aVR – the forgotten lead

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A George, PS Arumugham, VM Figueredo. aVR – the forgotten lead. Exp Clin Cardiol 2010;15(2):e36-e44.

Electrocardiography continues to be a focal point of modern medicine, and the electrocardiogram (ECG) continues to be the most frequently ordered cardiac test. Most of the clinical importance of the ECG rests on the invaluable information it renders in diagnosing acute coronary syndromes and cardiac arrhythmias. However, the ECG is a valuable tool and diagnostic aid in the evaluation of many other conditions such as pericarditis and pulmonary embolism. Of the electrocardiographic leads, aVR has traditionally received less attention in clinical evaluation of the ECG. The present study discusses instances with pictorial examples in which lead aVR provides valuable clinical information and makes a case for close attention being paid to this 'forgotten lead'.

Key Words: *Arrhythmia; aVR; ECG; Lead display*

Ever since the first electrocardiogram (ECG) of an intact human heart was recorded with a mercury capillary (Lippmann's) electrometer by Augustus Waller in 1887 (1,2), it is doubtful whether anyone could have envisioned the pivotal role that electrocardiography occupies in modern medicine. William Einthoven (1860 to 1927) is credited with the discovery of modern electrocardiography for which he was awarded the Nobel Prize for Physiology or Medicine in 1924 (2-4). Einthoven named the five electrical potentials in waves (PQRST) and developed the system of limb leads (I, II and III), which is still used today in determining the electrical axis of the heart.

Sir Thomas Lewis (1881 to 1945), building on studies pioneered by Einthoven, advanced electrocardiography into the clinical arena (3,4). Lewis also made seminal contributions to the study of arrhythmias, especially atrial fibrillation and heart blocks (5). In 1934, Frank Norman Wilson (1890 to 1952) first described the use of unipolar leads V_1 to V_6 (where V is the symbol for 'potential') as having an exploring and a reference electrode (6). The Wilson Central Terminal is the reference electrode obtained through a resistive network, combining the limb electrodes. The Wilson Central Terminal is used as the reference electrode for the unipolar precordial and augmented leads. Emanuel Goldberger (1913 to 1994) introduced the augmented uniploar limb leads (aVR, aVL and aVF) in 1942, which began the era of the standard 12-lead ECG as we know it today (7-9).

THE GOLDBERGER AUGMENTED UNIPOLAR LEADS

The augmented unipolar leads are of low electrical potential and are thus instrumentally augmented – hence the prefix 'a' (9).

TABLE 1
Augmented unipolar lead placement

Lead VR	Exploring electrode is connected to the right arm
Lead VL	Exploring electrode is connected to the left arm
Lead VF	Exploring electrode is connected to the left leg

Adapted from reference 10

The reference electrode is the mean of the potentials sensed by two of the three limb electrodes, with the exploring electrode being excluded from the reference electrode (Table 1). Thus, lead aVR is the augmented unipolar right arm lead and may be considered as looking into the cavity of the heart from the right shoulder. It follows that all normally upright deflections on the ECG will, under normal circumstances, be negative in this lead (10). This makes aVR a valuable lead, which is discussed below.

CLINICAL UTILITY OF LEAD aVR

The lead aVR is oriented to 'look' at the right upper side of the heart, and can provide specific information about the right ventricle outflow tract and basal part of the septum (10). Because of its location and the fact that it displays reciprocal information covered by leads aVL, II, V_5 and V_6, lead aVR is often ignored, even when considering complex ECGs (11,12).

AXIS DETERMINATION

Traditionally, the limb lead with the tallest R wave has been used to determine the electrical axis of the heart. Another method to determine the electrical axis of the heart involves

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Received for publication September 10, 2009. Accepted March 1, 2010

