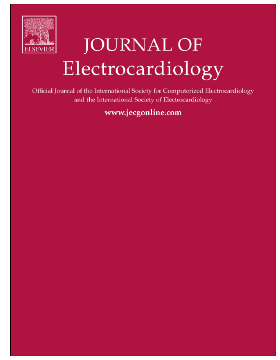
# Spatial QRS-T angle variants for prediction of all-cause mortality

Kück, Karina; Isaksen, Jonas Lynggaard; Graff, Claus; Skaaby, Tea; Linneberg, Allan; Hansen, Torben; Kanters, Jørgen K.

*Published in:*
Journal of Electrocardiology

*DOI (link to publication from Publisher):*
10.1016/j.jelectrocard.2018.05.011

*Publication date:*
2018




# Spatial QRS-T angle variants for prediction of all-cause mortality

Karina Kück, Jonas L. Isaksen, Claus Graff, Tea Skaaby, Allan Linneberg, Torben Hansen, Jørgen K. Kanters

PII: S0022-0736(18)30094-3
DOI: doi:10.1016/j.jelectrocard.2018.05.011
Reference: YJELC 52630

To appear in:

# Spatial QRS-T angle variants for prediction of all-cause mortality

Karina Kück[1], Jonas L. Isaksen[1,2], Claus Graff[2], Tea Skaaby[3], Allan Linneberg[3,4], Torben Hansen[5], and Jørgen K. Kanters[1*]

[1]Laboratory of Experimental Cardiology, Department of Biomedical Sciences, University of Copenhagen, Denmark

[2]Department of Health Science and Technology, Aalborg University, Denmark

[3]Center for Clinical Research and Prevention, Bispebjerg and Frederiksberg Hospital, The Capital Region, Copenhagen, Denmark

[4]Department of Clinical Medicine, Faculty of Health and Medical Sciences, University of Copenhagen, Copenhagen, Denmark

[5]Novo Nordisk Foundation Center for Basic Metabolic Research, Denmark

*Corresponding Author:

jkanters@sund.ku.dk

Jørgen K. Kanters
Laboratory of Experimental Cardiology, University of Copenhagen
Blegdamsvej 3
DK 2200 Copenhagen N
Denmark

## Abstract

**Background**: Many variants of the spatial QRS-T angle (QRS-Ta) are in use. We aimed to identify the best QRS-Ta for all-cause mortality prediction among different variants.

**Methods**: 6667 individuals from the Inter99 General Population Study were followed for a median of 12.7 years. Vectorcardiograms were calculated using the Kors and Inverse Dower matrices. The QRS-Ta was calculated using both mean and peak vectors of the QRS- and T-loops. Hazard ratios (HR) for abnormal QRS-Tas were calculated using a Cox's Proportional Hazard Model.

**Results**: The highest HR and largest AUC for all-cause mortality was obtained with the Kors matrix and the mean vector (HR=2.2, 95% confidence interval: [1.38;3.43] $p<0.001$, in men). There was interaction with the orientation of the QRS-T plane.

**Conclusion**: For optimal prediction of all-cause mortality, the mean vectors in the QRS- and T-loops of the Kors-derived vectorcardiogram should be used. QRS-T plane orientation affects mortality prediction.


**Keywords**: QRS-T angle, all-cause mortality, vectorcardiogram, transformation matrix, dominant vector

# I. Introduction

The spatial QRS-T angle (QRS-Ta) quantifies the difference in direction between the ventricular depolarization and repolarization. Multiple studies have shown that the QRS-Ta is a predictor for all-cause and cardiac mortality, but many of these studies were performed in elderly populations [1, 2]. Furthermore, the QRS-Ta has been used to improve risk stratification in patients with acute myocardial infarction [3], to aid in identifying new onset heart failure [4], to predict incident coronary heart disease [5], and to predict ventricular arrhythmias in patients with coronary heart disease [6].

Based on vectorcardiography, the QRS-Ta is readily obtainable from an electronic recording of the 12-lead ECG and risk prediction based on biomarkers such as the QRS-Ta may easily be implemented in the clinic [7].

However, much ambiguity exists in the calculation of the QRS-Ta. The vectorcardiogram (VCG) may be obtained directly by the use of Frank leads, or by conversion of the 12-lead digital ECG via transformation matrices [8]. Additionally, either the mean or the peak QRS and T vectors may be used in calculation of the QRS-Ta. Furthermore, projections of the QRS-Ta into the frontal and horizontal planes are common in the literature, adding another layer of variation to the calculation of the QRS-Ta.

The frontal QRS and T axes on the ECG are both reported using the full 360 degrees. By definition, the smallest angle between the two vectors is used. The angle could be calculated as either T minus QRS or QRS minus T, but in practice the positive number is always used (i.e. the sign is ignored). It is not known whether or not the orientation of the QRS-T plane matters in mortality prediction.

Thus, the aim of the present study was to identify the best QRS-Ta measurement for prediction of all-cause mortality in a middle-aged population, and to establish if the orientation of the QRS-T plane contains independent prognostic information.

## II. METHODS

Population:

A total of 6667 middle aged adults (49% men) with a mean age ± standard deviation (SD) of 46.3 ± 8.0 years were included from the Danish suburban population study Inter99 [9]. All participants were linked to the Danish Civil Registry to obtain data on mortality status. Participants in Inter99 were selected as an age-stratified (30, 35, 40, 45, 50, 55, and 60 years old) random sample from the Danish Civil Registry. The health examinations including ECG took place in years 1999-2001. All participants provided informed consent, and the Inter99 study was approved by the local ethics committee (KA 98 155).

Due to gender differences in repolarization men and women were analyzed separately. For a given measurement an abnormal group was defined as a value larger than the 95$^{th}$ percentile [10].

