Correction of ECG Variations Caused by Body Position Changes and Electrode Placement During ST-T Monitoring

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Abstract: *Background:* Electrocardiogram variations (ECG) due to body position changes and electrode placements are common problems of continuous ST-T monitoring. Body position changes may cause QRS and ST-T changes and trigger false alarms. Placement of arm and leg electrodes in a coronary care unit environment is usually near the thorax instead of standard position at the wrists and ankles. This may affect the limb leads and complicate diagnostic interpretation. The purpose of this study was to assess the effects of these sources of ECG variation and to correct for them. Continuous 12-lead ECG recordings were obtained from 160 patients admitted to the coronary care unit. Each patient underwent a body position test (supine, left-lateral, and upright position). Scalar and spatial approaches were investigated for reconstruction of the ECG in supine position. The scalar approach uses linear regression. The spatial approach transforms the ECG into a derived vestorcardiogram. The spatial QRS-loop is then rotated and scaled to match the vector loop in supine position and transformed back to a 12-lead ECG. *Materials and Methods:* To assess the effect of electrode placement, monitoring and standard limb leads were simultaneously recorded in a group of 80 patients. To map the monitoring leads to standard leads, general and patient-specific reconstruction coefficients were derived by linear regression from half of the patients and tested on the other half. Similarity between the reference and reconstructed ECGs was measured by correlation, similarity coefficient [(SC=1-RMS(residual error)/RMS(signal)], and difference in frontal QRS-Axis. *Results and Conclusion:* Only 14% (23 of 160) of the patients showed marked ECG changes (ST elevations, QRS-axis shifts, T-wave inversions). The scalar method (median correlation > 0.994, SC > 0.902, QRS axis difference 0 degrees) performed better than spatial (median correlation 0.946, SC > 0.792, QRS axis difference 0 degrees). Monitoring leads can be mapped to standard limb leads in good to excellent approximaiton. General reconstruction (median correlation 0.993 and SC 0.764) performed slightly worse than patient-specific reconstruction (median correlation 0.997 and SC 0.908). **Key words:** Electrocardiography, lead reconstruction, electrode placement.

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Table 1. Similarity Between Reference ECGs in Supine Position and Corrected ECGs for Different Body Position Changes of 160 Patients

Body Position	Scalar Correction: Correlation	Scalar Correction: Similarity Coefficient	Scalar Correction: QRS-axis Difference	Spatial Correction: Correlation	Spatial Correction: Similarity Coefficient	Spatial Correction: QRS-axis Difference
Left-lateral	0.995 (0.991,0.999)*	0.910 (0.875,0.935)	0 (−5,3)	0.949 (0.907,0.961)	0.800 (0.510,0.870)	0 (−7,4)
Right-lateral	0.994 (0.989, 0.999)	0.902 (0.855,0.940)	0 (−2,3)	0.946 (0.903,0.953)	0.792 (0.495,0.899)	0 (−2,3)
Upright	0.998 (0.991, 0.999)	0.906 (0.880,0.952)	0 (−2,4)	0.950 (0.910,0.963)	0.802 (0.506,0.901)	0 (−3,6)

*Values are median (interquartile range). NOTE. For each pair of ECGs, the average of the correlations and similarity coefficients over the 8 independent leads has been taken.

Electrocardiogram (ECG) variations caused by body position changes and electrode placements are common problems of continuous ST-T monitoring. Body position changes may cause QRS and ST-T changes and trigger false alarms (1–3). In addition, placement of arm and leg electrodes in a coronary care unit is usually near the thorax rather than at standard positions on wrists and ankles. This may affect the limb leads and complicate diagnostic interpretation (4–6). This study assesses the effects of these sources of ECG variation and corrects them.

Material and Methods

Continuous 12-lead ECG recordings were obtained from 160 patients admitted to the coronary care unit. For each patient, a series of controlled body position tests (left-lateral, right-lateral, and upright positions) were performed. Reference ECGs were obtained in the supine position. Scalar and spatial approaches were investigated for reconstructing the reference ECG during body position change. The scalar approach uses linear regression. The spatial approach transforms the ECG into a vectorcardiogram using the inverse Dower transformation (7). The spatial QRS loop is then rotated and scaled to match the vector loop in supine position, and transformed back to a 12-lead ECG (8).

