Computing the Spatial QRS-T Angle Using Reduced Electrocardiographic Lead Sets

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Abstract

The 'spatial QRS-T angle' (SA) is frequently determined using linear lead transformation matrices that require the entire 12-lead electrocardiogram (ECG). While this approach is adequate when using 12-lead ECG data that is recorded in the resting supine position, it is not optimal in monitoring applications. This is because maintaining a good quality recording of the complete 12-lead ECG in monitoring applications is difficult. In this research we assessed the differences between the 'gold standard' SA as determined using the Frank VGG and the SA as determined using different reduced lead systems (RLSs). The random error component (span of the Bland-Altman 95% limits of agreement) of the differences between the 'gold standard' SA and the SA values based upon the different RLSs was quantified. This was performed for all 62 RLSs that can be constructed from Mason-Likar (ML) limb leads I, II and all possible precordial lead subsets that contain between one and five of the

precordial leads V1 to V6. The RLS with the smallest lead set size that produced SA estimates of a quality similar to what is achieved using the ML 12-lead ECG was based upon ML limb leads I, II and precordial leads V1, V3 and V6. The random error component (mean [95% confidence interval]) associated with this RLS and the ML 12-lead ECG were found to be 40.74° [35.56°; 49.29°] and 39.57° [33.78°; 45.70°] respectively. Our findings suggest that a RLS that is based upon the ML limb leads I and II and the three best precordial leads can yield SA estimates of a quality similar to what is achieved when using the complete ML 12-lead ECG.

1. Introduction

The spatial QRS-T angle (SA) allows for the quantification of the relationship between ventricular depolarization and ventricular repolarization. A wide SA indicates an abnormal relationship between ventricular depolarization and repolarization [1]. Previous research has established the clinical value of the SA in different applications [2-4]. The SA is a vectorcardiographic parameter and typically identified using the Frank Vectorcardiogram (VCG) [5, 6]. However, the Frank VCG is not commonly recorded in present day clinical practice.

Instead, the SA is typically obtained from VCG data that is estimated or derived from the 12-lead electrocardiogram (ECG). The derived VCG data is typically obtained using linear lead transformation matrices. Different linear lead transformation matrices that allow for the derivation of Frank VCGs from 12-lead ECG data were previously developed [6, 7]. The Kors matrix has been

reported to yield the most accurate estimates of the SA when standard (distal limb electrodes) 12-lead ECG data is used [8, 9]. Previous research [10] has shown that the Guldenring matrix should be used when deriving the SA from the Mason-Likar (ML) 12-lead ECG [11]. This makes the Guldenring matrix the linear lead transformation matrix of choice in applications such as ECG monitoring where ML 12-lead ECG data is frequently recorded. However, the derivation of the SA from the ML 12-lead ECG using the Guldenring matrix requires ML limb leads I and II and the precordial leads V1 to V6. This is problematic as maintaining the electrical contact of the ten electrodes that are required for the recording of the ML 12-lead ECG can be challenging in monitoring applications [12, 13].

Vectorcardiography is based upon the assumption that the cardiac electrical activity can be approximated by a three-dimensional vector quantity that is frequently referred to as the heart-vector [14]. The three-dimensional model of the cardiac electrical activity allows for the derivation of the Frank VCG using a minimal number of three linearly independent ECG leads [15]. This allows for the derivation of the Frank VCG using reduced lead systems (RLSs) that contain ML limb leads I, II and a subset of the six precordial leads V1 to V6.

In this research we assess the estimation performance that is achieved when deriving the SA using the ML 12-lead ECG and each of the 62 different RLSs that are based upon ML limb leads I, II and any subset of the six precordial leads V1 to V6.

2. Material and methods

2.1. Body surface potential map data

Our research utilizes previously recorded body surface potential maps (BSPMs) of 726 subjects [16]. The BSPMs were recorded from 232 subjects with left ventricular hypertrophy (LVH), 265 subjects with myocardial infarction (MI) and 229 normal subjects. Each BSPM contained ECG data of 117 thoracic leads. All thoracic leads were recorded with respect to the Wilson Central Terminal (WCT). Three distal limb electrodes that were placed on the right and left wrist and the left ankle were used to derive the WCT. The 117 thoracic leads of each BSPM were recorded using thoracic electrodes placed on 81 anterior and 36 posterior recording sites. Each of the 117 thoracic leads was represented by one average QRS-T complex. Average QRS-T complexes were generated using 15 seconds of continuous ECG data.

The thoracic electrode array that was used to record the BSPMs did not cover all body locations from which body surface potentials were required. Body surface potentials that were required for our research but were not directly recorded by the thoracic electrode array were obtained through interpolation. Interpolation was performed using a two-step interpolation procedure that has previously been described in [17]. A concise description of the interpolation procedure follows. First, body surface potentials at locations that corresponded to the locations of the 352 nodes of the Dalhousie torso model [18] were derived from the recorded BSPM data. This was achieved using a Laplacian 3D interpolation procedure. Second, linear interpolation was used to derive

required body surface potentials that were located between the 352 nodes of the Dalhousie torso model.

Random sampling was used to partition the interpolated BSPM data into one training dataset (DTrain) and one testing dataset (DTest). Table 1 details the composition of DTrain and DTest.

TABLE 1

2.2. Mason-Likar 12-lead ECGs and reduced ECG lead sets

All 62 different RLSs and the ML 12-lead ECG were determined for each of the 726 subjects in the study population. First, the proximal ML limb leads were determined using the interpolated BSPM data. Second, the ML WCT was calculated using the ML limb leads. Third, the precordial leads of the ML 12-lead ECG were extracted from the BSPM data and measured with respect to the ML WCT.

2.3. Vectorcardiographic data

One Frank VCG was extracted for each of the 727 subjects in the study population. First, the body surface potentials at the locations of the Frank electrodes A, C, E, F, H, I and M were determined using the interpolated BSPM data. Second, the body surface potentials at the Frank electrode locations were

used to calculate the three Frank VCG leads X, Y and Z using the previously published set of equations (1) to (3) [19].

$$X = 0.610\varphi_A + 0.171\varphi_C - 0.171\varphi_I. \quad (1)$$

$$Y = 0.655\varphi_F + 0.345\varphi_M - 1.000\varphi_H. \quad (2)$$

$$Z = 0.1333\varphi_A + 0.736\varphi_M - 0.264\varphi_I - 0.374\varphi_E - 0.231\varphi_C. \quad (3)$$

Where φ_A, φ_C, φ_E, φ_F, φ_H, φ_I and φ_M denote the body surface potentials at the location of the Frank electrodes A, C, E, F, H, I and M respectively and X, Y and Z denote the three orthogonal Frank VCG leads.

We subsequently refer to all Frank VCGs that were obtained using (1) to (3) as 'gold standard' Frank VCGs.