Electrocardiograms:

Resting 12-lead ECG of 10-second duration were recorded at 500 Hz using the Cardiosoft system (GE Healthcare, Milwaukee, WI). The Marquette 12SL algorithm (version 21, GE Healthcare, Milwaukee, Wisconsin) was used to obtain median beats as well as markers for QRS complex onset and offset ($QRS_{on}$, $QRS_{off}$), and T-wave offset ($T_{off}$). No human overreading took place. The RR interval, QRS duration, and QT interval were obtained. The QT interval was corrected for heart rate using the method of Friderica (QTcF). The ECGs were converted to

VCGs by two different transformation matrices: the Kors and the Inverse Dower matrices [7, 11]. Additionally, a QRS-Ta estimate was obtained without VCG transformation by the method of Rautaharju [12].

The ECG to VCG conversion matrix by Kors et al. is based on multiple regression, thus minimizing the error between the true Frank VCG and the reconstructed VCG in the training set. [7] The Dower matrix was based on a torso model and the Inverse Dower matrix was obtained as the pseudo-inverse of the matrix [11]. The Rautaharju method uses single ECG lead amplitudes (V6, V5, aVF, and V2) to estimate the X-, Y-, and Z-components of the VCG and to directly calculate the QRS-Ta using the inverse cosine.

A Cartesian coordinate system was used with the positive X-axis pointed towards the left, the positive Y-axis pointed caudally, and the positive Z-axis pointed posteriorly [13].

<u>Vector calculations:</u>

The QRS loop was defined as all vectors from $QRS_{on}$ to $QRS_{off}$, and the T loop was defined as all vectors from $QRS_{off}$ to $T_{off}$. The dominant vector of a loop was determined in two ways: The *mean vector* of a loop was defined as the mean of all the vectors in the loop:

$$\overrightarrow{QRS_{mean}} = \frac{1}{QRS_{off} - QRS_{on}} \sum_{i=QRS_{on}}^{QRS_{off}} \overrightarrow{v(i)}$$

The *peak vector* of a loop is the vector with the largest magnitude, whereby the magnitude of a vector, v, was defined as:

$$|\vec{v}| = \sqrt{v_x^2 + v_y^2 + v_z^2}$$

The *spatial QRS-T angle* was defined as the angle between the dominant vectors of the QRS and T loops:

$$QRSTa = \text{acos}\frac{QRS_x * T_x + QRS_y * T_y + QRS_z * T_z}{|\overrightarrow{QRS}| * |\vec{T}|}$$

QRS-T plane orientation:

Figure 1 illustrates how two heart beats with equal spatial QRS-Ta can have opposite directions of the corresponding orientation vectors. In the frontal projection, the left panel shows a clockwise direction from the QRS vector to the T vector and therefore a posterior orientation vector. The right panel shows a counterclockwise direction from the QRS vector to the T vector in the frontal plane and therefore an anterior orientation. On figure 2, two real VCGs are shown with similar size QRS-Ta but opposite QRS-T plane orientations.

Anterior or posterior orientation can be defined mathematically using the *orientation vector* (n) defined as the cross product of the dominant mean QRS and T vectors:

$\vec{n} = \overrightarrow{QRS} \times \vec{T}$.

The Z-component of the orientation vector may be directed either anteriorly or posteriorly (Figs. 1 and 2), and this categorization was applied to stratify the population into two groups. Dichotomizing into anterior and posterior groups can also be made from the frontal plane directly (see legend of Fig 1), since the orientation is considered a binary property in this work. The frontal plane approach and the Z-component approach are equivalent.

Statistics

Statistical analyses were computed using the R statistical software package (version 3.4.3). A Cox's Proportional Hazard model with left truncation at entry and right censoring at end of follow-up/death was used for survival analysis. Hazard Ratios (HR) for abnormal groups were obtained relative to the normal groups. Predictors were also evaluated as continuous variables for which Receiver Operator Characteristics (ROC) curves were computed using the 'timeROC' package version 0.3 [14]. The Area Under the Curve (AUC) was calculated and used to compare the methods. Crude comparisons between groups were made using a Kaplan-Meier plot. Sensitivity analyses were performed with adjustment for QRS duration, left bundle branch block, right bundle branch block, and average R-to-R interval separately. Values were expressed as mean ± SD. A p-value <0.05 was considered significant.

## III. Results

Baseline demographics and ECG parameters are given in Table I. The cohort is a middle-aged Danish population of both men and women. The average person was slightly overweight and normotensive. In women, the heart rate was increased, the QTcF was longer, and the ECG-based frontal plane T-axis was increased. The mortality was (median follow-up time 12.8 years, [inter-quartile range: 12.1;13.3]) 5.5% in men and 3.8% in women.

Mean values and SD of the spatial QRS-Ta as well as 95$^{th}$ percentiles are given in Table II for all combinations of transformation matrices and vector types. On average, men had a larger QRS-Ta than women, and the angles computed with the Kors matrix were smaller compared to those calculated using the Inverse Dower matrix. Angles between the mean QRS and T vectors were systematically wider than those between the peak QRS and T vectors.

The top part of Table III shows the hazard ratios for all-cause mortality separated by gender and disregarding the orientation of the QRS-T plane. No increased risk of all-cause mortality was found with the use of the Inverse Dower matrix for QRS-Ta calculation. On the contrary, when the Kors matrix was applied, men with an abnormally wide QRS-Ta (> 95$^{th}$ percentile cut-off) had a more than two-fold risk of dying compared to those with a normal QRS-Ta.

Mortality prediction with the ECG-based QRS-Ta estimate by Rautaharju yielded a lower estimated of the HR compared to the QRS-Ta based on the Kors-derived VCG, and mortality could not be predicted in women with the Rautaharju method.

