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DIAGNOSIS OF CARDIOVASCULAR ANOMALIES USING ELECTRICAL BIOIMPEDANCE METHOD

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ABSTRACT

Electrical Bioimpedance method is used to explore the cardiovascular system. The objective of this work is to perform automatic diagnosis by processing the ICG signal which represents the aorta impedance variation during the heart cycle activity. ICG is detected by mean of two electrodes located at the level of the ascendant aorta. Automatic diagnosis method consists on preparing, first, a data base with a set of N cepstral parameters of 140 different normal cardiovasculars diseases. This data base corresponds to 14 classes Yk with 13 different cardiovascular diseases and 10 normal class. The classification of anonymous individuals is based on the determination of Fisher and Mahalanobis distance between anonymous disease and class Yk. Our method permits to calculate seven relevant cepstral parameters. The application of the discrimant analysis method has allows us to perform the diagnosis of 30 anonymous cases. The results found in this work indicate that 7 cepstral parameters are sufficient to perform the automatic diagnosis of the cardiovascular system abnormalities with 96.45% of percentage of correctly classified The major interest of this method is its especially useful for the exploration of cardiovascular system anomalies for emergency cases, children, elderly and pregnant women who can't support surgical operations especially at the level of the heart.

INTRODUCTION

Early several studies have been performed on medical signal processing in order to perform diagnosis for cardiovascular anomalies [1,2,3,4]. ECG, phonocatdiogram and doppler signal were the most important signals used for these dignosis [4,5,6]. However, the majority of the work in this area remains targeted on a temporal signal processing allowing the computation of Cardiac output, cardiac frequency, systolic ejection duration, systolic ejection fraction [6,7,8,9,10,11] ... The objective of this study is to design an automatic diagnosis of the cardio-vascular anomalies via a cepstral signal analysis. Our analysis shows the importance of the cepstral parameters for the classification of various cardiovascular diseases. In this work we proceed first to the description of the bioimpedance method then we describe the signals cepstral approach [8]. The method of discriminant analysis [8] will enable us to confirm the relevance of the cepstral parameters in the cardiovascular diseases diagnosis.

MATERIAL AND METHOD

A. Cardiovascular Bioimpedance method

Bioimpedance method, used in this study, consists of applying a low level rectangular current and high frequency (1mA, 30 kHz), through a pair of electrodes placed respectively in the front and above the leading edge of the heart [13,14,15]. Another pair of electrodes, placed on the chest of the patient at the level of aorta 2 or 3 cm apart, permit the detection of bioimpedance signal or impedance cardiogram signal [ICG] which represents bioimpedance variation ΔZ of the explored thoracic region. The aim of this paper is the analysis of ICG signal in order to carry out the diagnosis of cardiac diseases by means of cepstral processing of this signal using Fisher theory. [16,17,18**].**

B. Cepstral analysis

Cepstral method consists on considering that bioimpedance signal y(t) is the response of left ventricle aorta system to a cardiac excitation signal x(t) and the aorta pulsatile response h(t) (Fig. 1):

$$y(t) = x(t) * h(t) \quad (1)$$

(Temporal convolution product)

- First order cepstral

Cepstral analysis consists on the determination of excitation signal x(t) and impulse response h(t), in order to describe, separately, anomalies, respectively, in heart and aorta. Computation is carried out at the minimum phase (Φ = 0).

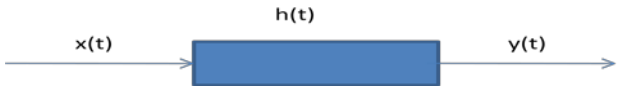

Figure.1. Cepstral model

Let :

$$Y_1(f) = FFT(y(t)) = FFT(x(t) * h(t))$$
$$Y_1(f) = FFT(x(t)).FFT(h(t)) = X(f).H(f)$$

Where:

$$X(f) = FFT(x(t))$$

$$H(f) = FFT(h(t))$$
$$|Y_1(f)|^2 = |X(f)|^2 . |H(f)|^2$$

Let:

$$Y_2(f) = Ln|Y_1(f)| = Ln|X(f)| + Ln|H(f)|$$
$$y_1(t) = FFT^{-1}(Y_2(f(t))) = x_1(t) + h_1(t)$$

$y_1(t)$ is the first order Cepstre C1

Where:

$$x_1(t) = FFT^{-1}(Ln|X(f(t))|)$$
$$h_1(t) = FFT^{-1}(Ln|H(f(t))|)$$

- Second order cepstral

Let:

$$X1(f) = FFT(x_1(t))$$
$$H_1(f) = FFT(h_1(t))$$
$$\overline{X_1}(f) = Exp(X_1(f))$$
$$\overline{H_1}(f) = Exp(H_1(f))$$

