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ScienceDirect
Journal of Electrocardiology 43 (2010) 302 – 309
JOURNAL OF Electrocardiology
www.jecgonline.com

When deriving the spatial QRS-T angle from the 12-lead electrocardiogram, which transform is more Frank: regression or inverse Dower?

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Received 20 January 2010

Abstract

Introduction: Our primary objective was to ascertain which commonly used 12-to-Frank-lead transformation yields spatial QRS-T angle values closest to those obtained from simultaneously collected true Frank-lead recordings.

Materials and Methods: Simultaneous 12-lead and Frank XYZ-lead recordings were analyzed for 100 postmyocardial infarction patients and 50 controls. Relative agreement, with true Frank-lead results, of 12-to-Frank-lead–transformed results for the spatial QRS-T angle using Kors' regression versus inverse Dower was assessed via analysis of variance, Lin's concordance, and Bland-Altman plots.

Results: Spatial QRS-T angles from the true Frank leads were not significantly different than those derived from the Kors' regression-related transformation but were significantly smaller than those derived from the inverse Dower-related transformation ($P < .001$). Independent of method, spatial mean QRS-T angles were also always significantly larger than spatial "maximum" ("peaks") QRS-T angles.

Discussion: Spatial QRS-T angles are best approximated by regression-related transforms. Spatial mean and spatial "peaks" QRS-T angles should not be used interchangeably.

Published by Elsevier Inc.

Keywords: Vectorcardiography; Spatial ventricular gradient; 3-Dimensional ECG; Lead reconstruction

Introduction

The spatial QRS-T angle has repeatedly been shown to have diagnostic[1-3] and prognostic[4-12] value. Changes in spatial QRS-T angles, for example, may be useful in evaluating efficacy of hypertension treatment,[1] diabetes mellitus,[3] incident coronary heart disease[2,10] and heart failure,[2,9,11] and most importantly the propensity for cardiac events[2,4,12] and mortality.[4-7,12] Of the various Frank-lead vectorcardiocardiographic (VCG) reconstruction methods used for approximating spatial QRS-T angle values from conventional 12-lead electrocardiogram (ECG) recordings,[13–16] arguably the 2 most common are the inverse Dower-related reconstruction technique[13] and the regression-related method of Kors et al.[14] Of these 2 methods, the latter has tended to demonstrate better performance in reconstructing the actual Frank XYZ-lead signals.[14,16] However, it remains unclear from the literature which of these methods actually best reconstructs those secondarily derived parameters, such as the spatial QRS-T angle, that have enough clinical importance to effectively drive a clinical need for 12-to-Frank-lead transformations.

Interestingly, in healthy, nonhospitalized individuals, mean values for the spatial mean (SM) QRS-T angle derived from inverse Dower-related reconstructions have typically ranged from 66 to 81 degrees,[8,17,18] whereas those derived from Kors' regression-related reconstructions have typically ranged from 44 to 65 degrees,[19,20] the latter evidently closer to mean values obtained from the true Frank leads (35-51 degrees).[21,22] To further complicate matters, the spatial QRS-T angle has often been measured as the angular difference between the "maximums" (peaks) of the 3-dimensional QRS and T loops (spatial "maximum" QRS-T angle)[1,3,23-25] rather than as the angle between the position

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0022-0736/$ – see front matter. Published by Elsevier Inc.
doi:10.1016/j.jelectrocard.2010.03.010

Table 1
Results for the control group, post-MI group, and total sample for the true Frank leads and for the Kors' regression-related and inverse Dower-related transformations

