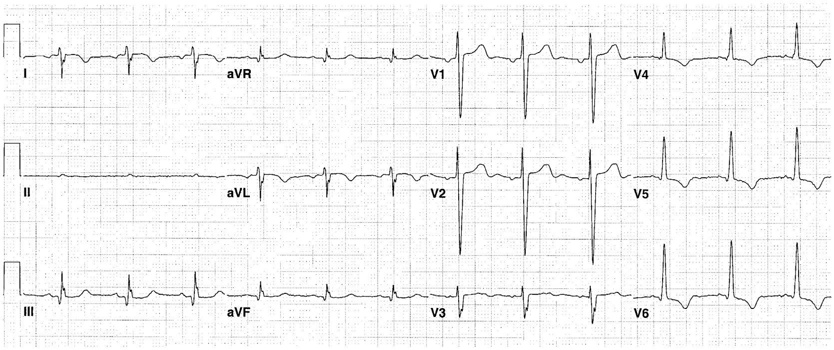

Fig. 5. RA/RL electrode reversal. The classic finding of an electrode misconnection involving the right leg is seen in lead II, in which the tracing is nearly flat line, or isoelectric. Because lead II normally depicts the RA→LL vector and a flat line results from the no potential difference between the leg electrodes, the RL electrode must be in the RA position (see Fig. 4). The other limb leads feature morphologic and amplitude changes from the patient's baseline, but these need not be remembered; the key is recognition of the flat line in lead II.

occur somewhat in parallel; that is, two inferior leads (II and aVF) become lateral (I and aVL, respectively), and vice versa (Fig. 7). Lead III is inverted, but the major QRS vector of lead III may be principally positive or principally negative in normal conditions, so this is not a red flag. Further obscuring this lead misconnection, lead aVR remains unaffected (Fig. 8).

Attention to the P-wave amplitude in leads I and II and P-wave morphology in lead III has been advanced as a means to detect LA/LL electrode misconnection. Normally the P wave in lead II is larger than that seen in lead I, because the normal P axis vector is between +45° and +60°, similar to the

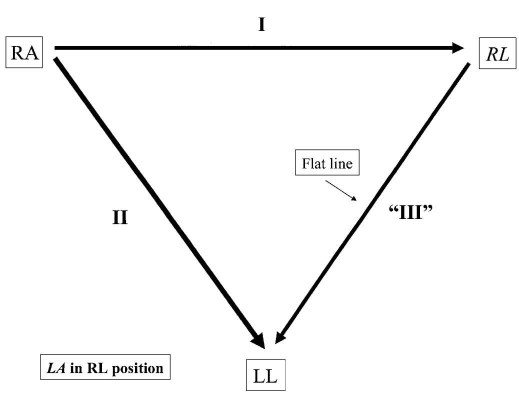

Fig. 6. Schematic of LA/RL electrode reversal. Reversal of the LA and RL electrodes (shown in italics) allows lead III (linking the LA and LL normally, but now linking RL and LL because of the misconnection) to demonstrate the lack of potential difference between the leg electrodes. Lead III thus features a flat line.

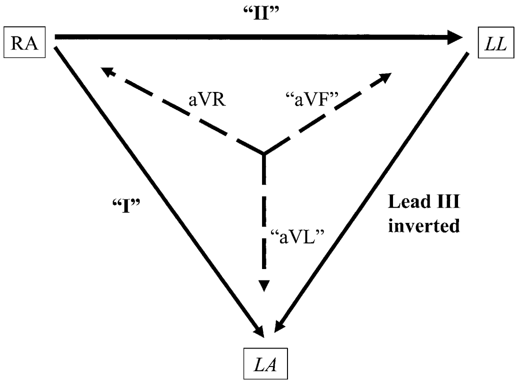

Fig. 7. Schematic of LA/LL electrode reversal. Reversal of the two left-sided electrodes (shown in italics) leads to the appearance of an inverted lead III. Furthermore, leads I and II are reversed, as are leads aVL and aVF. This results in two lateral leads (I and aVL) reversing with two inferior leads (II and aVF, respectively). Lead aVR remains unaffected. These changes result in an LA/LL reversal being the most difficult electrode reversal to detect.

