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Improved recording of atrial activity by modified bipolar leads derived from the 12-lead electrocardiogram

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Abstract This study investigates the use of multivariate linear regression to estimate three bipolar ECG leads from the 12-lead ECG in order to improve P-wave signal strength. The study population consisted of body surface potential maps recorded from 229 healthy subjects. P-waves were then isolated and population based transformation weights developed. A derived P-lead (measured between the right sternoclavicular joint and midway along the costal margin in line with the seventh intercostal space) demonstrated significant improvement in median P-wave root mean square (RMS) signal strength when compared to lead II (94 μV vs. 76 μV, $p < 0.001$). A derived ES lead (from the EASI lead system) also showed small but significant improvement in median P-wave RMS (79 μV vs. 76 μV, $p = 0.0054$). Finally, a derived modified Lewis lead did not improve median P-wave RMS when compared to lead II. However, this derived lead improved atrioventricular RMS ratio. P-wave leads derived from the 12-lead ECG can improve signal-to-noise ratio of the P-wave; this may improve the performance of detection algorithms that rely on P-wave analysis.

Keywords: P-wave; Derived leads; 12-Lead electrocardiogram; Atrial activity

Introduction

Accurate detection of the P-wave on the electrocardiogram (ECG) is important in the detection of arrhythmias [1]. Detection of the P-wave still presents a significant challenge for both human and computerized interpretation. Low signal-to-noise ratio (SNR) has prevented P-wave analysis from being utilized in many ECG monitoring systems [2]. This has resulted in an increased rate of false positives and false negatives when monitoring for atrial arrhythmias [3]. This study investigated three bipolar leads to enhance the recording of atrial activity: (a) the P-lead recorded between the right sternoclavicular junction and midway along costal margin in line with the seventh intercostal space [4] (b) The ES lead from the EASI lead system [5] recording between the xiphoid process and suprasternal notch and (c) the modified Lewis lead [6], recorded between the xiphoid process and the fifth right intercostal space adjacent to the sternum.

The 12-lead electrocardiogram

The 12-lead ECG is one of the most commonly used diagnostic tools in medicine. It is often recorded in one of two electrode configurations; (1) The standard 12-lead ECG where the limb electrodes are placed on the extremities i.e. the wrists and ankles and (2) the Mason–Likar 12-lead ECG [7] where the limb electrodes are repositioned to more proximal landmarks on the torso. The leads of the 12-lead ECG recorded in either of these configurations are suboptimal in capturing atrial activity [6,8,9]. Previous studies have shown that lead II and precordial lead V1 have the greatest P-wave signal strength when compared to all other leads of the 12-lead ECG [10].

Bipolar leads for improved P-wave signal strength

Sir Thomas Lewis first proposed an ECG lead specifically for the recording of atrial activity in 1913 [11]. During his work on atrial arrhythmias Lewis proposed a new bipolar lead recorded between the second and fourth right intercostal spaces adjacent to the sternum. The Lewis lead, however, is not widely implemented in clinical practice. Studies by Rodrigues et al. [8] and Bakker et al. [12] have demonstrated that, during

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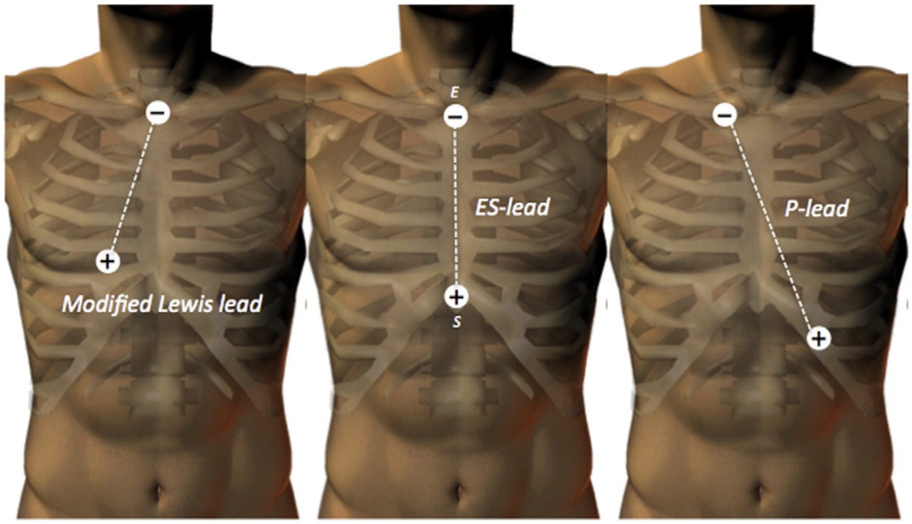

