A modified Lewis ECG lead system for wearable atrial fibrillation monitoring

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Introduction. Atrial fibrillation (AF) is the most common arrhythmia which is strongly associated with many cardiovascular conditions and increased risk of ischemic stroke [1]. The risk of stroke can be substantially reduced if AF is diagnosed in time and treated with oral anticoagulants. However, AF can be asymptomatic and therefore diagnosed when the stroke has already occurred. Furthermore, AF is a progressive disease and becomes more resistant to treatment when it is prolonged thus it is highly desirable to identify AF in the very beginning of arrhythmia development.

In ECG, AF is defined by a rapid and irregular heart rate and continuous disorganized atrial activity, known as f-waves. Since it is much easier to detect ventricular electrical activity than atrial activity, the majority of methods for AF detection are based on analysis of heart rate irregularity [2]. Nevertheless, such approach is not robust when ectopic beats or other irregular rhythms occur therefore it is beneficial to involve atrial activity information for the purpose of reducing false alarms [3]. Unfortunately, atrial activity analysis is complicated since it has much lower amplitude than ventricular activity and thus it is usually corrupted by noise.

When conventional 12-lead ECG system is used, the highest amplitude of atrial activity is observed in lead II during sinus rhythm, while precordial lead V_1 produces the highest amplitude during AF [4]. In order to detect the beginning of AF, long-term AF monitoring should be applied [5] therefore 12-lead ECG system becomes impractical and more convenient ECG lead configuration should be considered. Such lead placement nowadays known as a Lewis lead system was proposed in the very first book of electrocardiography [6], however, did not get a proper attention. Recently this technique was revived in the paper dealing with the wide QRS complex tachycardia [7]. Despite the fact that two leads of the Lewis configuration were proposed with the purpose to magnify atrial activity during AF, such lead placement requires that one electrode should be placed directly on the right side of the chest. It is well known, that electrode on the chest is very sensitive to hand movements therefore the Lewis lead configuration can be problematic for wearable applications.

To tackle the problem of the lack of specialized ECG lead system for wearable AF monitoring, we propose and quantify a modified Lewis ECG lead placement that does not require any electrode on moving muscles of the body. The aim of the present study is to compare the proposed lead configuration with the Lewis lead system in terms of atrial and ventricular activity amplitude in each lead.

Methods. The novel ECG lead configuration uses three leads from original Lewis lead system that are attached to the body with less muscles (see Fig. 1). Originally, Lewis leads L_1 and L_2 (see Fig. 1 b) have been proposed for atrial activity enhancement [6]. As an alternative we suggest a single lead denoted by M_1 (see Fig. 1 a). It should be noted that ECGs used in the study were recorded during sinus rhythm and we assume that similar tendencies will be seen during AF.

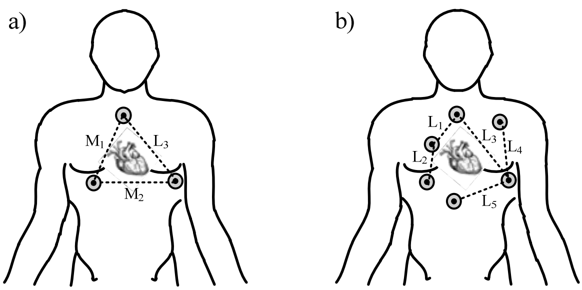

Fig. 1. The modified (a) and original (b) Lewis ECG lead placement. It has to be noted that the lead L_3 is equivalent in both lead configurations

Ten healthy volunteers (9 male) participated in the study. ECG signals were recorded using BIOPAC MP35 (BIOPAC Systems, Inc., Goleta, CA) biomedical data acquisition system using conventional Ag/AgCl electrodes (sampling rate – 1000 Hz, frequency range – 0.05-100 Hz, gain –1000). ECGs were acquired for each lead asynchronously. Amplitude of P wave and QRS complex for each volunteer was determined by finding mean peak to peak amplitude in 10 consecutive ECG beats. The overall results are expressed as mean and two-sided confidence interval (95%). The statistical significance of differences was determined using 2-sample t test. Statistical significance was assumed for $p < 0.05$.

Results. Figure 2 shows that the highest amplitude of both P wave (A_P) and QRS complex (A_{QRS}) is observed in the lead L_3. Surprisingly, both leads that were proposed for atrial activity enhancement (L_1 and L_2) have statistically significantly lower P wave amplitude than the lead L_3. However, due to the much lower amplitude of ventricular activity, leads L_1 and L_2 produce the highest atrial to ventricular activity ratio (A_P / A_{QRS}) of 0.197 ± 0.08 and 0.235 ± 0.148, respectively. When comparing to leads L_1 and L_2, the modified lead M_1 gives higher values for both atrial and ventricular activities, however, no significant difference was observed in A_P / A_{QRS} ratio. In contrast, the component of ventricular activity increases considerably in the lead M_2 thus, as a consequence, the lead M_1 has overall 5.2 times higher A_P / A_{QRS} ratio than the lead M_2. It should be noted that A_P / A_{QRS} ratio of the lead M_2 has narrow confidence interval thus it can be concluded that the latter lead could be valuable when enhanced ventricular activity is desirable.