2.4. Linear lead transformation matrices

One linear lead transformation matrix that allows for the derivation of the Frank VCG from RLS data was developed for each of the 62 different RLSs under investigation. The 62 linear lead transformation matrices were developed using the data in DTrain and multivariate linear regression as detailed in (4).

$$\boldsymbol{A_i} = [(\boldsymbol{RLS}_i^T \cdot \boldsymbol{RLS}_i)^{-1}\boldsymbol{RLS}_i^T] \cdot \boldsymbol{VCG}. \quad (4)$$

Where $i \in \{1, \dots, 62\}$ is an index variable that is used to indicate each of the 62 different RLSs, $\boldsymbol{A_i}$ denotes the $(2+n)\times 3$ linear lead transformation matrix of the i-th RLS, $\boldsymbol{RLS_i}$ denotes a $m_{Train}\times(2+n)$ matrix that contains the ECG data from

the 545 subjects in DTrain used by the i-th RLS, $n \in \{1, \ldots, 5\}$ denotes the number of precordial leads that are used in $\boldsymbol{RLS_i}$, m_{Train} denotes the total number of QRS-T sample values in each lead and for all subjects of DTrain, $\boldsymbol{VCG} = [\boldsymbol{X}, \boldsymbol{Y}, \boldsymbol{Z}]$ is a $m_{Train}\times 3$ matrix that contains the 'gold standard' Frank VCGs and the $m_{Train}\times 1$ vectors $\boldsymbol{X}$, $\boldsymbol{Y}$ and $\boldsymbol{Z}$ denote the three orthogonal Frank VCG leads.

We used the Guldenring matrix [10, 20] for the estimation of the Frank VCGs from the ML 12-lead ECGs. The Guldenring matrix was used as this matrix has, for ML 12-lead ECG data, previously been reported to yield estimates of the SA that are more accurate then what is achieved by the Kors matrix [10]. In addition, the Guldenring matrix has previously [20] been developed using multivariate linear regression and the data in DTrain. The Guldenring matrix is therefore identical to the transformation matrix that is obtained when using ML limb leads I, II and the precordial leads V1 to V6 of DTrain in (4).

2.5. Spatial QRS-T angle

Several different definitions of the SA have previously been used in research [7]. The definition of the SA that is used in our research is based upon the mean algebraic value of the QRS complex (mean spatial QRS axis) and the mean algebraic value of the T wave (mean spatial T axis) as computed from the Frank VCG using (5) and (6) respectively. The SA that is used in our research represents the angle between the mean spatial QRS axis and the mean spatial T axis and is determined using (7).

$$\boldsymbol{QRS} = \frac{1}{J_p - QRS_{ON}} \sum_{n=QRS_{ON}}^{J_P} \boldsymbol{VCG}(n). \quad (5)$$

$$\boldsymbol{T} = \frac{1}{T_{END} - J_P} \sum_{n=J_P}^{T_{END}} \boldsymbol{VCG}(n). \quad (6)$$

$$SA = arccos\left[\frac{\boldsymbol{QRS} \cdot \boldsymbol{T}}{|\boldsymbol{QRS}| \cdot |\boldsymbol{T}|}\right]. \quad (7)$$

Where $\boldsymbol{QRS}$ is the 1×3 mean vector of ventricular depolarization, $\boldsymbol{T}$ denotes the 1×3 mean vector of ventricular repolarization, QRS_{ON} is the sample index of the QRS onset, J_P denotes the sample index of the J-point, T_{END} is the sample index associated with the end of the T wave, n is the sample index variable, $\boldsymbol{VCG}$ is a m×3 matrix containing m sample values for each of the three VCG leads, $arccos[\cdot]$ denotes the arc-cosine and $|\cdot|$ refers to the magnitude of a vector.

2.6 Performance assessment

An assessment of the performance that is achieved when estimating the SA using the 62 different RLSs and the ML 12-lead ECG was conducted using the data in DTest. First, the Guldenring matrix and the lead transformation matrices of the 62 different RLSs were used to derive the VCGs of the 181 subjects in DTest. This was performed using (8).

$$\boldsymbol{VCG} = \boldsymbol{LS_i} \cdot \boldsymbol{A_i}. \quad (8)$$

Where i is a index variable, index values $i \in \{1, \dots, 62\}$ are used to denote one of the RLSs and $i = 63$ refers to the Guldenring matrix, $\boldsymbol{A_i}$ is a $(2 + n)$×3 linear lead transformation matrix, $\boldsymbol{LS_i}$ is a m×$(2 + n)$ matrix that contains the ECG data of the used lead system (ML 12-lead ECG or RLS) of one particular subject in

DTest, $n \in \{1, \ldots, 6\}$ denotes the number of precordial leads that are used by the lead system, $\boldsymbol{VCG} = [\boldsymbol{X}, \boldsymbol{Y}, \boldsymbol{Z}]$ is a $m \times 3$ matrix that contains the derived VCG data of one particular subject in DTest, m denotes the number of QRS-T sample values in each lead of the ECG data of one particular subject in DTest and the $m \times 1$ vectors $\boldsymbol{X}$, $\boldsymbol{Y}$ and $\boldsymbol{Z}$ denote the three orthogonal Frank VCG leads.

Second, the SA was calculated for all derived VCGs and all 'gold standard' Frank VCGs. Third, the differences between the SA values obtained from the derived VCGs and the 'gold standard' Frank VCG were calculated as detailed in (9).

$$\boldsymbol{\Delta SA_i} = \boldsymbol{SA_i} - \boldsymbol{SA_{Frank}} \tag{9}$$

Where i is as defined in (8), $\boldsymbol{SA_i}$ is a 1×181 vector that contains the SA values of all 181 subjects in DTest based upon VCG data that is derived using the i-th linear lead transformation matrix, $\boldsymbol{SA_{Frank}}$ is a 1×181 vector that contains the SA values based upon the 'gold standard' Frank VCGs of all subjects in DTest and $\boldsymbol{\Delta SA_i}$ is a 1×181 vector that contains the estimation errors made when computing the SA based upon VCG data that is derived using the i-th linear lead transformation matrix.

Forth, the systematic and the random error components of the error vectors $\boldsymbol{\Delta SA_i}$ were analyzed. The systematic error was quantified as the mean [95% confidence interval (CI)] of the estimation errors. We quantified the random error as the span of the Bland-Altman (BA) 95% limits of agreement [21] as detailed in (10).

$$RE_i = 2 \cdot 1.96 \cdot std(\boldsymbol{\Delta SA_i}). \quad (10)$$

Where RE_i denotes the magnitude of the random error component associated with the i-th RLS, $std(\cdot)$ denotes the standard deviation and $\boldsymbol{\Delta SA_i}$ denotes one of the estimation error vectors as defined in (9).

Fifth, a Pitman-Morgan test [22] (paired, two-sided, alpha level of significance = 0.05) was conducted. This test was used to test for the null hypothesis of equal random error magnitude associated with the ML 12-lead ECG and any of the 62 different RLSs. The findings of the Pitman-Morgan test were subsequently used to identify RLSs with random error components that are of similar magnitude as the random error component of the ML 12-lead ECG. Sixth, the root-mean-squared differences (RMSDs) between the 'gold standard' Frank VCG leads and the derived VCG leads were calculated. The RMSD values were used to identify the contribution of the different VCG leads to the $\boldsymbol{\Delta SA_i}$values.

3. Results

All RLSs under investigation were grouped in accordance to their lead set size. The RLSs in every group were sorted in accordance to the magnitude of the random error component. Figure 1 details the random error components associated with the grouped RLSs.

FIGURE 1

Figure 1. Random error of the SA and 95% confidence interval for the random error of the SA. The random error and the 95% confidence interval are shown

for the 62 different RLSs and the ML 12-lead ECG. The different RLSs are grouped in accordance to their lead set. A horizontal dashed line indicates the magnitude of the random error component that is achieved when the ML 12-lead ECG is used for the derivation of the SA. Cross markers indicate RLSs that are associated with statistically significantly (paired, two-sided, Pitman-Morgan test, alpha level of significance = 0.05) larger random error components when compared to what is achieved using the ML 12-lead ECG.