Table IV shows AUC of ROC for each method. AUC was largest with the Kors matrix using the mean vectors in men. On figure 3, the ROC curves for all men show superiority of the Kors matrix and the mean vector.

In the sensitivity analyses, adjustments were performed for R-to-R interval, QRS duration, left bundle branch block, and right bundle branch block, respectively, with similar findings (not shown).

*Posterior vs. anterior*

To test if the QRS-T plane orientation played a role, risk prediction was performed separately in the posterior and anterior groups (Tables III and IV, lower part). The QRS-Ta was only a good predictor in the posterior group, but not in the anterior group (figure 4). The AUC analyses revealed that QRS-T angle was best calculated using the Kors matrix and the mean vectors also in the subgroup analyses.

In the posterior group of men, only the QRS-Ta's obtained using the Kors matrix for ECG to VCG transformation were significant predictors for all-cause mortality. For women, a QRS-Ta calculated using the mean QRS and T vectors was a significant predictor whereas a QRS-Ta calculated with the use of the peak QRS and T vectors did not predict mortality. In women, risk prediction was only successful in the posterior group with similar performances by the Kors and Inverse Dower matrices. QRS and T vector orientations in the posterior vs. anterior groups are presented in the supplementary material.

# IV. DISCUSSION

This study shows that QRS-Ta-based prediction of all-cause mortality in a middle-aged population is best achieved using the QRS-Ta between the mean QRS and T vectors computed in a vectorcardiogram obtained with the Kors matrix. A novel finding is that the orientation of the QRS-T plane carries predictive information since only posterior QRS-Tas predicted mortality.

*Conversion methods*

The difference in mortality prediction for QRS-Tas calculated using the Kors or Inverse Dower matrices may owe to their differences in origin [7, 11]. Cortez and Schlegel [15] concluded that QRS-Ta calculated using the Kors matrix more closely resembled the true Frank QRS-Ta than those calculated using the Inverse Dower matrix. Schreurs et al. further added that short-cuts to avoid VCG synthetization cannot be recommended [16]. Brown and Schlegel [17] concluded that the Kors matrix was superior in disease detection compared to the Inverse Dower matrix, and Man et al. found the Kors matrix superior for arrhythmia detection [18].

We add, that the Kors matrix is superior to the Inverse Dower matrix for prediction of all-cause mortality in the middle-aged, general population. Among all participants, using the Inverse Dower matrix, we were only able to predict mortality in one subgroup with a barely significant result (p=0.03). With the Kors matrix, however, a stronger and more stable signal was obtained. When the population was split into posterior and anterior groups, the HRs calculated using the Kors matrix were increased in the posterior group, but nothing changed for the Inverse Dower matrix results (p=0.03 for posterior subgroup). The AUC analyses similarly revealed that the Inverse Dower-based QRS-Tas predicted mortality worse than the QRS-Ta based on the Kors matrix using the mean vectors.

*Mean vs. peak vector*

In the literature, two types of QRS-Tas have been used [2, 10, 15, 17, 19]. One method is based on the peak vectors of the QRS and T loops, the other is based on the mean vectors of each loop. If the loop is broad or very non-planar, the vectors can have very different orientations and the mean vector may better represent the loop since it is based on all loop vectors, whereas the peak vector is only a single measurement.

While these two variants of the QRS-Ta may appear similar, the peaks-based QRS-Ta is systematically smaller than the mean-based QRS-Ta (Table II), and the two QRS-Tas should thus not be used interchangeably [15, 19]. In 2016, Lingman et al. [19] used both the mean- and the peak-based QRS-Ta (with Frank leads) for prediction of sudden cardiac death in patients with acute coronary syndrome. They found a tendency for the mean vector to better predict mortality although the confidence intervals overlapped between the mean and the peak vector derived QRS-Ta.

We also found a tendency for the mean vector-based QRS-Ta overall to better predict mortality than the peak vector-based QRS-Ta, possibly because the former angle is more stable. Splitting the population based on QRS-T plane orientation, we found that the QRS-Ta better predicted mortality in the posterior group. In women, mortality was only successfully predicted using the mean vector-based QRS-Ta, in men the signal appeared stronger using the mean vector for the QRS-Ta.

*Increased risk of all-cause mortality*

Using the Kors matrix and the mean vectors, we found a HR of about 2. Kardys et al. found a similar HR in another European population [20]. The population that Kardys et al. examined was markedly older, and we now found that the QRS-Ta can also be used for middle aged individuals. The study by Kardys et al. also found that the QRS-Ta is a stronger predictor for cardiac death than total mortality.

The ARIC study found a more than 50% increased mortality risk for an abnormal QRS-Ta with correction for clinical data [10]. When they added ECG corrections, the spatial QRS-Ta only predicted all-cause mortality in women. The study population was very like that of ours in terms of age, gender, and follow-up time, but the Inverse Dower matrix was used, which may be a limitation to the study.

The NHANES III study [21] estimated the QRS-Ta from 12-lead peak-to-peak amplitudes without computing the VCG [12] and found remarkably similar results in a different population. Schreurs et al. [16] found that the QRS-Ta is most accurately calculated using the Kors matrix, but the NHANES III study surprisingly found that bypassing the VCG step (i.e. using the method of Rautaharju) might work in all-cause mortality prediction. In this work, the QRS-T angle estimation by ECG peaks for mortality prediction performed worse than the Kors matrix-derived QRS-Ta. Particularly, with the short-cut, mortality could not be predicted in women. Although the estimated QRS-Ta with the method of Rautaharju has some predictive power, it appears inferior to the QRS-Ta based on the mean vector and the Kors transformation.

