Modified Lewis ECG Lead System for Ambulatory Monitoring of Atrial Arrhythmias

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Abstract. *The analysis of atrial activity (AA) during atrial arrhythmias can be problematic when a reduced lead system is used due to low amplitude and noise. Although leads for AA enhancement were proposed many years ago by Sir Thomas Lewis, two electrodes need to be placed directly on the chest, and therefore arm movement artefacts are likely to occur. In this study, we propose a modified Lewis lead system better suited for ambulatory applications where the electrodes are placed in areas with less muscle. The proposed modification was compared to the Lewis leads as well as to the ES lead of the EASI system. Forty-one healthy volunteers and 8 patients with atrial fibrillation participated in the study. The results show that the proposed lead exhibits the best atrial-to-electromyographic activity ratio, with twice as large AA amplitude as the original leads. Furthermore, the atrial-to-ventricular activity ratio is 50% better than that of the ES lead. The results suggest that the proposed modification of the Lewis lead system has a potential to improve ambulatory monitoring of atrial arrhythmias.*

Keywords: Atrial activity enhancement; atrial fibrillation; Lewis ECG lead system

1. Introduction

While it is well-known that atrial fibrillation (AF) is a progressive disease, with brief episodes evolving into longer and eventually persistent, a recent debate has arisen whether brief episodes of AF are related to cryptogenic ischemic stroke [1], [2]. The hypothesis that brief AF episodes (< 30 s) can contribute to thrombus formation has yet to be proven, and thus automatic detection of very short episodes could accelerate more accurate diagnosis. The problem of false alarms due to electromyographic (EMG) noise, motion artefacts, and ectopic beats of commercial equipment for AF detection [3] forces cardiologists to review software-defined arrhythmia episodes manually, especially if AF events are brief [1], [2]. Since manual revision is exceedingly time-consuming and sometimes unreliable [4], increased accuracy of AF detection devices is required to ensure that brief AF events are detected in long-term ECG recordings.

Since most algorithms for AF detection are based solely on the analysis of RR interval irregularity, the many false positives still represent an unsolved problem. While attempts have been made to reduce the number of false positives by involving information on atrial activity (AA) in the AF detection process, the performance of such algorithms has turned out to not be better than those based on RR interval information [3]. The main reason for this outcome is that the conventional 12-lead ECG system, as well as reduced-lead modifications, are focused on ventricular activity (VA), and thus the electrode placement is not optimal for analysing AA. Due to the fact that AA amplitude is small compared to VA, an ECG lead with increased AA amplitude is beneficial to better discriminate between various arrhythmias of atrial origin (atrial tachycardia / flutter / fibrillation), as well other arrhythmias such as wide QRS complex tachycardia [5].

An ECG lead system for AA enhancement was proposed by Sir Thomas Lewis many years ago [6]. Unfortunately, this system requires that two electrodes are placed directly on the chest where arm movement artefacts may occur. In order to avoid leads on the chest muscles, the lead *ES* of the EASI lead system can be employed since it is potentially more immune to noise and offers a good projection of AA. However, there is so far a lack of studies which examine these properties for different leads.

In the present study, we propose a modified Lewis lead system where electrodes have been moved to a thorax area with less muscle. The purpose of the present study is to quantitatively evaluate different leads with respect to AA enhancement, including our proposed modified Lewis system in terms of AA amplitude, atrial-to-ventricular activity ratio, immunity to EMG noise, and motion artefacts. We anticipate that better understanding of the aforementioned properties will help to establish a lead well-suited for atrial arrhythmia monitoring.

2. Methods

The modified Lewis lead, denoted by L_{M1}, was obtained by removing electrode 2 and moving electrode 3 one intercostal space downwards (from 4^{th} to 5^{th}) in order to increase the immunity to arm movements (Fig. 1A). The modified lead system includes two additional leads L_{M2} and L_3. The proposed ECG lead system was compared to the original Lewis leads (L_1, L_2 and L_3) and the lead *ES*.