Let :

$$\hat{x}(t) = FFT^{-1}(\overline{X_1}(f))$$

$\hat{x}(t)$ is the second order Cepstre C2

$$\hat{h}(t) = FFT^{-1}(\overline{H_1}(f))$$

$\hat{h}(t)$ is the Cepstre C3

$\hat{x}(t)$ and $\hat{h}(t)$ are considered as the original signal provided, respectively, by heart and aorta. Fig. 2, shows the different steps of the cepstral algorithm.

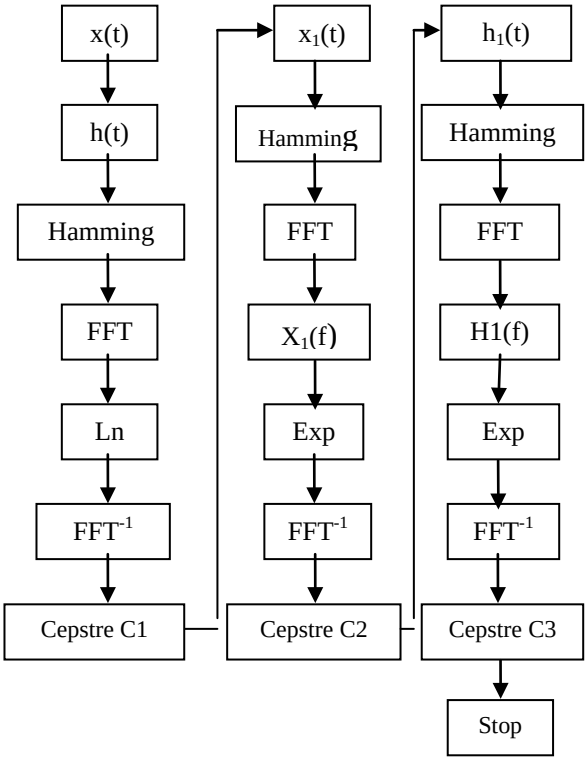

Figure. 2. Cepstral analysis

RESULT AND DISCUSSION

A. Temporal, spectral and cepstral parameters

In a previous study a statistical investigation, using the discriminant method analysis, has been performed [17,18]. This study consists to use 15 parameters: five temporal variables from bioimpedance signal and its derivative (A, C, O, X, S), 3 spectral parameters (r_1, r_2, r_3) and seven cepstrals variables (U, M, N, F, I, G, LF) (fig. 3 and 4) and (table 1).

Ben Salah et al. show [ ] that cepstral analysis permits to have the most relevant parameters for the diagnosis of the cardiovascular anomalies. The number of these relevant parameters are seven (Table1)

Our idea in this study is to use these seven cepstral parameters for the automatic diagnosis of the heart disease using Fisher's test. Cesptres C2 and C3 permit to provide these seven relevant parameters: U, M, N, F, I, G, LF (Table 2)

B. Discriminant analysis method

The principle of discriminant analysis is based on FISCHER theory and the criteria of "Step by Step". The relevant plethysmographic parameters represent the set of parameters which allows to have the maximum of matrix product $T^{-1}E$. Where T is whole covariance matrix, E is the interclass covariance matrix. The classification of anonymous individuals is based on the use of the FISHER formula [2]:

$$d(a, Y_k) = (a - y_k)' . T_{cov} . (a - y_k) \quad (2)$$

$d(a, Y_k)$ is the Fisher distance between an anonymous individual and class Yk, a is the anonymous individual defined by cepstral parameters, yk is the average of Yk classes, Tcov is whole covariance matrix.

Computed algorithms are expressed by a MAHAL 3 program [5]. The determination of the best discriminant parameters is carried out at each step from a basic sample (normal and cardiovascular diseases) with a minimal dimension Np calculated as follows with an error risk of 5% [8,17]:

$$Np\min = 2.25P + 8.7 = 25$$

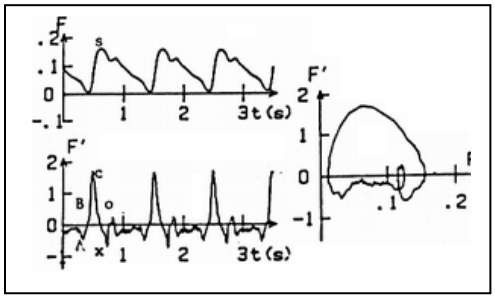

Figure 3. Temporal Parameters

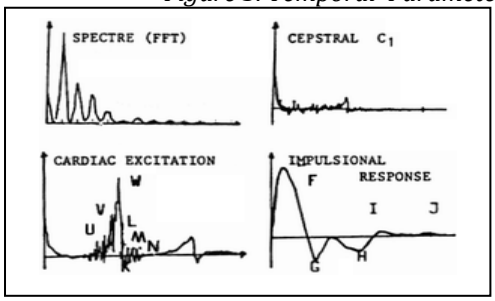

Figure 4. C2 and C3 Cepstral Parameters

Table 1. Temporal, spectral and cepstral parameters

Temporal parameters	A	Wave amplitude of the bioimpedance derivate signal
	C	
	O	
	X	
	S	Bioimpedance signal maximum amplitude
Spectral parameters	R1	Spectral parameters $ri = \frac{harmonic\ amplitude\ i}{fundamental\ amplitude}$
	R2	
	R3	
Cepstral parameters	U	Cepstral parameters (cardiac excitation amplitude: cepstral C2)
	M	
	N	

	F	Cepstral parameters (impulsional response amplitude: cepstral C3)
	I	
	G	
	LF	LF is the normalized width of wave F (aortic cepstral): $= \frac{L}{T}$, T is the cardiac period and L is the width of the wave F.

Table 2. Cepstral parameters

Cepstral parameters	U	M	N	F	I	G	LF
Number	1	2	3	4	5	6	7

P is the total cepstral parameters corresponding to the N classes

In order to perform more accuracy for our investigation we have used 140 different normal and cardiovasculars diseases (Fig.5). This data base corresponds to 14 classes Yk with 130 different cardiovascular diseases and 10 normal classes. (Table 3)

Bioimpedance parameters, proposed for the discrimination between the classes, are in this study 7 cepstral parameters.

After testing the seven parameters during the first step, the program indicates the parameter number 7 which represents the normalized width LF of the aortic cepstral. Therefore, the parameter number 7 is the best discriminant plethysmographic parameter. The best classified percentage of individual is then 65.31 % (Table 3).

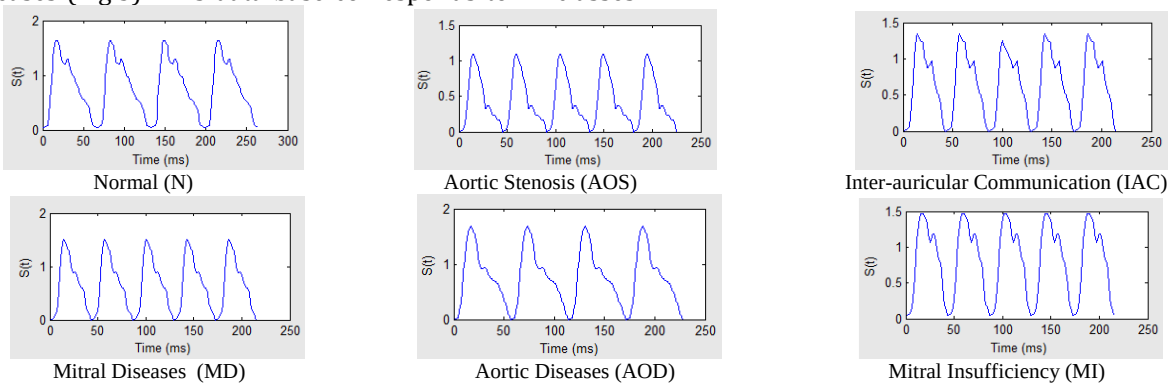

Figure 5. Example of normal and cardiovascular diseases bioimpedance signals

At steps number 2, 3 and 4, the program choose, respectively, parameters number 7, 5, 6 and 4 corresponding respectively to the parameters: LF, I, G and F. The classified percentage is then 87.02 %. At step 5, the percentage of classification reaches 94.77 % for the parameters are 7, 5, 6, 4, and 3 corresponding to the parameters: LF, I, G, F and N. Finally at step number 6 and 7 the program choose parameters 2 and 1 corresponding to M and U respectively with the percentage 95.2 % and 96.45 %.

The total 7 independent parameters (Table 3), gives 96.45% degree of best classification. Therefore Bioimpedance cepstral parameters with best discrimination are: 7(Lf), 5(I), 6(G), 4(F), 3(N), 6(M), and 7(U).