vector of lead II (+60°). With LA/LL reversal, however, the P wave is usually larger in lead I than in lead II, and thus serves as a hint even before looking at an old tracing. Furthermore, if a biphasic P wave appears in lead III, the second portion normally is deflected negatively; thus, if the terminal portion is positive, this too serves as a hint to LA/LL electrode reversal. Using these two features, reversal of LA and LL electrodes was detected in 90% of 70 cases in one report [7]. Tracings demonstrating atrial flutter make LA/LL electrode misconnection easier to detect, because the flutter waves—usually most salient in the inferior leads II, III, and aVF—would now appear most prominently in leads I, aVL, and III. Atrial fibrillation obviously would make LA/LL electrode reversal impossible to detect by P-wave or flutter wave characteristics [3,7].

Other less common limb electrode reversals

Misconnection of other limb electrodes (eg, RA/LL and both arms/both legs) involve multiple operator errors and thus are encountered less often. RA/LL reversal is easy to recognize, because upside-down P-QRS-T complexes appear in all leads except aVL, which is unaffected. Lead aVR thus appears normal—another hallmark of lead misconnection. Placing both leg electrodes on the arms but maintaining sidedness is best recognized by the flat line that appears in lead I—again, misplacement of the RL electrode to anywhere but the LL results in a near isoelectric appearance of the lead that connects the misplaced RL and LL electrodes. This occurs because that lead is showing no potential difference between the RL and LL electrodes, which have been misplaced on the arms (lead I position) [3].

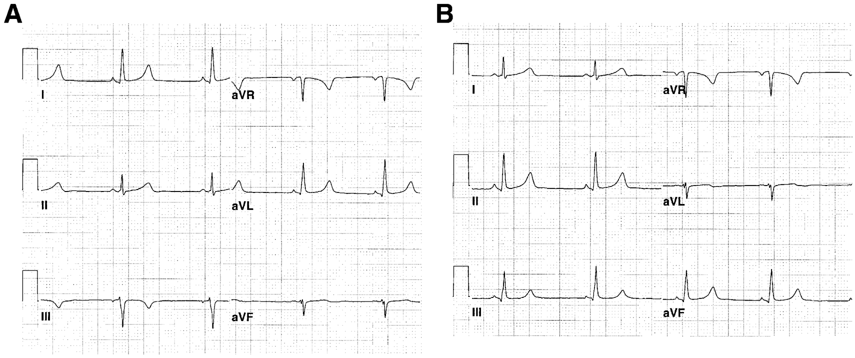

Fig. 8. LA/LL electrode reversal. Limb leads only are shown here from the same patient at two points in time. (*A*) LA/LL electrode reversal. (*B*) Tracing performed after the electrodes were repositioned correctly in this patient undergoing an ED evaluation for chest pain. Comparing (*A*) and (*B*), note that lead III is inverted, and the two other inferior leads (II and aVF) are actually the lateral leads (I and aVL, respectively), and vice versa. Scrutiny of the P wave in lead I suggests LA/LL misconnection in (*A*), because the amplitude of the P wave is larger in lead I than in lead II; this is abnormal. Note that the normally abnormal appearance of lead aVR, which is unaffected by this left-sided electrode reversal, adds to the subtlety of detection of this entity.

Precordial electrode misconnection and misplacement

If the limb leads are prone to misconnection, then the precordial electrodes are also vulnerable to this error. Precordial electrode misconnection is easy to decipher, however; what is more problematic is precordial electrode misplacement.

