CARDIAC DISEASES QUANTIFICATION OF BY TEMPORAL AND CEPSTRAL ANALYSIS OF PLETHYSMOGRAPHIC SIGNAL

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SUMMARY: A non invasive method for cardiac diseases quantification is described in this paper. The method uses discriminant analysis of temporal, spectral and cepstral parameters computed from the plethismographic signal which represents an impedance variation in explored thoracic region at the level of the ascending aorta. Two kinds of cardiac diseases were explored: mitral stenosis (MT) and aortic stenosis (A.S). Fifteen parameters were identified for cardiac discrimination (Five temporal parameters, three spectral and seven cepstral). Results are compared to those of Echo-Doppler method which revealed a correlation coefficient of R=0.761 representing a statistical significance of P< 0.001.

Key words: Electrical plethismography, impedance cardiography.

INTRODUCTION

Exploration of cardiovascular system for diagnosis and quantification of the lesion is becoming less invasive. Echographic and Doppler methods used have been in use since fifteen years. Eletrical plethismography (EP) is another non invasive method for cardiovascular exploration. Although used less by cardiac investigators, this method begins to prove itself. An early study (3,5,6) has shown that the analysis of plethismographic parameters allows diagnosis of some cardiac diseases.

This paper will present the quantification of some heart lesions using the relevant parameters of plethismographic signal (P.S).

MATERIALS AND METHODS

The plethysmographic method used in this study differs slightly from that of KUBICEK *et al.* (8) which takes the entire thoracic area into account. It consists of application of an electric current (3 KHz, 1 mA), which is harmless to the patient, by means of two electrodes placed respectively in front of and above the leading edge of the heart (Figure 1). Two electrodes placed on the chest of the patient at the level of aorta 2 or 3 cm apart permit perception of P.S representing impedance variation AZ of the explored thoracic region. Processing of P.S developed formerly

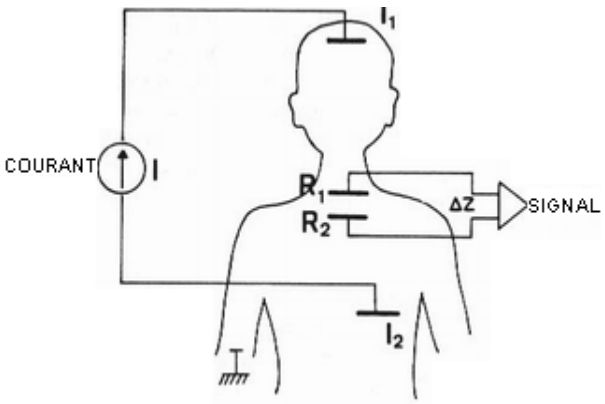

Figure 1: Plethysmographic Method.

(6), allows determination of filtered and amplified signals with an average amplitude of 200 mV.

During the signal recording, the patient must lie supine, relaxed and in expiratory apnea for period of 10 seconds.

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Recording and storage of P.S were accomplished by a HP 85B microcomputer. Signal processing was carried out by the same microcomputer and by a PDP 111 computer.

The obtained plethysmographic signal represents Z parameter variation, where Z is the impedance of explored ascending aorta.

Several methods may be used for P.D processing: A KUBICEK impedance method and the admittance method which we have developed during this study and are presenting in this communication.

According to KUBICEK's approach, cardiac output may be computed with the formula (1):

$$D = B\frac{60}{T}Ps\frac{L(\frac{dz}{dt})max.E}{Z^2}$$

T is the P.S period, Ps is the blood resistivity, L is the distance between electrodes, $(\frac{dz}{dt})$ max is the maximum slope of P.S, Z is the basic impedance, B is a correction factor, taking into account the chest size

$$B = \frac{Lt}{L}$$

Where LT is the distance between "xiphoide" and the base of the neck. The impedance method allows determination of cardiac output. The correlation between this method and thermodilution (6) gives the following results: correlation coefficient R=0, 761 and significance degree $p < 0.001$.

In order to improve correlation, results were have developed a new method of P.S exploration using the computation of (Y) atmittance parameter of explored aortic region (6). Cardiac output is then given by:

$$D = F\,B\frac{60}{T}Ps\,L(\frac{dy}{dt})max.E$$

Results show, a good correlation between admittance method and thermodilution (Figure 2): Correlation coefficient: R=0.945, $(\frac{dy}{dt})$ max represents the maximum slope of P.S where $Y(t) = \frac{1}{Z(t)}$ F is a factor depending on the age of the patient (6).

statistical significance $p < 0.001$.