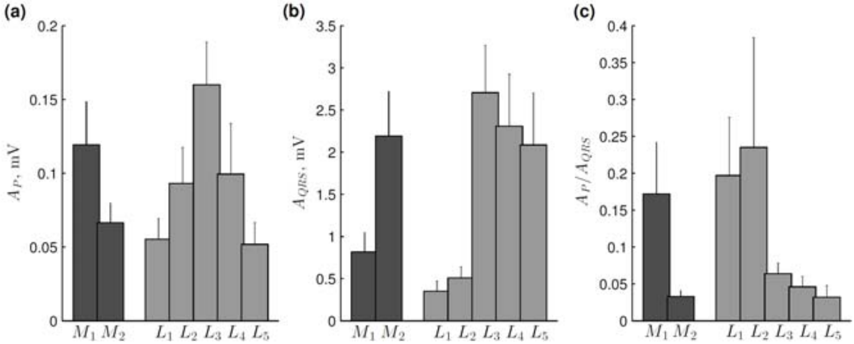

Fig. 2. The comparison of atrial (a) and ventricular (b) activity amplitude, and atrial to ventricular activity ratio (c) using modified and original Lewis ECG lead placement

The typical example of sinus rhythm ECG recorded using modified and original Lewis lead configuration is shown in Fig. 3. It can be observed that the modified lead M_1 produces higher P wave amplitude comparing to Lewis leads L_1 and L_2.

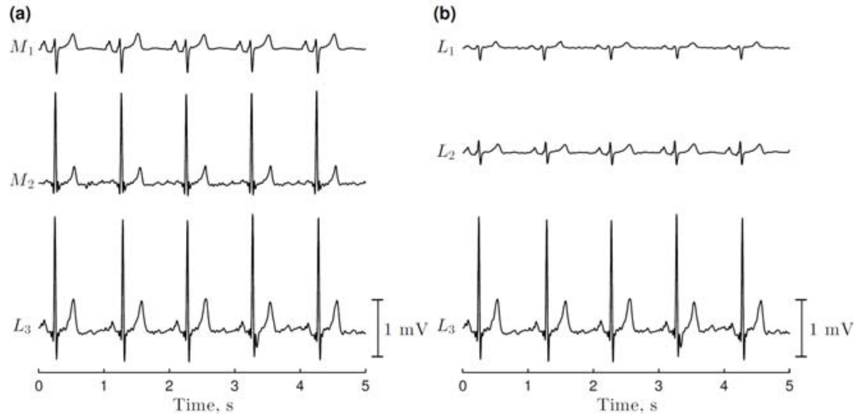

Fig. 3. ECGs recorded during sinus rhythm using modified (a) and original Lewis ECG lead systems (Lewis leads 1-3 are shown only)

Figure 4 shows ECGs recorded during AF and its transition to sinus rhythm using modified Lewis lead system. It is obvious that the lead M_1 has much higher atrial activity amplitude than the lead M_2. Interestingly, although P waves are clearly seen in both leads (the last 5 s) however, f-waves in the lead M_2 are too small to be reliably recognizable (the first 10 s).

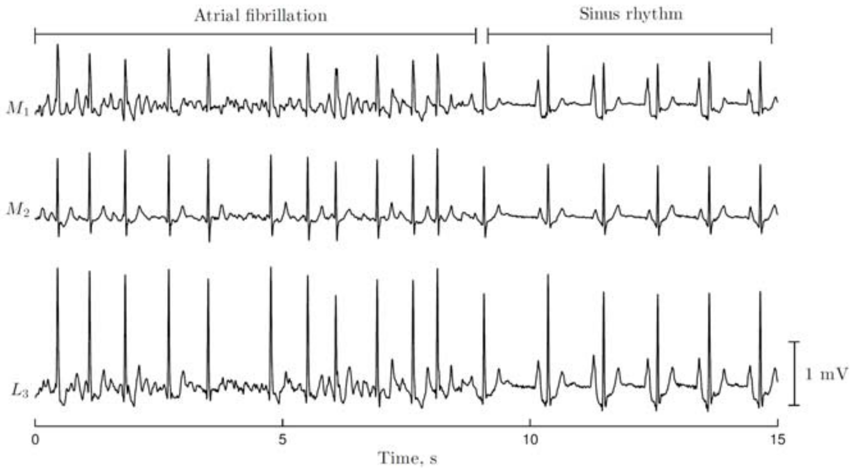

Fig. 4. An example of three lead ECG recorded during AF and its transition to sinus rhythm using modified Lewis lead system

Discussion and conclusions. The present study suggests that the proposed ECG lead system can be useful in special cases of wearable monitoring when high atrial to ventricular activity ratio is required. Despite the fact that electrophysiological mechanisms of AF are quite different from sinus rhythm, there is a reason to assume that similar trends will be maintained in AF (see Fig. 4). The study was conducted with the application of wearable AF monitoring, however, the proposed ECG lead placement could be useful as well for other atrial arrhythmia monitoring, for instance, atrial flutter or atrial tachycardia.

Presented study shows that the lead M_2 produces low atrial to ventricular activity ratio with the lowest inter-subject variability. This observation can be especially important for adaptive filtering applications when lead with negligible atrial activity is indispensable [8]. It is worth noting that the lead L_5 has even slightly lower atrial to ventricular activity ratio comparing to the lead M_2 (0.032 ± 0.016 and 0.033 ± 0.008, respectively), however, the lead L_5 is obtained using electrode on the upper part of the abdomen thus it can be less resistant to body motion artifacts.

The main limitation of the study is a small number of subjects. The results would be more reliable if more subjects with AF were included.

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