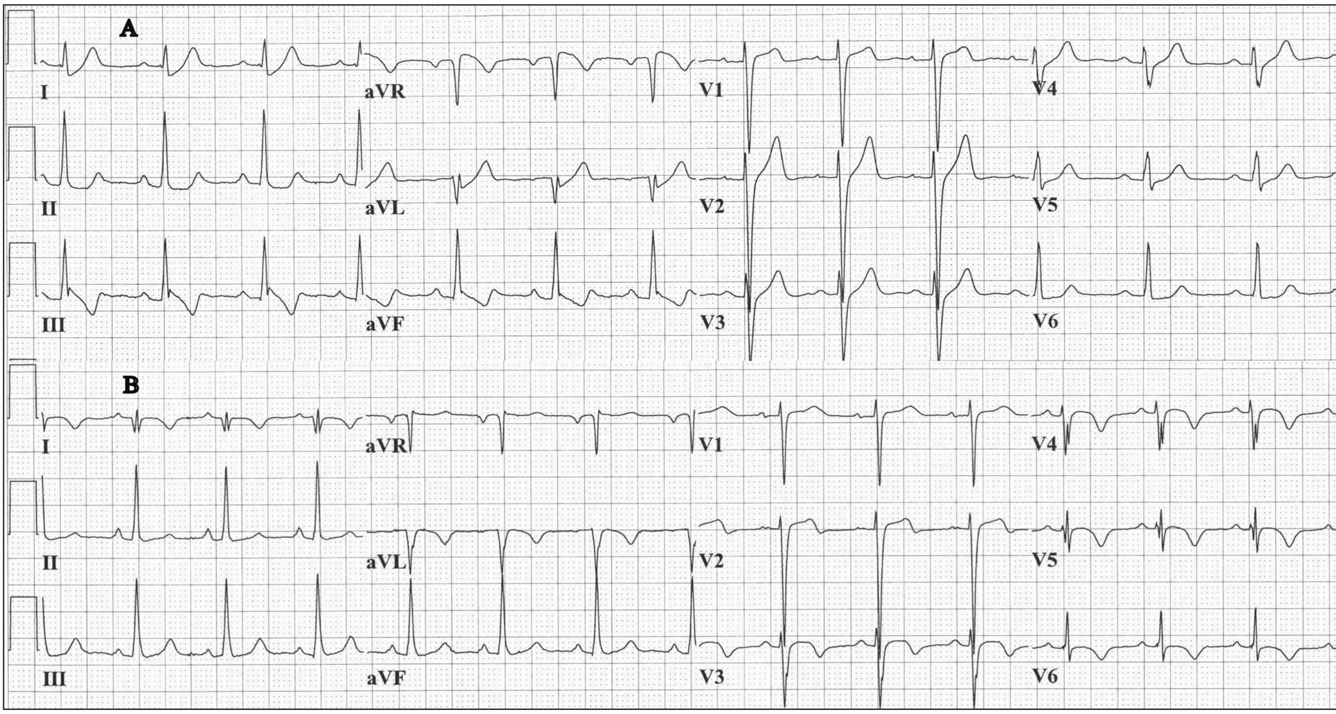

Figure 1) *Initial (***A***) and follow-up (***B***) electrocardiograms of a 44-year-old man presenting with chest heaviness and shortness of breath. Angiogram revealed a total proximal occlusion of the left anterior coronary artery without other significant disease. Note the greater ST elevation in aVR than in* V_1*. Also, note the hyperacute T waves in the precordial leads and the ST abnormalities in the inferolateral leads*

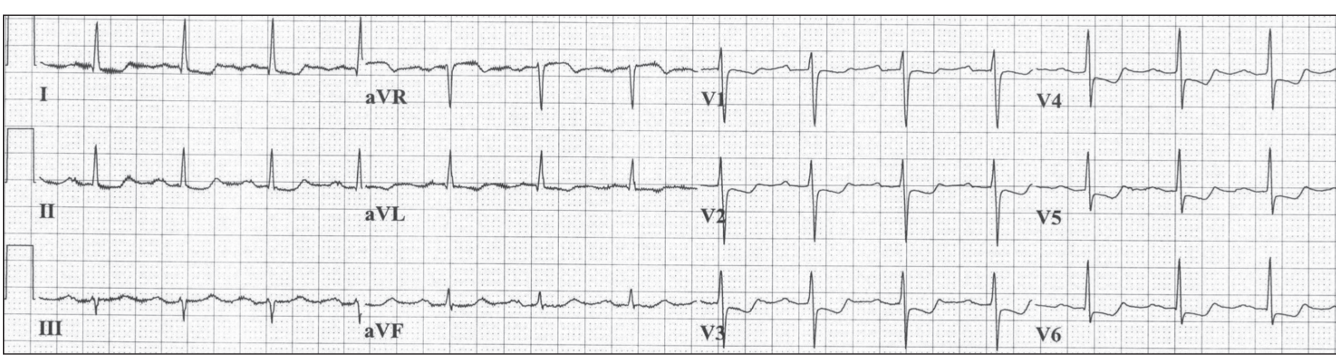

Figure 2) *Electrocardiogram of a 71-year-old woman presenting with chest pain. Angiogram revealed high-grade stenosis of the distal left main coronary artery involving the take-offs of the left anterior descending and circumflex coronary arteries. Note the ST elevation in aVR and the diffuse ST depressions*

seeking the lead with the deepest negative deflection or S wave. If aVR were noted to have the deepest S wave, it follows that the electrical axis should be directly opposite the hexiaxial reference system, ie, +30° (13).

ACUTE CORONARY SYNDROMES

Studies by Engelen et al (14) found that in acute anterior myocardial infarction, the ECG is a useful tool to predict the likely left anterior descending coronary artery (LAD) occlusion site. They found that ST segment elevation in aVR strongly predicted LAD occlusion proximal to the first septal perforator (Figure 1). Yamaji et al (15) observed that aVR ST segment elevation greater than the ST segment elevation in V_1 predicts acute left main coronary artery (LMCA) occlusion with a sensitivity of 81% and a specificity of 80% (Figure 2). This finding also predicts clinical outcomes. The authors also noted that the majority of published reports pertaining to LMCA occlusion, before their study, did not comment on lead aVR. Gaitonde et al (16) demonstrated in a prospective study that in acute myocardial infarction, patients with an ST segment elevation that is greater in lead aVR than in lead V_1 prompted early angiography, withholding of clopidogrel and early referral to coronary artery bypass grafting, resulting in improved clinical outcomes.

Kosuge et al (17,18) found that in patients with non-ST segment elevation myocardial infarction, ST segment elevation of 0.5 mm or greater in aVR was a useful predictor of LMCA or three-vessel coronary artery disease (sensitivity 78%, specificity 86%) (Figure 3). Furthermore, they found that aVR ST segment elevation was the strongest predictor of adverse