Parameter	Control group (n = 50)	Post-MI group (n = 100)	Total sample (n = 150)
SM QRS-T angle (°)-true Frank leads	54.4 ± 25.8	84.3 ± 39.8	74.3 ± 38.3
SM QRS-T angle (°)-Kors' regression	53.4 ± 26.0	91.4 ± 39.4	78.8 ± 39.7
SM QRS-T angle (°)-inverse Dower	70.0 ± 28[a,b]	98.3 ± 40.9[a]	88.9 ± 39.4[a,b]
SP QRS-T angle (°)-true Frank leads[c]	41.7 ± 27.1	68.9 ± 40.9	59.8 ± 38.9
SP QRS-T angle (°)-Kors' regression[c]	40.7 ± 23.5	76.4 ± 42.1	64.5 ± 40.6
SP QRS-T angle (°)-inverse Dower[c]	58.4 ± 27.8[a,b]	87.9 ± 45.7[a]	78.1 ± 42.9[a,b]
SVG magnitude (mV ∗ ms)-true Frank leads	98.3 ± 44.7	46.7 ± 22.0	63.9 ± 39.7
SVG magnitude (mV ∗ ms)-Kors' regression	101.9 ± 44.1	51.6 ± 25.2	68.4 ± 40.3
SVG magnitude (mV * ms)-inverse Dower	97.3 ± 44.3	54.0 ± 28.0	68.4 ± 39.8
SVG elevation (°)-true Frank leads	32.1 ± 11.0	28.3 ± 33.6	29.2 ± 28.2
SVG elevation (°)-Kors' regression	32.6 ± 9.9	24.7 ± 29.1	27.3 ± 24.7
SVG elevation (°)-inverse Dower	28.5 ± 11.4	20.1 ± 26.9	22.9 ± 23.2[a]
SVG azimuth (°)-true Frank leads	20.0 ± 21.7	−8.1 ± 62.3	1.3 ± 53.9
SVG azimuth (°)-Kors' regression	19.9 ± 17.6	−0.5 ± 64.7	6.3 ± 54.5
SVG azimuth (°)-inverse Dower	11.5 ± 20.0	−5.4 ± 70.9	0.3 ± 59.4

[a] Derived VCG result significantly differs from true Frank-lead result by ANOVA.
[b] Derived VCG results significantly differ from one another by ANOVA.
[c] SP QRS-T angle results significantly differ from SM QRS-T angle results.

vectors defined by the areas of these same loops (spatial "mean" QRS-T angle[4-11,17-22,26-29]—see Appendix 1 for our own understanding of the difference). Even more confusingly, healthy subjects have also typically had higher mean values for the spatial "mean" QRS-T angle than for the spatial "maximum" QRS-T angle (means for the latter ranging from 11 to 21 degrees for inverse Dower transformations[1,3,23] and from 42 to 51 degrees for the true Frank leads).[24,25] In the present study, we used Lin's concordance correlation coefficient to ascertain the relative concordance, to true Frank-lead results, of 12-to-Frank-lead–transformed results derived from Kors' regression-related versus inverse Dower-related reconstructions. Based on the comparatively smaller mean quadratic deviations from the true XYZ leads that have been noted for the Kors' regression method in the past,[16] we hypothesized that this method would also better approximate important secondarily derived VCG parameters such as the spatial QRS-T angle. We also sought to better define any differences between results for the SM versus spatial "maximum" ("peaks") QRS-T angles using both the true Frank leads and the 2 different reconstruction methods.

Methods

Data collection

The data were obtained from a publicly available source, the Physikalisch-Technische Bundesanstalt (PTB) Diagnostic ECG Database[30] available at http://www.physionet.org/physiobank/database/ptbdb/. The PTB ECG data were collected in the 1990s by Dr Michael Oeff et al at the Department of Cardiology of University Clinic Benjamin Franklin in Berlin, Germany, using a noncommercial prototype recorder that allowed the simultaneous acquisition of both 12-lead ECG and true Frank-lead VCG data stored at 1000 samples per second per channel. We focused our own analyses on data from: (1) PTB patients 001 through 101, all of whom were being evaluated for a recent myocardial infarction (MI) and (2) the first 50 "healthy controls" in the PTB database, beginning with PTB subject 0104, as specified by the PTB demographic files that accompany the recorded raw data. In the recent MI group, the mean (SD) age was 58.8 (11.3) years, and 72% were males. In the healthy control group, the mean (SD) age was 43.5 (14.7) years, and 76% were males.

Data analyses

The raw binary data files from the PTB database were processed using software developed by the authors at NASA's Johnson Space Center.[20,31] Initial analyses revealed that all of the selected files except recent MI-patient file 079 (which demonstrated a paced rhythm and was not analyzable) had, at a minimum, 40 QRS-T complexes that were acceptable for signal averaging in all channels when using a minimum cross-correlation cutoff of 97% against the signal-averaged QRS templates formed for each channel in each file, as previously described.[20,31] Thus, 40-complex signal averages were ultimately constructed for each patient's file, the principal purpose of signal averaging being to help eliminate any transient or nonreproducible effects that would more likely influence single complexes than signal averages, such as the precise location of a given complex within the respiratory cycle.

VCG parameters from the true and derived Frank leads

The principal VCG parameters studied were the SM and spatial "peaks" (SP) QRS-T angles, the magnitude of the spatial ventricular gradient (SVG), and the elevation and azimuth angles of the SVG. Time integrals (areas) for the *X*, *Y*, and *Z* signals were first determined separately for the QRS and T complexes by measuring the areas of the complexes above and below the baseline and subtracting negative areas from positive areas. The time integrals of the