Contents lists available at www.innovativejournal.in

INNOVATIVE JOURNAL OF MEDICAL AND HEALTH SCIENCE

Journal homepage: http://innovativejournal.in/ijmhs/index.php/ijmhs

ISSN No. 2277-4939

AUTOMATIC DIAGNOSIS OF MITRAL STENOSIS DISEASE BY IMPEDANCE CARDIOGRAPHY SIGNAL PROCESSING (ICG)

Tareq Hadidi

Prince Sattam Bin Abdulaziz University, Saudi Arabia

ARTICLE INFO

Corresponding Author:
Tareq Al Hadidi
College of Applied Medical Sciences. Prince Sattam, Bin Abdulaziz University, Saudi Arabia
hadidi2@hotmail.com

Keywords: Non invasive, Diagnosis, Bioimpedance, ICG, Cepstral analysis

DOI:http://dx.doi.org/10.15520/ijmhs.2017.vol7.iss1.152.

ABSTRACT

The diagnosis of cardiovascular diseases could be performed by several invasive and non-invasive methods. A non-invasive method for cardiac diseases quantification is described in this paper. Our method uses discriminant analysis of seven cepstral parameters computed from the Impedance cardiography signal (ICG) which represents an impedance variation in explored thoracic region at the level of the ascending aorta. In this study we have performed the assessment of two kinds of serious mitral stenosis (MS++) and very serious (MS+++) disease. These diseasesare already well known by conventional methods (cardiovascular catheterization and echo-Doppler methods). A data base of 62 subjects (10 normal and 52 with different kinds of cardiac diseases) is used. The sample of the mitral stenosis diseases is constituted by six cases. Results show that the fisher distances (d_{ij}) of mitral stenosis diseases are minimum which represents a confirmation of the nature of these diseases. These results are confirmed by Stewart Hamilton dilution method and Cardiac Echo-Doppler method.

INTRODUCTION

The diagnosis of the cardiovascular system anomalies is becoming less invasive. Cardiac Echo-Doppler methods have been in use since sixty years [13]. Non-invasive methods for the cardiovascular system exploration are increasingly felt. In this context cardiac Bioimpedance method represents an electric non-invasive method which could be used to perform automatic and less harm diagnosis of cardiovascular system anomalies [1, 2, 6, and 16]. Bioimpedancesignal represents the impedance variation of the explored corporal segment during cardiac activity [6, 9, 10, 11, 12].Bioimpedance method, used less by cardiac investigators, begins to prove itself [5]. In this study we will show that the analysis of cardiac Bioimpedance parameters allows the diagnosis of an example of serious mitral stenosis diseases using only seven cepstral relevant parameters.

MATERIAL AND METHOD

A. Bioimpedance Method

The bioimpedance method (Fig. 1) consists on the injection of a sinusoidal electric current using an injection circuit based on an oscillator providing a signal of high frequency (30 KHz) and low amplitude (15 V pp). The current intensity is about 1 mA (non-hazardous for the patient). The current application is performed through two electrodes of injection I1 and I2 placed on the chest. Bio-impedance signal is detected via two electrodes R1 and R2 placed at the level of the ascendant aorta segment (Fig. 1). The bioimpedance system, is built around the oscillator circuit and a signal acquisition system composed of an instrumentation amplifier type AD620 followed by a filter, detection, a compensation and an amplification circuit with three types of gain (thoracic and peripheral exploration) [14].

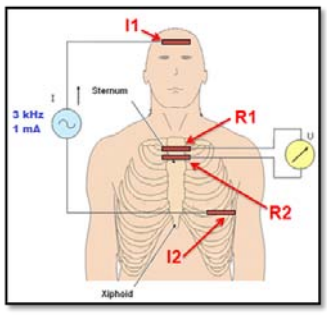

Figure 1 Bioimpedance Method

B. *Cardiac Echo-Doppler*

The diagnosis of heart disease by Cardiac Echo Doppler is based on the conversion of the Doppler signal eitherin curve of speed, either in frequency spectrum. The Doppler signal spectrum is the representation of the spectral density versus frequency. When blood flow is laminar, the red blood cells have the same direction of speed. The spectrum is then to narrow strips, linear and stable shaped M (normal case, figure). In the case of valvular stenosis, it appears a turbulent flow with an expanded spectrum. This information is very important for the assessment of the valvular stenosis severity degree. The Doppler method allows therefore the diagnosis of pure valvular stenosis severity. It is this method which will interest us for the quantification of mitral stenosis. The diagnosis of valve diseases is based on the determination of a number of

parameters, from the spectrum of the flow speed. These parameters are as following:

