Research Article

Accuracy of Cardiogoniometry Compared With Electrocardiography in the Diagnosis of Coronary Artery Disease

Behshid Ghadrdoost [1]; Majid Haghjoo [2]; Ata Firouzi [3,*]

[1]Rajaie Cardiovascular Medical and Research Center, Iran University of Medical Sciences, Tehran, IR Iran
[2]Cardiac Electrophysiology Research Center, Rajaie Cardiovascular Medical and Research Center, Iran University of Medical Sciences, Tehran, IR Iran
[3]Cardiovascular Intervention Research Center, Rajaie Cardiovascular Medical and Research Center, Iran University of Medical Sciences, Tehran, IR Iran

Corresponding author: Ata Firouzi, Cardiovascular Intervention Research Center, Rajaie Cardiovascular Medical and Research Center, Vali-Asr St., Niayesh Blvd, Tehran, IR Iran. Tel: +98-2123922163, Fax: +98-2123922340, E-mail: sep_par_71@yahoo.com

Background: Cardiogoniometry (CGM) is a novel spatiotemporal electrocardiographic method utilizing computer-assisted three-dimensional data on cardiac potentials.

Objectives: This study compares the accuracy of CGM and electrocardiography (ECG) by detecting coronary artery disease (CAD) with reference to angiography as a well-known gold standard.

Patients and Methods: A total of 390 patients undergoing coronary angiography with CAD were enrolled. CGM was performed a few hours prior to coronary angiography. A standard 12-lead ECG was recorded after the CGM. The CGM and ECG results were recorded and analyzed by an independent investigator blinded to all patient data and the results of the coronary angiography.

Results: The coronary angiography showed a normal coronary artery in 263 patients (67.4%). A median of CGM score was 1 (0–2), the minimum score was 0 and maximum score was 8. A total of 90 patients (31%) showed predefined ST-segment/T-wave changes in the resting 12-lead ECG. CGM yielded a sensitivity of 84% and specificity of 81% and the ECG yielded a sensitivity of 29% and specificity of 67% when compared with the coronary angiography.

Conclusions: CGM is a non-invasive technique recently developed for quantitative three-dimensional vectorial analysis of myocardial activity and detection of ischemia and infarction. This technique is clearly more sensitive and more specific than a standard resting 12-lead ECG.

Keywords: Vectorcardiography; Coronary Angiography; Electrocardiography

1. Background

The resting 12-lead electrocardiogram (ECG) is an established diagnostic test in evaluating patients with CAD. However, as a diagnostic tool, the procedure is limited by low sensitivity, particularly in stable and/or asymptomatic patients (1). Furthermore, automated interpretation of the ECG is not always reliable (2) and the diagnostic yield depends highly on the ECG expertise of the reader (3). Therefore, the exercise ECG has been established as the standard method in a primary setting for detection of CAD in patients with suspected stable angina pectoris or without symptoms. However, exercise ECGs are often not meaningful due to limited stress capacity of the patient or are even contraindicated (4).

CGM is a novel electrodiagnostic method that analyzes three-dimensional information on cardiac potentials (5, 6). Additionally, CGM provides quantitative computer analysis of this three-dimensional information. The rating does not require a qualitative evaluation by an expert. CGM showed a prospective diagnostic sensitivity of 64–79%, and a specificity of 82% in detecting CAD (6, 7).

2. Objectives

We therefore sought to investigate the accuracy of CGM compared with ECG to detect patients with CAD before coronary angiography as a gold standard method.

3. Patients and Methods

3.1. Patients

A total of 400 patients with suspected CAD, candidates for first elective coronary angiography, were enrolled. The study protocol was approved by our local Ethics Committee. Patients who had atrial fibrillation, frequent premature beats, left bundle branch block, severe valvular disease, and history of previous cardiac surgery were excluded. CGM was obtained a few hours prior to coronary angiography. Written informed consent was obtained from all patients before study. A cardiologist who performed the coronary angiography was blinded to the results of the ECG and CGM. All ECGs were analyzed by one independent investigator blinded to all patient data. All CGMs were obtained by

nurses who were blinded to the results of the ECG and angiography.