In the present study, all-cause mortality in the middle-aged general population was better predicted in men than in women. Most studies have not reported individual Hazard Ratios for men and women. Two large studies report conflicting findings in men and women [10, 21], and in the Women's Health Initiative, the QRS-Ta was found a predictor of mortality in women [22]. The latter study, however, only included post-menopausal women. In the present study, the mortality was lower (i.e. by a factor of 3-7) than in similar studies [10, 20, 21], especially in women where only 3.8% died. Compared to women, the mortality in men was 45% higher which may partly explain why the QRS-Ta was a better predictor in men than in women in this study.

*Orientation of the QRS-T plane*

The QRS-T plane spanned by the dominant QRS and T vectors practically never lies in the frontal plane, however in the literature, the projection of the spatial QRS-Ta into the frontal plane is common [17].

As previously mentioned, we hypothesized that the two opposite beats in Figs. 1 and 2 represent different physiological settings, and that they should be treated as such. To try to reject this hypothesis, we split the population into posterior and anterior groups and carried out the analyses independently.

We found that the QRS-Ta was only predictive of mortality in the posterior group and not in the anterior group. In men, for instance, using the mean vector and the Kors matrix, the AUC was 62.7% in the posterior group but only 55.2% in the anterior group. This finding strongly suggests that the orientation of the QRS and T vectors matter beyond simply the angle in the QRS-T plane.

The discussed findings suggest that the absolute value of the QRS-Ta is not the only prognostic marker within the QRS-Ta domain. Categorization into posterior and anterior group can also be performed based on the frontal plane QRS and T axis. If T axis > QRS axis (i.e. clockwise direction QRS to T), the VCG is categorized as posterior (Fig. 1).

The difference between the QRS-Ta methods were larger in the posterior group (Table IV). This finding is well explained by the fact that little to no prediction was possible in the anterior group, and thus the method matters not. Conversely, the methodology was important in the posterior group, since mortality prediction was possible.

The orientations of the QRS and T vectors in the posterior and anterior groups (supplementary figure S1) suggest small axis differences between the groups for both QRS and T axis, and deviations to the T axis have previously been associated with mortality. [23] It seems that certain combinations of QRS and T vector orientations predicts mortality better than the QRS-Ta alone, but posterior QRS-Ta remained a significant predictor even when QRS or T axis was included in the survival model (data not shown). The mechanism remains unknown, but may be due to identification of small disturbances of de/repolarization fronts.

*Automated and manual calculations*

Whereas the QRS-Ta can be calculated quickly by a computer programs in the research setting, in many cardiology clinics that is not an option. Matrix conversion from ECG to VCG by multiplication is only feasible for electronic ECGs, but the peak vectors can be estimated visually [24]. In the present study, the peak vectors were significantly poorer predictors than the mean vectors, and as such the visual method must be considered an option only when a digital approach cannot be taken. In that setting, the Rautaharju method might also be considered given the fact that it may be faster to compute the QRS-Ta using the Rautaharju method.

## V. Conclusion

For prediction of all-cause mortality in the general, middle-aged population, the QRS-T angle should be computed using the Kors matrix and the mean QRS and T vectors. A novel finding is that the relative orientation of the QRS and T vectors matters where mortality was better predicted in the posterior than in the anterior group.

## VI. Acknowledgements

The Inter99 study was initiated by Torben Jorgensen (principal investigator), Knut Borch-Johnsen (principal investigator on the diabetes part), Troels Thomsen, and Hans Ibsen. The current steering committee of the Inter99 study comprises Torben Jorgensen (principal investigator) and Charlotta Pisinger. The Inter99 study was funded by the Danish Research Councils, Health Foundation, Danish Centre for Evaluation and Health Technology Assessment, Copenhagen County, Danish Heart Foundation, Ministry of Health and Prevention, Association of Danish Pharmacies, Augustinus Foundation, Novo Nordisk, Velux Foundation, Becket Foundation, and Ib Henriksens Foundation.

# References


1. Voulgari, C., et al., *The spatial QRS-T angle: implications in clinical practice.* Curr Cardiol Rev, 2013. **9**(3): p. 197-210.
2. Oehler, A., et al., *QRS-T angle: a review.* Ann Noninvasive Electrocardiol, 2014. **19**(6): p. 534-42.
3. Raposeiras-Roubin, S., et al., *Usefulness of the QRS-T angle to improve long-term risk stratification of patients with acute myocardial infarction and depressed left ventricular ejection fraction.* Am J Cardiol, 2014. **113**(8): p. 1312-9.
4. Rautaharju, P.M., et al., *Electrocardiographic predictors of new-onset heart failure in men and in women free of coronary heart disease (from the Atherosclerosis in Communities [ARIC] Study).* Am J Cardiol, 2007. **100**(9): p. 1437-41.
5. Rautaharju, P.M., et al., *Electrocardiographic abnormalities that predict coronary heart disease events and mortality in postmenopausal women: the Women's Health Initiative.* Circulation, 2006. **113**(4): p. 473-80.
6. Borleffs, C.J., et al., *Predicting ventricular arrhythmias in patients with ischemic heart disease: clinical application of the ECG-derived QRS-T angle.* Circ Arrhythm Electrophysiol, 2009. **2**(5): p. 548-54.
7. Kors, J.A., et al., *Reconstruction of the Frank vectorcardiogram from standard electrocardiographic leads: diagnostic comparison of different methods.* Eur Heart J, 1990. **11**(12): p. 1083-92.
8. Vozda, M. and M. Cerny, *Methods for derivation of orthogonal leads from 12-lead electrocardiogram: A review.* Biomedical Signal Processing and Control, 2015. **19**: p. 23-34.
9. Jorgensen, T., et al., *A randomized non-pharmacological intervention study for prevention of ischaemic heart disease: baseline results Inter99.* Eur J Cardiovasc Prev Rehabil, 2003. **10**(5): p. 377-86.
10. Zhang, Z.M., et al., *Comparison of the prognostic significance of the electrocardiographic QRS/T angles in predicting incident coronary heart disease and total mortality (from the atherosclerosis risk in communities study).* Am J Cardiol, 2007. **100**(5): p. 844-9.
11. Edenbrandt, L. and O. Pahlm, *Vectorcardiogram synthesized from a 12-lead ECG: superiority of the inverse Dower matrix.* J Electrocardiol, 1988. **21**(4): p. 361-7.
12. Rautaharju, P.M., R.J. Prineas, and Z.M. Zhang, *A simple procedure for estimation of the spatial QRS/T angle from the standard 12-lead electrocardiogram.* J Electrocardiol, 2007. **40**(3): p. 300-4.
13. Macfarlane, P.W., *Lead Systems*, in *Comprehensive Electrocardiology*, P.W. Macfarlane, Editor. 2011, Springer.
14. Blanche, P., J.F. Dartigues, and H. Jacqmin-Gadda, *Estimating and comparing time-dependent areas under receiver operating characteristic curves for censored event times with competing risks.* Stat Med, 2013. **32**(30): p. 5381-97.
15. Cortez, D.L. and T.T. Schlegel, *When deriving the spatial QRS-T angle from the 12-lead electrocardiogram, which transform is more Frank: regression or inverse Dower?* J Electrocardiol, 2010. **43**(4): p. 302-9.
16. Schreurs, C.A., et al., *The spatial QRS-T angle in the Frank vectorcardiogram: accuracy of estimates derived from the 12-lead electrocardiogram.* J Electrocardiol, 2010. **43**(4): p. 294-301.
17. Brown, R.A. and T.T. Schlegel, *Diagnostic utility of the spatial versus individual planar QRS-T angles in cardiac disease detection.* J Electrocardiol, 2011. **44**(4): p. 404-9.
18. Man, S., et al., *Influence of the vectorcardiogram synthesis matrix on the power of the electrocardiogram-derived spatial QRS-T angle to predict arrhythmias in patients with ischemic heart disease and systolic left ventricular dysfunction.* J Electrocardiol, 2011. **44**(4): p. 410-5.