1. Maximum gradient $\Delta Pmax$ between the downstream and upstream of the orifice of the valve pressures considered.

For Halteet al. [8], the instant pressure gradient $\Delta P(t)$ and the maximum of ΔP are:

$$\Delta P(t) = P_2(t) - P_1(t) = 4.V^2(t) \quad (1)$$

$$\Delta Pmax = 4.V^2max \quad (2)$$

$P_1(t)$: Instantaneous pressure downstream of the valve.
$P_2(t)$: Instantaneous pressure upstream of the valve
$V(t)$: Flow downstream speed
If the pressure gradient is expressed in mmHg, the normal maximum speed is Vmax = 0.5 m/s, $\Delta Pmax = 8\ mmHg$
2. The average gradient ΔPa

$$\Delta Pa = \frac{\int_0^{T_D} \Delta P(t)dt}{T_D} = \frac{A}{T_D} \quad (3)$$

A: Area under the curve of pressure gradient
T_D: duration of diastole.
3. The time after which the pressure gradient drops by half: $T_{1/2}$ (decrease of speed up to $\frac{Vmax}{\sqrt{2}}$)

For example, $T_{1/2}$allows the assessment of the mitral stenosisseverity. The $T_{1/2}$ is very important in the diagnosis of the disease severity because it is independent of the flow and the cardiac frequency (for a normal subject the $T_{1/2}$ < 5 ms).
4. The surface valve S[8]:

$$S\ (cm^2) = \frac{220}{T_{1/2(ms)}} \quad (4)$$

Normal mitral surface: S = 5 cm^2.

C. Patient signal database

The bioimpedance signal database, used in this study, consists on the use of a set E composed of 62 subjects (10 normal and 52 with different kinds of cardiac diseases). This database corresponds to q=53 classes Y_k (52cardiac anomalies classes and 1 normal). Fig. 2 illustrates a normal bioimpedance signal.

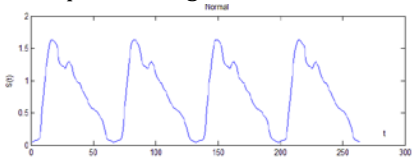

Figure2 Example of normal bioimpedance signal

The diagnosis of heart disease was done by confronting several invasive and non-invasive exploration techniques: Preliminary examination is performed by external auscultation, stethoscope and pressure sensor. Then an examination by echocardiography and an exploration by cardiac catheterization were performed. Finally the patient could undergo a digital angiography exploration if any.
As a result of all of these explorations, the medical staff of the service performs a meeting on the concerning case. After discussion, the type of heart disease is fixed and the patient is automatically registered for a cardiovascular thoracic bioimpedence exploration.
In this study the sample of anonymous patients is formed by two kinds of mitral stenosis: a moderately mitral stenosis (MS++, Fig. 3) and a severe mitral stenosis (MS+++, Fig. 4). These diseases are already well known by cardiac catheterization. The result is confirmed by cardiac echography method.

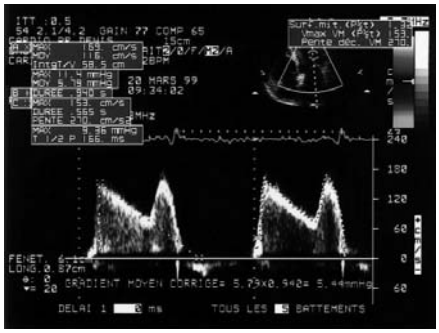

Figure3 Mitral stenosis MS++

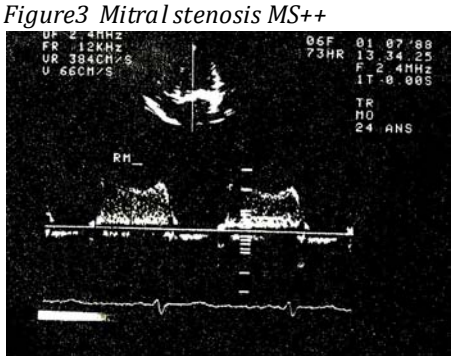

Figure4 Mitral stenosis MS+++

D. Discriminant linear function. Fischer theory

The automatic diagnosis is based on the classification of anonymous individuals. Then, we have to perform a partition of the base set E in distinct groups (or classes) q.This phase needs to define a ranking metric.
Consider an anonymous individual (a) (belongs or not to the set E) and a class Y_k with y_k the center or average of this class for a variable (parameter) i. The distance $d(a, Y_k)$between (a) and the class Y_k is given by the following Fischer discriminant linear function (5):

$$d(a, Y_k) = (a - y_k)'.{T_{cov}}^{-1}.(a - y_k) \quad (5)$$

T_{cov} is whole covariance matrix.
The square term a'T^{-1}a is common for the functions d(a,Y_k), so, for the classification, we can use the following function V_y(a):

$$V_y(a) = d(a,y) - a'^{T^{-1}}a = y_k{}'T^{-1}(y_k - 2a) \quad (6)$$

Then the classification of anonymous individuals is based on the use of the minimum of the function V_y(a) (Fisher formula) [15].