C. Automatic diagnosis

Automatic diagnosis method consists on preparing, first, a data base with a set of the seven cepstral parameters of different bioimpedance signal according to different cardiac diseases. This data base is composed from n classes Yk corresponding to 140 classes (normal and cardiac disease).

The classification of anonymous individuals is based on the use of FISHER formula (2). Minimum dij distance, between a and the Yi, classes provides the kind of cardiac disease. Investigation has concerned a data base of 140 kinds of signal: 10 normal and 130 pathological cases (Table 4). The number of cross indicates the severity of the disease.

Thirty cases of anonymous signals are used composed from 5 anomalies (six subjects for each cases): AO.S+(a_{11}, a_{12}, a_{13}, a_{14}, a_{15}, a_{16}), AO.I+(a_{21}, a_{22}, a_{23}, a_{24}, a_{25}, a_{26}), I.A.C.+++ (a_{31}, a_{32}, a_{33}, a_{34}, a_{35}, a_{36}), M.I.+ (a_{41}, a_{42}, a_{43}, a_{44}, a_{45}, a_{46}), M.S++ (a_{51}, a_{52}, a_{53}, a_{54}, a_{55}, a_{56}). The diagnosis of these thirty anonymous cases is confirmed by Echo-Doppler method. Table 5 shows affectation of these cases.

Table 3. Step by step analysis

Steps	Parameters	Percentage
1	7	65.31 %
2	7, 5	82.73 %
3	7, 5, 6	84,77 %
4	7, 5, 6, 4	87.02 %
5	7, 5, 6, 4, 3	94.77 %
6	7, 5, 6, 4, 3, 2	95.20 %
7	7, 5, 6, 4, 3, 2, 1	96.45 %

Table 4. Basic sample of average cepstral parameters

(AO.I: aortic insufficiency, AO.S: aortic stenosis, AO.D: aortic diseases ; M.I: Mitral Insufficiency, M.S: Mitral stenosis, M.D: Mitral diseases ; PS: pulmonary stenosis ; IVC: Inter-ventricle communication ; IAC: inter-atrium communication ; CMP: Cardio-myopathie)

	Np	F	LF	U	M	N	I	G
Normal	10	1	0.49	0.19	0.21	0.17	0.05	0.32
M.D.+	4	1.4	2.11	0.44	0.02	0.01	0	0
AO.I.+	4	0.78	0.54	0.18	0.20	0.17	0.05	0.49
AO.S.+	4	0.17	0.88	0.17	0.21	0.17	0.05	0.30
AO.D.+	4	1.16	0.89	0.19	0.21	0.16	0	0.30
M.I.+	4	1.4	1.57	0.15	0.05	0.05	0	0.30
M.S.+	4	1.11	0.79	0.10	0.03	0.02	0.19	0.11
I.A.C+	4	1.2	0.75	0.15	0.15	0.10	0.04	0.30
M.AO.D+	4	1.2	0.95	0.31	0.25	0.10	0.04	0.35

T.I.&M.D+	4	1.5	2.5	0.54	0.03	0.02	0	0
P.S.+	4	0.78	0.54	0.18	0.20	0.17	0.05	0.49
I.D.+	4	1.6	2.1	0.45	0.02	0.02	0	0
I.V.C+.	4	1.16	0.89	0.19	0.21	0.16	0	0.30
C.M.+	4	1.5	2.01	0.5	0.019	0.01	0	0
M.D.++	3	1.44	2.21	0.54	0.12	0.11	0.1	0.1
AO.I.++	3	0.88	0.64	0.28	0.30	0.27	015	0.59
AO.S.++	3	0.27	0.98	0.27	0.31	0.27	0.15	0.40
AO.D.++	3	1.26	0.99	0.29	0.31	0.26	0.1	0.40
M.I.++	3	1.5	1.67	0.25	0.15	0.15	0.1	0.40
M.S.++	3	1.21	0.89	0.20	0.13	0.12	0.29	0.21
I.A.C++	3	1.3	0.85	0.25	0.25	0.20	0.09	0.40
M.AO.D++	3	1.3	1.05	0.41	0.35	0.20	0.14	0.45
T.I.&M.D++	3	1.6	2.6	0.55	0.13	0.12	0.1	0.1
P.S.++	3	0.88	0.64	0.28	0.30	0.27	0.15	0.59
I.D.++	3	1.65	2.2	0.50	0.03	0.03	0.05	0.05
I.V.C.++	3	1.26	0.99	0.29	0.31	0.26	0.05	0.40
C.M.++	3	1.6	2.21	0.55	0.3	0.11	0.04	0.06
M.D.+++	3	1.60	2.31	0.64	0.22	0.21	0.2	0.2
AO.I.+++	3	0.98	0.74	0.38	0.40	0.37	0.25	0.69
AO.S.+++	3	0.37	0.1	0.37	0.41	0.37	0.25	0.50
AO.D.+++	3	1.36	0.11	0.39	0.41	0.36	0.2	0.50
M.I.+++	3	1.6	1.77	0.35	0.25	0.25	0.2	0.50
M.S.+++	3	1.31	0.99	0.30	0.23	0.22	0.39	0.31
I.A.C+++	3	1.4	0.95	0.35	0.3	0.25	0.10	0.50
M.AO.D+++	3	1.43	1.15	0.51	0.36	0.25	0.16	0.55
T.I.&M.D+++	3	1.65	2.65	0.6	0.23	0.15	0.14	0.13
P.S.+++	3	0.98	0.65	0.32	0.35	0.3	0.16	0.6
I.D.+++	3	1.7	2.3	0.55	0.13	0.04	0.04	0.06
I.V.C.+++	3	1.36	1.09	0.39	0.41	0.36	0.1	0.5
C.M.+++	3	1.7	2.2	0.6	0.35	0.21	0.05	0.07