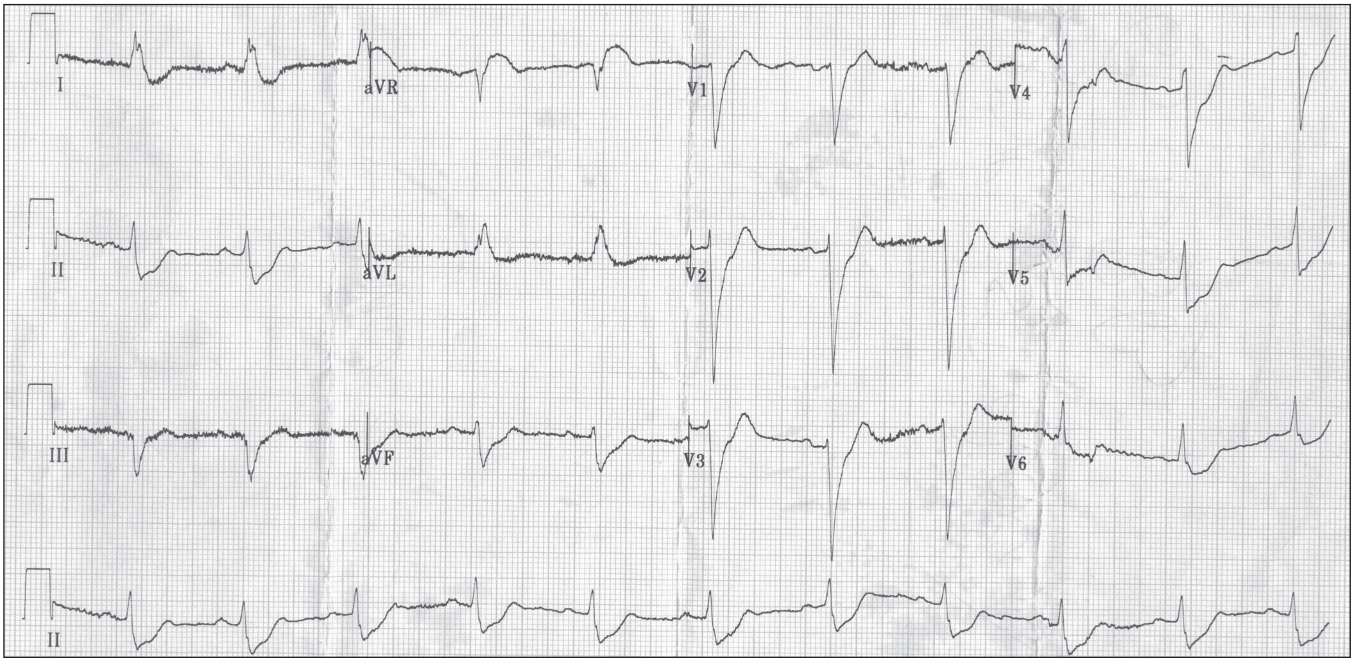

Figure 3) *Electrocardiogram of a 54-year-old man with chest pain and a history of coronary artery bypass surgery. Angiogram revealed an occluded left main coronary artery, a subtotal occlusion of the left anterior descending coronary artery after the anastamosis of the left internal mammary artery, an ostial stenosis of the saphenous vein graft to the obtuse marginal artery, and a diffuse moderate disease of the right coronary artery. Note the ST elevation in aVR, the ST depressions in the anterior and inferior leads, and the ST elevations in I and aVL that make it appear as though there is a bundle branch block*

events at 90 days in patients with non-ST segment elevation myocardial infarction. Barrabes et al (19), in a study of 775 patients with their first non-ST segment elevation myocardial infarction, showed that aVR ST segment elevation was associated with higher rates of in-hospital death, recurrent ischemia and heart failure.

Kotoku et al (20) reported on the relationship between the ST segment level in lead aVR and the length of the LAD. ST segment levels (especially in leads II and V_6), the site of LAD occlusion and the length of the LAD affect the ST segment level in lead aVR in patients with a first ST elevation acute anterior wall myocardial infarction. Proximal LAD occlusion is associated with ST segment elevation in lead aVR, while a long LAD occlusion is associated with ST segment depression in lead aVR. Kotoku et al (21) also reported that a prominent Q wave in lead −aVR in anterior wall acute myocardial infarction is related to severe regional wall motion abnormality in the apical and inferior regions, with an LAD wrapping around the apex.

LMCA occlusion is another clinical situation in which prompt diagnosis by the clinician can help initiate life-saving invasive therapy. The typical electrocardiographic finding in patients with preserved flow through the LMCA is widespread ST segment depression maximally in leads V_4 to V_6, with inverted T waves and ST segment elevation in lead aVR (22). ST elevation in lead aVR, when accompanied by either anterior ST elevation or widespread ST segment depression, may indicate LMCA occlusion.

Kanei et al (23) reported in a study of 106 patients that ST segment depression in lead aVR in inferior wall ST segment elevation myocardial infarction predicts left circumflex infarction or larger right coronary artery infarction involving a large posterolateral branch. In a study (24) of 142 patients with first anterior wall myocardial infarction, ST elevation in lead aVR, ST elevation in lead V_{3R} of at least 1.5 mm and ST elevation in lead V_1 of at least 2.0 mm were associated with the presence of a small conal branch not reaching the interventricular septum during anterior wall acute myocardial infarction.

As discussed above, lead aVR can give invaluable clues regarding the level and extent of coronary occlusion, and help the angiographer plan his or her interventional approach. Furthermore, ST elevation in aVR is a strong predictor of in-hospital death and 90-day major adverse cardiac events.

STRESS TESTING

Lead aVR is valuable in stress testing because it represents electrical forces oriented toward the cavity of the heart. It has been shown that exercise-induced ST depression in V_5 and concomitant ST elevation in aVR may detect significant left anterior descending coronary artery stenosis in patients with single-vessel disease (25). Another study (26) of more than 100 patients showed that exercise-induced ST segment elevation in lead aVR was useful in predicting LMCA disease (sensitivity 92.9%, specificity 48.6%). ST segment elevation in lead aVR during exercise testing was found to be more strongly correlated with positive tests such as nuclear imaging and coronary angiography, compared with right precordial lead changes (27). ST segment elevation in lead aVR is associated with a reversible defect in the anterior LAD territory regardless of the presense of ST segment depression in other leads (28).