F. Relevant cepstral parameters

A previous statistical investigation was performed using the discriminant method analysis, [7, 4]. The choice of the best discrimination variables, which discriminate at best all the classes, is based on the criteria of Maximize E and minimize D as following:

E and D are respectively the interclassand the intra class covariance matrix. E and D are definedrespectively by the terms E_{ij} and D_{ij}.

$$E_{ij} = \sum_{k=1}^{q} \frac{N(k)}{N}(x_{ki} - \overline{x_{ki}})(x_{kj} - \overline{x_{kj}}) \quad (7)$$

N(k) : number of individuals in the class Y_k
N : total number of individuals in the set E
x_{ki} , x_{kj}: the i^{th} and j^{th} variables relative to K^{th} class.
$\overline{x_{ki}}$, $\overline{x_{kj}}$: average of the i^{th} and j^{th}variable for the class Y_k

$$D_{ij} = \sum_{k=1}^{q} \frac{N(k)}{N}(x_{ni}^k - \overline{x_{ki}})(x_{nj}^k - \overline{x_{kj}}) \quad (8)$$

x_{ni}^k , x_{ni}^k : i^{th} and j^{th} variable relative to the n^{th} individual and the k^{th} class.
Romeder [15] shows that E+D correspond to the whole covariance matrix:

$$T = E + D \quad (9)$$

$$T_{ij} = \frac{1}{N}\sum_{n=1}^{N}(x_{ni} - \overline{x_i})(x_{nj} - \overline{x_j}) \quad (10)$$

In an earlier study [7], we have established that the choice of the best discrimination variables is based on the use of the step by step method which allows the determination of the set of variables which maximize the trace of matrix $T^{-1}E$.

The method for the determination of the best discriminant variables will be as following: we have, initially, the matrix T and E of order p. At the first step, for each variable, the program calculates the trace of $T_1^{-1}E_1$ (first order) and holds the variable V1 which gives the maximum trace. At the second step we use T_2 and E_2 of second order relative to the previous variable V1 and another added variable then we calculate the trace of $T_2^{-1}E_2$ and so on...

Fig. 5 shows the spectrum, the cepstrum. C1, C2 and C3 of the ICG Signal. U, M, N are the cardiac excitation amplitude parameters and F, I, J are the impulsion response amplitude parameters, LF is the normalized width of wave F (aorticcepstral).

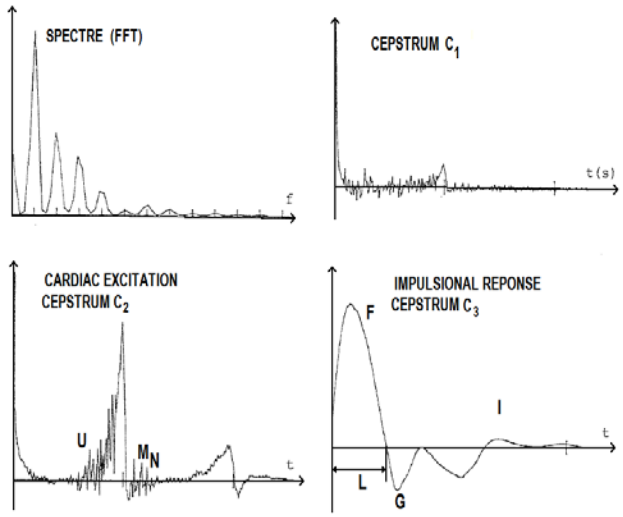

Figure5CepstrumC1, C2 and C3

The ideais to use the seseven cepstral parameters for the automatic diagnosis of the heart disease using Fisher's test. Cepstrums C2 and C3 permit to provide the seseven relevant parameters: (Table 1).

RESULTS AND DISCUSSION

A. Automatic diagnosis

Automatic diagnosis method starts by preparing the database presented above, with a set of the seven cepstral parameters of different bioimpedance signal according to different cardiac diseases. (Table 2)

Then, we performed a classification of anonymous individuals based on the FISHER formula (6). Minimum (d_{ij}) distance, between (a) and the Y_i, classes provides the kind of cardiac disease.