The best performing RLS (lowest random error component) and the worst performing RLS (highest random error component) of each lead set size were identified. Table 2 details the random error and the systematic error associated with the ML 12-lead ECG as well as for the best and the worst performing RLS of a given lead set size.

TABLE 2

Table 3 details the RMSDs between the 'gold standard' Frank VCG leads and derived VCG leads for the ML 12-lead ECG as well as for the best and the worst performing RLS of a given lead set size.

TABLE 3

The linear model in (11) was designed to assess whether the mean RMSD between the 'gold standard' Frank VCG leads and the derived VCG leads of the i-

th RLS predict the random error magnitude of the i-th RLS. The model in (11) was designed using bootstrapped linear regression and the data in DTest.

$$\dot{RE}_i = b_0 + b_x(\overline{RMSD}x_i - \overline{RMSD}x) + b_y(\overline{RMSD}y_i - \overline{RMSD}y) + b_z(\overline{RMSD}z_i - \overline{RMSD}z). \quad (11)$$

Where b_0, b_x, b_y and b_z are the coefficients of the linear model, $\overline{RMSD}x_i$, $\overline{RMSD}y_i$ and $\overline{RMSD}z_i$ denote the mean RMSD between the 'gold standard' Frank VCG leads and the derived VCG leads of the i-th RLS, $\overline{RMSD}x$, $\overline{RMSD}y$ and $\overline{RMSD}z$ denote the mean RMSD between the 'gold standard' Frank VCG leads and the derived VCG leads across all RLSs under investigation.

The coefficients in (11) were developed using bootstrapped linear regression and the data in DTest. The performance of the linear model in (11) was assessed using the Pearson product-moment correlation coefficient calculated between the predicted ($\dot{RE}_i$) and the actual random error magnitude RE_i of all RLSs. The coefficient b_y was removed from (11) as it was found not to be statistically significantly different from zero at the alpha level of 0.05. The linear model with the remaining coefficients is provided in (12).

$$\ddot{RE}_i = 59.24 + 0.31(\overline{RMSD}x_i - \overline{RMSD}x) + 0.47(\overline{RMSD}z_i - \overline{RMSD}z). \quad (12)$$

Where $\overline{RMSD}x_i$, $\overline{RMSD}x$, $\overline{RMSD}z_i$ and $\overline{RMSD}z$ is as defined in (11), $\ddot{RE}_i$ refers to the predicted random error magnitude of the i-th RLS.

The 95% confidence intervals of b_0, b_x and b_z were determined to be (54.15; 64.33), (0.24; 0.38) and (0.42; 0.51) respectively. The Pearson product-moment correlation coefficient (mean [95% confidence interval]) between the predicted $\ddot{RE}_i$ value and the observed RE_i values was found to be 0.978 [0.977; 0.979].

4. Discussion

It is possible to derive the SA using different RLSs that utilize ML limb leads I, II and any number of precordial leads. This research has shown that the quality of the derived SA is dependent upon which and how many precordial leads are used by the RLS. It was observed that the best performing RLS based upon three precordial leads was able to derive the SA with a random error magnitude that is similar (mean = 40.74°; 95% confidence interval = [35.56°; 49.29°]) to what is achieved when using the ML 12-lead ECG (mean = 39.57°; 95% confidence interval = [33.78°; 45.70°]).

The random error magnitudes of the different RLSs that are detailed in Figure 1 are point estimates and therefore subject to sampling error. This means that the ranking of RLSs that have only small differences between their associated random error magnitudes may be subject to variation when using a different partitioning of the study population when assembling DTrain and DTest. Bootstrapping was used to quantify the effect of the sampling error on the differences in random error magnitude of adjacently ranked RLSs. The 95% upper confidence limit of the differences in the random error magnitudes for RLSs that interchanged their rank due to the sampling error was found to be

relatively small (mean across all adjacently ranked RLSs = 4.3°, standard deviation = 2.5°). This finding indicates that only adjacently ranked of RLSs with similar random error magnitudes may be subject to rank interchanges. Variations in the ranking of RLSs that may occur when using the data of different subjects in the datasets DTrain and DTest will therefore have little influence on the overall performance of specific RLSs (whether a RLS is ranked on rank 19 or rank 20 is of little practical importance provided that the random error magnitudes of both RLSs are similar).

It can be seen in Table 2 that the worst performing RLSs based upon one, two and three precordial leads lack anterior-posterior information. This is due to the absence of precordial leads V1, V2 and V3 in these RLSs. Table 3 demonstrates that the lack of this anterior-posterior information causes high estimation error levels for Frank VCG lead Z. This increased error level for Frank VCG lead Z can, based upon the linear model in (12), be identified as the source for the increased level of random error that is associated with the worst performing RLSs.

Conversely, the best performing RLSs that are based upon one, two or three precordial leads provide anterior-posterior information through the utilization of precordial leads V1 to V3.

It may seem counter intuitive that the $\overline{RMSDy_i}$ values were found not to contribute to the mean random error magnitude of the RLSs. However, the superior-inferior information that was used in all of the assessed RLSs was solely provided by ML limb lead II. This lead is utilized by all of the assessed RLSs. A consequence of this is a relatively low variation (standard deviation = 2.68μV) of the $\overline{RMSDy_i}$ values across all assessed RLSs. This observation is in agreement with the heart-vector model of the cardiac electrical activity in accordance to

which the precordial leads contain solely horizontal-plane information. This explains why variations of the $\overline{RMSDy_i}$ value are a poor predictor of the random error magnitude of any of the assessed RLSs. Nevertheless, it is speculated that the $\overline{RMSDy_i}$ value will be a useful predictor of (contributor to) the random error magnitude in situations where RLSs with a varying amount of superior-inferior information are compared.

5. Conclusion

In this paper we reported upon the SA estimation performance of all possible RLSs that are based on ML limb leads I, II and any possible combination of the six precordial leads V1 to V6.

The findings in Figure 1 and Table 2 suggest that the best performing RLS based upon three precordial leads (ML limb leads I, II and precordial leads V1, V3, and V6) can yield estimates of the SA that are as good as what is achieved when deriving the SA using the ML 12-lead ECG.

Furthermore, our findings provide guidance when deciding upon a RLS for SA monitoring applications. In addition, the findings of this research can be used to estimate the effect that the loss of precordial electrodes during a SA monitoring application might have on the quality of the derived SA values.

