



Inter-lead correlation analysis for automated detection of cable reversals in 12/16-lead ECG

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ABSTRACT

Background and objective: A crucial factor for proper electrocardiogram (ECG) interpretation is the correct electrode placement in standard 12-lead ECG and extended 16-lead ECG for accurate diagnosis of acute myocardial infarctions. In the context of optimal patient care, we present and evaluate a new method for automated detection of reversals in peripheral and precordial (standard, right and posterior) leads, based on simple rules with inter-lead correlation dependencies.

Methods: The algorithm for analysis of cable reversals relies on scoring of inter-lead correlations estimated over 4s snapshots with time-coherent data from multiple ECG leads. Peripheral cable reversals are detected by assessment of nine correlation coefficients, comparing V6 to limb leads: (I, II, III, –I, –II, –III, –aVR, –aVL, –aVF). Precordial lead reversals are detected by analysis of the ECG pattern cross-correlation progression within lead sets (V1–V6), (V4R, V3R, V3, V4), and (V4, V5, V6, V8, V9). Disturbed progression identifies the swapped leads.

Results: A test-set, including 2239 ECGs from three independent sources—public 12-lead (PTB, CSE) and proprietary 16-lead (Basel University Hospital) databases—is used for algorithm validation, reporting specificity (Sp) and sensitivity (Se) as true negative and true positive detection of simulated lead swaps. Reversals of limb leads are detected with Se = 95.5–96.9% and 100% when right leg is involved in the reversal. Among all 15 possible pairwise reversals in standard precordial leads, adjacent lead reversals are detected with Se = 93.8% (V5–V6), 95.6% (V2–V3), 95.9% (V3–V4), 97.1% (V1–V2), and 97.8% (V4–V5), increasing to 97.8–99.8% for reversals of anatomically more distant electrodes. The pairwise reversals in the four extra precordial leads are detected with Se = 74.7% (right-sided V4R–V3R), 91.4% (posterior V8–V9), 93.7% (V4R–V9), and 97.7% (V4R–V8, V3R–V9, V3R–V8). Higher true negative rate is achieved with Sp > 99% (standard 12-lead ECG), 81.9% (V4R–V3R), 91.4% (V8–V9), and 100% (V4R–V9, V4R–V8, V3R–V9, V3R–V8), which is reasonable considering the low prevalence of lead swaps in clinical environment.

Conclusions: Inter-lead correlation analysis is able to provide robust detection of cable reversals in standard 12-lead ECG, effectively extended to 16-lead ECG applications that have not previously been addressed.

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1. Introduction

The standard 12-lead electrocardiogram (ECG) is a routine non-invasive clinical investigation for the management of acute and chronic cardiovascular diseases [1]. It is sensitive to anterior, inferior and left-lateral projection of the cardiac electrical activity [2], as illustrated in Fig. 1. Although the redundancy of information contained in different perspectives from multiple leads is used to improve recognition of ECG abnormalities [1], there are areas of the heart that are not directly assessed by a 12-lead ECG, and thus posterior and right ventricular acute myocardial infarctions (AMI) are likely to be misdiagnosed, which might critically delay the early intervention and treatment [3]. In patients with ischemic-like chest pain, the use of additional leads might not only confirm the presence of AMI, but also provide a more accurate reflection of the true extent of myocardial damage [4,5]. Four additional right precordial leads (V3R, V4R, V5R, V6R), placed as a mirror image to the standard precordial electrode positions, are administered in the clinical setting for screening the right ventricle for diagnosis of right ventricular AMI in patients with inferior infarction [1,6,7]. Standards recommend detection of ST-segment elevation >0.5 mm in leads V3R and V4R [8], reported to be moderately sensitive and specific for right ventricular injury (V4R: sensitivity Se = 88–100%, specificity Sp = 78–82%, 83–92% diagnostic accuracy [4]). Examination of three additional posterior chest leads (V7, V8, V9) on the same horizontal plane as V6 gives a view to the posterior wall of the left ventricle and has been administered for diagnosis of posterior AMI associated with occlusion of the circumflex artery or dominant right coronary artery, not always seen in the standard 12-lead ECG [4,9–12]. ST-segment elevation >0.5 mm in posterior leads V8 and V9 is sensitive for posterior wall infarction [8] (as high as 90%, with predictive accuracy up to 93.8% [4,7]). Due to the distance of the heart (which is more anterior in the chest), the voltages recorded in the posterior leads are often small in amplitude [4,7], which requires a high-resolution ECG recording system.

