Normal limits of ECG measurements related to atrial activity using a modified limb lead system

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Abstract

Objective: The present study was designed to derive the normal limits of a new ECG lead system aimed at enhancing the amplitude of atrial potentials through the use of bipolar chest leads.

Methods: Sixty healthy male subjects, mean age 38.85±8.76 years (range 25 to 58 years) were included in this study. In addition to a standard 12-lead ECG, a modified limb lead (MLL) ECG was recorded for 60 sec with the RA electrode placed in the 3rd right intercostal space slightly to the left of the mid-clavicular line, the LA electrode placed in the 5th right intercostal space slightly to the right of the mid-clavicular line and the LL electrode placed in the 5th right intercostal space on the mid- clavicular line.

Results: In the frontal plane, the modification of limb electrode positions produced significant changes compared to standard limb lead I and II. The mean P wave amplitude was 111±17μV in MLL I and 64±16μV in standard limb lead (SLL) I ($p<0.001$). Similarly it was 118±22μV in MLL II and 100±27μV in SLL II. No statistically significant changes were seen in V_1-V_6 due to modification of the Wilson central terminal electrode positions.

Conclusion: The modification of limb electrode placement leads to changes in the amplitude of the P waves in the MLL leads I and II compared to SLL leads I and II in healthy subjects. These changes may be of importance in the detection of atrial electrical activity.

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Key words: atrial activity, electrocardiogram, healthy volunteers, modified limb electrode positions

Introduction

The standard positioning of the limb lead electrodes for recording the electrocardiogram was first devised by Einthoven (1). Wilson et al. (2) subsequently introduced unipolar leads and chest lead positions were later standardized (3). In conditions where limbs become clinically inaccessible, the modified limb electrode position on the torso address the problem (4). Mason et al. (5) proposed alternative limb electrodes for use in exercise stress testing.

A variety of modified limb electrode configurations placed on the torso has been proposed for varying situations (6-9). However, the relocation of limb electrode positions to the torso has an effect on the wave amplitudes in the frontal plane of the ECG and significant changes in measurements have been noted as a result (10-18). It has also been reported that with a modified limb electrode placement, no significant changes were observed in the ECG waveform of the transverse plane, as the precordial leads are unchanged (19, 20).

In addition to the modification of limb electrode positions, several other alternative lead systems, placed on the human torso, exist for recording and studying the electrical activity of the atria (21). Lewis et al.(22) first described the use of special leads to study the atrial waves in the case of atrial fibrillation, and found that the atrial oscillations are maximal when the electrodes were placed over the right atrium. Further study by Drury et al. (23) described the presence of maximal atrial oscillations during atrial fibrillation using sternal and antero-posterior leads, which was in agreement with the initial study of Lewis. Holzman (24) observed the presence of the largest atrial deflection when the exploring electrode was placed to the right of the sternum. Lian et al. (25) studied the atrial rhythm by placing the exploring electrode on the manubrium sterni. Schoenewald (26) obtained a clearer P wave than in standard lead II by placing the explor-

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ing electrode on the right border of the sternum, at the level of the third intercostal space. Evans (27) studied the atrial activity in lead CR1 in cases of atrial fibrillation and showed that the atrial oscillations were prominent in his lead system. Barker et al. (28) showed that by placing an electrode over the upper part of the sternum and another over the ensiform process, it is possible to record a large atrial P wave when the P waves are small and indistinct in the standard leads of the same patients.

The clinical significance of six unipolar precordial chest leads, placed on the human torso for studying the electrical activity of the left and right ventricles is well established (29). Sivaraman et al. (30) described a novel modification of limb electrode placement for unmasking the atrial Ta wave in healthy subjects and in patients with different degrees of AV block. In the present study, the authors report on the normal limits of P wave amplitudes and axis using this system.

Methods

Subjects

Healthy male subjects were used for this study. None had hypertension or any other clinical abnormality that might affect the cardiovascular system. Smokers were excluded from this study which was approved by the institute ethics committee. Before data recording, all subjects gave informed consent to their participation in this study.

Modified limb electrode placement

The modified limb electrode placement which produces the modified limb lead (MLL) system is as follows (Fig. 1). The right arm electrode is placed on the subject's third right intercostal space, slightly to the left of the mid-clavicular line. The left arm electrode is placed in the 5th right intercostal space, slightly to the right of the mid-clavicular line and the left leg electrode is placed in the 5th right intercostal space, on the mid-clavicular line. The right leg electrode is placed on the subject's right ankle. The polarity of the right arm electrode is negative and the polarity of the left arm and left leg electrode is positive and with this polarity the MLL ECG was recorded and analyzed. The standard precordial leads V_1-V_6 are essentially unchanged during the MLL recordings.