In addition to the cardiac output, electrical plethysmography can determine other cardiovascular parameters, such as systolic volume, ejection time etc…. These parameters are used by physician in the diagnosis of cardiac diseases. For the P.S analysis we began with the verification of signal reliability and presentability. Next, processing algorithms were carried out in order to compute temporal, spectral and cepstral parameters which are used to diagnose cardiac diseases.

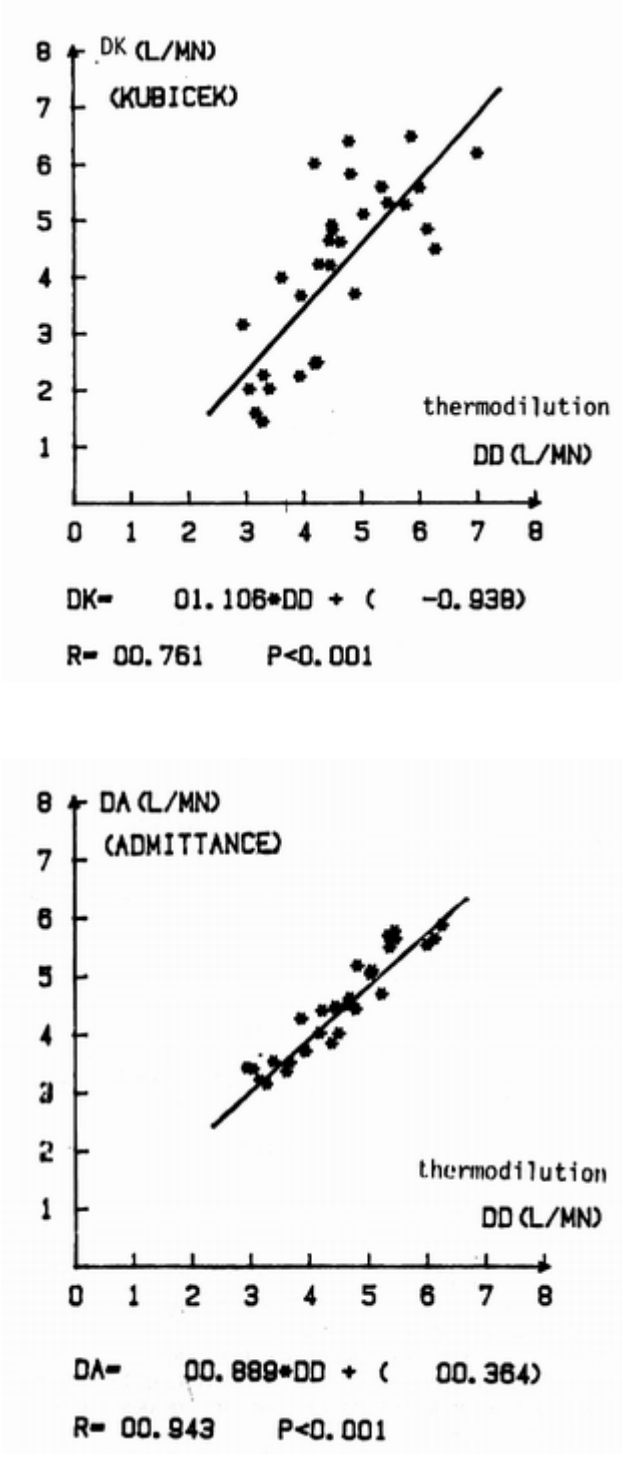


Figure 2: Correlation.

SIGNAL TYPE: AO.I
FISHER COEFFICIENT: F= .46409
RISK ALPHA = .05
STUDENT COEFFICIENT: t= 1.96
AVERAGE M= 43.93733
SNEDECOR COEFFICIENT FS= I
CONCLISION:
STATIONARI TY: TEST CONFIRMED

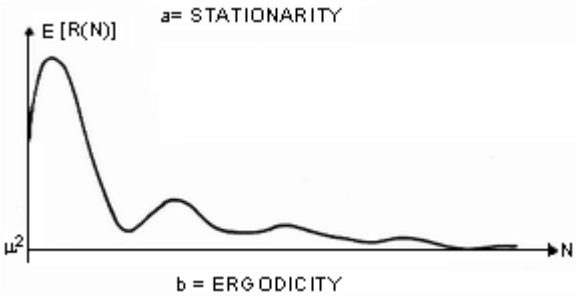


Figure 3: Stationarity and Ergodicity.