An important problem in the recording of multilead ECGs is the improper placing of electrodes on the body [13], considering relatively frequent human mistake rates of: 36% for precordial electrode misplacement with more than 3.2 cm from the proper anatomical landmarks [14]; 0.8% and 7.5% for limb lead interchanges in 12-lead ECG and Holter devices, respectively [15]; and 0.4% and 4% for 12-lead ECG reversals in clinical and intensive care settings, respectively [16]. The proportion of inadvertent electrode reversals is suggested to be higher for the non-routine 16-lead ECG in an emergency setting: 5%, 8%, 8% and 19% for limb leads, standard chest leads, posterior V8–V9 leads and right precordial V3R–V4R leads, respectively [17]. Electrode placement errors can produce prominent changes in the ECG waveform morphology [18–20] and pathological patterns mimicking ectopic atrial rhythm, bundle branch blocks, ventricular hypertrophy, ventricular pre-excitation, dextrocardia, simulation or concealing of myocardial ischemia or infarction [21–27] that might generally result in incorrect data interpretation, erroneous diagnosis and lack of proper therapy if not opportunely corrected [1,8]. The REVERSE mnemonic has been suggested as a useful tool that could be easily followed by the medical staff to identify common electrode placement errors produced by typical abnormal ECG patterns [27], and ECG interpretation in the context of the patient's history is advised [22]. Confirmation with a second ECG is usually required, although less common lead placement errors are often difficult to be detected and might remain concealed. In the context of the optimal patient care, saving of money, time and valuable data, the recent recommendations on ECG standardization and interpretation advise training of the medical staff on the avoidance of lead switches and guidelines for their recognition, as well as incorporation of automated lead-switch detection algorithms into digital ECG devices [1].

Extended reviews of the most common cases for 12-lead ECG reversals reveal their typical effect on the P-QRS-T morphology alteration together with some basic principles for recognition of different lead reversals [21,22,24,25,27]. The implementation of these principles into automated lead-switch

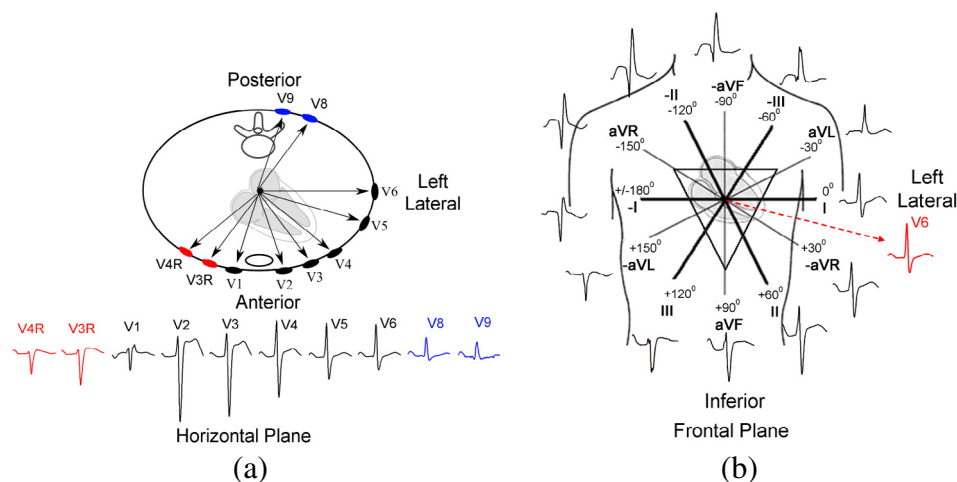


Fig. 1 – Acquisition of cardiac electrical activity via 16-lead ECG. The inter-lead normal PQRST progression is shown in (a) 10 precordial leads on the horizontal plane and (b) 6 standard limb leads (positive and inverted projection) on the frontal plane, compared to V6.

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