Precordial electrode misconnection—usually the inadvertent swapping of two precordial electrodes—results in an interruption of the normal graded transition of R-wave growth and S-wave regression as one scans the precordial leads from right (V1) to left (V6). Moreover, this normal transition is reverted back to in the next electrode that is placed properly [3,5]. When the ECG seems to have a new T-wave change or change in QRS amplitude/ morphology in just one or two precordial leads, it is thus wise to consider precordial electrode reversal. It should be routine practice to survey the R- and S-wave transitions across the precordial leads when first examining the ECG to exclude precordial electrode misconnection.

Similarly, new T-wave changes or changes in the QRS complex may be caused by precordial electrode misplacement—a common problem given that each individual's chest anatomy is unique, making correct anatomic placement a challenge in some cases. When new Q waves, ST segment changes, or T-wave changes are encountered on an ECG being compared with a baseline tracing, one must examine "the company it keeps." For example, when comparing new and old tracings, if a new T-wave inversion occurs in lead V3 with no change in those seen in V4–V6, the amplitude and morphology of the QRS complexes in lead V3 should be compared between the two tracings. If the QRS complexes are dissimilar between the two tracings, it is possible that the precordial electrodes—and here specifically the V3 electrode—were placed differently on the two occasions. Placement of the right precordial electrodes V1 and V2 an interspace too high or too low may result in the appearance or masking, respectively, of an incomplete right bundle branch block pattern [8].

Artifact

Electrocardiographic artifact is a commonly encountered phenomenon and in most cases is recognized easily. Often caused by patient movement (voluntary or involuntary), other sources should be considered, such as 60 cycle-per-second interference from nearby sources of alternating current and electrode and cable problems. Electrode performance is enhanced by connection to dry, non-hairy skin away from bony prominences [9,10].

More challenging and clinically significant is the differentiation of electrocardiographic artifact from real disease, such as dysrhythmia (Fig. 9). Several key features have been advanced that favor pseudodysrhythmia over true dysrhythmia, including (1) absence of symptomatology or hemodynamic variation during the event, (2) normal ventricular complexes appearing among dysrhythmic beats, (3) association with body movement, (4) instability of baseline tracing during and immediately following the alleged dysrhythmia, and (5) synchronous, visible notching consistent with the underlying ventricular rhythm marching through the pseudodysrhythmia [8,11,12].

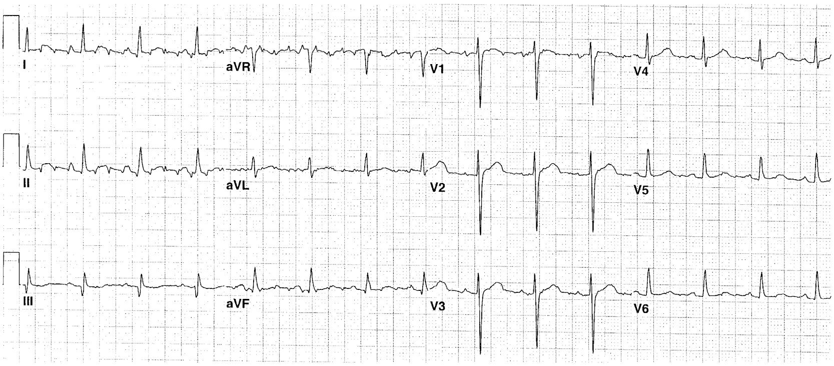

Fig. 9. Patient movement artifact mimicking dysrhythmia. This tracing was recorded on an asymptomatic patient who presented to the ED looking for a psychiatric medication refill. Several leads (I, II, V1, aVF, and aVR) demonstrate what seems to be flutter waves at a rate of 300 bpm. Closer inspection of other leads (III and V3–V6) reveals normal sinus rhythm. The flutter waves were secondary to the patient's parkinsonian tremor, likely resulting from neuroleptic use.

Summary

The ECG can be affected by processes, such as operator error and environmental issues, that are not reflective of yet may mimic underlying disease. As such, the emergency physician should be aware of the manifestations of common limb electrode misconnections, electrode misplacement, and artifact.

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