



## Surface 12 lead electrocardiogram recordings using smart phone technology

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### Abstract

**Importance:** AliveCor ECG is an FDA approved ambulatory cardiac rhythm monitor that records a single channel (lead I) ECG rhythm strip using an iPhone. In the past few years, the use of smartphones and tablets with health related applications has significantly proliferated.

**Objective:** In this initial feasibility trial, we attempted to reproduce the 12 lead ECG using the bipolar arrangement of the AliveCor monitor coupled to smart phone technology.

**Methods:** We used the AliveCor heart monitor coupled with an iPhone cellular phone and the AliveECG application (APP) in 5 individuals.

**Results:** In our 5 individuals, recordings from both a standard 12 lead ECG and the AliveCor generated 12 lead ECG had the same interpretation.

**Conclusions:** This study demonstrates the feasibility of creating a 12 lead ECG with a smart phone. The validity of the recordings would seem to suggest that this technology could become an important useful tool for clinical use. This new hand held smart phone 12 lead ECG recorder needs further development and validation.

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### Keywords:

AliveCor ECG; Electrocardiogram; 12 lead; Smart phone ECG

### Introduction

The standard 12 lead electrocardiogram (ECG) has been used clinically for over 100 years for the diagnosis of ischemic heart disease and cardiac arrhythmias [1–3]. New technology today allows for a standardized single lead recording to be obtained by a computerized monitoring bipolar device that is coupled and wirelessly connected to a smart phone [4–7].

The standard bipolar limb leads of the 12 lead ECG can be theoretically reproduced with simple bipolar connections of the limbs according to Einthoven's triangle [1,2]. The augmented interpolated limb leads (VR, VL, VF) can also be re-created theoretically by connecting the exploring electrode to the focus limb and the other two limbs to the negative pole of the recording bipolar device [3]. Similarly, the chest leads can be created with a bipolar arrangement: the positive electrode is on the chest (at V1, V2, V3, V4, V5, V6) and the distant negative electrode is on the lower left leg, at a distance from the heart. In this initial feasibility trial, we attempted to reproduce the 12 lead

ECG using the bipolar arrangement of the AliveCor monitor coupled to smart phone technology.

### Methods

#### Patient population

We used the AliveCor heart monitor coupled with an iPhone cellular phone and the AliveECG application (APP). The population for this smart phone 12-lead ECG feasibility study included 5 individuals: two normal individuals with a narrow QRS complex and three with a wide QRS complex: one each with right bundle branch block, left bundle branch block, and dextrocardia (Table 1). Each of these individuals had a standard 12 lead ECG performed with a MAC5500, multichannel ECG machine. In case #1 with a narrow QRS and case #2 with a left bundle branch block, the standard 12 lead ECG and the smart phone created ECG were recorded at the same sitting and using the same electrode placements on the arms, left lower leg just above the ankle and the precordial leads. Case #3 is a healthy competitive cyclist who had the smart phone generated 12 lead ECG performed

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by the authors and one week later had a standardized ECG performed by a heart station technician. Case #4 had the standard tracing performed one week prior to surgical removal of a esophageal cancer and the smart phone tracing performed on day 4 post operation. Case #5 has dextrocardia and had the standard tracing on admission for endocarditis and the smart phone tracing performed 2 days later.

#### AliveCor technology and modification

The AliveCor device consist of FDA approved (1) hardware, a bipolar electrode case that fits on a smart phone to record the hearts electrical activity and (2) software to process, save and transmit the single lead electrocardiogram. An APP on the smart phone (AliveECG) transforms the electrical signal to ultrasound. The smart phone's microphone will receive the ultrasound signal and transmit the electrocardiogram as a wireless PDF format.

#### Smart phone ECG recording

The AliveCor device is a standardized, bipolar single lead recorder. Using the principles of Einthoven's triangle, the standard ECG bipolar and interpolated limb leads can be reproduced. To record the standard bipolar limb leads; the AliveCor case was adapted with adhesive ECG tabs (Kendall, MT710 Diagnostic Tab Electrodes). These standard adhesive tabs are placed on the right and left forearms and the lower left leg just above the ankle. The adhesive tabs are used for the precordial leads (V1, V2, V3, V4, V5, V6) and are placed on the chest using the standard locations [1,2]. Using three 24 inch insulated wires with mini alligator clips, the standard bipolar (leads: I, II, III) and interpolated (aVR, aVL, aVF) limb leads and the precordial leads are recorded in successive order (Fig. 1). For the augmented limb leads, we used a positive lead as the exploring electrode and the other two limb leads are connected to the negative pole. For the six chest leads, the positive electrode is the exploring electrode while the indifferent electrode is negative and is located on the distant left leg. Using the principles of the Einthoven's triangle and Goldberger modification, the standardized AliveCor ECG can be modified to obtain a 12 lead ECG recording [2,3].