The test sample is composed ofsix patients relative to two kinds of cardiac diseases (3 cases of MS++ and 3 cases of MS+++), (Fig. 6).MS++ (d_{1I}, d_{2I}, d_{3I} ; I varies from 1 to 53);,MS+++ (d_{1j}, d_{2J}, d_{3j} ; j varies from 1 to 14),. The diagnosis of these six anonymous cases is already confirmed by Echo-Doppler method.

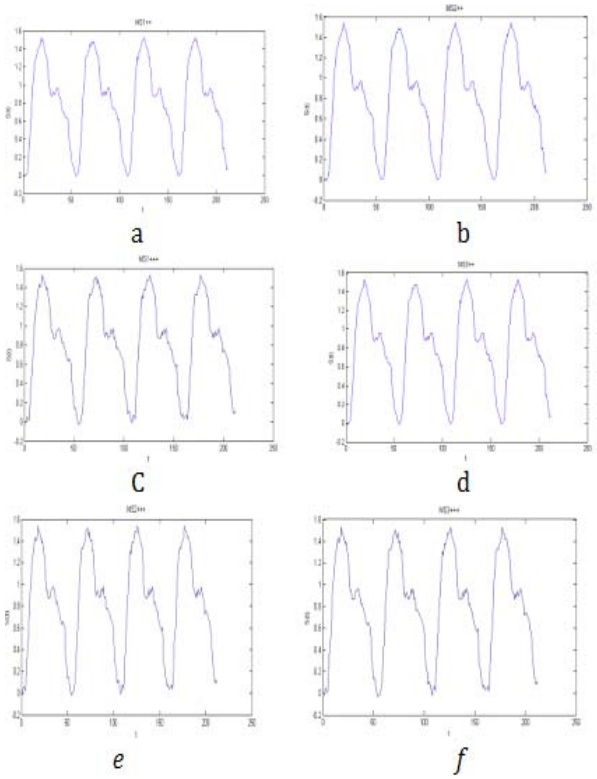

Fig. 6 Example of diagnosis sample (a: MS_1++ ; b: MS_2++ ; c: MS_3++ ; d: MS_1+++; e:MS_2+++; f: MS_3+++)

Table 1. Cepsral parameters

Cepstral parameters	U	Cepstral parameters (cardiac excitation amplitude: cepstrum C2)
	M	
	N	
	F	Cepstralparameters (impulsionalresponse amplitude: cepstrum C3)
	I	
	G	
	LF	LF is the normalized width of wave F (aortic cepstral): L/T, T is the cardiac period and L is the width of the wave F.

Table 2 and 3 illustrates the results of our investigations. The two cases of cardiac diseases are checked. The minimum d_{ij} distance between one patient and the different classes indicate the kind of the cardiac disease.

B. Discussion

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 the 6patients with MS++ and MS+++. Indeed our results demonstrate that patients corresponding to (dij) Fisher distancehave been allocated respectively to the two previous classes: MS++: d1-20 = 0.19 ; d2-20=0.11 ; d3-20=0.18 and MS+++: d1-33=0.1; d2-33=0.15 ; d3-33=0.2.

At this level we can perform an average test between the classes:

A: MS+ ; MS++ ; MS+++ (Table 4 and Fig. 7)

The average test (ε_a)is given by [3]

$$\varepsilon_a = \frac{|A_1 - A_2|}{\sqrt{\frac{\sigma_1^2 + \sigma_2^2}{n}}} \qquad (9)$$

Ai: Average of dij ; σi: Standard deviation ; n: number of patients

Table 2. Basic sample of average cepstral parameters (53 classes)(AO.I: aortic insufficiency, AO.S: aortic stenosis, AO.D: aortic diseases ; M.I: Mitral Insufficiency, M.S: Mitral stenosis, M.D: Mitral disease; PS: pulmonary stenosis ; IVC: Inter-ventricle communication ; IAC: inter-atrium communication; CMP: Cardio-myopathy)