To assess the effect of electrode placement, monitoring and standard limb leads were simultaneously recorded in a group of 80 patients. To map the monitoring leads to the standard leads, general reconstruction coefficients were derived by linear regression from half of the patients and tested on the other half. Also, patient-specific reconstruction was performed.

Similarity between the reference and reconstructed ECGs was measured by correlation, similarity coefficient [1-RMS(residual error)/RMS(signal)], and difference in frontal QRS-axis.

Results

Only 14% (23 of 160) of the patients showed marked ECG changes (ST elevations, QRS-axis shifts, T-wave inversions) due to changes in body position. Figures 1 and 2 illustrate the effect of a left-lateral position change and the correction of ECG and ST-trends. In general, different body position changes are equally well corrected, but scalar correction is superior to spatial correction (Table 1). As shown in Table 2, standard leads I and II can accurately be reconstructed from the corresponding leads in monitoring position, especially when patient-specific reconstruction is applied.

Table 2. Similarity Between Leads Derived From Electrodes in Monitoring and Standard Limb Positions on a Test Set of 40 Patients

Reconstruction Method	Correlation: Lead I	Correlation: Lead II	Similarity Coefficient: Lead I	Similarity Coefficient: Lead II	QRS-axis Difference
None	0.989 (0.976,0.997)*	0.994 (0.977,0.997)	0.755 (0.661,0.805)	0.683 (0.478,0.791)	−2 (−4,3)
General	0.993 (0.984, 0.998)	0.996 (0.980,0.999)	0.764 (0.660,0.870)	0.802 (0.661,0.846)	0 (−2,3)
Patient-specific	0.997 (0.992, 0.998)	0.998 (0.990,0.999)	0.908 (0.867,0.924)	0.916 (0.833,0.949)	1 (−1,2)

*Values are median (interquartile range).

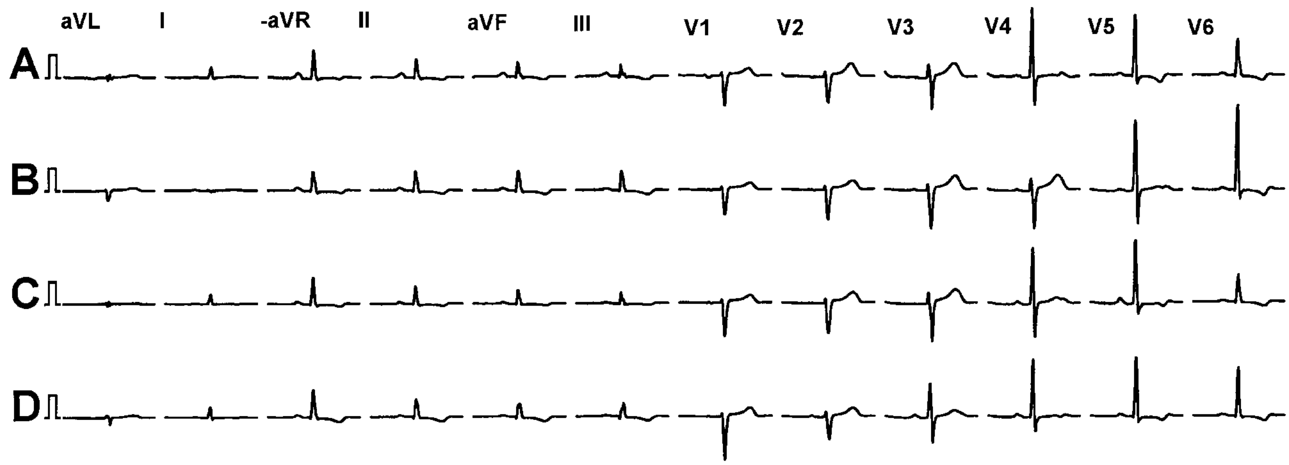

Fig. 1. Example of ECG correction for body position change. (A) Reference ECG with the patient in supine position; (B) ECG with the patient in left-lateral position; (C) Reconstructed supine ECG using the scalar method; (D) Reconstructed supine ECG using the spatial method.