In order to prove that P.S represents cardiovascular activity we have applied resting and ergometric tests to normal controls and to patients with various cardiac diseases.

Results show that P.S can be utilized in resting patients and during exercize (Figure 3). We have observed that the signal stability and ergodicity are not altered by the mode of signal acquisition (inspiratory or expiratory apnea). P.S is therefore representative of cardiovascular activity during the signal acquisition. This P.S represents impedance variation of the explored aorta independently of acquisiton time. P.S is ergodic, then the determination of signal statistic parameters can be accomplished from a simple sampling (signal reliability).

The aim of P.S analysis is the determination of temporal spectral and ceptral parameters which describe physiological and pathological states of the cardiovascular system. Temporal parameters are computed from P.S and its derivative.

The processing derivative of signal is accomplished by LAGRANGE Method (1): First derivation F (t) has been approximately by a polynom of seventh rate:

$$F'(t) = \frac{1}{12T}(F(t-) - 8F(t-1) + 8F(t1)) - F(+2))$$

T is the sampling period. Figure 4 shows the processing orginigram of P.S derivative.

P.S spectrum is determined by the computation of fast FOURIER transform (F.F.T.): Let (Y(t) be the response of left ventricle-aorta system to a cardiac excitation signal x(t) and h(t) the aortic pulsatile response. Then: y(t) = x(t) *h(t) (product of temporal convolution). Cepstral analysis consists of differentiation of the excitation x(t) and the pulsatile response h(t), in order to derive a

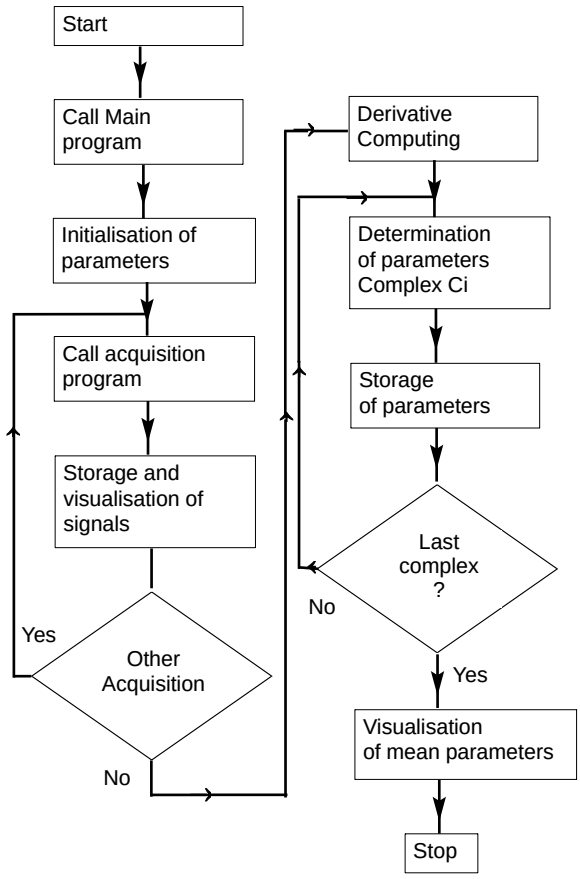


Figure 4: Acquisition and processing of plethysmographic signal.