3.2. Cardiogoniometry Protocol

During CGM recording, patients laid in a supine position and after a normal expiration, held their breath for 12–15 seconds during measurement. The CGMs were recorded by an independent investigator blinded to all patient data, including the results of the angiography. A standard 12-lead ECG was recorded after the CGM. The principles of the CGM have been published in detail elsewhere (6-8). Briefly, four electrodes were placed perpendicular at four points on the patients thorax: point 1, at point V4 of Wilson, in the 5th intercostal space on mid clavicular line; point 2, at a point opposite to electrode 1 on back (at point V8 of Wilson); point 3 located perpendicularly above electrode 1 at 0.7 times the distance between point 1 and 2; and point 4 placed to the right of point 3 at the same distance between points 1 and 3 horizontally. The leads are defined as below: 4-2: D (dorsal), 4-1: A (anterior), 2-1: I (inferior), 4-3: Ho (horizontal), and 3-1: Ve (vertical) (Figure 1) (http://www.enverdis.com/cardiogoniometry/). Points 4-2-1 defined the oblique sagittal plane OSP and points 4-3-1 defined the frontal plane. The third plane was orthogonal to the two other planes and contained point 3 and it was the sagittal plane perpendicular to the OSP. Projection X was oriented in an anterodorsal direction and crossed the OSP and the sagittal plane perpendicularly. Projection Y was oriented in a baso-apical direction and lays in the OSP (4-2-1) and the frontal plane (4-3-1). Projection Z was oriented in the superior-inferior direction relative to the OSP and laid in the frontal plane (4-3-1) and the sagittal plane perpendicular to the OSP. The direction of X-, Y-, and Z-axis and the magnitude of potential for reach point determined T time. (Figure 2) (http://www.enverdis.com/cardiogoniometry/). These vectors can be represented as a loop (Figure 3) (http://www.enverdis.com/cardiogoniometry/).

CGM software in addition to showing three-dimensional loops also displays the maximum range of the reference vectors. The parameters obtained from CGM can be divided into the following main classes as follows: angles, amplitudes, shapes, and eccentricities describing the P-, R-, and T-loops, potential distributions of the P-, R-, and ST/T-loops in octants, and velocities (absolute and ratios) of the P-, R-, and T-loops. In a normal situation, the maximum vectors of R and T (depolarization and repolarization) are located directly to each other and within the standard fields (Figure 4) but in pathologic situation the maximum vectors of R and T are distinctly running in different directions, the T maximum vectors are scattered. Thus, indicating ischemia, the R maximum vectors are clearly located outside of standard field and are strongly scattered (Figure 5).

### 3.3. Twelve-Lead Electrocardiography

The resting 12-lead ECG was recorded prior to coronary angiography. All ECGs were analyzed by one independent investigator blinded to all patient data. ECGs with persistent or transient horizontal or down-sloping ST depression ≥ 0.05 mV in two contiguous leads and/or T inversion ≥ 0.1 mV in two contiguous leads with prominent R wave were regarded as indicative of myocardial ischemia. Therefore, all registered positive; with all other patients registered as negative (9, 10). Statistical analysis: Statistical analyses were performed with SPSS (ver 15; SPSS Inc. Chicago, Illinois). Data were expressed as mean values ± standard deviation for interval and count (%) for categorical variables. The McNemar test was performed to compare sensitivities, specificities, and the diagnostic accuracy of CGM and ECG. P values < 0.05 were considered significant.

4. Results

4.1. Demographic and Clinical Findings

A total of 400 patients were enrolled in this study. Ten patients who had atrial fibrillation, left bundle branch block, and severe valvular disease were excluded. A total of 390 patients (316 men, mean age: 54 ± 11 years) who were candidates for coronary angiography were included and patients suspected of having CAD and present with new onset chest pain, elevated cardiovascular risk, abnormal echocardiogram, positive stress ECG test, and/or myocardial perfusion scintigraphies (11, 12). All patients were in sinus rhythm at the time of the study and 90 patients (31%) showed predefined ST-segment/T-wave changes in resting 12-lead ECGs. Coronary angiography showed normal coronary artery in 263 patients (67.4%), one-vessel disease in 65 patients (16.7%), two-vessel disease in 39 patients (10%), and three-vessel disease in 23 patients (5.9%). Clinically significant CAD has been defined as one or more lesions with > 70% stenosis or diameter narrowing (> 50% for left main CAD). Minimal coronary disease is defined at that time as maximal stenosis < 50% (13).
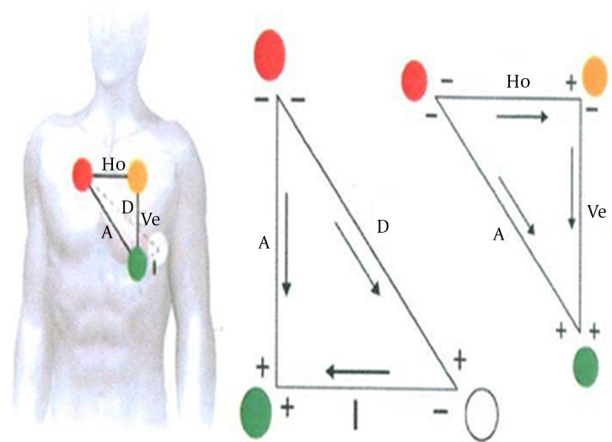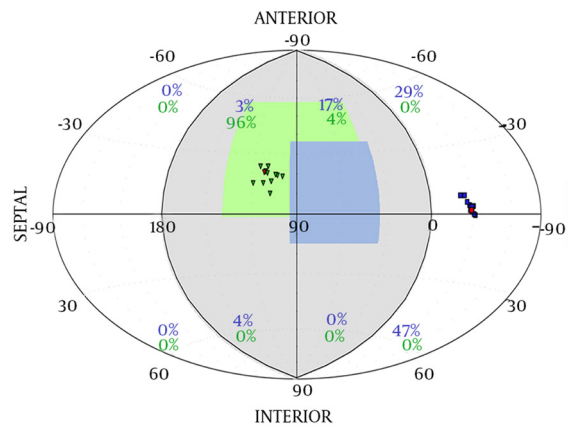

