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The synthesized vectorcardiogram resembles the measured vectorcardiogram in patients with dyssynchronous heart failure

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Abstract

Background: The use of vectorcardiography (VCG) has regained interest, however, original Frank-VCG equipment is rare. This study compares the measured VCGs with those synthesized from the 12-lead electrocardiogram (ECG) in patients with heart failure and conduction abnormalities, who are candidate for cardiac resynchronization therapy (CRT).

Methods: In 92 CRT candidates, Frank-VCG and 12-lead ECG were recorded before CRT implantation. The ECG was converted to a VCG using the Kors method (Kors-VCG) and the two methods were compared using correlation and Bland–Altman analyses.

Results: Variables calculated from the Frank- and Kors-VCG showed correlation coefficients between 0.77 and 0.90. There was a significant but small underestimation by the Kors-VCG method, relative bias ranging from −1.9% ± 4.6% (QRS-T angle) to −9.4% ± 20.8% (T area).

Conclusion: The present study shows that it is justified to use Kors-VCG calculations for VCG analysis, which enables retrospective VCG analysis of previously recorded ECGs in studies related to CRT.

Keywords: Vectorcardiography; Kors method; Electrical dyssynchrony; Cardiac resynchronization therapy

Introduction

With the use of vectorcardiography (VCG), the size and direction of the electrical forces generated by the heart are recorded and displayed in three dimensions. The VCG consists of three orthonormal leads X, Y, and Z, containing phase information between these leads. This technique was first described 101 years ago by Williams [1]. The VCG technique was almost abandoned and the 12-lead electrocardiogram (ECG) became the clinical standard, because of the need for special VCG recording equipment, the lack of a standard VCG-lead system [2–4], the impracticality of a back electrode in many of these systems, and the complexity to interpret the different loop morphologies for diagnosis [5,6]. The interest in the diagnostic value of the VCG has, however, never completely subsided and with today's computer technology the vector loops can be synthesized from the 12-lead ECG resulting in a revival of the VCG.

Several systems of three orthonormal leads have been described for recording the VCG, though the most commonly used one is the 8-electrode system according to Frank [4]. Due to limited availability of Frank-VCG recording systems, the VCG is commonly synthesized from the 12-lead ECG. This is achieved by multiplying 8 independent ECG leads (two limb leads and all six precordial leads) by a matrix. Recent studies demonstrated that the Kors-derived VCG results in the best approximation of the Frank-VCG [5,7–9].

The matrix proposed by Kors et al. is based on a learning set from the Common Standards for Electrocardiography (CSE) multilead library, including both patients and healthy individuals, and was generated by multiple linear regression [8]. Although the Kors-VCG nicely resembles the Frank-VCG in previous studies [5,7–9], a comparison has never been made for patients with heart failure and a left ventricular (LV) conduction delay, mostly due to left bundle branch block (LBBB). These patients are commonly treated with cardiac resynchronization therapy (CRT). CRT has been shown to improve cardiac pump function, heart failure symptoms, quality of life, and survival [10]. Although the effects of CRT in large clinical trials are impressive on a

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group level, the benefits in individuals vary considerably; the non-response rate to this therapy is still 30–50% [11]. To reduce the risk of complications and the unnecessary use of expensive products, patient selection should be improved. Recent studies have shown that the VCG could play an important role in the selection of patients for CRT [12,13] or in the optimization of the CRT settings [14]. Therefore, the current study aims to compare the Frank-VCG and the Kors-VCG in patients with heart failure and LV conduction delay focusing on vectorcardiographic variables relevant to resynchronization of the ventricles.

Methods

Patient population

The patient population used in this study has been described previously [13]. It consisted of 138 consecutive patients with heart failure, who were scheduled for implantation of a CRT device at the Maastricht University Hospital between September 2010 and June 2012. Excluded were patients with an intrinsic QRS duration < 120 ms (n = 13) or previous RV pacing during either the VCG (n = 22) or ECG recording (n = 2). Another 9 patients were excluded due to technical disturbances, multiple ectopic beats or missing ECGs. This resulted in a final population of 92 patients. The project was approved by the ethics committee of Maastricht University Hospital and was conducted in accordance with the Declaration of Helsinki. All participants gave written informed consent prior to investigation.