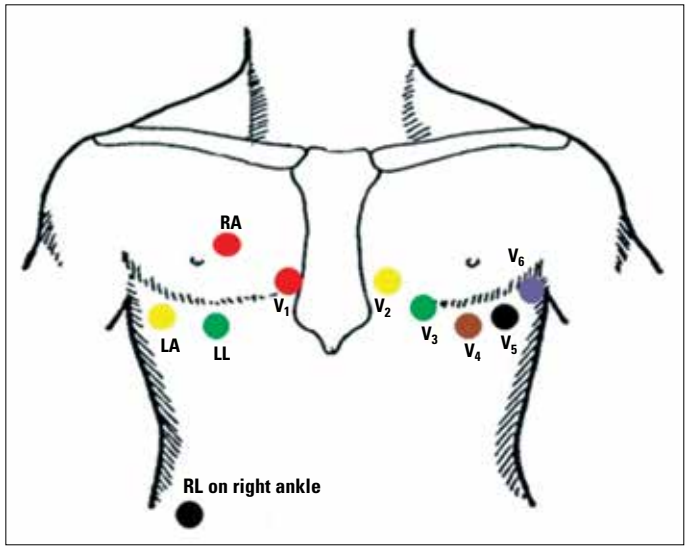

Figure 1. Modified limb electrode placement. The precordial leads V_1-V_6 are unchanged

Data acquisition and analysis

Each subject's systolic, diastolic and mean blood pressure was measured using a patient monitoring system (Cardio Care India Pvt. Ltd). A digital ECG recorder (EDAN SE-1010 PC ECG system, EDAN Instruments, Inc., China) operating at 1000 samples per second with a frequency response of 0.05Hz to 150Hz was used to acquire ECG data. ECGs could be printed at variable gain from 2.5 mm/mV to 20 mm/mV and variable paper speed of 5 mm/s to 50 mm/s. The standard 12-lead ECG and the modified limb lead ECG were recorded at the standard ECG paper speed of 25 mm/sec and 10 mm/mV with the EDAN SE-1010 ECG system. Various measurements such as PR interval and P wave amplitude were recorded from the EDAN printout.

Statistical analysis

Data are expressed as mean±standard deviation. The Student t-test was used to analyze paired and unpaired data. The Shapiro-Wilkinson W test was used for testing normality of the data. Linear regression analysis was performed on the data for the mean distribution of the p axis. All tests were two-sided and $p<0.001$ was considered statistically significant. The collected data were statistically evaluated using Win STAT in Excel for Windows (Microsoft Office 2010).

Results

Sixty healthy male subjects of mean age 38.9±8.8 (range 25 to 58) years with normal body composition were recruited. All the measured ECG data were found to be normally distributed. All 12 lead ECGs were reported as being within normal limits. An example of the standard 12 lead ECG recorded at standard ECG paper speed and gain with the EDAN ECG system is shown in Figure 2. The modified limb lead ECG, recorded in the same healthy male subject using the EDAN system is shown in Figure 3.

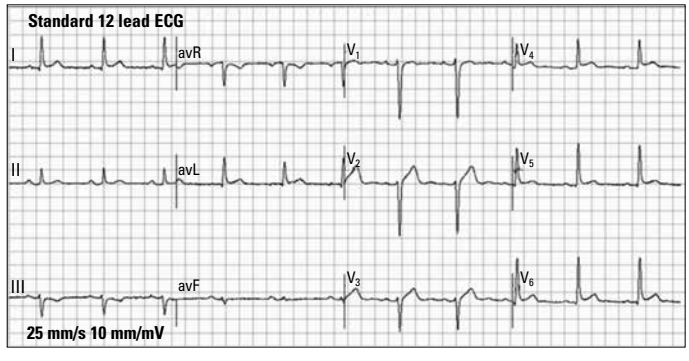

Figure 2. Standard 12-lead ECG of a healthy male subject. The R wave has maximum amplitude in all the leads. The atrial P wave amplitudes are minimal compared with the R wave amplitudes in the limb leads

It is seen that very large QRS amplitude changes take place with the modification of the limb electrode positions. As the left arm electrode and left leg electrode are beside each other in the modified limb electrode position, lead III was essentially seen as flat trace in all the recordings. The modified limb lead ECG is in agreement with the time relationships between the electrical activity of the atrial and the ventricular phenomenon, described by Tranchesi et al. (31).