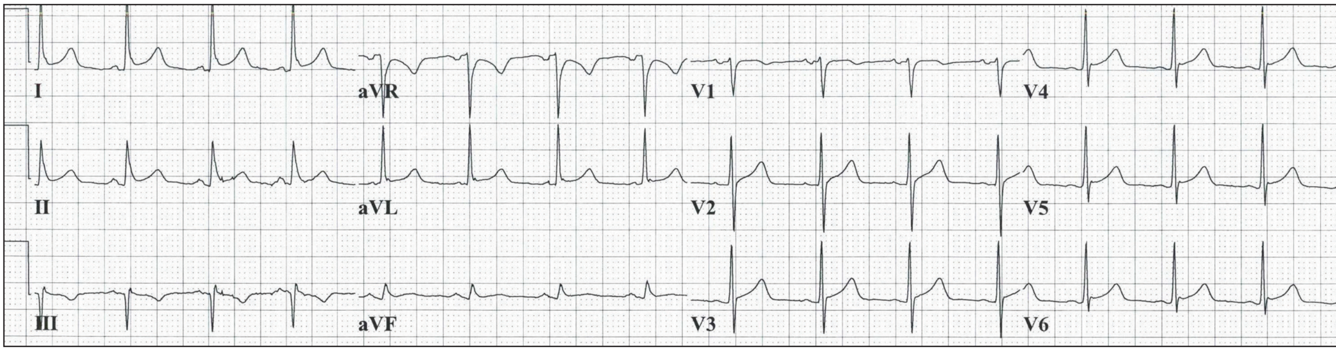

Figure 4) *Electrocardiogram of a 68-year-old woman two days after coronary artery bypass surgery with small pericardial effusion seen on an echocardiogram. Note the diffuse ST elevation, except for the ST depression in aVR. There is evidence for PR depression in I, II and aVL, and PR elevation ('knuckle' sign) in aVR*

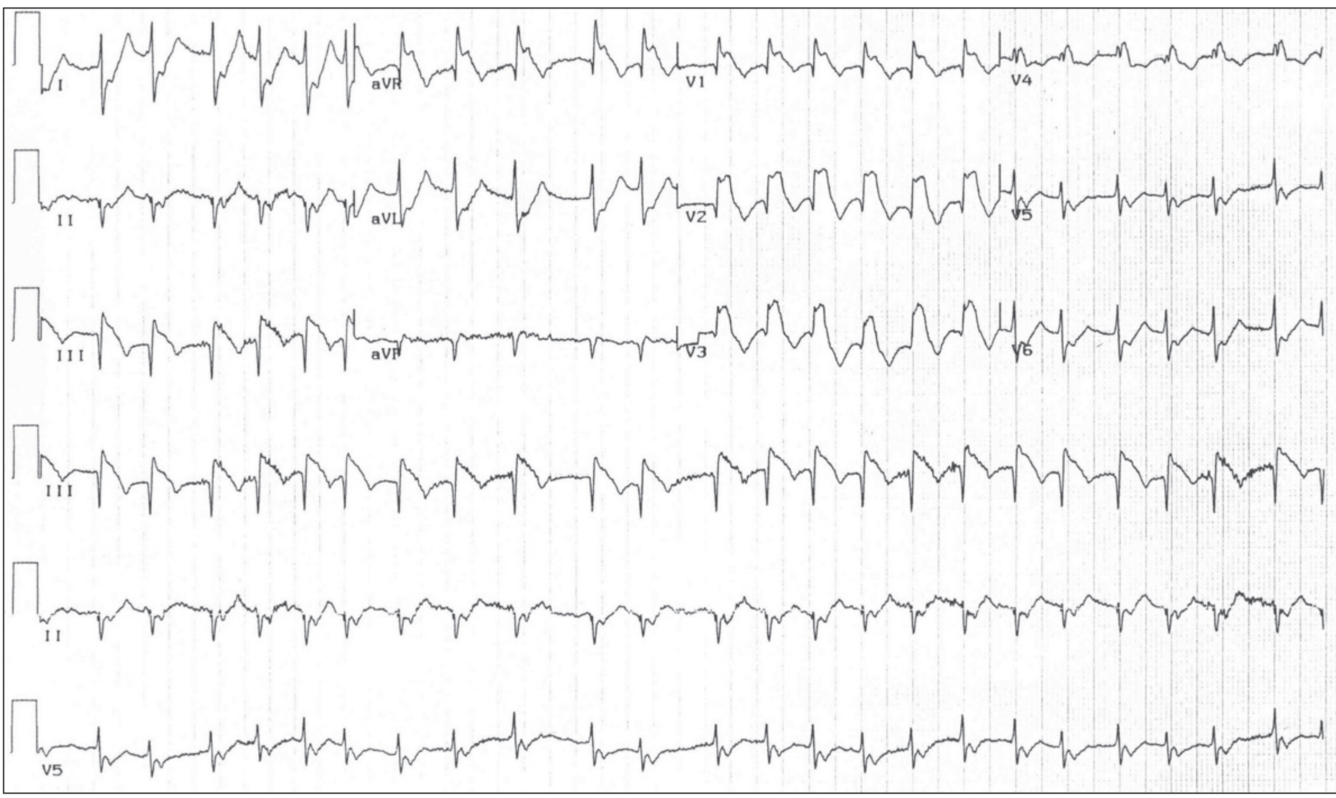

Figure 5) *Electrocardiogram of a 54-year-old woman presenting with an acute pulmonary embolus. Note the 'SIQ3T3' pattern. Additional findings include atrial fibrillation, right axis deviation, incomplete right bundle branch block, and ST elevation in aVR and V_1*

ACUTE PERICARDITIS

The ECG is frequently abnormal in cases of pericarditis, with diffuse ST segment elevations and PR segment depressions in most leads. Reciprocal ST segment depression and PR segment elevation ('knuckle' sign) in lead aVR are characteristic and help in supporting a diagnosis of acute pericarditis (Figure 4) (29,30).

ACUTE PULMONARY EMBOLISM

Acute pulmonary embolism distorts right heart hemodynamics and gives rise to a variety of ECG findings including the classic $S_1Q_3T_3$ pattern (S wave in lead I, Q wave in lead III and T wave inversion in lead III). ST segment elevation in aVR is believed to be due to acute right ventricular overload, transient hypoxia from impaired coronary flow or increased myocardial oxygen demand (Figure 5) (31,32).