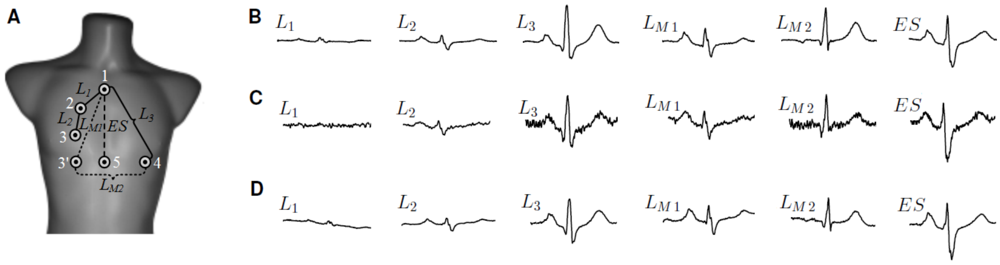

Fig. 1. ECG electrodes placement and ECG signal examples: ECG leads selected for investigation (each line type indicates leads of separate lead system) (A); ECG beats recorded during rest (B), weight holding (C), and exercising on elliptical trainer (D). Note that weight holding increases EMG activity, while exercising on elliptical trainer increases baseline wander.

Two groups of participants were enrolled in the study. The first group was 41 healthy volunteers (16 women), 25.0 ± 5.9 years old, with body mass index (BMI) of 22.2 ± 3.2 kg/m^2. The second group was 8 patients (3 women) with AF, 64.8 ± 9.6 years old, with BMI of 28.7 ± 4.3 kg/m^2. The healthy volunteers were included for the purpose of evaluating artefact related properties, e.g., EMG noise and baseline wander, induced by physical exercise. In order to investigate the peak-to-peak amplitude of AA, the healthy volunteers were asked to sit at rest for one minute. Then, they were instructed to perform two consecutive standardized physical activities which stimulate EMG noise and baseline wander. EMG noise was induced by holding a 1 kg weight with each straight arm horizontally when standing, while workout was performed on an elliptical trainer in order to increase baseline wander. The ECG was recorded simultaneously for each type of activity using the Quark T12x Telemetry Stress Testing ECG recording device (Cosmed, Rome, Italy).

The amplitudes of AA and VA was determined for each healthy volunteer by finding the mean peak-to-peak amplitude in consecutive beats of 1-min ECG segments recorded at rest. EMG noise was extracted by high-pass filtering the ECG signal recorded during weight holding according to the procedure described in [7]. Then, the root-mean-square (RMS) value (γ_{EMG}) of the high-pass filtered signal was computed. Baseline wander was acquired by low-pass filtering (cut-off frequency at 0.5 Hz) 1-min ECG segment recorded during workout on the elliptical trainer. Baseline wander was quantified by the RMS value (γ_{BW}) of the low-pass filtered signal.

The AA amplitude (A_{AA}), the VA amplitude (A_{VA}) and the ratios A_{AA}/A_{VA}, A_{AA}/γ_{EMG}, A_{AA}/γ_{BW} were estimated for each of the studied leads. For AF patients, only amplitude-related properties were computed excluding physical activities. Since relatively large-amplitude f-waves are usually observed in the bipolar limb lead *II* [8], this lead was included for comparison. The mean peak-to-peak amplitude of AA was computed in individual f-waves appearing in the TQ interval so that the influence of VA would be minimal. The overall results are expressed as mean and two-sided confidence interval (95%). The statistical significance of the differences was determined using 2-sample *t*-test.

3. Results

Figure 2A shows that the AA (P wave) amplitudes in L_{M1} and *ES* are nearly 3 times higher than in the original Lewis leads L_1 and L_2. However, due to the markedly suppressed amplitude of VA, the Lewis leads produce the highest A_{AA}/A_{VA} ratio of 0.24 ± 0.04 and 0.23 ± 0.04 for L_1 and L_2, respectively (Fig. 2B). The modified lead L_{M1} has a ratio A_{AA}/A_{VA} (0.23 ± 0.04) similar to that of the original Lewis leads, however, the ratio A_{AA}/A_{VA} of *ES* is significantly lower (0.15 ± 0.02, $p < 0.001$). Moreover, L_{M1} gives the highest AA amplitude comparing to the level of EMG noise and provides statistically significantly higher A_{AA}/γ_{EMG} ratio (5.12 ± 0.72) than the Lewis leads and *ES* (see Fig. 2C). Despite the highest ratio A_{AA}/A_{VA}, the low amplitude of AA in L_1 gives 2.9 times lower A_{AA}/γ_{EMG} ratio than in L_{M1}. Figure 2D demonstrates that the level of baseline wander does not change significantly for any of the AA enhancing leads.

