Correction of ECG Variations Due to Non-Standard Electrode Positions

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Abstract

Electrode positions for continuous monitoring of the 12-lead ECG are different from those for recording a standard 12-lead ECG. To reduce noise and to minimize false alarms, proximal placement of the limb leads is preferred over the standard location at the wrists and ankle. These differences are often associated with apparent frontal QRS-axis shifts, disappearing Q-waves in the inferior leads, and marked changes of R amplitudes in leads I and II. These changes make it difficult to compare ECGs. This study presents a general and patient-specific method to correct for these changes.

1. Introduction

Electrode positions for continuous monitoring in a clinical environment are different from those for recording of a standard 12-lead resting ECG. To reduce noise and to minimize false alarms, proximal placement of the extremity electrodes is preferred over the standard location at the wrists and ankle.

In previous investigations by Sevilla [1], Pahlm [2], and Krucoff [3], changes between standard and monitoring ECGs are often associated with frontal QRS-axis shifts, disappearing Q-waves in the inferior leads and marked changes of R amplitudes in leads I and II. These changes make it difficult to compare ECGs in retrospect.

The purpose of this study was to provide a method to correct for these changes using general and patient-specific reconstruction methods.

2. Materials and methods

2.1. Study population

The study population consisted of 80 subjects who were admitted to the coronary care unit of the University Hospital Rotterdam due to chest pain or suspicion of acute myocardial infarction. The subjects were predominantly male (59 of 80) with an average age of 65 years (range: 36-78). At the start of the recording, all patients were hemodynamically stable and free of chest pain, ongoing ischemia or infarction.

2.2. Data collection

For each subject, two 9-lead ECGs were recorded using a standard 12-lead ECG patient monitor (SC7000, Siemens, Danvers, USA). This setup was first described by Pahlm [2,4] and allows simultaneous recording of the limb leads in standard and in monitoring position. In this modified 12-lead configuration, the electrodes V2, V3 and V5 remain on the standard chest position and the V1, V4 and V6 electrodes are placed on the monitoring locations RA, LA, and LL (Figure 1) at the Mason-Likar positions [5]. With these electrode measurements, leads I and II can be computed off-line for the monitoring positions.
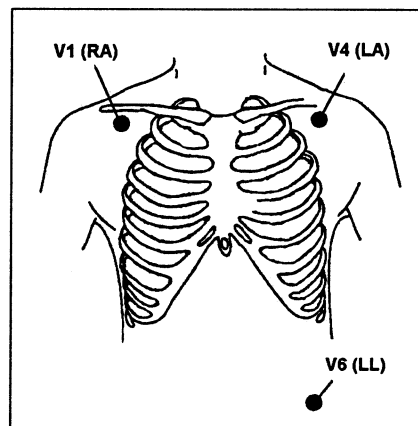

Figure 1. Alternative placements of the electrodes V1, V4 and V6 on the monitoring locations RA, LA, and LL.

The ECGs were recorded at a sampling rate of 500 Hz with a resolution of 2.5 μV, for 10 seconds. ECG samples, measurements and diagnostic statements were obtained from the output of the Siemens resting ECG program.

2.3. Data analysis

We performed a cross-validation analysis ('leave-one-out'), because of the limited size of our data set. For each recording, general reconstruction coefficients were computed from the remaining recordings and were applied to the ease at hand.
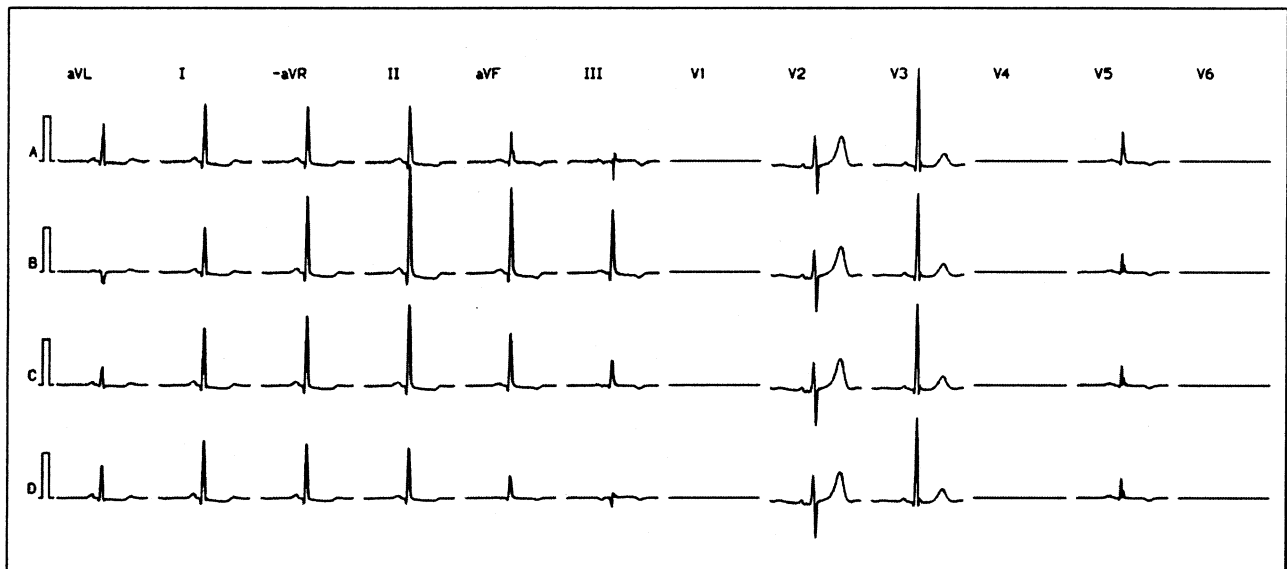
Figure 2. Example of ECG correction from monitoring to standard locations: (A) Reference ECG with the extremity electrodes placed on the ankle and wrists; (B) ECG with the extremity electrodes in monitoring locations; (C) Corrected ECG using general coefficients (D) Corrected ECG using patient-specific coefficients.