ARRHYTHMIAS

The morphology of the P wave in lead aVR can be used to differentiate atrial tachyarrhythmias. A positive P wave in aVR during tachycardia favours atrioventricular nodal re-entry tachycardia (Figure 6) (11). A negative P wave in aVR suggests a focal right atrial tachycardia (Figure 7) (33). Ho et al (34) found that ST segment elevation in aVR during narrow QRS complex tachycardia suggests atrioventricular re-entry through an accessory pathway as the mechanism of the tachycardia.

The morphology of the R wave in lead aVR has been used to risk-stratify patients with Brugada syndrome (35). In patients

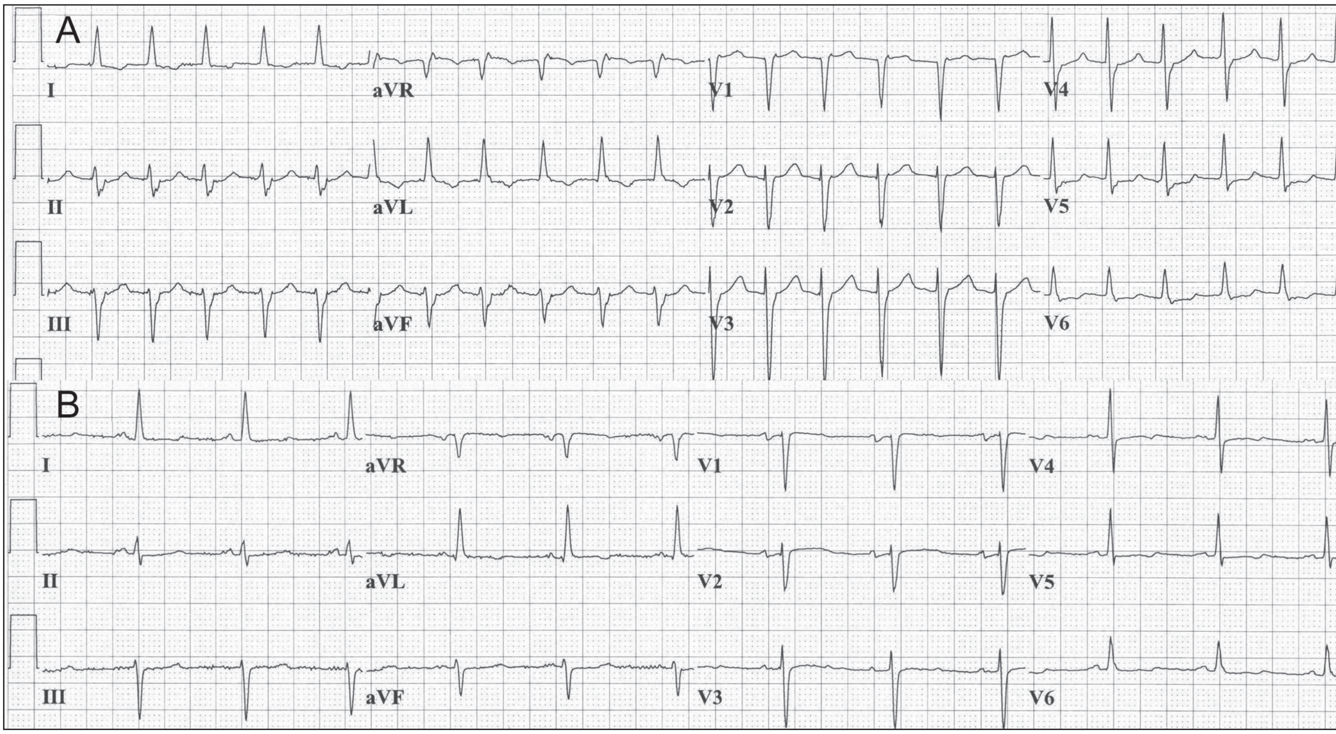

Figure 6) *Electrocardiograms from a patient during atrioventricular nodal reentry tachycardia (AVNRT) (**A**) and while in sinus rhythm (**B**). Note the positive P wave in aVR at the end of the QRS complex during AVNRT that is not present while in sinus rhythm*

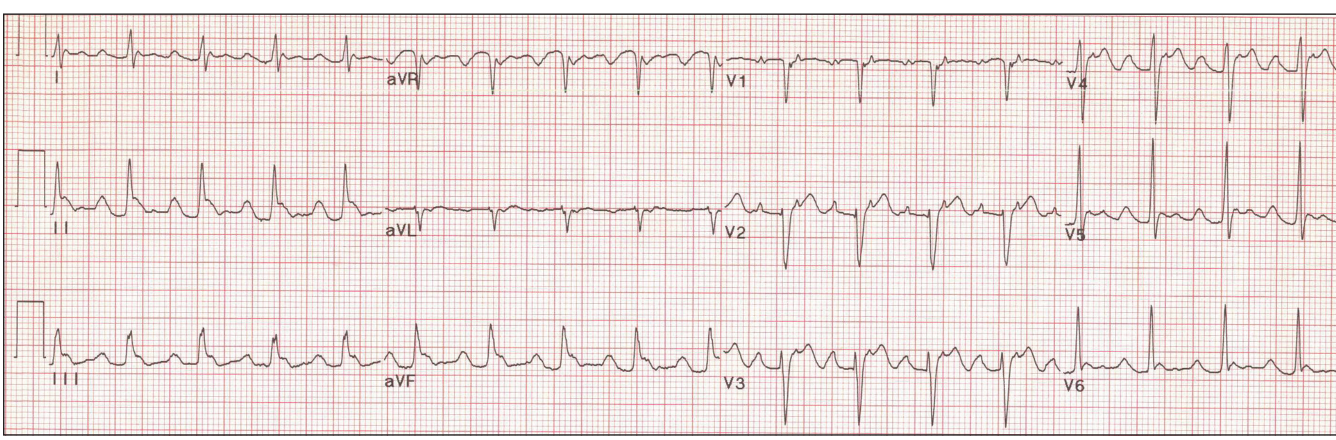

Figure 7) *Electrocardiogram showing atrial tachycardia with 2:1 conduction. Note the negative P waves in aVR*