Table 5a. Anonymous individual affection

	d_{11}	d_{12}	d_{13}	d_{14}	d_{15}	d_{16}	d_{21}	d_{22}	d_{23}	d_{24}	d_{25}	d_{26}	d_{31}	d_{32}	d_{33}
Normal	100	99.9	98.9	99.5	99.2	99.4	99	99.9	97.9	100	99.8	99.7	99.2	99.9	100
M.D.+	55.3	65.3	75.5	57.3	54.3	74.2	85.3	75.3	74.2	77.3	64.3	84.2	58.3	77.3	88.5
AO.I.+	22.2	32.1	28.1	27.4	29.1	20.1	**0.11**	**0.10**	**0.10**	**0.12**	**0.13**	**0.09**	27.4	29.1	20.1
AO.S.+	**0.10**	**0.09**	**0.11**	**0.12**	**0.10**	**0.08**	5.2	4.9	6.2	4.6	0.10	8.1	4.9	8.6	4.6
AO.D.+	12.2	13.5	12.4	14.4	15.2	16.3	5.3	3.5	2.4	4.4	5.2	6.3	14.4	15.2	16.3
M.I.+	54.9	65.8	53.4	75.1	45.9	52.8	64.9	75.4	6./	85.1	55.9	72.9	95.1	75.1	82.8
M.S.+	78.1	87.2	67.3	78.2	88.9	47.8	88.1	97.2	57.9	88.2	70.8	67.9	78.2	88.9	47.8
I.A.C+	88.6	78.6	67.4	78.5	78.1	58.3	88.9	78.5	67.4	88.5	98.5	68.3	78.5	78.1	58.3
M.AO.D+	7.22	8.4	9.3	10.8	11.6	12.9	8.23	9.5	10.3	11.8	9.6	11.9	10.8	11.6	12.9
T.I.&M.D+	87.9	87.8	97.5	77.5	84.1	88.1	88.9	89.9	98.4	78.6	85.2	98.1	77.5	84.1	88.1
P.S.+	98.5	94.5	91.4	96.2	91.8	88.2	99.5	93.4	92.4	96.7	93.1	84.2	96.2	91.8	88.2
I.D.+	95.6	90.4	92.1	89.6	90.0	97.1	96.6	91.3	97.2	88.6	91.0	98.2	89.6	90.0	97.1
I.V.C+.	94.8	93.7	95.4	87.8	88.9	91.8	95.8	94.1	98.5	87.1	88.4	98.8	87.8	88.9	91.8
C.M.+	98.3	97.3	92.2	99.1	88.5	97.5	97.3	98.3	92.9	99.4	98.5	91.5	99.1	88.5	97.5
M.D.++	88.22	87.3	85.7	81.5	82.4	90.4	87.2	88.3	85.4	81.9	83.5	94.4	81.5	82.4	90.4
AO.I.++	55.99	40.9	41.1	35.7	25.99	45.1	5.99	4.9	4.1	3.1	2.9	4.1	35.7	25.99	45.1
AO.S.++	2.44	3.33	4.45	3.5	2.1	2.9	8.54	10.3	11.5	13.5	12.2	12.1	3.5	2.1	2.9
AO.D.++	4.66	5.7	4.5	4.1	5.2	8.8	10.7	11.7	12.5	14.1	14.2	14.1	4.1	4.2	4.99
M.I.++	54.99	55.5	64.3	59.89	58.1	55.8	55.2	65.4	74.3	89.4	68.1	55.9	59.8	58.1	55.8
M.S.++	55.21	65.3	51.4	52.5	59.5	58.4	56.1	75.4	81.4	92.5	58.5	78.4	52.5	59.5	58.4
I.A.C++	89.3	87.4	88.5	85.4	82.9	90.4	99.3	88.1	89.5	85.3	84.9	91.4	85.4	82.9	90.4
M.AO.D++	10.5	11.4	12.8	10.8	10.8	10.1	11.5	21.4	13.8	13.7	15.1	12.1	10.8	10.8	10.1
T.I.&M.D++	88.3	87.5	86.5	89.3	91.3	90.9	89.3	88.4	87.5	89.4	91.9	91.9	89.3	91.3	90.9
P.S.++	91.3	90.4	92.5	89.4	92.8	95.3	81.3	91.4	93.8	89.5	92.7	85.3	89.4	92.8	95.3
I.D.++	88.7	84.7	85.1	88.7	90.2	91.2	87.7	85.7	85.1	89.7	91.2	92.2	88.7	90.2	91.2
I.V.C.++	95.6	94.5	93.7	98.1	92.5	96.7	94.6	94.9	93.8	97.1	94.5	86.7	98.1	92.5	96.7
C.M.++	96.1	94.5	96.8	99.1	94.2	93.6	96.8	94.4	91.8	90.9	94.5	94.6	99.1	94.2	93.6
M.D.+++	88.22	88.5	87.4	88.9	84.9	87.6	88.9	89.5	97.4	84.8	89.9	89.6	88.9	84.9	87.6
AO.I.+++	5.99	6.8	10.4	6.5	8.8	9.4	6.99	7.8	10.5	6.4	4.8	3.4	6.5	8.8	9.4
AO.S.+++	3..66	3..8	4..6	2.99	3.1	3..7	10..7	11..8	12..4	12.0	14.1	13..7	2.99	3.1	3..7
AO.D.+++	5.9	8.5	6.4	7.4	5.4	5.9	15.9	18.5	16.4	11.5	12.9	11.9	7.4	5.4	5.9
M.I.+++	45.66	45.0	47.7	4/.5	48.8	49.1	49.6	55.1	67.7	77.5	58.8	79.1	4/.5	48.8	49.1
M.S.+++	55.22	55.1	54.3	59.4	57.1	58.4	75.1	65.1	55.4	79.4	67.1	59.4	59.4	57.1	58.4
I.A.C+++	86.1	85.1	96.0	88.5	89.4	87.9	98.2	98.3	97.4	88.4	87.4	98.8	0.11	0.12	0.10
M.AO.D+++	15.6	17.6	18.5	18.4	19.4	20.6	14.6	11.5	10.5	15.4	14.6	15.6	18.4	19.4	20.6
T.I.&M.D+++	88.2	89.9	87.4	81.7	90.2	89.2	87.3	88.4	88.5	82.7	90.9	89.8	81.7	90.2	89.2
P.S.+++	90.2	91.5	92.4	89.4	90.9	92.2	91.2	92.5	92.9	89.5	95.9	94.2	89.4	90.9	92.2
I.D.+++	94.2	95.4	96.4	90.2	96.2	97.4	95.2	95.6	96.9	91.2	95.2	98.9	90.2	96.2	97.4
I.V.C.+++	88.3	89.4	91.3	87.3	85.5	89.4	89.8	87.4	92.3	87.6	85.9	88.4	87.3	85.5	89.4