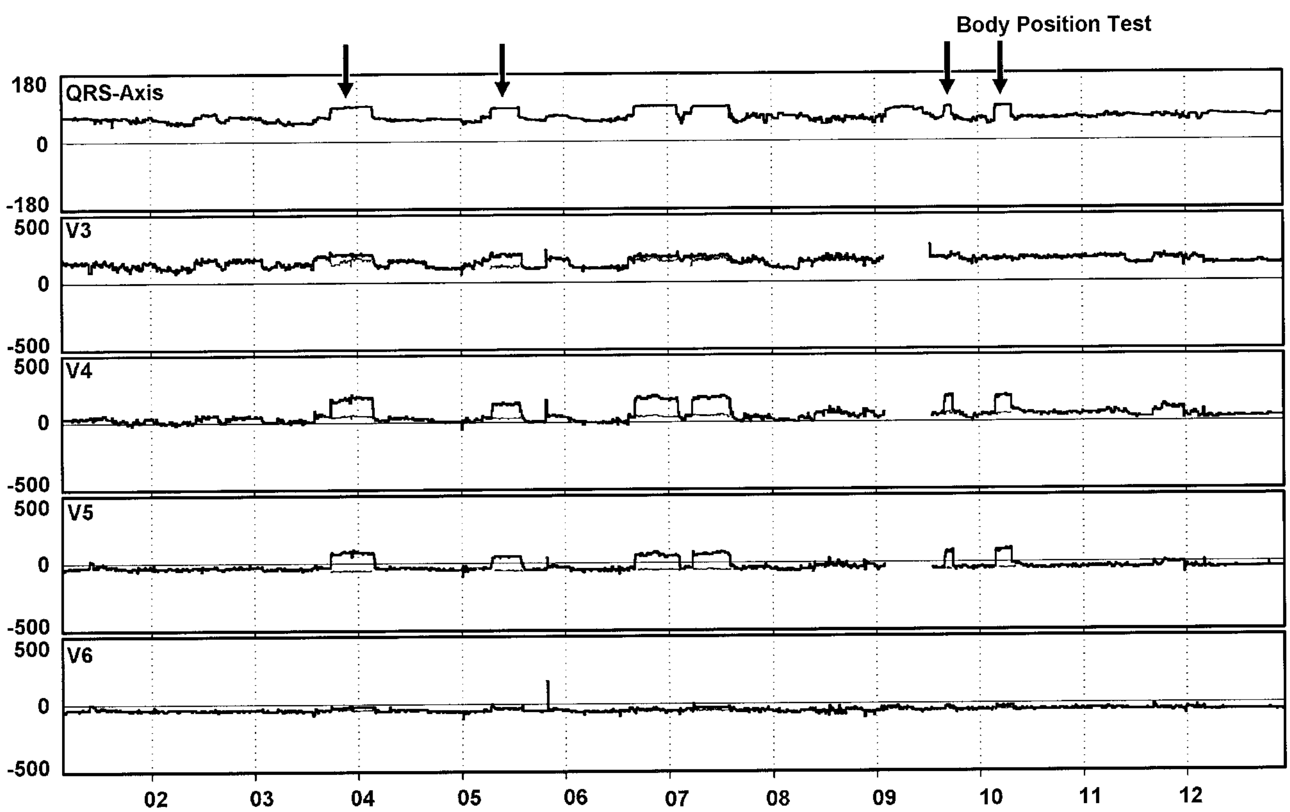

Fig. 2. Example of body position corrections for the ST amplitude at 60 ms after QRS offset in leads V3 to V6 of the patient shown in Figure 1. The arrows indicate periods during the night when the patient turned to left-lateral position. Two body position tests were performed around 10 a.m. The original ST trend is represented by the thick lines; thin lines during the left-lateral position changes indicate the corrected trend.

Conclusion

Results indicate that, in our population, ECG variations caused by body position changes can be corrected with the scalar method; the spatial method performs less well. Monitoring leads can be mapped to standard limb leads in good to excellent approximation.

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