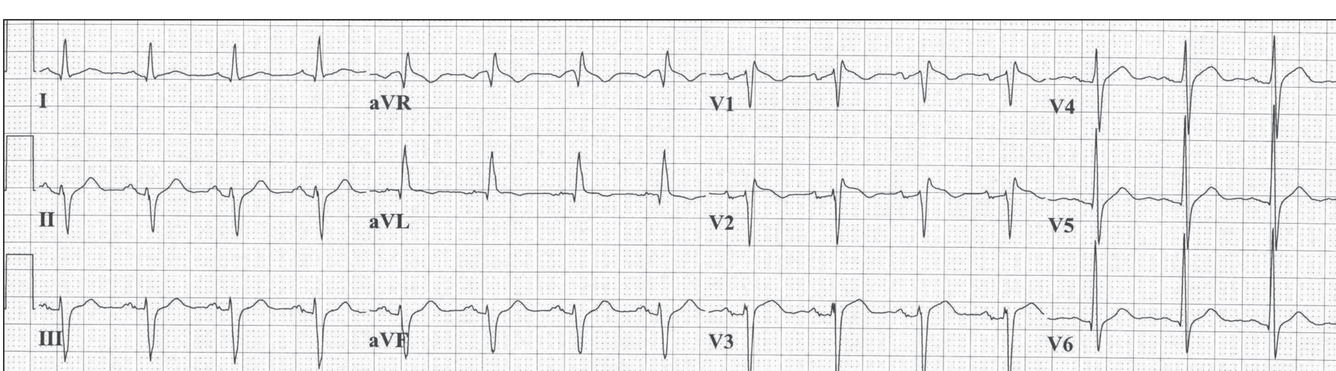

Figure 8) *Electrocardiogram of a 46-year-old man with multiple syncopal episodes who was found on electrophysiological testing to have inducible ventricular fibrillation. Note the Brugada pattern in V_1 and V_2, and the 'aVR sign' (prominent R wave) in aVR*

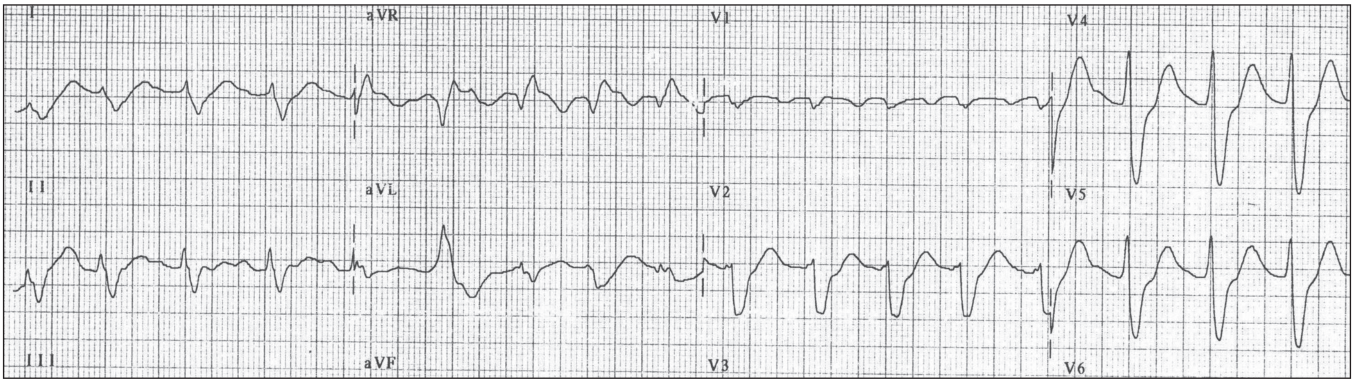

Figure 9) *Electrocardiogram from a 39-year-old woman with a tricyclic antidepressant overdose. Note the sinus tachycardia, the QRS widening, the corrected QT prolongation and the 'terminal R wave' (R wave 3 mm or greater) in aVR*

with Brugada syndrome, a prominent R wave in lead aVR – also known as the 'aVR sign' – portends a greater risk for arrhythmic events (Figure 8) (36).

TRICYCLIC ANTIDEPRESSANT POISONING

Overdose of tricyclic antidepressants is a leading cause of death in the United States (37). QRS duration is the cardiac parameter mostly followed in cases of tricyclic antidepressant overdose, because it has been shown that a QRS duration of 100 ms or greater is predictive of seizures and arrhythmias (38). Liebelt et al (39), in a study of 79 patients with tricyclic antidepressant overdose, showed that the amplitude of the terminal R wave (3 mm or greater) in aVR and the ratio of the R wave to the S wave in aVR are better predictors of seizures and arrhythmias in these patients, than QRS interval (Figure 9 and Table 2) (39).