Figure 1. Configuration and Data Registration by Leads A, D, and Ve
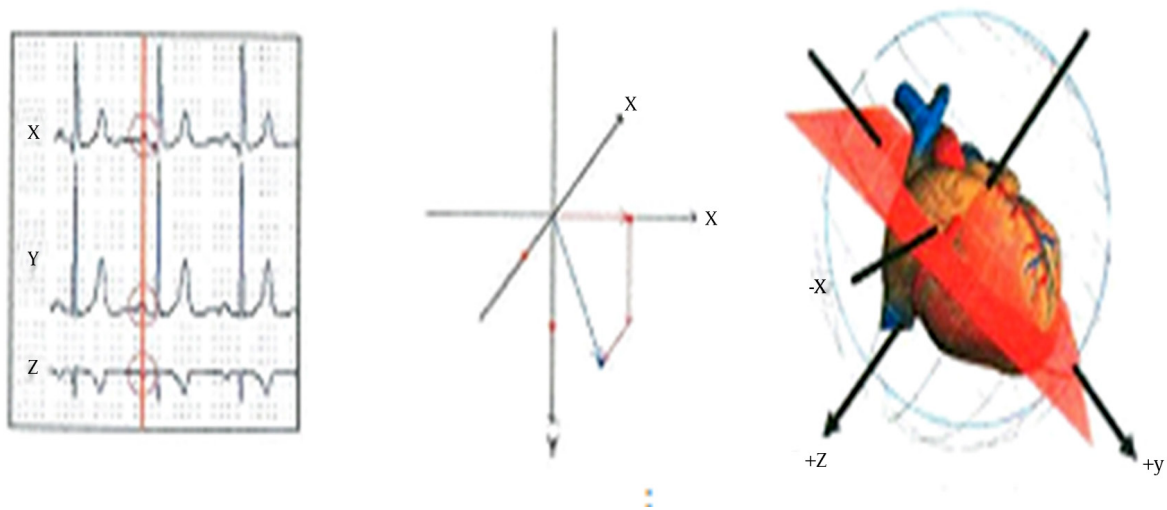
Figure 2. Determination of a Loop Point at Time t Form the X, Y, and Z Channels
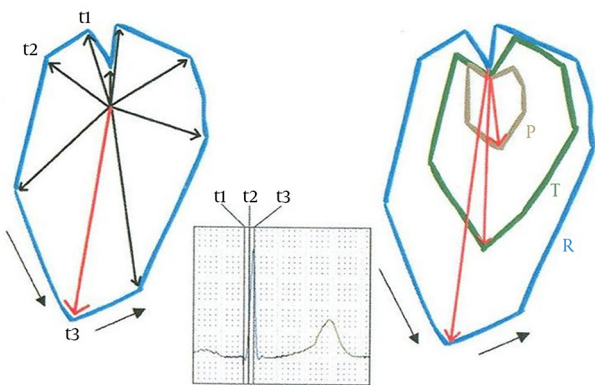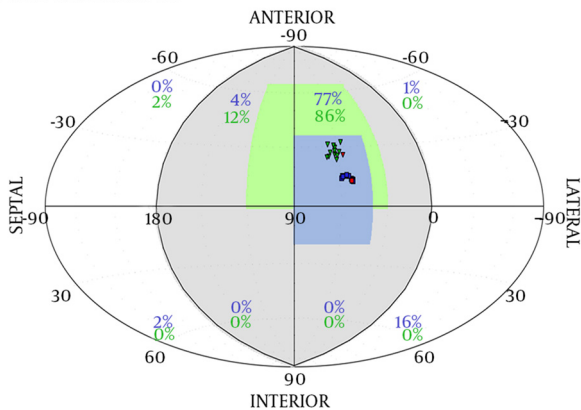