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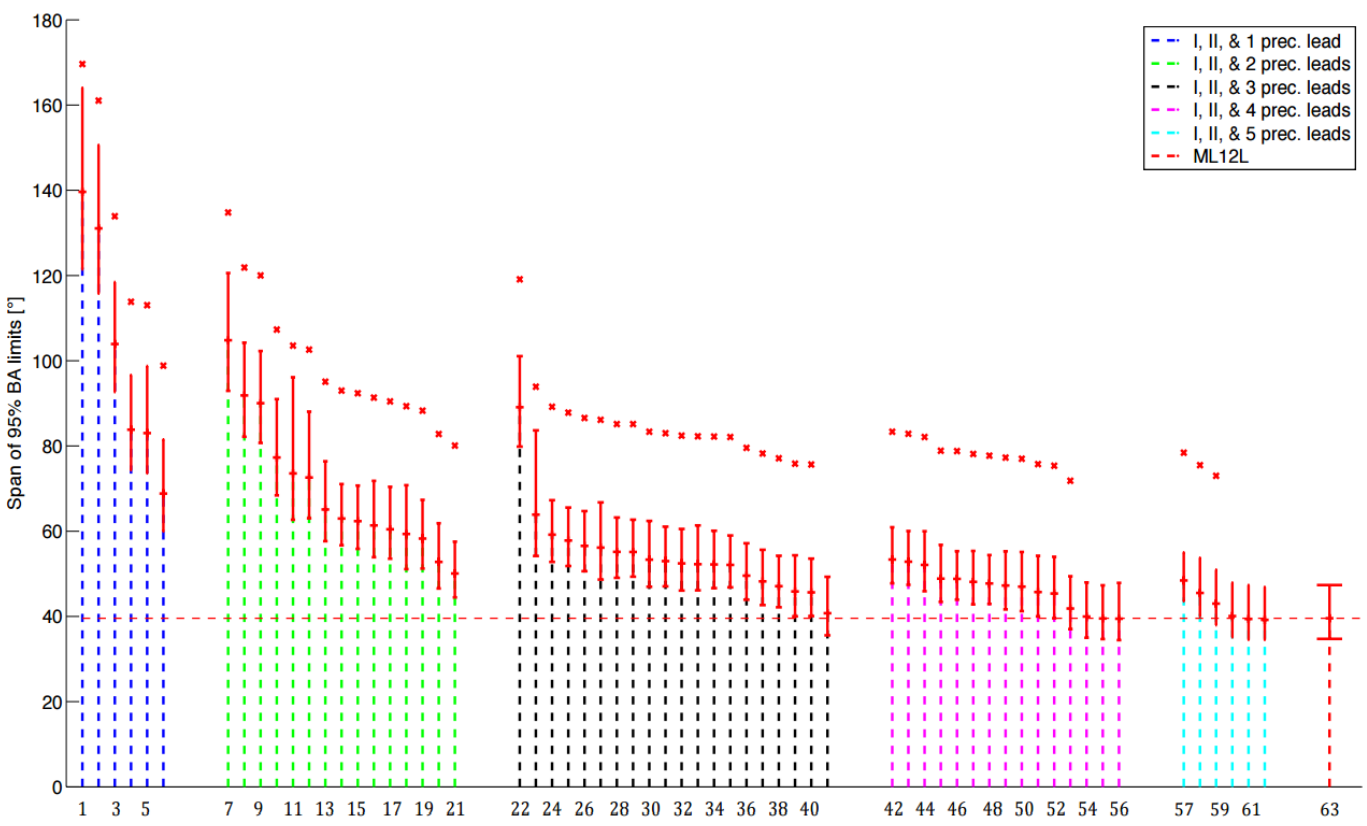

#	Lead set	#	Lead set
1	I, II, V6	33	I, II, V3, V4, V5
2	I, II, V5	34	I, II, V2, V3, V5
3	I, II, V4	35	I, II, V2, V4, V6
4	I, II, V2	36	I, II, V3, V5, V6
5	I, II, V1	37	I, II, V3, V4, V6
6	I, II, V3	38	I, II, V2, V3, V6
7	I, II, V5, V6	39	I, II, V1, V3, V5
8	I, II, V4, V5	40	I, II, V1, V4, V6
9	I, II, V4, V6	41	I, II, V1, V3, V6
10	I, II, V1, V2	42	I, II, V2, V3, V4, V5
11	I, II, V1, V6	43	I, II, V2, V4, V5, V6
12	I, II, V2, V6	44	I, II, V1, V2, V3, V4
13	I, II, V1, V5	45	I, II, V1, V2, V4, V5
14	I, II, V2, V5	46	I, II, V2, V3, V4, V6
15	I, II, V2, V4	47	I, II, V3, V4, V5, V6
16	I, II, V2, V3	48	I, II, V2, V3, V5, V6
17	I, II, V1, V4	49	I, II, V1, V2, V5, V6
18	I, II, V1, V3	50	I, II, V1, V4, V5, V6
19	I, II, V3, V4	51	I, II, V1, V3, V4, V5
20	I, II, V3, V5	52	I, II, V1, V2, V3, V5
21	I, II, V3, V6	53	I, II, V1, V2, V4, V6
22	I, II, V4, V5, V6	54	I, II, V1, V3, V5, V6
23	I, II, V1, V2, V6	55	I, II, V1, V3, V4, V6
24	I, II, V2, V3, V4	56	I, II, V1, V2, V3, V6
25	I, II, V2, V4, V5	57	I, II, V2, V3, V4, V5, V6
26	I, II, V1, V2, V5	58	I, II, V1, V2, V3, V4, V5
27	I, II, V1, V2, V3	59	I, II, V1, V2, V4, V5, V6
28	I, II, V1, V2, V4	60	I, II, V1, V3, V4, V5, V6
29	I, II, V2, V5, V6	61	I, II, V1, V2, V3, V5, V6
30	I, II, V1, V5, V6	62	I, II, V1, V2, V3, V4, V6
31	I, II, V1, V4, V5	63	I, II, V1, V2, V3, V4, V5, V6
32	I, II, V1, V3, V4		

Figure 1. Random error of the SA and 95% confidence interval for the random error of the SA. The random error and the 95% confidence interval are shown for the 62 different RLSs and the ML 12-lead ECG. The different RLSs are grouped in accordance to their lead set. A horizontal dashed line indicates the magnitude of the random error component that is achieved when the ML 12-lead ECG is used for the derivation of the SA. Cross markers indicate RLSs that are associated with statistically significantly (paired, two-sided, Pitman-Morgan test, alpha level of significance = 0.05) larger random error components when compared to what is achieved using the ML 12-lead ECG.

Table 1. Composition of test dataset (DTest) and training dataset (DTrain).

Dataset	#normal[a]	#LVH[b]	#MI[c]	#total[d]
DTest	58	57	66	181
DTrain	174	172	199	545

[a]Number of normal subjects in dataset; [b]Number of subjects with LVH in dataset; [c]Number of subjects with MI in dataset; [d]Total number of subjects in dataset.

Table 2. Estimation performance when deriving the spatial QRS-T angle using the Mason-Likar 12-lead ECG and 62 different RLS. The random error and the systematic error for the best and the worst performing RLS of a given lead set size are provided.

Number of precordial leads used	Lead set Classification [Best[a]/Worst[b]]	Lead set	Random error [°] mean [95% CI][c]	Systematic error [°] mean [95% CI][d]
6	N/A[e]	I, II, V1, V2, V3, V4, V5, V6	39.57 [33.78; 45.70]	3.74 [2.25; 5.17]
5	Best	I, II, V1, V2, V3, V4, V6	39.20 [33.04; 45.56]	3.65 [2.19; 5.09]
	Worst	I, II, V2, V3, V4, V5, V6	48.52 [43.58; 54.96]	4.88 [3.07; 6.68]
4	Best	I, II, V1, V2, V3, V6	39.45 [32.99; 45.37]	2.67 [1.19; 4.11]
	Worst	I, II, V2, V3, V4, V5	53.34 [47.73; 60.85]	5.25 [3.29; 7.24]
3	Best	I, II, V1, V3, V6	40.74 [35.56; 49.29]	3.34 [1.81; 4.83]
	Worst	I, II, V4, V5, V6	89.10 [79.88; 101.12]	-12.60 [-15.84; -9.26]
2	Best	I, II, V3, V6	50.08 [43.25; 56.39]	-0.14 [-1.99; 1.73]
	Worst	I, II, V5, V6	104.80 [92.96; 120.68]	-14.00 [-17.78; -9.99]
1	Best	I, II, V3	68.83 [58.72; 78.74]	-0.20 [-2.67; 2.45]
	Worst	I, II, V6	139.62 [121.57; 164.33]	-15.24 [-20.21; -9.87]

[a]Best performing lead set of a given lead set size; [b]Worst performing lead set of a given lead set size; [c]Bootstrapped bias- corrected and accelerated 95% confidence intervals of the random error component, Confidence intervals of the random error component are based on 20000 bootstrap replicates; [d]Bootstrapped bias- corrected and accelerated 95% confidence intervals of the systematic error component, Confidence intervals of the systematic error component are based on 20000 bootstrap replicates; [e]Not applicable as there is only one lead set based upon the six precordial leads V1 to V6.