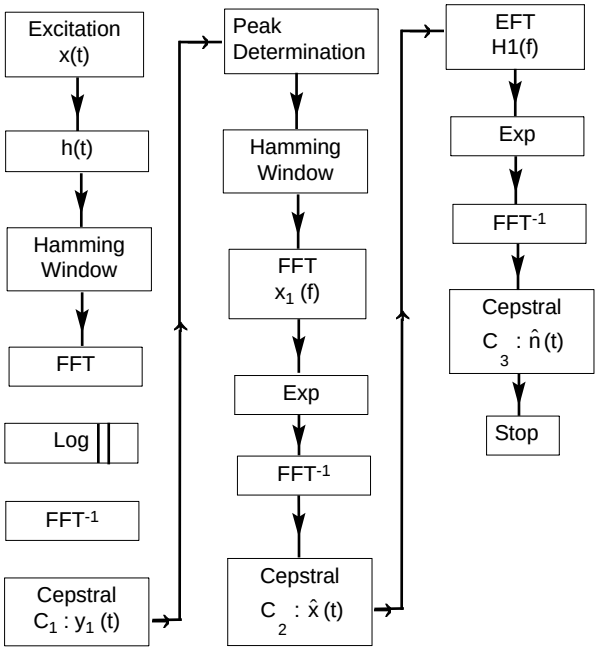


Figure 5: Processing of spectral and cepstral plethysmographic signal.

separate picture of each factor. In the cardiac situation, we have considered, computation is carried out at the minimum phase $\Phi = 0)$ (6,7).

Let: Y1 (f) = FFT (y(t)) = FFT (x(t)* h(t)

Y1 (f) = X (f) H (f)

1 Y1 (f) 1^2 = 1 X(f) 1^2 1 H(f) 1^2

Y2 (f) = Log 1 Y1 (f) 1 = log 1 X(f) 1 + Log 1 H(f) 1

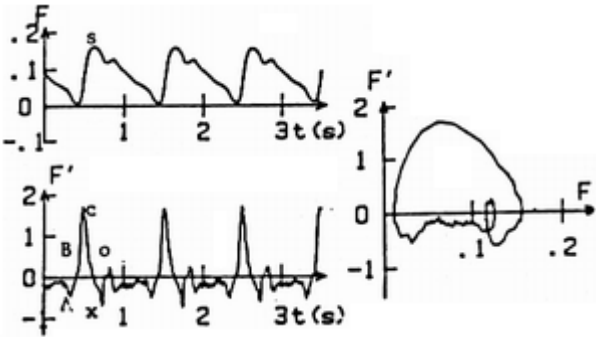
Let: Y1 (t) = FFT^{-1} (Y2 (f)) = x1 (t) + h1 (t)

Where: x1 (t) = FFT^{-1} (X(f)) and h1 (t) = FFT^{-1} (X(f))

Y1(t) is called real cepstral of P.S. The cepstral $\hat{x}(t)$ and $\hat{y}(t)$, corresponding respectively to x(t) and y (t) are determined according to the organism of Figure 5.

In the first part of this study we have showed that P.S processing by impedance or admittance method permits us to compute some parameters as cardiac output, systolic ejection period… These parameters such are used by cardiologist for the diagnosis or the quantification of cardiac diseases. Temporal, spectral and cepstral analysis of P.S allow the computation of some parameters obtained from derivation, spectral and cepstral signal. These parameters, computed by a profound signal processing give considerable information regarding pathological state of cardiovascular system. P.S and its derivative are characterized by ten parameters (Figure 6): corrected ventricular ejection:

Figure 6: Plethysmographic signal, its derivative and phase plan (normal).



$Ec = \frac{E}{\sqrt{T}}$, E is the ventricular ejection period

-Plethysmographic amplitude of wave S; seven amplitude of F(t) waves: A, B, C, 0, X, Y, Z; derivative width: L.

Table 1 shows the average of temporal parameters obtained from 140 kinds of signal (normal and pathological cases). Three spectral parameters have been calculated for the diagnosis. These parameters are defined as follows:

$$ri = \frac{\text{Amplitude of harmonic } (i+1)}{\text{Amplitude of the fundamental}} \quad \text{where } i = 1,2,3$$

Table 1: Temporal Parameters.