19. Lingman, M., et al., *Value of the QRS-T area angle in improving the prediction of sudden cardiac death after acute coronary syndromes.* Int J Cardiol, 2016. **218**: p. 1-11.
20. Kardys, I., et al., *Spatial QRS-T angle predicts cardiac death in a general population.* Eur Heart J, 2003. **24**(14): p. 1357-64.
21. Whang, W., et al., *Relations between QRS|T angle, cardiac risk factors, and mortality in the third National Health and Nutrition Examination Survey (NHANES III).* Am J Cardiol, 2012. **109**(7): p. 981-7.
22. Rautaharju, P.M., et al., *Electrocardiographic predictors of incident congestive heart failure and all-cause mortality in postmenopausal women: the Women's Health Initiative.* Circulation, 2006. **113**(4): p. 481-9.
23. Kors, J.A., et al., *T axis as an indicator of risk of cardiac events in elderly people.* Lancet, 1998. **352**(9128): p. 601-5.
24. Cortez, D., et al., *Visual transform applications for estimating the spatial QRS-T angle from the conventional 12-lead ECG: Kors is still most Frank.* J Electrocardiol, 2014. **47**(1): p. 12-9.

*Table I: Demographics and ECG basics.* Baseline characteristics for the population by gender.

| | Total | Men | Women | p |
|---|---|---|---|---|
| **n** | 6667 | 3255 (49%) | 3412 (51%) | |
| **Age [years]** | 46.3 ± 8.0 | 46.7 ± 8.0 | 46.0 ± 8.0 | <0.001 |
| **Ethnicity** | | | | 0.6 |
| **Nothern European, n (%)** | 6405 (96.1%) | 3125 (96%) | 3280 (96.1%) | |
| **Other, n (%)** | 262 (3.9%) | 130 (4.0%) | 132 (3.9%) | |
| **BMI [kg/m$^2$]** | 26.3 ± 4.6 | 26.8 ± 4.0 | 25.9 ± 5.1 | <0.001 |
| **Systolic BP [mmHg]** | 130 ± 18 | 134 ± 17 | 127 ± 18 | <0.001 |
| **Diastolic BP [mmHg]** | 82 ± 11 | 85 ± 11 | 80 ± 11 | <0.001 |
| **Heart Rate [bpm]** | 67 ± 11 | 65 ± 11 | 68 ± 11 | <0.001 |
| **RR [ms]** | 922 ± 150 | 944 ± 158 | 900 ± 138 | <0.001 |
| **QTcF [ms]** | 417 ± 19 | 412 ± 18 | 421 ± 18 | <0.001 |
| **QRS duration [ms]** | 92 ± 11 | 97 ± 11 | 87 ± 9 | <0.001 |
| **Frontal R axis (ECG) [°]** | 39 ± 32 | 35 ± 33 | 43 ± 30 | <0.001 |
| **Frontal T axis (ECG) [°]** | 41 ± 22 | 39 ± 23 | 43 ± 20 | <0.001 |

BMI: body mass index; BP: blood pressure. Measurements and demographics are reported as mean ± standard deviation.