Table 3. Root mean squared difference values calculated between the derived VCG leads and the 'gold standard' Frank VCG leads. Root mean squared differences are provided for the best and the worst performing RLS of a given lead set size.

Number of precordial leads used	Lead set Classification [Best[a]/Worst[b]]	Lead set	RMSD [μV] of Frank lead X mean [95% CI][c]	RMSD [μV] of Frank lead Y mean [95% CI][d]	RMSD [μV] of Frank lead Z mean [95% CI][e]
6	N/A[f]	I, II, V1, V2, V3, V4, V5, V6	34.6 [31.4; 38.9]	52.1 [48.1; 57.7]	47.1 [43.3; 51.9]
5	Best	I, II, V1, V2, V3, V4, V6	35.5 [32.2; 40.1]	52.8 [48.8; 58.8]	48.4 [44.6; 53.0]
	Worst	I, II, V2, V3, V4, V5, V6	35.4 [32.0; 39.9]	53.8 [49.7; 59.3]	69.1 [64.1; 75.5]
4	Best	I, II, V1, V2, V3, V6	40.1 [36.4; 44.9]	53.6 [49.5; 59.1]	52.4 [48.4; 57.1]
	Worst	I, II, V2, V3, V4, V5	47.8 [43.5; 53.2]	54.9 [50.6; 60.3]	74.6 [69.6; 80.6]
3	Best	I, II, V1, V3, V6	40.5 [37.1; 45.0]	53.3 [49.1; 59.1]	53.6 [49.6; 58.4]
	Worst	I, II, V4, V5, V6	35.2 [31.8; 39.8]	59.0 [54.7; 63.9]	144.8 [133.0; 161.0]
2	Best	I, II, V3, V6	43.1 [39.6; 47.9]	55.2 [51.0; 60.5]	79.2 [73.4; 85.9]
	Worst	I, II, V5, V6	37.2 [33.9; 41.3]	63.0 [58.1; 68.9]	170.6 [157.6; 186.0]
1	Best	I, II, V3	85.7 [78.9; 94.3]	55.2 [51.0; 60.4]	83.4 [77.4; 90.3]
	Worst	I, II, V6	55.0 [50.9; 60.1]	64.3 [59.2; 70.8]	235.3 [218.7; 254.5]

[a]Best performing lead set of a given lead set size; [b]Worst performing lead set of a given lead set size; [c]Bootstrapped bias- corrected and accelerated 95% confidence intervals of the root mean squared difference (RMSD) between the 'gold standard' Frank VCG lead X and the derived VCG lead X, Confidence intervals of the random error component are based on 20000 bootstrap replicates; [d]Bootstrapped bias-corrected and accelerated 95% confidence intervals of the root mean squared difference (RMSD) between the 'gold standard' Frank VCG lead Y and the derived VCG lead Y, Confidence intervals of the random error component are based on 20000 bootstrap replicates; [e]Bootstrapped bias- corrected and accelerated 95% confidence intervals of the root mean squared difference (RMSD) between the 'gold standard' Frank VCG lead Z and the derived VCG lead Z, Confidence intervals of the random error component are based on 20000 bootstrap replicates; [f]Not applicable as there is only one lead set based upon the six precordial leads V1 to V6.

Coefficients and performance metrics of the lead transformation matrices for the 62 RLSs under investigation.

ECG / VCG leads	I	II	V1	V2	V3	V4	V5	V6	Systematic error [°]	Random error [°]
X	0.8830	0.2810	-0.0190	NOT USED.	NOT USED.	NOT USED.	NOT USED.	NOT USED.		
Y	-0.2150	0.6940	0.1550	NOT USED.	NOT USED.	NOT USED.	NOT USED.	NOT USED.	6.0	83.0
Z	-0.4790	-0.2730	-1.0320	NOT USED.	NOT USED.	NOT USED.	NOT USED.	NOT USED.		
X	0.8950	0.2790	NOT USED.	-0.0140	NOT USED.	NOT USED.	NOT USED.	NOT USED.		
Y	-0.2920	0.6700	NOT USED.	0.0690	NOT USED.	NOT USED.	NOT USED.	NOT USED.	11.7	83.8
Z	0.0600	-0.1650	NOT USED.	-0.5180	NOT USED.	NOT USED.	NOT USED.	NOT USED.		
X	0.8750	0.2970	NOT USED.	NOT USED.	0.0180	NOT USED.	NOT USED.	NOT USED.		
Y	-0.3300	0.6400	NOT USED.	NOT USED.	0.0850	NOT USED.	NOT USED.	NOT USED.	-0.2	68.8
Z	0.3260	0.0710	NOT USED.	NOT USED.	-0.6180	NOT USED.	NOT USED.	NOT USED.		
X	0.7820	0.2430	NOT USED.	NOT USED.	NOT USED.	0.1280	NOT USED.	NOT USED.		
Y	-0.3340	0.5800	NOT USED.	NOT USED.	NOT USED.	0.0830	NOT USED.	NOT USED.	-17.6	103.9
Z	0.3730	0.5140	NOT USED.	NOT USED.	NOT USED.	-0.6260	NOT USED.	NOT USED.		
X	0.5890	0.0710	NOT USED.	NOT USED.	NOT USED.	NOT USED.	0.4090	NOT USED.		
Y	-0.2980	0.5860	NOT USED.	NOT USED.	NOT USED.	NOT USED.	0.0470	NOT USED.	-20.9	131.0
Z	0.1210	0.4790	NOT USED.	NOT USED.	NOT USED.	NOT USED.	-0.3720	NOT USED.		
X	0.6930	-0.0120	NOT USED.	NOT USED.	NOT USED.	NOT USED.	NOT USED.	0.5480		
Y	-0.2490	0.6340	NOT USED.	NOT USED.	NOT USED.	NOT USED.	NOT USED.	-0.0420	-15.2	139.6
Z	-0.4790	-0.2270	NOT USED.	NOT USED.	NOT USED.	NOT USED.	NOT USED.	0.9140		
X	0.9160	0.2840	0.0400	-0.0330	NOT USED.	NOT USED.	NOT USED.	NOT USED.		
Y	-0.2020	0.6950	0.1770	-0.0130	NOT USED.	NOT USED.	NOT USED.	NOT USED.	10.1	77.3
Z	-0.2240	-0.2450	-0.5640	-0.2580	NOT USED.	NOT USED.	NOT USED.	NOT USED.		