TABLE 2
Electrocardiogram parameters in tricyclic antidepressant poisoning

Features	Seizure or arrhythmia (n=17)	No seizure or arrhythmia (n=62)
R_{aVR}, mm	4.4±2.3 (0.5–9.0)	1.8±1.4 (0.0–5.5)
R/S_{aVR}	1.4±1.2 (0.0–4.5)	0.5±0.7 (0.0–5.0)
QRS interval, ms	147±57 (60–260)	96±28 (60–260)

Data are presented as mean ± SD (range). R_{aVR} is the amplitude of the terminal R wave in lead aVR; R/S_{aVR} is the R wave/S wave ratio in lead aVR. Adapted from reference 39

DEXTROCARDIA AND LEAD REVERSAL

With dextrocardia, the heart is situated in the right chest due to a primary reversal of the primitive cardiac loop (40). Here, the P wave, QRS complex and T wave are all directed inferiorly and to the right, and the ECG has an appearance of the arm leads being reversed (10,41). In both dextrocardia and lead reversal due to incorrect lead placement, the P wave and QRS complex are upright in lead aVR. In case of lead reversal, the precordial pattern (V_1 to V_6) is normal (Figures 10A, 1B and 1C). With dextrocardia (Figure 10D), the QRS voltage gradually diminishes from V_1 through V_6 as the leads are placed further left away from the heart in the right chest.

TENSION PNEUMOTHORAX

The postulated causes for electrocardiographic changes associated with tension pneumothorax include displacement of the heart, rotation of the heart, acute right ventricular dilation and air in the thoracic cavity (42,43). PR segment elevation in inferior ECG leads and PR segment depression in lead aVR have been reported in left-sided pneumothorax by Strizik and Forman (44).

TAKOTSUBO SYNDROME

Stress-induced cardiomyopathy, also known as takotsubo or apical ballooning syndrome, has been reported to result in transient ST segment elevation in lead aVR, along with ST segment elevation in leads I, II, III, aVF and V_2 to V_6 (45,46). Reversible diffuse impairment of coronary microcirculation leading to transient global myocardial ischemia, possibly due to a catecholamine surge, is generally accepted as the mechanism producing this acute myocardial infarction picture (47).

CONDUCTION ABNORMALITIES

Warner et al (48) proposed new and improved electrocardiographic criteria for the diagnosis of left anterior hemiblock. They demonstrated a greater degree of accuracy in diagnosing left anterior hemiblock using criteria based on the fact that the peak of the terminal R wave in lead aVR occurs later than the peak of the terminal R wave in lead aVL, compared with using frontal plane QRS axis criteria (Figure 11).

CONCLUSION

Lead aVR has multiple clinical applications and is a useful tool for interpreting ECGs. However, it is often overlooked, even by experienced ECG readers. Careful attention to this lead during evaluation of the ECG can aid in the diagnosis of acute LMCA or proximal LAD occlusion, affecting timing and type of therapy, and predicting prognosis in patients with acute myocardial infarction. Noting changes in aVR can aid in the diagnosis in clinical scenarios, including pulmonary embolism, tricyclic antidepressant overdose, dextrocardia and lead reversal. Clinical training curriculums need to impart the importance of systematic evaluation of all leads while interpreting the ECG. An interesting suggestion by Palhm et al (49) is to adopt an orderly, as opposed to classical, electrocardiographic limb lead display (Figure 12). They demonstrated that such a display results in greater diagnostic accuracy in less time. Nevertheless, aVR – the forgotten lead – can be a useful tool in the diagnosis and prognosis of many clinical syndromes.