*Table II: QRS-T angles.* Average QRS-T angles by transformation method and dominant vector and cut-off values for abnormal groups.

| | **Total** | **Men** | **Women** | **p** |
|---|---|---|---|---|
| **n** | 6667 | 3255 | 3412 | |
| **Spatial QRS-T angle [°]** | | | | |
| Kors matrix, mean vector | 54 ± 26 | 58 ± 27 | 50 ± 25 | <0.001 |
| Kors matrix, peak vector | 37 ± 26 | 41 ± 28 | 33 ± 23 | <0.001 |
| Inverse Dower matrix, mean vector | 76 ± 27 | 81 ± 27 | 72 ± 26 | <0.001 |
| Inverse Dower matrix, peak vector | 41 ± 29 | 46 ± 32 | 35 ± 24 | <0.001 |
| Rautaharju method | 83 ± 29 | 87 ± 30 | 80 ± 27 | <0.001 |
| **95$^{th}$ percentile cut-off angle [°]** | | | | |
| Kors matrix, mean vector | | 108 | 95 | |
| Kors matrix, peak vector | | 101 | 67 | |
| Inverse Dower matrix, mean vector | | 128 | 119 | |
| Inverse Dower matrix, peak vector | | 123 | 80 | |
| Rautaharju method | | 134 | 125 | |

Measurements are reported as mean ± standard deviation or as a single cut-off. p-value is for difference in males vs. females.

*Table III: The QRS-Ta as a predictor for all-cause mortality.* HRs with 95% confidence interval are shown for the abnormal groups relative to the normal groups. If plane orientation carries no information, similar results should be obtained in the posterior and anterior groups.

| **Conversion method** | | **Kors matrix** | | **Inverse Dower matrix** | | **Rautaharju** |
|---|---|---|---|---|---|---|
| **Dominant vector** | | **Mean** | **Peak** | **Mean** | **Peak** | |
| **All participants** | **Men** n = 3255 | 2.17*** [1.38;3.43] | 1.84* [1.13;3.01] | 1.66 [1.00;2.79] | 1.64 [0.98;2.74] | 1.92* [1.16;3.17] |
| | **Women** n = 3412 | 1.68 [0.93;3.05] | 1.45 [0.78;2.69] | 1.91* [1.07;3.39] | 1.65 [0.91;3.00] | 1.60 [0.86;2.96] |
| **Posterior group** | **Men** n = 1836 | 2.82*** [1.69;4.70] | 2.23** [1.26;3.96] | 1.73 [0.93;3.22] | 1.50 [0.76;2.95] | 2.04* [1.12;3.70] |
| | **Women** n = 2039 | 2.16* [1.08;4.32] | 1.61 [0.74;3.51] | 2.12* [1.06;4.24] | 1.80 [0.86;3.74] | 1.76 [0.81;3.83] |
| **Anterior group** | **Men** n = 1419 | 0.61 [0.15;2.50] | 0.54 [0.13;2.21] | 0.62 [0.15;2.53] | 1.15 [0.41;3.20] | 0.95 [0.30;3.05] |
| | **Women** n = 1373 | 0.66 [0.16;2.72] | 1.65 [0.65;4.18] | 1.39 [0.50;3.90] | 0.99 [0.31;3.21] | 2.33 [0.98;5.49] |

* p-value < 0.05, ** p-value < 0.01, *** p-value < 0.001. HR: Hazard Ratio. Mean: Based on the mean vector as dominant vector. Peak: Based on the peak vector as the dominant vector. The Rautaharju method computes the QRS-T angle in one step without intermittent QRS and T vectors.

*Table IV: The QRS-Ta as a predictor for all-cause mortality.* Area under the Receiver-Operator Characteristics (ROC) curve are presented. Stars indicate difference to the ROC curve obtained using the mean vector and the Kors matrix.

| Conversion method | | Kors matrix | | Inverse Dower matrix | | Rautaharju |
|---|---|---|---|---|---|---|
| **Dominant vector** | | **Mean** | **Peak** | **Mean** | **Peak** | |
| **All participants** | **Men** n = 3255 | 61.4% | 55.5%*** | 56.9%*** | 56.4%** | 53.3%*** |
| | **Women** n = 3412 | 60.3% | 59.3% | 57.4%** | 61.2% | 55.1%** |
| **Posterior group** | **Men** n = 1836 | 62.7% | 57.4%* | 58.3%*** | 59.0% | 52.9%*** |
| | **Women** n = 2039 | 59.6% | 62.1% | 57.0%** | 62.2% | 54.0%** |
| **Anterior group** | **Men** n = 1419 | 55.2% | 48.7%* | 53.4% | 49.3%* | 54.0% |
| | **Women** n = 1373 | 61.3% | 53.9%* | 57.6%* | 58.9% | 56.4% |

*,**,**; p< 0.05, 0.01, 0.001 vs. mean vector, Kors matrix.