ECG / VCG leads	I	II	V1	V2	V3	V4	V5	V6	Systematic error [°]	Random error [°]
X	0.7540	0.2340	-0.1730	NOT USED.	0.1050	NOT USED.	NOT USED.	NOT USED.		
Y	-0.2530	0.6800	0.1100	NOT USED.	0.0310	NOT USED.	NOT USED.	NOT USED.	4.1	59.3
Z	-0.0070	-0.1030	-0.4730	NOT USED.	-0.3810	NOT USED.	NOT USED.	NOT USED.		
X	0.6800	0.1380	-0.1510	NOT USED.	NOT USED.	0.1930	NOT USED.	NOT USED.		
Y	-0.2410	0.6760	0.1380	NOT USED.	NOT USED.	0.0240	NOT USED.	NOT USED.	2.4	60.4
Z	-0.2030	-0.0790	-0.8530	NOT USED.	NOT USED.	-0.2620	NOT USED.	NOT USED.		
X	0.5590	0.0300	-0.0640	NOT USED.	NOT USED.	NOT USED.	0.4220	NOT USED.		
Y	-0.2270	0.6840	0.1530	NOT USED.	NOT USED.	NOT USED.	0.0160	NOT USED.	4.2	65.1
Z	-0.3520	-0.1750	-1.0140	NOT USED.	NOT USED.	NOT USED.	-0.1650	NOT USED.		
X	0.7000	0.0020	0.0880	NOT USED.	NOT USED.	NOT USED.	NOT USED.	0.6070		
Y	-0.2360	0.6620	0.1670	NOT USED.	NOT USED.	NOT USED.	NOT USED.	0.0690	5.2	73.6
Z	-0.5560	-0.3900	-0.9860	NOT USED.	NOT USED.	NOT USED.	NOT USED.	0.2550		
X	0.7970	0.2030	NOT USED.	-0.1890	0.2200	NOT USED.	NOT USED.	NOT USED.		
Y	-0.3270	0.6440	NOT USED.	0.0070	0.0780	NOT USED.	NOT USED.	NOT USED.	5.2	61.4
Z	0.2520	-0.0180	NOT USED.	-0.1770	-0.4280	NOT USED.	NOT USED.	NOT USED.		
X	0.7570	0.1460	NOT USED.	-0.0830	NOT USED.	0.1980	NOT USED.	NOT USED.		
Y	-0.3170	0.6470	NOT USED.	0.0570	NOT USED.	0.0350	NOT USED.	NOT USED.	6.9	62.4
Z	0.2450	0.0120	NOT USED.	-0.4270	NOT USED.	-0.2640	NOT USED.	NOT USED.		
X	0.5950	0.0430	NOT USED.	-0.0280	NOT USED.	NOT USED.	0.4160	NOT USED.		
Y	-0.3130	0.6540	NOT USED.	0.0680	NOT USED.	NOT USED.	0.0300	NOT USED.	9.4	63.0
Z	0.2360	-0.0280	NOT USED.	-0.5090	NOT USED.	NOT USED.	-0.2430	NOT USED.		
X	0.6400	-0.0140	NOT USED.	0.0540	NOT USED.	NOT USED.	NOT USED.	0.6360		
Y	-0.3250	0.6320	NOT USED.	0.0780	NOT USED.	NOT USED.	NOT USED.	0.0830	10.2	72.6
Z	0.0210	-0.2110	NOT USED.	-0.5070	NOT USED.	NOT USED.	NOT USED.	0.0990		

ECG / VCG leads	I	II	V1	V2	V3	V4	V5	V6	Systematic error [°]	Random error [°]
X	0.7650	0.1370	NOT USED.	NOT USED.	-0.1440	0.2810	NOT USED.	NOT USED.		
Y	-0.3220	0.6510	NOT USED.	NOT USED.	0.0960	-0.0190	NOT USED.	NOT USED.	2.6	58.3
Z	0.2950	0.0270	NOT USED.	NOT USED.	-0.6620	0.0770	NOT USED.	NOT USED.		
X	0.5980	0.0450	NOT USED.	NOT USED.	-0.0360	NOT USED.	0.4340	NOT USED.		
Y	-0.3200	0.6490	NOT USED.	NOT USED.	0.0870	NOT USED.	-0.0150	NOT USED.	1.3	52.8
Z	0.2800	0.0290	NOT USED.	NOT USED.	-0.6270	NOT USED.	0.0710	NOT USED.		
X	0.5900	-0.0390	NOT USED.	NOT USED.	0.0870	NOT USED.	NOT USED.	0.6500		
Y	-0.3590	0.6060	NOT USED.	NOT USED.	0.0920	NOT USED.	NOT USED.	0.0660	-0.1	50.1
Z	0.2290	-0.0430	NOT USED.	NOT USED.	-0.5940	NOT USED.	NOT USED.	0.2200		
X	0.5850	0.0510	NOT USED.	NOT USED.	NOT USED.	-0.0710	0.4950	NOT USED.		
Y	-0.2900	0.6220	NOT USED.	NOT USED.	NOT USED.	0.1270	-0.1090	NOT USED.	-13.5	91.9
Z	0.0630	0.2130	NOT USED.	NOT USED.	NOT USED.	-0.9390	0.7780	NOT USED.		
X	0.5790	-0.0670	NOT USED.	NOT USED.	NOT USED.	0.1330	NOT USED.	0.5560		
Y	-0.3200	0.6010	NOT USED.	NOT USED.	NOT USED.	0.0830	NOT USED.	-0.0380	-12.7	90.0
Z	0.0520	0.0240	NOT USED.	NOT USED.	NOT USED.	-0.6180	NOT USED.	0.8800		
X	0.5700	-0.0380	NOT USED.	NOT USED.	NOT USED.	NOT USED.	0.2760	0.3270		
Y	-0.2910	0.6260	NOT USED.	NOT USED.	NOT USED.	NOT USED.	0.0950	-0.1190	-14.0	104.8
Z	0.0160	-0.1250	NOT USED.	NOT USED.	NOT USED.	NOT USED.	-1.1060	1.8030		
X	0.5670	-0.0580	NOT USED.	NOT USED.	NOT USED.	0.0850	0.1180	0.4580		
Y	-0.2960	0.5830	NOT USED.	NOT USED.	NOT USED.	0.1830	-0.2440	0.1640	-12.6	89.1
Z	0.0350	0.0360	NOT USED.	NOT USED.	NOT USED.	-0.6870	0.1670	0.7420		
X	0.5550	-0.0430	NOT USED.	NOT USED.	0.0360	NOT USED.	0.2130	0.4190		
Y	-0.3400	0.6080	NOT USED.	NOT USED.	0.1200	NOT USED.	-0.1170	0.1920	0.1	49.6
Z	0.2460	-0.0410	NOT USED.	NOT USED.	-0.5690	NOT USED.	-0.1050	0.3330		