General coefficients for leads I and II were calculated using linear regression. Patient-specific coefficients for each ECG were also computed and applied.

Overall waveform similarity was assessed by correlation and by similarity ($SC=1.0-RMS_{error}/RMS_{signal}$) [6] between the QRS-T complexes of the original and reconstructed leads I and II. In addition, we determined the difference between the QRS-axis in the frontal plane.

Unless specified otherwise, values are reported as average and standard deviation.

3. Results

Recordings were obtained from 80 patients. The amplitudes in leads I and II in the monitoring positions were overall higher than the amplitudes of leads I and II in standard position. Frontal QRS-axis shifts were observed between the standard and monitoring limb leads. Differences greater than 30 degrees were found in 18 cases (22.5%). In 4 recordings, Q-wave changes were found. Small differences were observed between the original and corrected precordial leads. Differences between the central terminals were also small (5±4 μV), and remained in the order of the quantization level.

Similarity results of the standard and monitoring ECGs, before and after general and patient-specific correction, are presented in table 1. In the uncorrected situation, average correlations for leads I and II were relatively high (>0.955), but were overall lower than for the corrected ECGs. The standard deviation of lead I was larger than lead II. The similarity coefficients of the uncorrected ECGs were moderate and also had large standard deviations.

Performance of general correction was high. The corrected and standard ECG waveforms were very similar in most patients. Figure 2 shows an example of a corrected recording using general and patient-specific coefficients. Average correlations (>0.97) between the standard and reconstructed waveforms were much higher than the uncorrected average correlations, but the standard deviations remained large. Similar results were obtained for the averages and standard deviations of the similarity coefficients.

Patient-specific performances were overall better than general. Average correlations for lead I and II were much higher (>0.99) with small standard deviations. Similarity coefficients also increased greatly, while the standard deviations decreased substantially.

The average QRS-axis difference in the uncorrected situation was −10 degrees with a large standard deviation of 25 degrees. However, the median QRS-axis difference was −2 degrees with an interquartile range of (−3, 4). Thus, most QRS-Axis differences were very small, but the standard deviations were affected by the 18 cases with differences greater than 30 degrees. For general correction, the average QRS-axis difference was very small (−1.9 degrees), but still showed a high standard deviation (26 degrees). For patient-specific correction, the standard deviation substantially decreased, while the average difference remained small.

Finally, we split the data in equally sized learning and test sets and determined general reconstruction coefficients from the learning set. When these were applied to the test set, similar results were obtained. Average correlations for lead I and II were 0.969±0.109 and 0.984±0.033, and average similarity results were 0.764±0.221 and 0.785±0.162.

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Table 1: Similarity results between leads derived from electrodes in monitoring and in standard positions.

Correction method	Correlation		Similarity Coefficient		QRS-axis difference
	Lead I	Lead II	Lead I	Lead II	
None	0.955 ± 0.186 *	0.982 ± 0.036	0.684 ± 0.246	0.621 ± 0.253	−10 ± 25
General	0.970 ± 0.138	0.986 ± 0.037	0.741 ± 0.236	0.784 ± 0.170	−1.9 ± 26
Patient-specific	0.990 ± 0.028	0.993 ± 0.015	0.891 ± 0.082	0.899 ± 0.097	2 ± 10

* mean ± standard deviation

4. Discussion

This study shows that limb leads can be mapped from monitoring to standard limb leads positions using general and patient-specific coefficients. General correction performs worse than patient-specific.

A practical application of these methods is that ECGs recorded with a bedside monitor can be corrected and allow serial comparison with previously recorded standard ECGs.

Furthermore, these methods can also be applied during online ST-T monitoring. During retrospective ST-T analysis, the ST trends and complexes of the limb leads can be corrected to the standard position. With the same techniques, it is also possible to correct any ECG from standard limb lead positions to the monitoring position.

In a previous investigation by Bartosik [4], general coefficients were computed from a set of 30 patients. The limb leads in this study were mapped from positions introduced by Krucoff [7] to standard positions. We also applied the Bartosik-coefficients to our data set (not reported), but found that these coefficients performed slightly worse. A possible explanation is that general correction is influenced by the placement of the electrodes, while patient-specific is not provided that the electrode locations do not change during monitoring. Patient-specific correction can be applied in any position, but requires the additional recording of a 9-lead ECG. For general reconstruction, it may also be possible to select a particular set of coefficients depending on the particular lead set used. Automatic detection of the electrode locations [8] can be used for selecting the appropriate general coefficients.

In this study, we only calculated performance results for leads I and II. Even though lead III and the augmented leads can be calculated from these independent leads, errors may accumulate. We also did not compare the diagnostic statements between the standard ECGs and the corrected ECGs.

5. Conclusion

Mapping ECG leads from monitoring positions to standard positions is possible using general and patient-specific coefficients. Patient-specific correction gives a better performance than general corrections, but requires

the recording of an additional ECG. General correction can be still applied with high accuracy provided that the electrode positions are known.

References

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