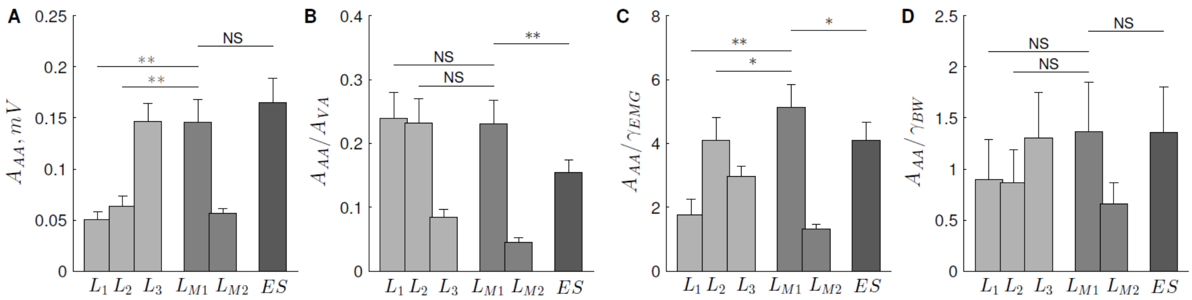

Fig. 2. Healthy volunteers results: the comparison of atrial activity amplitude (A), atrial to ventricular activity ratio (B), atrial to electromyographic activity ratio (C), and atrial activity to baseline wander ratio (D) in different ECG leads. Data represent mean ± CI (95 %); *$p \leq 0.05$, **$p \leq 0.001$, NS for $p > 0.05$.

The results computed from the AF signals show similar A_{AA} and A_{AA}/A_{VA} tendencies as were observed for healthy volunteers (Table 1). The amplitude of AA (f-waves) in L_{M1} is nearly twice as large as in *II*, while A_{AA}/A_{VA} in L_{M1} is 3.5 times higher than in *II*.

Table 1. Results from AF patients: the comparison of AA amplitude in leads of the modified lead system (L_{M1}, L_{M2}, L_3) and lead *II* when AF signals are analyzed. Values shown are mean ± CI (95 %).

Lead	L_{M1}	L_{M2}	L_3	*II*
A_{AA}, mV	0.16 ± 0.09	0.04 ± 0.02	0.13 ± 0.07	0.09 ± 0.05
A_{AA}/A_{VA}	0.21 ± 0.11	0.04 ± 0.03	0.09 ± 0.06	0.06 ± 0.04

4. Discussion

The aim of the present study is to gain better understanding of the properties of ECG leads considered to be suitable for AA enhancement. The potential use of the Lewis lead configuration in clinical practice was recently promoted by Bakker et al. [5], however, according to the findings of this study, very low AA amplitude makes the Lewis leads prone to EMG noise. For long-term monitoring, we suggest the use of the modified Lewis lead which was demonstrated to have twice as large AA amplitude, therefore offering better immunity to EMG noise. Another interesting finding is that L_{M2} is associated with 5 times lower atrial-to-ventricular activity ratio than is L_{M1}, together with a low inter-subject variability. This finding can be especially important for f-wave extraction from ECG signal using adaptive filtering approach when a lead with negligible atrial activity is required [9].

5. Conclusions

This study shows that the modified Lewis lead has the best atrial to electromyographic activity ratio and produces twice as large amplitude of atrial activity as does the original leads. The results suggest that the proposed modification of the Lewis lead system has potential to improve ambulatory monitoring of atrial arrhythmias.

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