ECG / VCG leads	I	II	V1	V2	V3	V4	V5	V6	Systematic error [°]	Random error [°]
X	0.5790	-0.0670	NOT USED.	NOT USED.	0.0000	0.1330	NOT USED.	0.5560		
Y	-0.3550	0.6150	NOT USED.	NOT USED.	0.1220	-0.0450	NOT USED.	0.0980	1.0	48.2
Z	0.2270	-0.0480	NOT USED.	NOT USED.	-0.6090	0.0230	NOT USED.	0.2030		
X	0.5890	0.0480	NOT USED.	NOT USED.	-0.0120	-0.0520	0.4810	NOT USED.		
Y	-0.3240	0.6500	NOT USED.	NOT USED.	0.0980	-0.0230	0.0060	NOT USED.	1.6	52.3
Z	0.2930	0.0250	NOT USED.	NOT USED.	-0.6600	0.0720	0.0070	NOT USED.		
X	0.5630	-0.0360	NOT USED.	0.0180	NOT USED.	NOT USED.	0.2520	0.3740		
Y	-0.3220	0.6330	NOT USED.	0.0800	NOT USED.	NOT USED.	-0.0120	0.0960	7.6	55.1
Z	0.1800	-0.1650	NOT USED.	-0.4300	NOT USED.	NOT USED.	-0.5250	0.6450		
X	0.5790	-0.0670	NOT USED.	0.0000	NOT USED.	0.1330	NOT USED.	0.5550		
Y	-0.3380	0.6210	NOT USED.	0.0670	NOT USED.	0.0270	NOT USED.	0.0670	5.4	52.1
Z	0.1560	-0.0940	NOT USED.	-0.3860	NOT USED.	-0.2970	NOT USED.	0.2780		
X	0.5880	0.0440	NOT USED.	-0.0120	NOT USED.	-0.0530	0.4760	NOT USED.		
Y	-0.3070	0.6530	NOT USED.	0.0530	NOT USED.	0.0490	-0.0270	NOT USED.	6.1	57.8
Z	0.1910	-0.0210	NOT USED.	-0.4040	NOT USED.	-0.3450	0.1530	NOT USED.		
X	0.5680	-0.0660	NOT USED.	-0.0920	0.1810	NOT USED.	NOT USED.	0.6120		
Y	-0.3540	0.6110	NOT USED.	0.0190	0.0730	NOT USED.	NOT USED.	0.0740	3.8	47.1
Z	0.1940	-0.0870	NOT USED.	-0.1520	-0.4380	NOT USED.	NOT USED.	0.1570		
X	0.5980	0.0450	NOT USED.	-0.0010	-0.0360	NOT USED.	0.4340	NOT USED.		
Y	-0.3200	0.6490	NOT USED.	0.0010	0.0860	NOT USED.	-0.0140	NOT USED.	5.1	52.2
Z	0.2680	-0.0050	NOT USED.	-0.1920	-0.4080	NOT USED.	-0.0340	NOT USED.		
X	0.7710	0.1410	NOT USED.	0.0500	-0.2190	0.3180	NOT USED.	NOT USED.		
Y	-0.3240	0.6500	NOT USED.	-0.0150	0.1190	-0.0300	NOT USED.	NOT USED.	6.0	59.2
Z	0.2620	0.0060	NOT USED.	-0.2680	-0.2630	-0.1200	NOT USED.	NOT USED.		

ECG / VCG leads	I	II	V1	V2	V3	V4	V5	V6	Systematic error [°]	Random error [°]
X	0.5750	-0.0350	0.0130	NOT USED.	NOT USED.	NOT USED.	0.2660	0.3430		
Y	-0.2220	0.6660	0.1750	NOT USED.	NOT USED.	NOT USED.	-0.0280	0.0970	3.4	53.3
Z	-0.3160	-0.3190	-0.8420	NOT USED.	NOT USED.	NOT USED.	-0.5100	0.7620		
X	0.5700	-0.0730	-0.0200	NOT USED.	NOT USED.	0.1420	NOT USED.	0.5430		
Y	-0.2530	0.6520	0.1520	NOT USED.	NOT USED.	0.0190	NOT USED.	0.0610	1.8	45.6
Z	-0.2820	-0.2310	-0.7590	NOT USED.	NOT USED.	-0.2980	NOT USED.	0.3910		
X	0.5680	0.0330	-0.0400	NOT USED.	NOT USED.	-0.0440	0.4700	NOT USED.		
Y	-0.2340	0.6810	0.1320	NOT USED.	NOT USED.	0.0370	-0.0260	NOT USED.	2.2	53.0
Z	-0.2700	-0.1420	-0.7860	NOT USED.	NOT USED.	-0.4040	0.2830	NOT USED.		
X	0.5110	-0.0770	-0.1200	NOT USED.	0.1450	NOT USED.	NOT USED.	0.6390		
Y	-0.2820	0.6430	0.1160	NOT USED.	0.0360	NOT USED.	NOT USED.	0.0770	3.3	40.7
Z	-0.0740	-0.1880	-0.4580	NOT USED.	-0.3700	NOT USED.	NOT USED.	0.1760		
X	0.5690	0.0320	-0.0480	NOT USED.	-0.0120	NOT USED.	0.4260	NOT USED.		45.8
Y	-0.2540	0.6790	0.1110	NOT USED.	0.0300	NOT USED.	0.0030	NOT USED.	4.4	
Z	-0.0040	-0.1000	-0.4750	NOT USED.	-0.3800	NOT USED.	-0.0070	NOT USED.		
X	0.7650	0.1370	0.0010	NOT USED.	-0.1450	0.2820	NOT USED.	NOT USED.		
Y	-0.2520	0.6760	0.1170	NOT USED.	0.0200	0.0120	NOT USED.	NOT USED.	4.5	52.4
Z	-0.0090	-0.0820	-0.5090	NOT USED.	-0.3290	-0.0590	NOT USED.	NOT USED.		
X	0.6220	-0.0200	-0.0320	0.0690	NOT USED.	NOT USED.	NOT USED.	0.6390		
Y	-0.2340	0.6630	0.1690	-0.0020	NOT USED.	NOT USED.	NOT USED.	0.0680	8.3	63.9
Z	-0.2930	-0.3160	-0.5800	-0.2350	NOT USED.	NOT USED.	NOT USED.	0.1490		
X	0.5530	0.0290	-0.0750	0.0060	NOT USED.	NOT USED.	0.4220	NOT USED.		
Y	-0.2150	0.6870	0.1730	-0.0110	NOT USED.	NOT USED.	0.0140	NOT USED.	8.1	56.6
Z	-0.0540	-0.1250	-0.5100	-0.2770	NOT USED.	NOT USED.	-0.1980	NOT USED.		

ECG / VCG leads	I	II	V1	V2	V3	V4	V5	V6	Systematic error [°]	Random error [°]
X	0.7400	0.1400	-0.0310	-0.0690	NOT USED.	0.2000	NOT USED.	NOT USED.		
Y	-0.2260	0.6760	0.1680	-0.0170	NOT USED.	0.0260	NOT USED.	NOT USED.	6.2	55.1
Z	-0.0150	-0.0720	-0.4780	-0.2150	NOT USED.	-0.2390	NOT USED.	NOT USED.		
X	0.7990	0.2040	0.0040	-0.1910	0.2200	NOT USED.	NOT USED.	NOT USED.		
Y	-0.2380	0.6700	0.1660	-0.0610	0.0670	NOT USED.	NOT USED.	NOT USED.	4.3	56.1
Z	-0.0130	-0.0980	-0.4980	0.0280	-0.3980	NOT USED.	NOT USED.	NOT USED.		
X	0.5640	-0.0560	NOT USED.	NOT USED.	0.0110	0.0700	0.1260	0.4630		
Y	-0.3360	0.6020	NOT USED.	NOT USED.	0.1090	0.0330	-0.1580	0.2130	1.8	48.1
Z	0.2680	-0.0760	NOT USED.	NOT USED.	-0.6380	0.1920	-0.3400	0.4530		
X	0.5660	-0.0570	NOT USED.	0.0040	NOT USED.	0.0810	0.1210	0.4620		
Y	-0.3170	0.6050	NOT USED.	0.0610	NOT USED.	0.1120	-0.1950	0.2180	5.7	52.8
Z	0.1720	-0.1070	NOT USED.	-0.3910	NOT USED.	-0.2310	-0.1510	0.3950		
X	0.5510	-0.0540	NOT USED.	-0.0410	0.0860	NOT USED.	0.1810	0.4370		
Y	-0.3420	0.6030	NOT USED.	-0.0170	0.1410	NOT USED.	-0.1300	0.2000	4.8	47.7
Z	0.2210	-0.1040	NOT USED.	-0.2330	-0.2880	NOT USED.	-0.2860	0.4340		
X	0.5790	-0.0670	NOT USED.	-0.0010	0.0020	0.1320	NOT USED.	0.5560		
Y	-0.3590	0.6120	NOT USED.	-0.0250	0.1590	-0.0640	NOT USED.	0.1010	4.8	48.8
Z	0.1780	-0.0850	NOT USED.	-0.2900	-0.1670	-0.2010	NOT USED.	0.2420		
X	0.5780	0.0420	NOT USED.	-0.0450	0.0590	-0.0940	0.4940	NOT USED.		
Y	-0.3280	0.6470	NOT USED.	-0.0170	0.1250	-0.0390	0.0110	NOT USED.	5.3	53.3
Z	0.2270	-0.0120	NOT USED.	-0.2850	-0.2130	-0.1940	0.0890	NOT USED.		
X	0.5610	-0.0630	-0.0150	NOT USED.	NOT USED.	0.0930	0.1130	0.4520		
Y	-0.2380	0.6340	0.1440	NOT USED.	NOT USED.	0.1040	-0.1990	0.2200	1.9	47.0
Z	-0.2770	-0.2370	-0.7620	NOT USED.	NOT USED.	-0.2690	-0.0680	0.4450		