C.M.+++	88.9	89.9	87.8	88.8	91.9	90.9	87.8	89.2	88.8	88.7	91.1	95.9	88.8	91.9	90.9

Table 5b. Anonymous individual affection

	d_{34}	d_{35}	d_{36}	d_{41}	d_{42}	d_{43}	d_{44}	d_{45}	d_{46}	d_{51}	d_{52}	d_{53}	d_{54}	d_{55}	d_{56}
Normal	99	99.9	97.9	88.9	98.5	97.4	100	99.9	98.9	99.7	d_{13}	d_{14}	d_{15}	d_{16}	d_{21}
M.D.+	85.3	75.3	74.2	8.23	9.5	10.3	11.8	9.6	11.9	66.2	98.9	99.5	99.2	99.4	99
AO.I.+	88.1	89.6	79.9	88.9	89.9	98.4	78.6	85.2	98.1	77.3	75.5	57.3	54.3	74.2	85.3
AO.S.+	5.2	4.9	6.2	99.5	93.4	92.4	96.7	93.1	84.2	55.1	28.1	27.4	29.1	20.1	**0.11**
AO.D.+	5.3	3.5	2.4	96.6	91.3	97.2	88.6	91.0	98.2	53.7	77.4	88.5	78.9	68.3	88.1
M.I.+	64.9	75.4	6.5	**0.08**	**0.09**	**0.10**	**0.05**	**0.09**	**0.01**	26.3	12.4	14.4	15.2	16.3	5.3
M.S.+	88.1	97.2	57.9	7.3	8.3	9.9	9.4	9.5	9.5	2.22	3.4	5.1	4.9	5.8	1.9
I.A.C+	88.9	78.5	67.4	87.2	88.3	85.4	81.9	83.5	94.4	49.6	67.3	78.2	88.9	47.8	88.1
M.AO.D+	8.23	9.5	10.3	5.99	4.9	4.1	3.1	2.9	4.1	75.1	67.4	78.5	78.1	58.3	88.9
T.I.&M.D+	88.9	89.9	98.4	8.54	10.3	11.5	13.5	12.2	12.1	98.2	9.3	10.8	11.6	12.9	8.23
P.S.+	99.5	93.4	92.4	10.7	11.7	12.5	14.1	14.2	14.1	14.6	97.5	77.5	84.1	88.1	88.9
I.D.+	96.6	91.3	97.2	55.2	65.4	74.3	89.4	68.1	55.9	87.3	91.4	96.2	91.8	88.2	99.5
I.V.C+.	95.8	94.1	98.5	56.1	75.4	81.4	92.5	58.5	78.4	91.2	92.1	89.6	90.0	97.1	96.6
C.M.+	97.3	98.3	92.9	99.3	88.1	89.5	85.3	84.9	91.4	95.2	95.4	87.8	88.9	91.8	95.8
M.D.++	87.2	88.3	85.4	11.5	21.4	13.8	13.7	15.1	12.1	44.2	92.2	99.1	88.5	97.5	97.3
AO.I.++	5.99	4.9	4.1	89.3	88.4	87.5	89.4	91.9	91.9	88.6	85.7	81.5	82.4	90.4	87.2
AO.S.++	8.54	10.3	11.5	81.3	91.4	93.8	89.5	92.7	85.3	55.8	41.1	35.7	25.99	45.1	5.99
AO.D.++	10.7	11.7	12.5	87.7	85.7	85.1	89.7	91.2	92.2	69.5	4.45	3.5	2.1	2.9	8.54
M.I.++	55.2	65.4	74.3	4.6	9.9	9.8	7.1	9.5	8.7	22.3	4.5	4.1	5.2	8.8	10.7