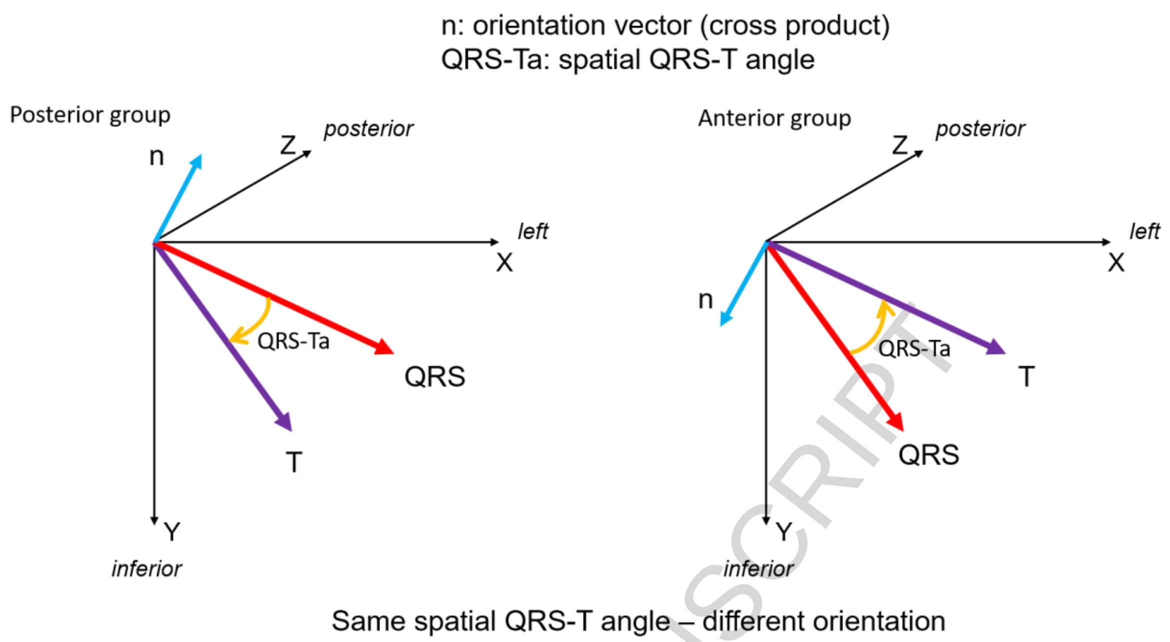



*Fig. 1: Same spatial QRS-T angle – different orientation.* Two equal QRS-Ta measurements may have different orientations of the orientation vector (n). Patients were categorized as having either a posterior (left panel) or anterior (right panel) orientation vector depending on the direction of the orientation vector (n). From the front, the posterior type QRS-T angle appears to have a clockwise direction from QRS to T and the anterior type a counterclockwise direction. To determine posterior vs. anterior direction, only the frontal plane projection is needed. If the frontal QRS axis is 30° and the frontal T axis 55°, the direction from QRS to T is clockwise and the orientation vector, n, will have a posterior rather than an anterior direction (i.e. a Z-component >0 when Z is directed positively towards the back).

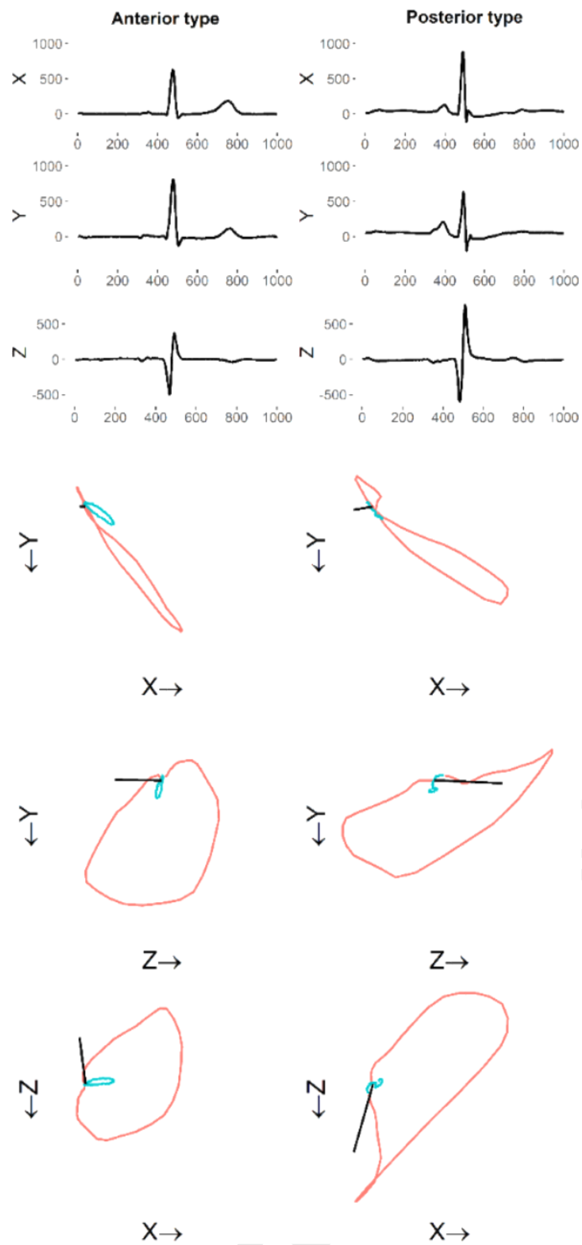



*Fig. 2: QRST angle and plane orientation.* The left panel shows a vectorcardiogram with an anterior orientation (the Z-component of the orientation vector, n, is negative). The spatial mean-vector QRS-T angle is 39°. The right panel shows a vectorcardiogram with a posterior orientation. That QRS-T angle is 45°. In the bottom half, the black straight line is the projection of the scaled orientation vector, n, and arrows indicate the positive direction for the axis. In both examples, the orientation vector is almost perpendicular to the frontal plane, but in opposite directions.

