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Journal of Electrocardiology xx (2016) xxx – xxx

JOURNAL OF Electrocardiology

www.jecgonline.com

Left arm/left leg lead reversals at the cable junction box: A cause for an epidemic of errors☆

Poonam Velagapudi, MD, Mohit K. Turagam, MD, Sherry Ritter, MD, Mary L. Dohrmann, MD*

Division of Cardiovascular Medicine, University of Missouri School of Medicine, Columbia, MO, USA

Abstract Medical errors, especially due to misinterpretation of electrocardiograms (ECG), are extremely common in patients admitted to the hospital and significantly account for increased morbidity, mortality and health care costs in the United States. Inaccurate performance of an ECG can lead to invalid interpretation and in turn may lead to costly cardiovascular evaluation. We report a retrospective series of 58 sequential cases of ECG limb lead reversals in the ER due to inadvertent interchange in the lead cables at the point where they insert into the cable junction box of one ECG machine. This case series highlights recognition of ECG lead reversal originating in the ECG machine itself. This case series also demonstrates an ongoing need for education regarding standardization of ECG testing and for recognizing technical anomalies to deliver appropriate care for the patient.

Keywords: ECG; Lead reversal; Medical errors; Lead misplacement

Background

Medical errors are extremely common in patients admitted to the hospital and significantly account for increased morbidity, mortality and health care costs in the United States [1]. The 12-lead electrocardiogram (ECG) is one of the most widely used diagnostic tests in the emergency room (ER) in patients presenting with both cardiac and non-cardiac conditions for identification of myocardial infarction, arrhythmias and structural heart disease. Currently, ECGs are performed and recorded in hospitals by multifaceted personnel, including paramedical staff, registered nurses and certified nursing assistants who may not have sufficient training in standardized ECG recording. Inaccurate performance of an ECG can lead to invalid interpretation and in turn may lead to costly cardiovascular evaluation. Unnecessary hospital admission may contribute to patient-related adverse events and increased health care costs [2–4]. We report a retrospective series of 58 sequential cases of ECG limb lead reversals in the ER due to inadvertent interchange in the lead cables at the point where they insert into the cable junction box of one ECG machine.

Methods

We performed a retrospective chart review of the electronic medical records of 58 patients who presented to the University of Missouri Health Center (MUHC) ER between July 5 and July 8, 2014. The ECGs performed at MUHC are decentralized; that is, all patient care areas perform their own ECGs. In the MUHC ER, 100 personnel, including emergency medical technicians (EMT) and nurses, are trained to perform ECGs. During each 12-h shift, 2 designated EMTs are primarily responsible for performing ECGs, with nurses available as needed. The Cardiac Testing lab at MUHC is responsible for the education of all personnel who perform ECGs and for the maintenance of the ECG equipment. The ECGs performed are electronically transmitted to the centralized ECG database for interpretation by a cardiologist. Between July 5 and July 8, 2014, sixty-one ECGs on 58 patients were performed on a single ECG machine (designated as ER1) in the MUHC ER with left arm and left leg (LA/LL) lead reversal. Awareness of this error occurred on July 8 when the interpreting cardiologist noted an inordinate number of ECGs with lead reversals from the ER1 machine. This prompted a retrospective review of all ECGs between those dates.

Results

The majority of the 58 patients who presented to the ER were diagnosed with non-cardiac conditions, such as pneumonia, hip fracture, sepsis, acute renal failure, COPD exacerbation,

☆ All authors have no conflict of interest to declare.

* Corresponding author at: University of Missouri Health Science Center, CE 306, 1 Hospital Drive, Columbia, MO 65212.

E-mail address: dohrmannm@health.missouri.edu

http://dx.doi.org/10.1016/j.jelectrocard.2016.06.011

0022-0736/

gastrointestinal bleeding, seizures and encephalopathy. Only 18 of the 58 patients (31%) had a cardiac-related diagnosis, including chest pain, syncope, non-ST-elevation myocardial infarction, heart failure, atrial fibrillation, hypertensive emergency and stroke.

Lead reversal was accurately identified in the ER in only 1 patient after the interpretation by a cardiologist was available via the central database. Lead reversal was not identified in the ER in 34 patients (59%) and was omitted in documentation in 23 patients (40%). The initial computer interpretation of the ECG failed to recognize LA/LL lead reversal in any ECG.

Only 23 of 61 ECGs (38%) were interpreted correctly initially by the interpreting cardiologist. However, it was not until there were 10 ECGs on successive patients on July 7–8, a retrospective re-evaluation of all ECGs from the ER1 machine was performed. Revision of the initial ECG interpretation was made by the cardiologist in an additional 19 ECGs (31%), except on those ECGs that could not be reliably interpreted.

The reasons for inability to accurately interpret ECGs included no available comparative prior ECG, baseline motion artifact, low QRS voltage in frontal leads, non-sinus rhythm (atrial pacing, atrial fibrillation, ectopic atrial rhythm), additional lead reversals (right arm/right leg reversal, bilateral arm/leg reversal), and prior ECG with lead reversal.