Study design

One day before CRT implantation, a VCG and 12-lead ECG were recorded. In some cases (n = 25) the 12-lead ECG was not recorded at the same date, but near this date (with a median of 12 days, ranging between 1 and 57 days). Both VCG and ECG were recorded at rest and in supine position.

The VCGs were recorded as described earlier [13], using 8 electrodes according to the Frank orthogonal lead system at a sampling frequency of 500 Hz for 5 minutes after which the complexes were averaged over a period of one minute (Coronet II System, Ortivus AB, Danderyd, Sweden).

The ECGs were recorded at a frequency of 250 Hz and stored digitally as PDF files in the MUSE Cardiology Information system (GE Medical System). The digital data of the 12-lead ECGs were extracted from the PDF files using Inkscape version 2 (Boston, MA, USA) as described previously [12]. A VCG was then synthesized by multiplying the voltages in the digital ECG leads by the Kors matrix [7].

VCG analysis

Both the Frank-VCG and the Kors-VCG were analyzed offline using customized software described previously [12,15]. This software calculates the different VCG variables described here. The QRS duration and QT interval were defined as the duration between the beginning of the QRS complex and the end of the QRS complex or T wave, respectively. Subsequently, the maximal QRS vector and T vector were found by the maximal distance between the origin of the 3D loop and a point on the QRS- and T-vector loop, respectively. The size and direction of these maximal vectors were expressed by the vector amplitude, azimuth (angle in the transversal plane with backward vector directions being negative) and elevation (angle in the craniocaudal direction with downward vector directions being < 90°), as described by Wecke et al. [16] Furthermore, the areas of the QRS- and T-loops were computed by numerical integration as the area between the curve and the baseline in the X, Y, and Z direction between the beginning and ending of the QRS complex or T wave, respectively, and calculated as $(QRS^2_{area,x} + QRS^2_{area,y} + QRS^2_{area,z})^{1/2}$ or $(T^2_{area,x} + T^2_{area,y} + T^2_{area,z})^{1/2}$ [7]. The QRS-T angle was derived from the two vectors of the QRS- and T-integrals.

Statistical analysis

The statistical analysis was performed using IBM SPSS statistics software version 21 (SPSS Inc, Chicago, IL). Continuous and discrete variables are presented as mean ± standard deviation (SD) and counts (percentages), respectively. To compare the recorded Frank-VCG outcomes with the Kors-VCG outcomes, a paired t-test was performed and the Pearson correlation coefficient was calculated. Furthermore, a Bland–Altman analysis was used to show the differences between the two VCG methods. The mean difference between the measured and calculated values is defined as bias and the 95% upper and lower limits of agreement (LoA) were defined as bias ± 1.96*SD (of the

Table 1
Baseline characteristics of the 92 included patients.

Patient characteristics	N = 92
Age (years)	67 ± 9
Female (n, %)	33 (36)
Heart rate (BPM)	69 ± 12
BMI (kg/m^2)	27 ± 5
Ischemic HF etiology (n, %)	50 (54)
Atrial fibrillation (n, %)	23 (25)
Diabetes mellitus (n, %)	30 (33)
NYHA class	
I (n, %)	9 (10)
II (n, %)	40 (43)
III (n, %)	33 (36)
IV (n, %)	1 (1)
Unknown (n, %)	9 (10)
LBBB (n, %)	73 (79)
LVEF (%)	26 ± 7
LVEDV (ml)	195 ± 58
QRS duration (ms)	168 ± 17
QT interval (ms)	458 ± 39
β-Blocker (n, %)	83 (90)
ACE-inhibitor/ARB (n, %)	81 (88)
Loop diuretics (n, %)	62 (67)
Ald-antagonist (n, %)	29 (32)

Variables are shown as counts (percentage) or mean ± standard deviation when appropriate. BMI: body mass index, HF: heart failure, NYHA: New York Heart Association, LBBB: left bundle branch block, LVEF: left ventricular ejection fraction, LVEDV: left ventricular end diastolic volume, ACE: angiotensin-converting enzyme, ARB: angiotensin II type 1 receptor blocker, Ald-antagonist: aldosterone antagonist.