ECG / VCG leads	I	II	V1	V2	V3	V4	V5	V6	Systematic error [°]	Random error [°]
X	0.5060	-0.0680	-0.0810	NOT USED.	0.0800	NOT USED.	0.1910	0.4350		
Y	-0.2800	0.6380	0.0980	NOT USED.	0.0660	NOT USED.	-0.0910	0.1730	3.3	40.0
Z	-0.0670	-0.1990	-0.5070	NOT USED.	-0.2880	NOT USED.	-0.2400	0.4320		
X	0.5450	-0.0800	-0.0540	NOT USED.	0.0370	0.1170	NOT USED.	0.5620		
Y	-0.2860	0.6430	0.1090	NOT USED.	0.0470	-0.0120	NOT USED.	0.0850	2.8	39.5
Z	-0.1130	-0.1850	-0.5350	NOT USED.	-0.2430	-0.1370	NOT USED.	0.2650		
X	0.5360	0.0280	-0.0790	NOT USED.	0.0430	-0.0840	0.4960	NOT USED.		
Y	-0.2440	0.6800	0.1200	NOT USED.	0.0130	0.0260	-0.0180	NOT USED.	3.4	45.7
Z	-0.0610	-0.1070	-0.5270	NOT USED.	-0.2870	-0.1410	0.1110	NOT USED.		
X	0.5220	-0.0500	-0.0720	0.0510	NOT USED.	NOT USED.	0.2580	0.3740		
Y	-0.2230	0.6660	0.1740	0.0010	NOT USED.	NOT USED.	-0.0280	0.0980	6.2	47.3
Z	-0.1070	-0.2600	-0.5050	-0.2000	NOT USED.	NOT USED.	-0.4790	0.6400		
X	0.5390	-0.0810	-0.0720	0.0320	NOT USED.	0.1370	NOT USED.	0.5600		
Y	-0.2460	0.6540	0.1640	-0.0070	NOT USED.	0.0200	NOT USED.	0.0570	4.3	41.8
Z	-0.1250	-0.1940	-0.5010	-0.1600	NOT USED.	-0.2740	NOT USED.	0.3070		
X	0.5470	0.0300	-0.0730	0.0200	NOT USED.	-0.0510	0.4810	NOT USED.		
Y	-0.2100	0.6850	0.1710	-0.0240	NOT USED.	0.0470	-0.0390	NOT USED.	5.1	48.9
Z	-0.0900	-0.1150	-0.4950	-0.1810	NOT USED.	-0.3370	0.1870	NOT USED.		
X	0.5350	-0.0770	-0.0600	-0.0670	0.1840	NOT USED.	NOT USED.	0.6170		39.5
Y	-0.2640	0.6430	0.1600	-0.0490	0.0640	NOT USED.	NOT USED.	0.0610	2.7	
Z	-0.0980	-0.1880	-0.5190	0.0680	-0.4090	NOT USED.	NOT USED.	0.1980		
X	0.5560	0.0310	-0.0740	0.0330	-0.0350	NOT USED.	0.4400	NOT USED.		
Y	-0.2230	0.6810	0.1710	-0.0750	0.0840	NOT USED.	-0.0280	NOT USED.	4.1	45.4
Z	-0.0170	-0.1010	-0.5000	0.0310	-0.4020	NOT USED.	0.0060	NOT USED.		

ECG / VCG leads	I	II	V1	V2	V3	V4	V5	V6	Systematic error [°]	Random error [°]
X	0.7510	0.1340	-0.0380	0.0680	-0.2210	0.3210	NOT USED.	NOT USED.		
Y	-0.2320	0.6800	0.1720	-0.0960	0.1280	-0.0440	NOT USED.	NOT USED.	5.1	52.1
Z	-0.0010	-0.0810	-0.4880	-0.0380	-0.2870	-0.0810	NOT USED.	NOT USED.		
X	0.5370	0.0280	-0.0720	-0.0120	0.0580	-0.0930	0.4990	NOT USED.		
Y	-0.2310	0.6800	0.1720	-0.0960	0.1270	-0.0430	-0.0010	NOT USED.	4.3	45.5
Z	-0.0530	-0.1060	-0.4960	-0.0570	-0.2190	-0.1820	0.1220	NOT USED.		
X	0.5390	-0.0810	-0.0720	0.0320	0.0000	0.1370	NOT USED.	0.5600		
Y	-0.2660	0.6450	0.1660	-0.1020	0.1640	-0.0740	NOT USED.	0.0920	3.7	39.2
Z	-0.1030	-0.1840	-0.5040	-0.0550	-0.1810	-0.1700	NOT USED.	0.2690		
X	0.5090	-0.0690	-0.0740	-0.0080	0.0870	NOT USED.	0.1870	0.4370		
Y	-0.2440	0.6360	0.1710	-0.0940	0.1390	NOT USED.	-0.1440	0.2000	3.7	39.4
Z	-0.0640	-0.2000	-0.5000	-0.0090	-0.2810	NOT USED.	-0.2460	0.4340		
X	0.5230	-0.0710	-0.0760	0.0380	NOT USED.	0.0820	0.1250	0.4620		
Y	-0.2210	0.6380	0.1700	-0.0160	NOT USED.	0.1090	-0.2050	0.2160	4.6	43.0
Z	-0.1100	-0.2030	-0.4970	-0.1660	NOT USED.	-0.2210	-0.1210	0.4010		
X	0.5190	-0.0720	-0.0670	NOT USED.	0.0580	0.0420	0.1430	0.4580		
Y	-0.2520	0.6320	0.1260	NOT USED.	0.0200	0.0870	-0.1890	0.2220	3.2	40.1
Z	-0.0760	-0.1970	-0.5160	NOT USED.	-0.2740	-0.0270	-0.2100	0.4170		
X	0.5590	-0.0580	NOT USED.	-0.0180	0.0390	0.0520	0.1340	0.4600		
Y	-0.3370	0.6010	NOT USED.	-0.0050	0.1160	0.0280	-0.1550	0.2120	4.9	48.4
Z	0.2100	-0.1000	NOT USED.	-0.2610	-0.2300	-0.0650	-0.2290	0.4060		