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Cardiovascular Cartography - A New Non-Invasive Technique to Detect Coronary Artery Disease

Kumar RV[1], Shirbur GN[1], Augustus R.J.[2], Lakotosh J[3], Jakobicz I[3]
[1]Center for Artificial Intelligence & Non-Linear Studies (CAINS), Scalene Cybernetics, India
rajah@vsnl.com

[2]Austin Systems Inc, Maryland, USA
asi@austinsysinc.com

[3]ASKIT kft, Budapest, Hungary.
jakobicz@askit.hu

Abstract

A multi-variable mathematical model specific to each individual can be designed to obtain the nominal basal haemodynamic behavior. By superimposing the measured data obtained from the individuals, on a predictive model, a pattern, called cardiovascular cartography (CCG) can be generated. In a pilot study it was observed that Coronary Artery Disease (CAD) characteristically altered the CCG pattern. These alterations were carefully analyzed using artificial neural networks and the exact status of the coronary insufficiency was reconstructed on a realistic geometry coronary model. A strong correlation was found to exist between functional structures and structural functions. This study was designed to assess the feasibility of using such modeling and cartography techniques to detect the primary presence and assess the severity of CAD.

1. Introduction

3-D mathematical modeling and simulation, using high-speed computation, enables non-linear haemodynamics [1,2,3] of an individual obtained by a beat-to-beat recording of the cardiac cycle (fig.1). Using the **Heamotron 3G, cardiovascular cartography system,** the cardiac cycle was mapped against the predictive mathematical model of the cardiovascular system. Using neural network computing, a predictive model of the individual is created. The measured haemodynamic behavior is superimposed on the predictive model. The resultant dynamic deviation is represented in a form called ***Cardiovascular Cartogram***. The resultant deviation difference is distributed as ***pressure zone, volume zone, and time zone*** and ***flow zone*** in a clockwise direction on the Cardiovascular Cartogram (fig 2). The Cardiovascular Cartogram is scale independent, but has positivity and negativity, thereby indicating the deviation difference, reflecting physiological, pathological or compensatory phenomena and thus assesses the efficacy and function of the cardiovascular system.

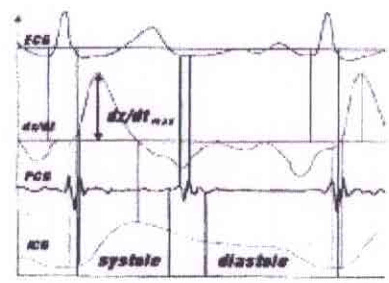

Fig. 1. The Cardiac Cycle

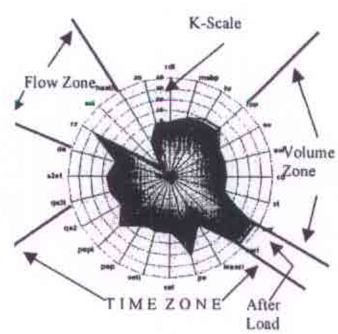

Fig 2. Cardiovascular Cartogram

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The pattern of change that occurs in the flow zone of the Cardiovascular Cartogram (***Contractility, Acceleration, after load, ventricular depolarization to peak ejection delays)*** is obviously related to the Anterioseptal regions of the myocardium, the pattern of change in the Volume zone (***Rate pressure product, Stroke Volume, Cardiac output, preload***) is related to Inferioseptal regions of the myocardium and the Time zone (***intracycle timings, LV ejection rate***) is related to the lateral regions of the myocardium. Looking back in the ICU, it is these factors that one tries to correct in situations where there is a full-blown myocardial infarction in these respective regions. These changes reach a threshold in a full blown acute myocardial Infarction but the changes start at a stage when the reduction of blood flow to the region in question begins. This may be due to reduced cellular activity due to reduced cellular oxygen supply that is secondary to proportional blood flow reduction and thus impaired stretch in the myocardial fibers, resulting in re-modeling (or re-adjusting) the cellular functionality.

Since similar changes are also mimicked in other cardiovascular disorders, it is essential to differentiate between those and CAD. To establish the primary presence of CAD one has to carefully analyze the pattern of blood flow. The ***Vertical Acceleration Detector*** (VAD) is a special device that picks up subsonic waves that are transmitted from the heart to the chest wall, similar to the seismic waves that get transmitted from deep inside the earth to the surface during an earthquake. The VAD picks up subsonic signals through out the cardiac cycle, which includes all components of the first and second heart sounds. Specialized digital signal processing and analysis enables the detection and extraction of micro variations in the subsonic activity during early, mid and late diastolic passive filling phase.

Our major concern is in the diastolic passive filling phase of the cardiac cycle since maximal coronary filling occurs during this point in time and is the only arterial system in the body that gets filled during this phase. The second component - the second heart sound - is of prime importance as this signifies the onset of diastole. The turbulence in coronary flow is differentiated and extracted during a period when there is maximal coronary flow that is used to detect the primary presence of coronary obstruction. The characteristics of the turbulence signify the possible regions from which these signals originate.

This information essentially produces one dimension of the problem at hand. When it is associated with Zonal (Pressure, Volume, Time and Flow) behavior obtained from the deviation difference from the resultant cardiovascular cartogram, one can obtain a three dimensional array of information that is suitable for image reconstruction.

The first part of the reconstruction is to identify the ischemic zones and reconstruct the regions on the short axis slices of the LV muscle mass.(Fig.3). This enables one to identify the major vessels supplying the region in the majority of the population. The appropriate site of the possible lesions are embedded on the realistic geometry coronary model. One can then obtain a realistic geometry three-dimensional reconstruction of the most probable location of coronary occlusion [4,5,6]. Fig.4.