	Ec (s)	L (s)	A (Ω /s)	B (Ω /s)	C (Ω /s)	O (Ω /s)	X (Ω /s)	Y (Ω /s)	Z (Ω /s)	S (Ω)
Normal	0.28	0.21	0.20	0.10	0.65	0.10	0.25	0.00	0.00	0.06
RAO	0.39	0.21	0.23	0.20	0.51	0.00	0.23	0.00	0.10	0.04
I.AO	0.36	0.32	0.32	0.20	0.98	0.00	0.39	0.00	0.3	0.10
M.AO	0.33	0.24	0.18	0.20	0.61	0.5	0.34	0.00	0.00	0.6
R.M	0.33	0.16	0.41	0.10	0.71	0.05	0.36	0.05	0.20	0.06
I.M	0.30	0.21	0.39	0.00	0.57	0.10	0.26	0.00	0.20	0.06
M.M	0.29	0.24	0.28	0.10	0.60	0.05	0.36	0.00	0.00	0.05
R.P	0.33	0.20	0.35	0.20	0.53	0.15	0.22	0	0.10	0.05
RM and I.AO	0.32	0.26	0.32	0	0.74	0	0.48	0	0	0.05
MM and I.T	0.27	0.19	0.09	0	0.40	0	0.30	0.05	0	0.04
C.IS	0.32	0.25	0.05	0.05	0.39	0	0.17	0	0.10	0.04
CIV	0.29	0.23	0.60	0	0.74	0	0.35	0	0.20	0.18
CIA	0.32	0.19	0.31	0.20	0.60	0.10	0.23	0.10	0.15	0.05
CMP	0.23	0.22	0.40	0.20	0.38	0.05	0.23	0	0.21	0.04

Table 2: Spectral Parameters.

	r1	r2	r3
Normal	0.47	0.33	0.12
I-Ao	0.35	0.10	0.08
R-Ao	0.41	0.18	0.12
M-Ao	0.65	0.24	0
I-M	0.7	0.16	0.12
RM	0.47	0.16	0.12
MM	0.48	0.05	0
RP	1.1	0.45	0.12
MM-Ao	0.47	0.12	0.12
MM+IT	0.58	0.05	0
C IS	0.61	0.29	0.04
CIV	0.57	0.08	0.04
CIA	0.57	0.33	0.12
C.M.P	0.53	0.20	0.10

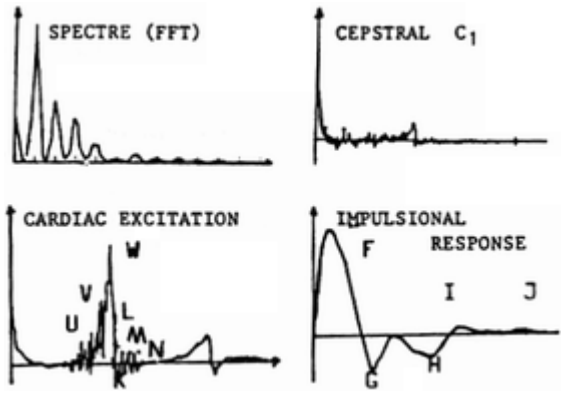


Figure 7: Spectral and cepstral (Noral subject).

Table 3: Cepstral Parameters.

	$\hat{x}(t)$							$\hat{n}(t)$					
	U	V	W	K	L	M	N	F	G	H	I	J	LF/T
Normal	0.19	0.45	1	0.12	0.24	0.21	0.17	1	0.32	0.25	0.05	0.03	0.49
I-Ao	0.18	0.44	1	0.13	0.23	0.20	0.17	0.78	0.49	0	0.05	0	0.54
R.Ao	0.17	0.43	1	0.12	0.20	0.21	0.17	1.16	0.30	0	0.05	0	0.88
M.Ao	0.19	0.44	1	0.12	0.23	0.21	0.16	1.16	0.30	0.12	0	0	0.89
I.M.	0.15	0.45	0.98	0.10	0.36	0.05	0.05	1.4	0	0	0	0	1.57
R.M	0.10	0.35	1	0.15	0.05	0.03	0.02	1.11	0.11	0	0.19	0	0.79
M.M	0.18	0.44	1	0.12	0.23	0.02	0.01	1.4	0	0	0	0.03	2.11
R.P	0.15	0.40	1	0.15	0.20	0.20	0.15	1	0.31	0.11	0.05	0	0.45
RM+IAo	0.15	0.40	1	0.13	0.05	0.05	0.05	1.16	0.30	0	0	0	0.86
MM+IT	0.40	0.60	0.70	0.05	0.30	0.05	0.05	0.78	0.5	0	0.14	0	0.50
C.I.S	0.59	0.43	0.79	0.24	0.29	0.24	0.12	0.76	0.51	0.24	0.14	0.05	0.56
C.I.V	0.24	0.33	1	0.07	0.33	0.19	0.05	0.84	0.43	0	0.16	0	0.64
C.I.A	0.05	0.45	0.88	0.19	0.17	0.19	0.05	1.24	0	0.14	0	0	0.80
C.M.P	0.29	0.60	0.88	0.24	0.14	0.14	0.05	1.22	0.14	0	0.03	0	0.75