Figure 3. Representation of Loop Generation on the Time Curve and Determination of the Maximum Vectors

Figure 5. Pathologic Potential Propagation

Figure 4. Healthy Potential Propagation

4.2. Cardiogoniometry

Main diagnoses were normal CGM in 235 patients (60%) and abnormal CGM in 155 patients (40%). Median of CGM score was 1 (0–2), the minimum score was 0 and maximum score was 8. CGM yielded a sensitivity of 84 (95% CI: 75.32% to 88.99%), a specificity of 81 (95% CI: 76.54% to 86.23%), a positive predictive value (PPV) of 69% (95% CI: 61.12% to 76.20%), and a negative predictive value (NPV) of 89% (95% CI: 87.16% to 94.72%) (Table 1).

The standard resting 12-lead ECG yielded a sensitivity of 29% (95% CI: 22.12% to 38.68%), a specificity of 67% (95% CI: 60.12% to 75.01%), a NPV of 55% (95% CI: 48.08% to 62.31%), and a PPV of 42% (95% CI: 31.88% to 53.09%) (Table 2).

The CGM score was also significantly associated with the number of abnormal coronary arteries (P value > 0.001) and the score was significantly higher in two- and three-

vessel-disease patients. CGM yielded a sensitivity of 84% and specificity of 81% and ECG yielded a sensitivity of 29% and specificity of 67% compared with coronary angiography.

Table 1. Diagnostic Yield of Cardiogoniometry Compared With Gold Standard of Coronary Angiography

Variables	Cardiogoniometry [a]	95%CI
Sensitivity	84 [b]	75.32-88.99 [b]
Specificity	81 [b]	76.54-86.23 [b]
Positive predictive value	69 [b]	61.12-76.20 [b]
Negative predictive value	89 [b]	87.16-94.72 [b]
Positive likelihood ratio	4.62	3.54-6.03
Negative likelihood ratio	0.19	0.13-0.29

[a] P value < 0.001.
[b] Data are presented as %.

Table 2. Diagnostic Yield of 12-Lead Electrocardiography Compared With Gold Standard of Coronary Angiography [a]

Variables	Resting 12-Lead ECG [b]	95%CI
Sensitivity	29 [c]	22.12-38.68 [c]
Specificity	67 [c]	60.12-75.01 [c]
Positive predictive value	42 [c]	31.88-53.09 [c]
Negative predictive value	55 [c]	48.08-62.31 [c]
Positive likelihood ratio	0.93	0.66 to 1.32
Negative likelihood ratio	1.03	0.88 to 1.21

[a] Abbreviation: ECG, electrocardiography.
[b] P value < 0.001.
[c] Data are presented as %.

5. Discussion

Non-invasive detection of myocardial ischemia has been done by using ECG, echocardiography, and myocardial perfusion imaging for a long time. Although the ECG has become indispensable in cardiology and is available in every hospital, there are limitations that make ECG unsuitable for detecting CAD: ECG is neither sensitive nor specific with respect to ST-segment depressions and inverted T waves and pathological Q-waves not frequently found in all patients with previous myocardial infarction (1). Recently, CGM as a novel method has been developed with the addition of a third dimension in the analysis of the hearts electrical potential. This method is simpler than ECG (4-lead instead of 12-lead) and provides exact cardiac three-dimensional electrophysiological data (13).

The current study was performed at a referral center

of cardiology on 400 patients with suspected CAD who were candidates for coronary angiography. The CGM score correlated significantly with the number of affected coronary arteries. The score was significantly higher in two-vessel and three-vessel-disease patients. CGM yielded a sensitivity of 83%, a specificity of 88%, a PPV of 69%, and a NPV of 84.3%. The accuracy of CGM with reference to coronary angiography as a gold standard was 0.53. The defined ECG criteria for detection of coronary artery ischemia yielded a sensitivity of 26%, a specificity of 67%, a PPV of 39.4%, and a NPV of 65%. The accuracy of ECG with reference to coronary angiography was 0.11. Schupbach et al. (14) studied 793 patients with CAD and reported a sensitivity of 64% and specificity of 84% for CGM and a sensitivity of 53% and a specificity of 75% for ECG, which is similar to the findings of the current study. Saner et al. have reported a sensitivity of 79% and a specificity of 82% for CGM in the detection of ischemic heart disease (15).