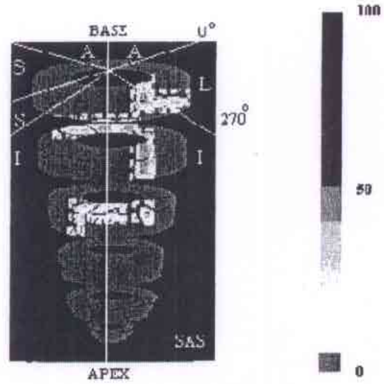

Fig 3. Short axis slices

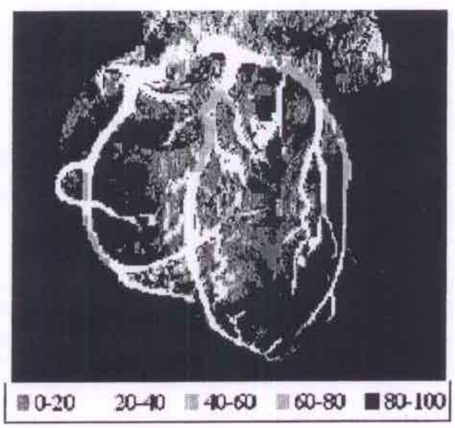

Fig 4. 3D CCG reconstruction

2. Clinical trials

CCG recordings in a supine position using 6 pairs of disposable electrodes and a VAD positioned with a double sided adhesive, were obtained from 3642 patients with the following protocol in the outpatient clinics of various medical centers in India, of which 273 (43 females; mean age 46 years) patients were scheduled for coronary angiography at the Manipal Heart Foundation, Bangalore, India. The recordings of 1024 beats included beat-to-beat stroke volume, systolic time intervals, flow turbulence and arterial blood pressure.

3. Protocol

1. The individual was made to abstain from all drugs that alter cardiac haemodynamics for a period of 12 hours prior to the test. We have found that there is no significant change in the test results between 12 hours abstinence and longer periods (CCG is based on relative beat-to-beat changes and not on absolute values. If drugs do not interfere with the relative changes, this is sufficient).
2. Alcohol plays an important role, mainly due to its diuretic property. The individuals were told to abstain from alcohol for a period of 24 hours prior to the test.
3. The individuals abstained from all types of stimulants like coffee, tea and other soft drinks for a period of 12 hours prior to the test.
4. Individuals were generally fasting but a light breakfast of a glass of milk and a biscuit or two, to three hours prior to the test was allowed.
5. The test was conducted on an empty bladder and with the individuals relaxed during the entire procedure.

Since Coronary Angiography is considered a "gold standard" for assessment of coronary occlusion, it was used to validate this non-invasive technique. A single investigator blinded to the angiography data interpreted these cardiovascular cartograms and the reconstructed images.

4. Results

The CCG was positive for CAD in 204 patients and negative in 69 patients. Angiographically, CAD was present in 218 patients and absent in 55 patients. The sensitivity, specificity, positive predictive accuracy (PPA) and negative predictive accuracy (NPA) of this technique for detecting CAD respectively were 91%, 92%, 98% and 75%. Though there is no direct relation between the epicardial coronary occlusion and regional flow, the following table 1, indicates our finding in regional flow reduction and the epicardial vessel supplying the region [7,8,9].

5. Discussion

The Cardiovascular Cartography technique is adequately sensitive and specific in the detection of CAD, even at a very early stage of the disease. The diagnostic accuracy is indicated in Fig 5 below. Data was taken from " The Dawn of a new era - Non-Invasive coronary imaging" R. Erbel, MD. Herz 1996; 21, 75~77, and compared with CCG results.

The technique of Cardiovascular Cartography is a reliable non-invasive tool to screen and detect the presence and assess the severity of CAD. CCG results compare favorably with other available invasive and non-invasive tests to detect CAD and can be a low cost solution for mass screening of a population for detection of early CAD. Early detection aids in early intervention or prevention, saving millions of lives.

6. Acknowledgements

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	Primary presence of CAD	Anterioseptal region (LAD)	Inferioseptal region (RCA)	Lateral region (LCX)
Sensitivity	91 %	83 %	80 %	72 %
Specificity	92 %	76 %	74 %	80 %
PPA	98 %	85 %	80 %	81 %
NPA	75 %	74 %	74 %	70 %
Mean Accuracy	91 %	81 %	78 %	75 %

Table 1. Sensitivity and specificity.

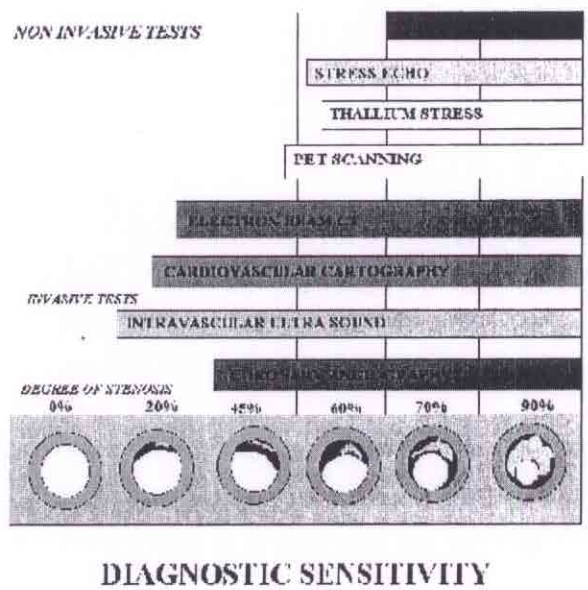

Fig 5. Diagnostic Sensitivity