Fig. 1. Electrode positions for the recording of the (a) Modified Lewis lead (b) ES-lead and (c) P-lead to improve P-wave signal strength.

wide-QRS tachycardia, the Lewis lead improves P-wave detection when P-waves are not visible on the 12-lead ECG. Petrénas et al. [6] recently suggested a modification of the original Lewis lead for ambulatory monitoring. This involved placement of the negative electrode at the xiphoid process and the positive electrode in the fifth right intercostal space adjacent to the sternum. This modification provided a more than 3-fold improvement in atrial signal strength over the original Lewis lead. The Barker lead [13], also known as the vertical sternal lead or ES on the EASI lead system, is another bipolar lead that has previously been reported to improve P-wave amplitude. Herzog et al. have demonstrated that the Barker lead improves P-wave amplitude in comparison to both the leads of the standard 12-lead ECG and the original Lewis lead [14]. More recently, we have reported on experiments that have shown that the greatest P-wave signal strength from the surface ECG can be captured from electrodes placed at the right sternoclavicular junction and the left costal margin in line with the seventh intercostal space [4]. The electrode positions for the ES-lead, modified Lewis lead and P-lead can be seen in Fig. 1.

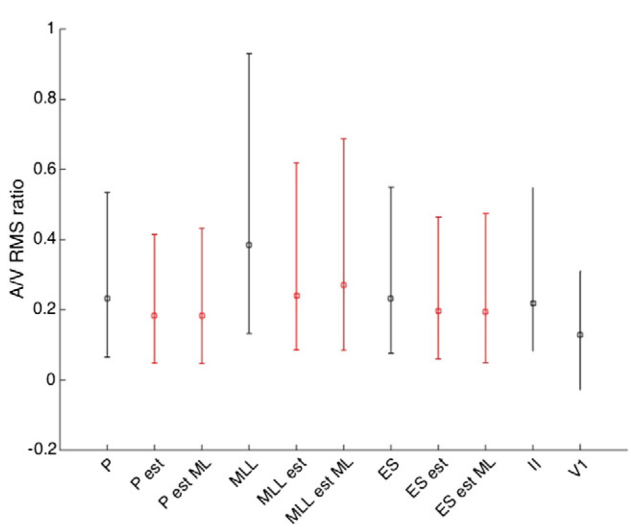

Fig. 2. P-wave RMS for the recorded and derived P-wave leads from standard 12-lead ECG compared to leads II and V1. The median P-wave RMS from lead II (72 μV) increased by 22 μV to 94 μV for the derived P-lead ($p < 0.001$). A small but significant improvement in P-wave RMS was also evident from the ES lead (76 μV vs. 72 μV, $p = 0.0054$).

Atrial arrhythmias

The prevalence of (AF) fibrillation is increasing with some describing it as a global epidemic currently affecting 2% of the general population [15]. Diagnosis of AF on the 12-lead ECG is performed on the basis of three main distinguishing features; an irregular R-R interval, absence of the P-wave and a fibrillatory wave on the baseline ECG. However, in many cases P-waves are not clearly visible on the 12-lead ECG, making the diagnosis of AF more challenging. This can lead to a misdiagnosis of AF resulting in incorrect and often dangerous treatments methods [16].

Ventricular tachycardia

Atrioventricular (AV) dissociation is a condition whereby the atria and ventricles do not work in synchronicity. AV dissociation is the most specific diagnostic criterion for determining if the origin of an arrhythmia is supraventricular or ventricular in nature [17]. However, AV dissociation is difficult to determine from the 12-lead ECG due to low amplitude or non-distinguishable P-waves. Previous studies have shown that the recording of the Lewis lead in patients with wide-QRS tachycardia can improve the recording of P-waves, which were not visible on the 12-lead ECG [8,12,17].

Lead transformations

Lead systems such as the Frank leads [18] and vessel specific leads [19] have previously been derived from the 12-lead ECG to supplement diagnostic information without changing the standard practical procedure of 12-lead ECG acquisition. In a similar way, this study aims to provide three sets of population based transformation weights. These weights could then be implemented to derive three P-wave leads from the 12-lead ECG to improve P-wave signal strength.