Table 2 presents different spectral parameters. The cepstral of normal and pathological P.S is composed of the cepstral of cardiac excitation (x(t) and aortic signal h(t), x(t) is characterized by seven parameters representing the amplitude of different cepstral waves: U, V, W, K, L, M, N (Figrue 7). The aortic cepstral h(t) is defined by six parameters: five parameters representing the amplitude of different aortic waves F,G,H,I,J (Figure 7); one parameter representing normalized width of aortic cepstral Lf.

Table 3 presents cepstral parameters relative to normal and pathological cases. P.S analysis shows that this signal can be represented by 26 parameters for diagnosis and quantification of cardiovascular diseases. We have carried out, then, a discriminant analysis of these parameters, in order to obtain:

1. Determination of plethysmographic relevant parameters for the diagnosis.

2. Diagnosis of cardiac diseases and quantification of the extent of the lesions.

RESULTS

The principle of discriminant analysis is based on FISCHER theory and the criteria of "Step by Step". The relevant plethysmographic parameters represent the seet of parameters which allows to have the maximum of matrix product $T^{-1}E$. Where T is whole covariance matrix, E is the

Table 4: Discriminant Plethysmographic Parameters.

Parameters	E_C	L	A	B	C	O	X	Z	S	r_1	r_2	r_3	U	L	M	N	F	G	I	L
Numbers	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Table 5: Discriminant Analysis

STEPS	PARAMETERS	PERCENTAGE
1	20	64.29
2	20, 5	85.71
3	20, 5, 3	83.93
4	20, 5, 3, 17	85.71
5	20, 5, 3, 17, 9	89.29
⋮	⋮	⋮
8	20, 5, 3, 17, 9, 6, 19, 7	94.64
⋮	⋮	⋮
17	20, 5, 3, 17, 9, 6, 19, 7, 9, 18 11, 17, 16, 10, 11, 13, 15	75.00
⋮	⋮	⋮
20	20, 5, 3, 17, 9, 6, 19, 7, 9, 18 11, 17, 16, 10, 11, 13, 15, 15, 15, 12	80.36

a- Step by Step Analysis

Parameter	Number
LF	20
C	5
A	3
F	17
S	9
O	6
I	19
X	7
G	18
r_2	11
N	16
r_1	10
U	13
M	15
r_3	12