P wave axis

Compared to the standard 12-lead ECG, modified limb electrode placement results in a frontal plane P wave axis shift. The distribution of the P wave axis in the standard limb lead (SLL) system and MLL system is shown in Figure 4A. Figure 4B shows the distribution of the mean P wave axis of standard electrode positions (x-axis) versus the change in the axis measurement, when the electrodes are moved to the modified positions. The frontal plane P wave axis measurements are shown in Table 1. The frontal P wave axis in the modified limb lead system has an average value of 31±4° relative to the revised lead directions associated with the MLL system leads I and II. The mean difference of the P wave axis between the standard and modified limb electrode (S-M) was found to be 27°. The difference in P wave axis between the standard and the modified limb electrode placement system is statistically significant ($p<0.001$).

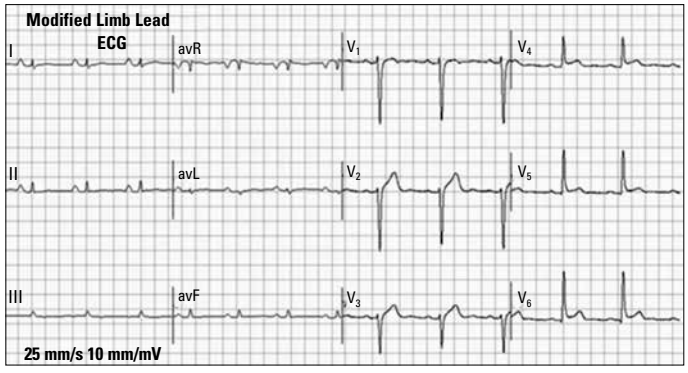

Figure 3. Modified limb lead ECG of the same healthy male subject used in the standard 12 lead ECG. The MLL ECG shows the presence of large P wave amplitudes and reduced R wave amplitudes in the limb leads

P wave amplitudes

Consequent to the frontal plane axis shift produced by the modification of the limb electrode positions, it is noted that P wave amplitude differences occur in the frontal plane leads. The plot of mean±SE of P wave amplitudes in MLL and SLL recordings is shown in Figure 4C. The amplitude values of the modified limb electrode P waves are shown in Table 2.

Intervals

Modification of limb electrode has no effect on the temporal aspects of the ECG waveform as shown in Table 3.

Discussion

The novel modification of the limb electrode positions was originally designed to facilitate the study of atrial Ta waves in healthy male subjects with a view to studying Ta waves in patients with AV block (30). The normal human atrial depolarization wavefront advances from the sinus node in the right atrium and through the left atrial muscle, resulting in a mean P vector which moves in a direction somewhat similar to the lead II axis in the conventional 12 lead system. The mean P wave axis is therefore approximately 60° and was indeed found to be 58°±16° (Table 1).

It goes without saying that the major QRS components of the modified limb lead system are greatly changed compared to the amplitudes from leads I, II, III derived from the standard lead position. Indeed, lead III is essentially a relatively flat tracing because the left arm and left leg electrodes are placed close together on the torso.

In the modified limb lead system, the measurement of axis is to some extent meaningless. The directions associated with the modified lead I and lead II are relatively close so the use of conventional equations to derive P vector axis based on the Einthoven Triangle lead to values for P axis which have no physiological meaning whatsoever. However, for the sake of completeness, they are presented in Table 1. It can be seen that the range of approximately 20° is significantly reduced, compared to the normal range of 70°. This is a consequence of having the modified limb lead system.