M.S.++	56.1	75.4	81.4	96.8	14.4	11.8	15.9	14.5	18.6	**0.10**	**0.11**	**0.12**	**0.09**	**12**	**0.05**
I.A.C++	99.3	88.1	89.5	88.9	89.5	97.4	84.8	89.9	89.6	75.1	51.4	52.5	59.5	58.4	56.1
M.AO.D++	11.5	21.4	13.8	6.99	7.8	10.5	6.4	4.8	3.4	8.2	8.5	8.4	8.9	9.4	9.3
T.I.&M.D++	89.3	88.4	87.5	10..7	11..8	12..4	12.0	14.1	13..7	14.6	12.8	10.8	10.8	10.1	11.5
P.S.++	81.3	91.4	93.8	15.9	18.5	16.4	11.5	12.9	11.9	87.3	86.5	89.3	91.3	90.9	89.3
I.D.++	87.7	85.7	85.1	49.6	55.1	67.7	77.5	58.8	79.1	91.2	92.5	89.4	92.8	95.3	81.3
I.V.C.++	94.6	94.9	93.8	75.1	65.1	55.4	79.4	67.1	59.4	95.2	85.1	88.7	90.2	91.2	87.7
C.M.++	96.8	94.4	91.8	98.2	98.3	97.4	88.4	87.4	98.8	89.8	93.7	98.1	92.5	96.7	94.6
M.D.+++	88.9	89.5	97.4	14.6	11.5	10.5	15.4	14.6	15.6	3.44	96.8	99.1	94.2	93.6	96.8
AO.I.+++	6.99	7.8	10.5	87.3	88.4	88.5	82.7	90.9	89.8	88.6	87.4	88.9	84.9	87.6	88.9
AO.S.+++	10..7	11..8	12..4	91.2	92.5	92.9	89.5	95.9	94.2	55.6	10.4	6.5	8.8	9.4	6.99
AO.D.+++	15.9	18.5	16.4	95.2	95.6	96.9	91.2	95.2	98.9	55.7	4..6	2.99	3.1	3..7	10..7
M.I.+++	49.6	55.1	67.7	89.8	8.4	2.3	7.6	5.9	5.4	28.9	6.4	7.4	5.4	5.9	15.9
M.S.+++	75.1	65.1	55.4	7.8	19.2	18.8	11.7	11.1	19.9	2.99	4.7	4.5	4.8	4.1	4.6
I.A.C+++	0.12	0.08	0.07	88.9	78.5	67.4	88.5	98.5	68.3	96.8	54.3	59.4	57.1	58.4	75.1
M.AO.D+++	14.6	11.5	10.5	8.23	9.5	10.3	11.8	9.6	11.9	7.4	6.0	8.5	8.4	7.9	8.2
T.I.&M.D+++	87.3	88.4	88.5	18.9	19.9	8.4	18.6	15.2	198.1	10.4	18.5	18.4	19.4	20.6	14.6
P.S.+++	91.2	92.5	92.9	99.5	93.4	92.4	96.7	93.1	84.2	4..6	87.4	81.7	90.2	89.2	87.3
I.D.+++	95.2	95.6	96.9	96.6	91.3	97.2	88.6	91.0	98.2	6.4	92.4	89.4	90.9	92.2	91.2
I.V.C.+++	89.8	87.4	92.3	95.8	94.1	98.5	87.1	88.4	98.8	47.7	96.4	90.2	96.2	97.4	95.2
C.M.+++	87.8	89.2	88.8	97.3	98.3	92.9	99.4	98.5	91.5	54.3	91.3	87.3	85.5	89.4	89.8