b- Relevant Parameters

Table 6: Data File

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'ANALYSE', 6, 15, 15, ,3
8, 8, 8, 8, 8, 8
'RAO+ '
'RAO++'
'RAO+++'
'RM+'
'RM++'
'RM+++'
. 23 , . 51 , 0 , . 23 , . 04 , . 41 , . 18 , . 12 , . 17 , . 21 , . 17 , 1 . 16 , . 30 , . 05 , . 88
. 24 , . 52 , 0 , . 24 , . 05 , . 42 , . 19 , . 13 , . 18 , . 22 , . 18 , 1 . 17 , . 31 , . 06 , . 89
. 25 , . 53 , 0 , . 25 , . 05 , . 42 , . 20 , . 14 , . 185 , . 23 , . 18 , 1 . 19 , . 32 , . 065 , . 892
. 255 , . 53 , 0 . 01 , . 26 , . 06 , . 43 , . 21 , . 14 , . 17 , . 24 , . 18 , 1 . 2 , 33 , . 07 , . 9
. 21, . 50 , 0 , . 22 , . 03 , . 40 , . 18 , . 10 , . 16 , . 20 , . 155 , 1 . 13 , . 29 , . 04 , . 85
. 21, . 50 , . 01 , . 2 , . 04 , . 41 , . 18 , . 125 , . 17 , . 20 , . 17 , 1 . 15 , . 31 , . 055 , . 87
.22 , . 51 , 0 , . 22 , . 045 , . 40 , . 18 , . 124 , . 17 , . 21 , . 165 ,1 . 14 , . 32 , . 06 , . 88
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.24 , . 46 , . 01 , . 19 , . 025 , . 42 , . 18 , . 11 , . 17 , . 21 , . 17 , 1 . 26 , . 30 , . 055 , . 85
.245 , . 47 , 0 , . 19 , . 03 , . 43 , . 19 , . 12 , . 165 , . 22 , . 175 , 1 , 27 , . 31 , . 055 , . 86
.23 , . 45 , 0 , . 175 , . 029 , . 41 , . 165 , . 10 , . 16 , . 22 , . 15 , 1 . 22 , . 312 , . 045 , . 92
.23 , . 44 , 0 , . 17 , . 03 , . 40 , . 155 , . 095 , . 155 , . 22 , . 145 , 1 . 21 , . 30 , . 04 , . 81
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.225 , . 41 , . 011 , . 21 , . 01 , . 4 , . 17 , . 1 , . 17 , . 24 , . 155 , 1 . 37 , . 31 , . 04 , . 86
.23 , . 42 , 0 , . 215 , . 011 , . 415 , . 17 , . 11 , . 175 , . 24 , . 16 ,1 . 39 , . 32 , . 045 , .88
.23 , . 41 , 0 , . 2 , . 01 , . 40 , . 165 , . 105 , . 165 , . 225 , . 155 , 1 . 37 , . 31 , . 04 , . 85
.22 , . 40 , 0 , . 19 , . 01 , . 39 , . 16 , . 105 , . 160 , . 220 , . 154 , 1 . 36 , . 305 , . 04 , . 85
.23 , . 40 , 0 , . 199 , . 015 , . 38 , . 17 , . 11 , . 16 , . 225 , . 153 , 1 , 365 , . 31 , . 04 , 86
.225 , . 39 , 0 , . 20 , . 017 , . 38 , . 175 , . 116 , . 16 , . 23 , . 154 , 1 , 40 , . 31 , . 045 , . 87
.23 , . 39 , 01 , . 2 , . 017 , . 39 , . 176 , . 117 , . 161 , . 231 , . 154 , 1 , 41 , . 3 , . 045 , . 87
.41 , . 71 , . 05 , . 37 , . 06 , . 47 , . 16 , . 11 , . 10 , . 03 , . 02 , 1 . 12 , 1 , . 11 , . 19 , . 80
.42 , . 72 , . 055 , . 38 , . 065 , . 48 , . 16 , . 112 , . 105 , . 03 , . 02 , 1 . 1 , . 11 , . 2 , . 8
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.43 , . 73 , . 062 , . 395 , . 071 , . 492 , . 174 , . 115 , . 11 , . 3 , . 022 , 1 .1 , . 121 , . 211 , . 812
.405 , . 7 , . 045 , . 35 , . 055 , . 465 , . 155 , . 11 , . 09 , . 029 , . 019 , 1 .1 , . 10 , . 18 , . 79
.40 , . 69 , . 043 , . 34 , . 053 , . 463 , . 154 , . 11 , . 08 , . 028 , . 018 , 1 . 1 , . 10 , . 175 , . 785
.40 , . 68 , . 042 , . 33 , . 052 , . 462 , . 155 , . 11 , . 075 , . 027 , . 017 , 1 . 11 , . 10 , . 174 , . 786
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.24 , . 50 , . 0 , . 22 , . 038 , . 40 , . 19 , . 11 , . 18 , . 22 , . 175 , 1 . 15 , .  31 , . 055 , . 89
.49 , . 75 , . 053 , . 42 , . 062 , . 48 , . 163 , . 11 , . 064 , . 021 , . 011 , 1 . 14 , .  07 , . 23 , . 30
.59 , . 81 , . 053 , . 47 , . 062 , . 48 , . 18, . 125 , . 029 , . 012 , . 005 , 1 . 09 , .  036 , . 31 , . 81
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DATA FILE

interclass ovariance matrix. The classification of anomious individuals is based on the use of the FISHER formula: d(a, Yk)= (a -yk)' T(a-yk), where a is the anomious individual, yK is the average of Yk class. Computed algorithms are expressed by a MAHAL 3 program (6). The determination of the best discriminant parameters is carried out at each step from a basic sample, the dimension of which N is calculated as follows (9).

N=2.35 P + 12.3

where P is the total of several parameters. The discriminate program also uses a sample of anonymous individuals. Plethysmographic parameters, proposed for the discrimination between the classes, are 20 parameters (6 parameters are nonsignificant for all the classes). After testing the twenty parameters during the first step, the program indicates the parameter number 20 which represents the normalized width LF of the aortic cepstral. Therefore, the parameter number 20 is the best discriminant plethismographic parameter. The best classified percentage of individual is then 64.29 % (Table 5).