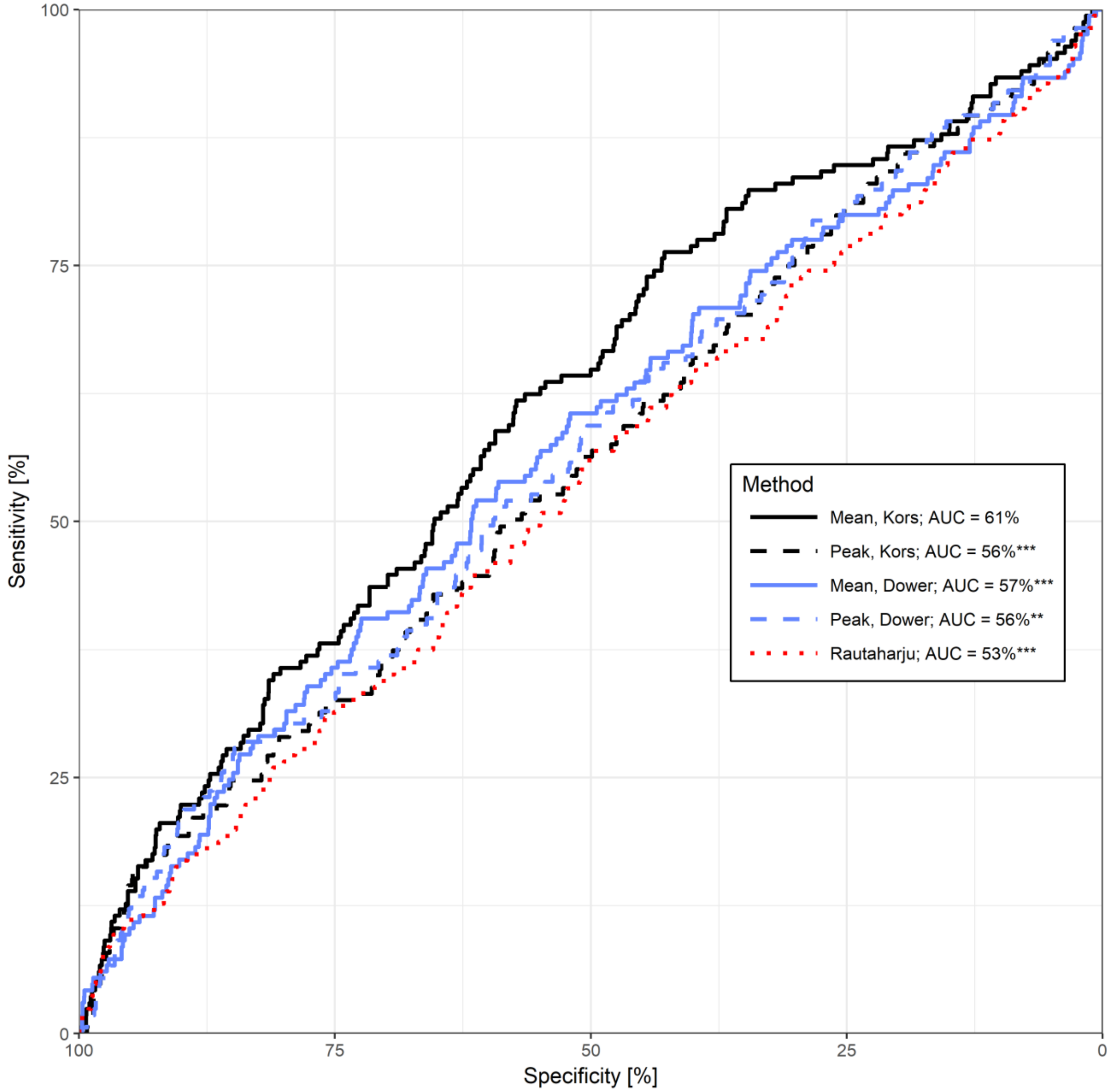



*Fig. 3: Receiver Operator Characteristics curves for all men (n=3255).* The largest area under the curve was found for the QRS-T angle calculated using the mean vectors and the Kors matrix (61%). Stars indicate significant levels compared to Mean, Kors. AUC, Area under curve; **, p<0.01; ***, p<0.001.

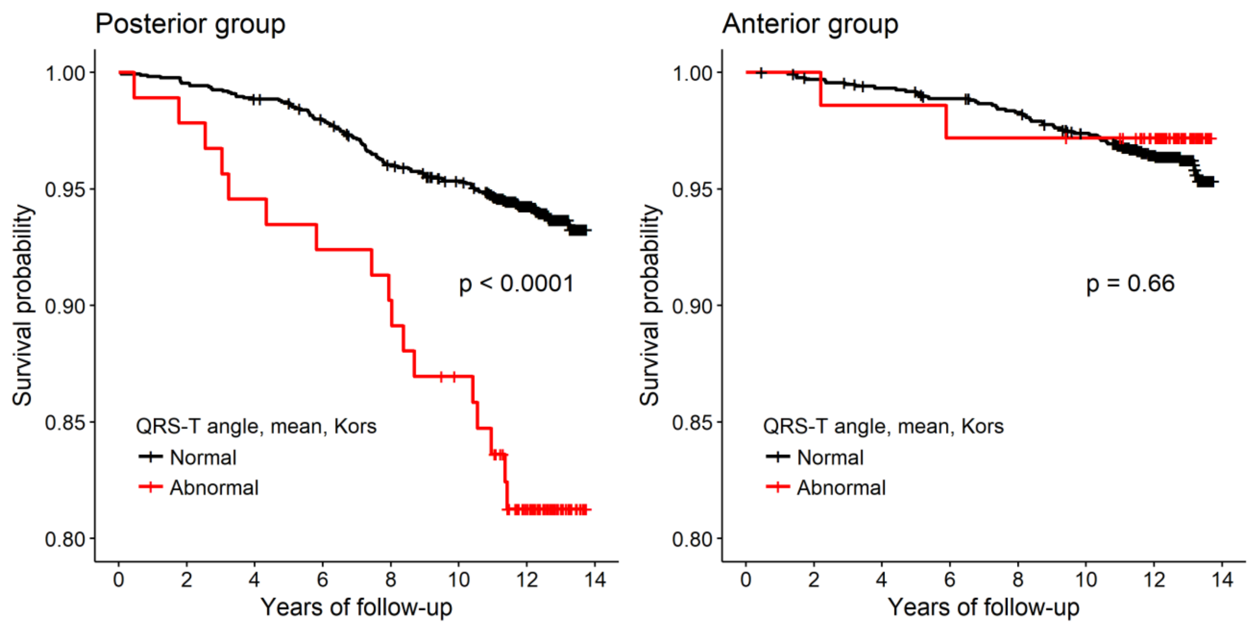



*Fig. 4: Kaplan-Meier survival curves for men stratified into the posterior (n=1836) or anterior (n=1419) group.* The QRS-T angle predicts mortality in the posterior group, but not in the anterior group.

Highlights

- A better way to calculate QRS-T angle is presented
- The orientation of the QRS-T plane is important
- QRS-T angle-based mortality prediction was better in males than in females