The results of the present study should be interpreted in the light of certain limitations. There may be a referral bias as all patients were sent to a tertiary medical center for invasive cardiac assessment due to suspected myocardial ischemia. Therefore, our results may not be generalized to other populations.

The results of this present study show that CGM is a useful method to diagnose CAD with better diagnostic accuracy than 12-lead ECGs does. CGMs can replace resting 12-lead ECGs in screening patients for myocardial ischemia because they are easier to use and do not need for an expert reader.

Acknowledgements

Authors' Contributions

Conducted the project and management: Ata Firouzi. Conducted the study, clinical study, and revised the manuscript: Majid Haghjoo. Collected the data, data analysis, and prepared the manuscript: Behshid Ghadrdoost.

Funding/Support

References

1. Birkemeyer R, Toelg R, Zeymer U, Wessely R, Jackle S, Hairedini B, et al. Comparison of cardiogoniometry and electrocardiography with perfusion cardiac magnetic resonance imaging and late gadolinium enhancement. *Europace.* 2012;**14**(12):1793–8.
2. Huebner T, Goernig M, Schuepbach M, Sanz E, Pilgram R, Seeck A, et al. Electrocardiologic and related methods of non-invasive detection and risk stratification in myocardial ischemia: state of the art and perspectives. *Ger Med Sci.* 2010;**8**:Doc27.
3. Tolg R, Zeymer U, Birkemeyer R, Wessely R, Eggebrecht H,

Bocksch W, et al. Cardiogoniometry as a diagnostic tool in patients with acute coronary syndromes: results of the CGM@ACS trial. *Clin Res Cardiol.* 2012;**101**(9):727–36.

4. Sanz E, Steger JP, Thie W. Cardiogoniometry. *Clin Cardiol.* 1983; **6**(5):199–206.
5. Drew BJ, Pelter MM, Lee E, Zegre J, Schindler D, Fleischmann KE. Designing prehospital ECG systems for acute coronary syndromes. Lessons learned from clinical trials involving 12-lead ST-segment monitoring. *J Electrocardiol.* 2005;**38**(4 Suppl):180–5.
6. Guglin ME, Thatai D. Common errors in computer electrocardiogram interpretation. *Int J Cardiol.* 2006;**106**(2):232–7.
7. Holmvang L, Hasbak P, Clemmensen P, Wagner G, Grande P. Differences between local investigator and core laboratory interpretation of the admission electrocardiogram in patients with unstable angina pectoris or non–q-wave myocardial infarction (a thrombin inhibition in myocardial ischemia [trim] substudy). *Am J Cardiol.* 1998;**82**(1):54–60.
8. Sanz E, Schüpach M. Cardiogoniometry: a non-invasive electrocardiographic method to diagnose ischemic heart disease at rest. *GMS Med Inform Biom Epidemiol.* 2009;**5**(3).
9. Huebner T, Schuepbach WM, Seeck A, Sanz E, Meier B, Voss A, et al. Cardiogoniometric parameters for detection of coronary artery disease at rest as a function of stenosis localization and distribution. *Med Biol Eng Comput.* 2010;**48**(5):435–46.
10. Jeyaraj D, Ashwath M, Rosenbaum DS. Pathophysiology and clinical implications of cardiac memory. *Pacing Clin Electrophysiol.* 2010;**33**(3):346–52.
11. Demir OM, Alfakih K, Plein S. Current international guidelines for the investigation of patients with suspected coronary artery disease. *Eur Heart J Cardiovasc Imaging.* 2014;**15**(12):1422–4.
12. Long P, Liu J. GW25-e2172 Obstructive Sleep Apnea and Gensini Score in Suspected Coronary Artery Disease Patients. *J Am Coll Cardiol.* 2014;**64**(16_S).
13. Mazzadi AN, Andre-Fouet X, Costes N, Croisille P, Revel D, Janier MF. Mechanisms leading to reversible mechanical dysfunction in severe CAD: alternatives to myocardial stunning. *Am J Physiol Heart Circ Physiol.* 2006;**291**(6):H2570–82.
14. Schupbach WM, Emese B, Loretan P, Mallet A, Duru F, Sanz E, et al. Non-invasive diagnosis of coronary artery disease using cardiogoniometry performed at rest. *Swiss Med Wkly.* 2008;**138**(15-16):230–8.
15. Saner H, Baur HR, Sanz E, Gurtner HP. Cardiogoniometry: a new noninvasive method for detection of ischemic heart disease. *Clin Cardiol.* 1983;**6**(5):207–10.