A standard 12 lead recording was made using a Mac 5500 recorder. In case #1 and case #2, the authors performed the standard 12 lead recording and used the same exact sites for the smart phone recording. In case #3, case #4 and case #5, the standard Mac 5500 12 lead ECG was performed by an ECG technician. The precordial lead electrode placements were not exactly the same sites as those used for the AliveCor recordings that were done at a different setting.

#### Results of the 5 individual recordings

The clinical characteristics of the 5 individuals in this feasibility study are described in Table 1.

Case #1 is a 67 year old male with a normal echocardiogram, ejection fraction 0.55, normal chamber sizes, and normal valve function. A standard 12 lead electrocardiogram (ECG) and then a sequential AliveCor 12 lead ECG are performed using the same lead tabs on the limbs and chest.

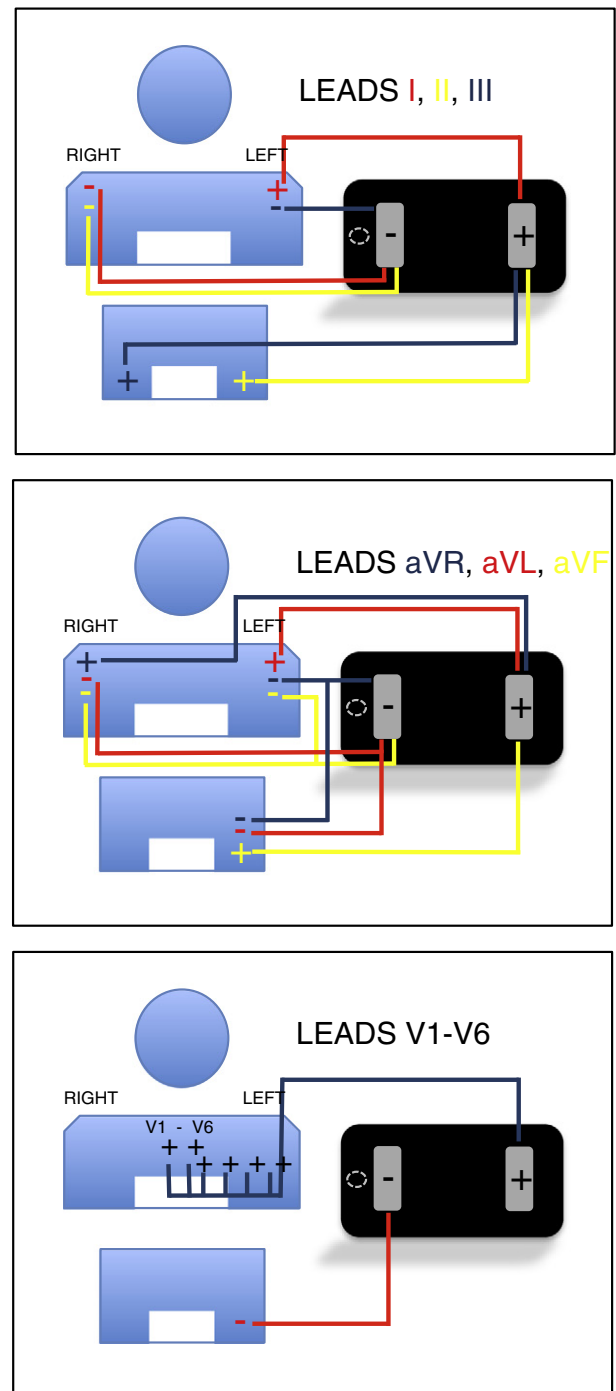


Fig. 1. AliveCor ECG recording. Panel A: Bipolar limb lead recordings (I, II, III) using Einthoven's triangle format. Panel B: Unipolar limb lead recordings (aVR, aVL, aVF) using the method of Goldberger with the focus exploring electrode as positive and the other two limbs as the negative. Panel C: Precordial leads V1–V6: with the positive exploring electrode on the chest and the negative electrode on the distant lower left leg.

Both the Mac 5500 standard 12 lead ECG and the AliveCor generated 12 lead ECG have the same interpretation. Both show sinus rhythm, normal intervals; normal axis +60 degrees; left atrial abnormality and left ventricular hypertrophy by voltage. The AliveCor tracing is a sequential obtained ECG and demonstrates the presence of a sinus arrhythmia. In Fig. 2, there are comparisons of the two tracings. The email PDF transfer of the AliveCor version is reconstructed for printing the 12 lead. Despite the

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