*D. **Discussion***

From table 4, it can be noted that the parameter 7 (LF) has the best discriminating power with a percentage of well classed 64.29%, which confirms the results found by Ben Salah and al. [8,17].

At step 7 the percentage of well class reaches 96.45%. This result is slightly better than the one we found in previous work using 15 bioimpedance parameters: 94.64% of percentage of correctly classified.

The results found in this work indicate that the seven cepstral parameters defined above are sufficient to perform the automatic diagnosis of the cardiovascular system abnormalities.

The effectiveness of the cepstral parameters classification is confirmed by the exact allocation of 29 anonymous individuals per 30. Indeed our results demonstrate that patients aij have been allocated respectively to the five previous classes: AO.S+, AO.I+, I.A.C.+++, M.I.+, M.S++. However we remark that one subject from MS++ is not well allocated to its class. The percentage of well classed is 96.67%.

At this level we can perform a comparison between the two percentage : p1 = 96.54 % and 96.67 % using the percentage test:

$n_1 = 140$; $q_1 = 96.45\%$

$n_2 = 30$; $q_2 = 96.67\%$

The Sq test is given by [19]

$S_q = \sqrt{QP(\frac{1}{n_1} + \frac{1}{n_2})}$ and $Q = \frac{n_1 q_1 + n_2 q_2}{n_1 + n_2}$ (P = 1 - Q)

The following condition of normality must be verified:

$n_1Q > 5$ and $n_2Q > 5$

Q = 96.49 % P = 3.51 %

$n_1Q = 135.086 > 5$ $n_2Q = 28.947 > 5$

The condition of normality is verified:

The percentage test is then: Sq = 0.201 < (risk = 5 %)

The difference between the two percentage is then not significant with the risk of 5 %. We can advance that the percentage of well classed concerning the seven cepstral parameters is confirmed by the location of the anonymous individual.

CONCLUSION

Automatic quantification of cardiac diseases has been carried out using discriminant analysis method based on the processing of bioimpedance signal. The discrimination uses analysis of seven cepstral parameters. Classification has been performed using a fundamental data base composed of 140 classes (10 none normal and 130 cases of diseases). Method ste by step gives an excellent degree of discrimination 96.45 %. The intelligent method performed in this study permits to confirm the classification of three anonymous patients. Quantification results obtained by the bioimpedance signals analysis is confirmed by those obtained with Echo-Doppler method. Researches are actually orientated for the investigation of peripheral cardiovascular system with the use of hemodynamic bioimpedance and ECG parameters

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