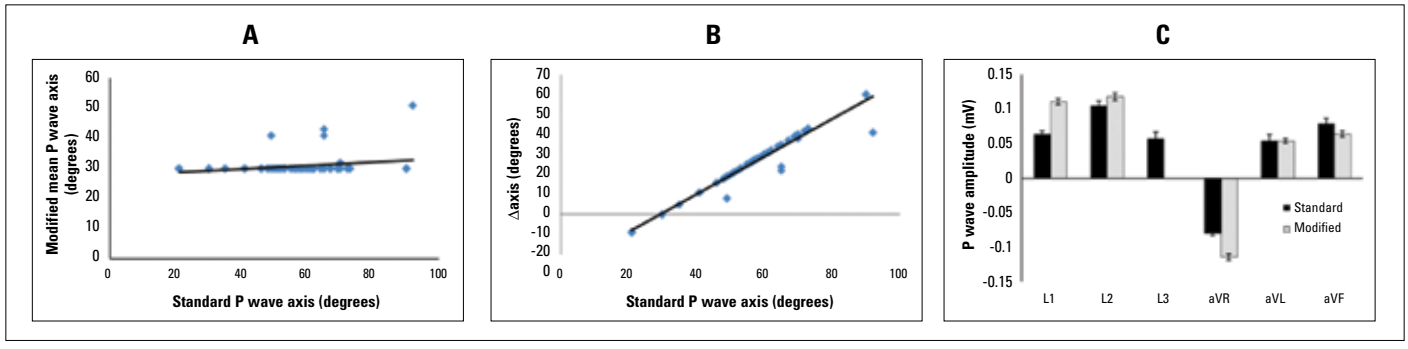

Figure 4. (A) Distribution of mean P wave axis in the standard limb electrode positions and the modified limb electrode positions. (B) Distribution of mean P wave axis in the standard limb electrode positions (x-axis) versus the change in the measurement when the electrodes are moved to the modified positions. The equation of the regression line is ΔP axis (°)=27.66-0.942 *P where P is the P wave axis. (C) Plot of mean±SE of P wave amplitudes for the standard and the modified electrode positions

Table 1. Changes in the waveform frontal plane axis

Electrocardiographic axis in degrees for healthy subjects ECG								
	Standard limb leads (SLL)			Modified limb leads (MLL)			Difference	
	Mean	SD	Range	Mean	SD	Range	S-M	*P* value*
P axis	57.93	15.51	21 to 92	30.96	3.68	30 to 51	26.97	<0.001
SD - standard deviation; *Paired sample t-test								

Table 2. ECG waves with the standard and modification of the limb electrode positions. Mean values are listed for the difference (M-S) in which positive values indicate an increase in amplitude and negative values indicate a decrease caused by modification. Percentage gains in mean amplitudes are also provided. Amplitudes are in microvolts. N/A=not applicable

Measurement	Lead	Standard position (SLL)		Modified position (MLL)		Modified-Standard position (% change)
		Mean	SD	Mean	SD	Mean
P amplitude	I	64	18	111	17	47 (73.4%)
	II	100	27	118	22	18 (18.0%)
	III	57	38	0	0	-57 (N/A)
	aVR	-80	10	-114	18	34 (42.5%)
	aVL	54	36	68	13	14 (25.9%)
	aVF	70	30	64	15	-6 (-0.09%)
MLL - modified limb leads; SD - standard deviation; values are in micro volts; SLL - standard limb leads						

Table 3. Modification produced no measurable temporal changes in the ECG waveform in all frontal planes

	Standard limb lead (SLL) ECG			Modified limb lead (MLL) ECG			
	Mean	SD	Range	Mean	SD	Range	*P* value*
PR Interval	160.16	9.76	140 to 176	161.16	8.76	144 to 177	>0.001
QRS wave	94.38	8.71	78 to 109	92.98	9.23	78 to 106	>0.001
QT Interval	341.23	21.36	302 to 380	344.57	19.98	302 to 388	>0.001
SD - standard deviation; *Paired sample t-test; values are in milliseconds							

The modified limb lead system was designed to study the amplitude and duration of the Ta wave associated with atrial repolarization. This aspect will be presented in a separate paper. The lead system needs to be evaluated in patients, perhaps with atrial infarction or even pericarditis, to see what changes might be found in the P wave amplitude and the PR segment, which may be depressed in inferior leads and possibly elevated in aVR and V1 (32).

Study limitations

The results of the present study are valid only for resting, supine healthy male subjects. No healthy female subjects were included in this study.

Conclusion

The conventional ECG has significant limitations in analyzing atrial depolarization and repolarization wave patterns. This modified limb lead system may throw more light on atrial depolarization and repolarization vectors which are the major trigger for many of the atrial arrhythmias.

The modification of limb electrode placement enhances the amplitude of the P wave compared to the standard limb leads. It remains to be examined further in patients with various forms of heart block and other cardiac arrhythmias and ideally, at some stage in the future, patients with acute myocardial infarction.

Conflict of interest: None declared.

Peer-review: Externally peer-reviewed.

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