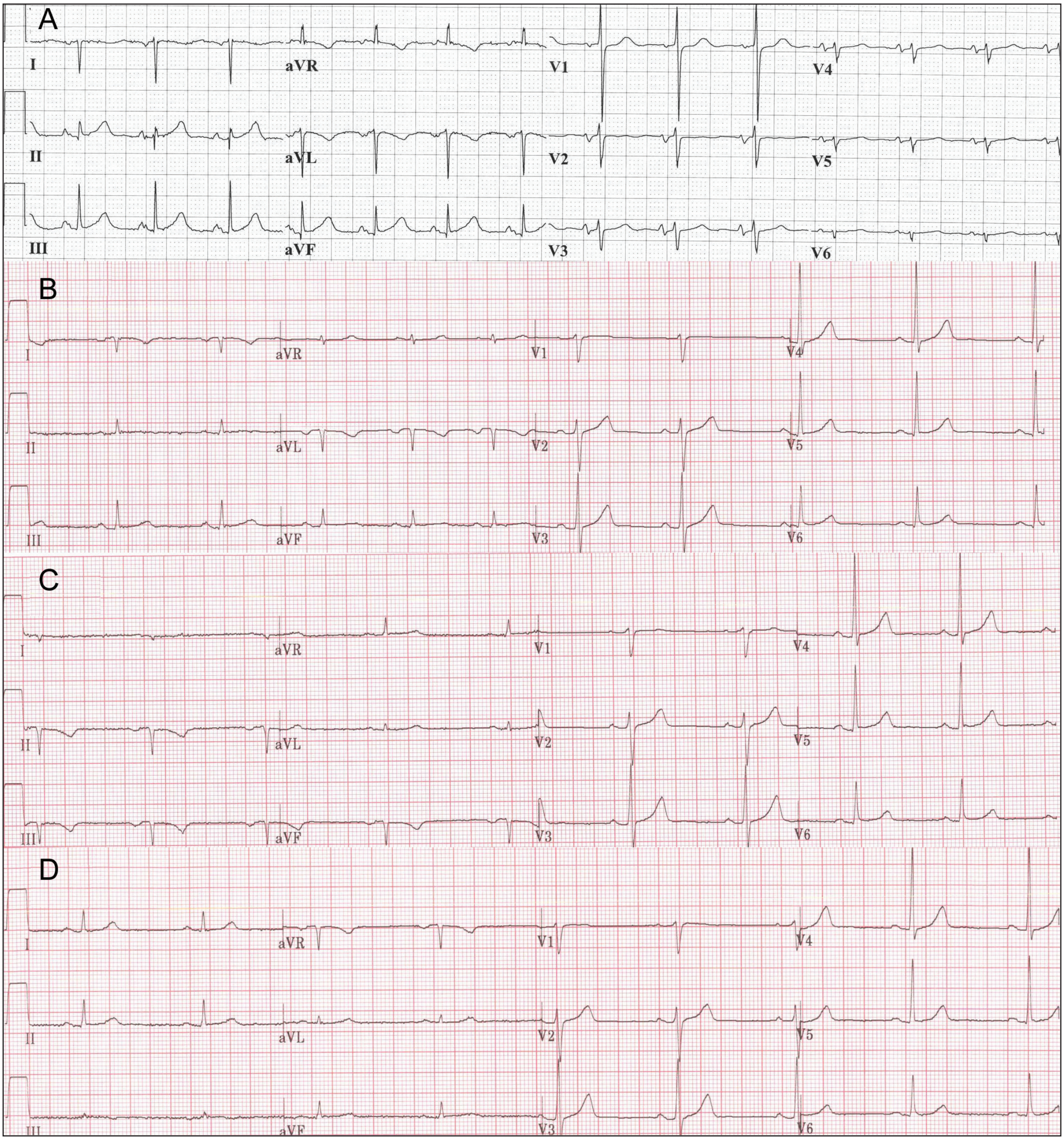

Figure 10) *Electrocardiograms showing right arm-left arm lead reversal (**A**), right arm-left leg lead reversal (**B**), corrected electrocardiogram (**C**) and dextrocardia (**D**). Note, with dextrocardia, QRS voltage gradually diminishes as the leads are placed further left away from the heart in the right chest*

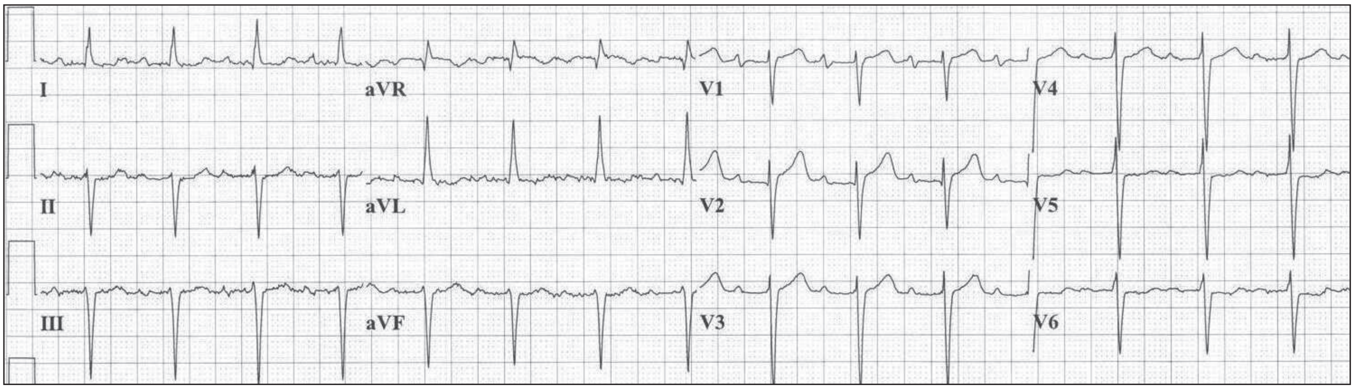

Figure 11) *Electrocardiogram demonstrating a left anterior fascicular block. Note, the terminal R wave in aVR occurs later than in aVL*

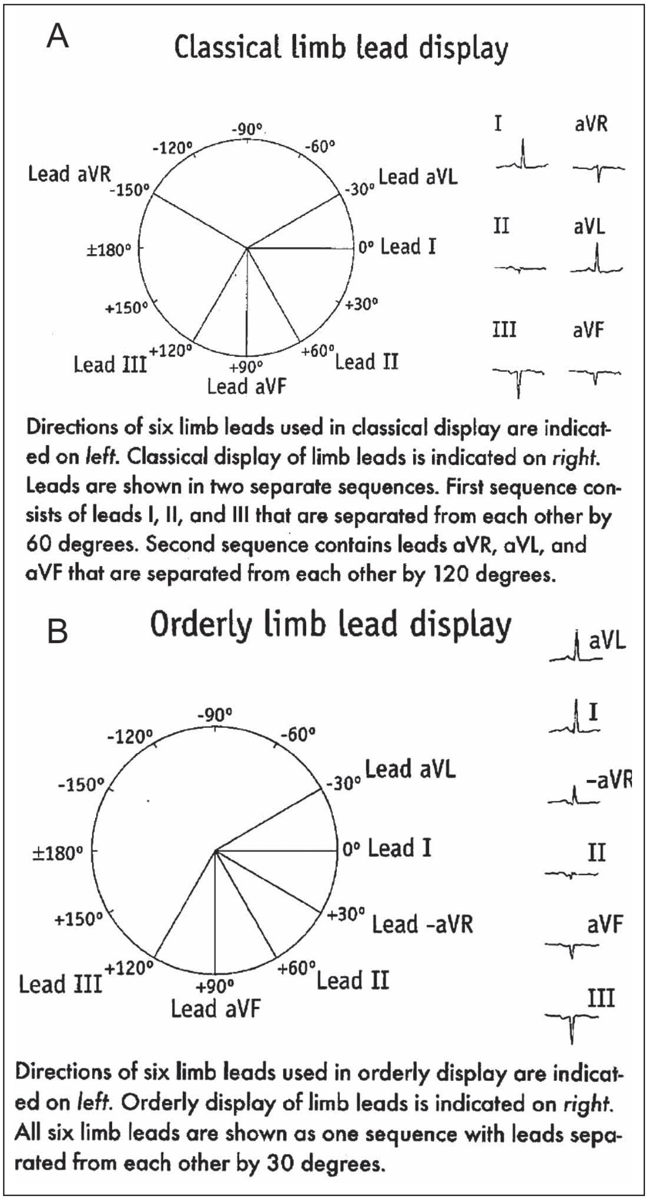

Figure 12) *Classical (***A***) and orderly (***B***) limb lead displays*

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