At steps number 2, 3 and 4, the program choose, respectively, parameters number 5, 3 and 17 corresponding respectively to the waves C, A and F waves respectively. At step 8 the percentage of classification reaches 94.64% the parameters are 20, 5, 3, 17, 9, 6, 19, 7. Finally at step number 20 the program posts the maximum of the total 15 independent parameters (Table 5). Therefore plethismographic parameters with best discrimination are: 20(Lf), 5(C), 3(A), 17(F), 9(S), 6(0), 19(I), 7(X), 18(G), 11(r2), 16(N), 10(rl), 13(U), 15(M), 12(r3).

DISCUSSION

Among relevant plethismographic parameters one can note the absence of systolic Ejection period Ec. This parameter is one of the basic parameters used in the diagnosis of cardiac disorders. The absence of Ec is due to the fact that information contained in Ec has been implicitly included in the five temporal parameters described previously: 3(A), 5(C), 6(0), 7(X), and 9(S). A variation of parameter Ec has an influence on the P.S form and especially on systolic Slope which is measured by the maximum of derivative amplitude corresponding to parameter number 5(C).

Quantification of cardiovascular diseases is investigated by the relevant plethismographic parameters: 5 temporal, 3 spectral and 7 cepstral parameters. The discriminant analysis has been accomplished on a basic sample with 48 individuals divided into 6 groups (or classes), corresponding to different cardiac diseases: three cases of aortic stenosis (AS) Moderate, Severe and very Severe; three cases of mitral stenosis (MS) Moderate, Severe and very Severe.

The sample of anonymous individuals consists in three patients, previously examined by Echo-Dopler Method. The cases considered are: a Moderate aortic Stenosis (AS+), Severe mitral stenosis (MS ++) and very Severe mitral Stenosis (MS +++) corresponding respectively to the groups number: 1, 5, and 6. The different plethismographic parameters which provide all informations, related to basic and anonymous samples, were stored in the same file "INPUT.DAT". After the determination of the standard deviation of different parameters, the program chooses at step number one the parameter n°13 (wave U of Cepstral $\hat{x}(t)$.

Classification percentage is, then 56.25% (Table 7).

This percentage stays constant until step number 4. At

Table 7: Cardiac Disease Quantification.

STEPS	PARAMETERS	PERCENTAGE
1	13	56 , 25
2	13, 13	56 , 25
3	13, 13, 14	56 , 25
4	13, 13, 14, 15	56 , 25
5	13, 13, 14, 15, 12	89 , 58
6	13, 13, 14, 15, 12, 8	95 , 83
I I I I I	I I I I I	I I I I I
14	13, 13, 14, 15, 12, 8, 7 8, 8, 14, 12, 10, 11, 12	83 , 33
15	13, 13, 14, 15, 12, 8, 7 8, 8, 14, 12, 10, 11, 12, 13	83 , 33

Table 8: Anonimous Individual Affection.

Num	Affect	/GP 1	/GP 2	GP 3	/GP 4	/GP 5	GP 6
1	1	0.10	5.10	1.30	7.98	6.87	7.00
2	5	6.84	5.50	5.24	0.40	0.10	1.36
3	6	7.07	9.90	7.45	3.51	1.04	0.02

step n°6, the program gives a classification percentage of 95.83%. This percentage decreases at next Step (n°7). The program posts, then, the effectation of anonymous individuals (Table 8).

Results show that the anonymous patients have been correctly classified respectively in the groups number 1 (AS+), 5 (MS++) and 6 (MS+++). These results agree with those obtained by Echo-Doppler Method.

CONCLUSION

The quantification of some cardiac diseases has been carried out using discriminant analysis method based on the processing of plethismographic signal. The discrimination, using analysis of temporal Spectral and Cepstral parameters of plethismographic signal, determine relevant parameters needed for the classification of anonymous patients. The total number of discriminant parameters is 15(5 temporal, 3 spectral and 7 cepstral). Quantification results obtained by the analysis of plethismographic signals are confirmed by those obtained with Echo-Doppler method. Researches are actually orientated for the investigation of peripheral cardiovascular system.

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