Hospital admission occurred in 30 of the 58 patients (52%). Based on documentation it did not appear that the failure to recognize lead reversal was the major factor in clinical decision by the ER for hospital admission or further monitoring and testing. However, it cannot be entirely ruled out that an incorrect ECG interpretation may have played a role.

On July 8, as a result of inspection of the ER1 machine, it was discerned that the LA/LL leads were physically interchanged at the point where they insert into the cable junction box of the ECG machine. We presume that the ECG cables had been detached from the ECG machine for cleaning but had not been correctly reattached. Fig. 1 shows the cable junction box of the Mortara 350 series ER1 machine that was utilized for all ECGs performed in the ER and illustrates the LA/LL leads detached from the cable hub.

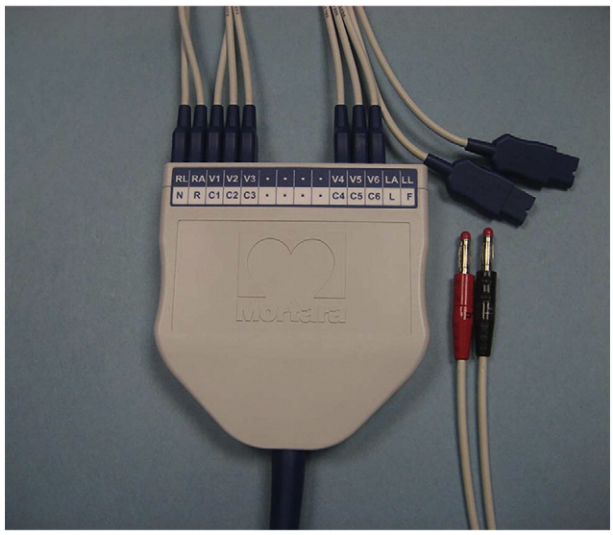

Fig. 1. LA/LL lead cables disconnected from the cable box. There is a probability for error if lead cables are not inserted in their correct specified location after cleaning, which leads to reversal errors on the ECG. Note that each lead has a universal color code.

Discussion

In this case series of 58 patients, LA/LL lead reversal was not accurately interpreted in most patients who presented to the ER, both by the ED staff and the interpreting cardiologist. LA/LL lead reversal is difficult to recognize, especially in the absence of a comparative ECG or in the presence of artifact, non-sinus rhythm, paced rhythm and additional lead reversals.

When compared to a correctly performed previous ECG, LA/LL lead reversal alters all limb lead findings except lead aVR. Lead I and II switch places, lead aVF and aVL switch places, and lead III inverts, which makes it difficult to detect by an inexperienced physician. Recognizing reversal of aVF and aVL is especially apparent if a comparison ECG is available. Criteria for visual recognition of all the common lead reversals have been published, which stress both the P wave and QRS axes [5]. A P-wave algorithm including a negative P wave in lead III and a P wave in lead I taller than the P wave in lead II was reported as criteria to suspect LA/LL lead reversal with an accuracy of 90% in sinus rhythm [6]. However, another study in 9072 ECGs using the above P-wave algorithm reported a specificity of 38% and a sensitivity of 90% [7]. In a study of 10,906 ECGs using artificial neural networks to detect either LA/LL lead reversal or reversals of adjacent precordial leads, the sensitivity of the networks ranged between 45 to 83% and was higher than that of the conventional computer programs, which were 0.1 to 10%; the sensitivity of the neural network for specifically detecting LA/LL lead reversal was 58% [8]. Another method for automatic detection of lead misplacement reported specificity and sensitivity of ≥99.5% and ≥93%, respectively, for detection of common lead reversals, except for detection of LA/LL lead reversal, which had a sensitivity of 17.9% [9].

ECG lead misplacement is reported in 0.4–4% of all ECGs performed [10]. Not all limb lead misplacements will affect ECG interpretation. However, some examples of lead misplacement have been associated with serious consequences. Truncal or non-standard placement of limb leads can cause pseudo-infarct pattern of both inferior and lateral infarcts as well as cause disappearance of inferior and posterior myocardial infarcts [11] or can cause right axis deviation [12]. In a study by Bond et al., incorrect placement of V1 and V2 electrodes in the second intercostal space affected the clinical diagnosis in 17–24% of patients, including a missed diagnosis of ST elevation myocardial infarction in 11% [13]. LA/LL lead reversal is least likely to give a pseudo-myocardial infarction pattern. In one series of 838 ECGs, the most commonly encountered electrode misplacement was the right arm/left arm lead reversal, which accounted for 20% of lead reversals while LA/LL lead reversal was the least common [10]. Hedén et al. reported that LA/LL lead reversal occurred in 5.7% of ECGs in their series [8]. Fig. 2 demonstrates the ECGs of a patient in our series with LA/LL lead reversal (Fig. 2A) and after correct lead placement (Fig. 2B).