	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.+	1	1.4	2.11	0.44	0.02	0.01	0	0
AO.I.+	1	0.78	0.54	0.18	0.20	0.17	0.05	0.49
AO.S.+	1	0.17	0.88	0.17	0.21	0.17	0.05	0.30
AO.D.+	1	1.16	0.89	0.19	0.21	0.16	0	0.30
M.I.+	1	1.4	1.57	0.15	0.05	0.05	0	0.30
M.S.+	1	1.11	0.79	0.10	0.03	0.02	0.19	0.11
I.A.C+	1	1.2	0.75	0.15	0.15	0.10	0.04	0.30
M.AO.D+	1	1.2	0.95	0.31	0.25	0.10	0.04	0.35
T.I.&M.D+	1	1.5	2.5	0.54	0.03	0.02	0	0
P.S.+	1	0.78	0.54	0.18	0.20	0.17	0.05	0.49
I.D.+	1	1.6	2.1	0.45	0.02	0.02	0	0
I.V.C+.	1	1.16	0.89	0.19	0.21	0.16	0	0.30
C.M.+	1	1.5	2.01	0.5	0.019	0.01	0	0
M.D.++	1	1.44	2.21	0.54	0.12	0.11	0.1	0.1
AO.I.++	1	0.88	0.64	0.28	0.30	0.27	015	0.59
AO.S.++	1	0.27	0.98	0.27	0.31	0.27	0.15	0.40
AO.D.++	1	1.26	0.99	0.29	0.31	0.26	0.1	0.40
M.I.++	1	1.5	1.67	0.25	0.15	0.15	0.1	0.40
M.S.++	1	1.21	0.89	0.20	0.13	0.12	0.29	0.21
I.A.C++	1	1.3	0.85	0.25	0.25	0.20	0.09	0.40
M.AO.D++	1	1.3	1.05	0.41	0.35	0.20	0.14	0.45
T.I.&M.D++	1	1.6	2.6	0.55	0.13	0.12	0.1	0.1
P.S.++	1	0.88	0.64	0.28	0.30	0.27	0.15	0.59
I.D.++	1	1.65	2.2	0.50	0.03	0.03	0.05	0.05
I.V.C.++	1	1.26	0.99	0.29	0.31	0.26	0.05	0.40
C.M.++	1	1.6	2.21	0.55	0.3	0.11	0.04	0.06
M.D.+++	1	1.60	2.31	0.64	0.22	0.21	0.2	0.2
AO.I.+++	1	0.98	0.74	0.38	0.40	0.37	0.25	0.69
AO.S.+++	1	0.37	0.1	0.37	0.41	0.37	0.25	0.50
AO.D.+++	1	1.36	0.11	0.39	0.41	0.36	0.2	0.50
M.I.+++	1	1.6	1.77	0.35	0.25	0.25	0.2	0.50
M.S.+++	1	1.31	0.99	0.30	0.23	0.22	0.39	0.31
I.A.C+++	1	1.4	0.95	0.35	0.3	0.25	0.10	0.50
M.AO.D+++	1	1.43	1.15	0.51	0.36	0.25	0.16	0.55
T.I.&M.D+++	1	1.65	2.65	0.6	0.23	0.15	0.14	0.13
P.S.+++	1	0.98	0.65	0.32	0.35	0.3	0.16	0.6
I.D.+++	1	1.7	2.3	0.55	0.13	0.04	0.04	0.06
I.V.C.+++	1	1.36	1.09	0.39	0.41	0.36	0.1	0.5
C.M.+++	1	1.7	2.2	0.6	0.35	0.21	0.05	0.07
M.D.++++	1	1.80	2.51	0.84	0.42	0.41	0.31	0.35
AO.I.++++	1	1.18	0.94	0.58	0.60	0.57	0.45	0.89
AO.S.++++	1	0.56	0.3	0.57	0.63	0.47	0.49	0.70
AO.D.++++	1	1.57	0.31	0.59	0.65	0.55	0.41	0.70
M.I.++++	1	1.82	1.99	0.55	0.47	0.35	0.3	0.68
M.S.++++	1	1.49	1.13	0.51	0.43	0.45	0.51	0.51
I.A.C++++	1	1.58	1.21	0.58	0.51	0.45	0.30	0.65
M.AO.D++++	1	1.63	1.35	0.71	0.56	0.45	0.36	0.75
T.I.&M.D++++	1	1.85	2.85	0.82	0.43	0.35	0.34	0.23
P.S.++++	1	1.17	0.85	0.82	0.6	0.56	0.36	0.75
I.D.++++	1	1.88	2.52	0.75	0.33	0.24	0.21	0.26
I.V.C.++++	1	1.56	1.29	0.59	0.61	0.46	0.30	0.7
C.M.++++	1	1.91	2.4	0.81	0.55	0.41	0.21	0.17

Table 3. Anonymous individual affection

N°	Classes	d_{1I}	d_{2I}	d_{3I}	d_{1J}	d_{2J}	d_{3J}
1	Normal	99.7	88.9	98.5	97.4	100	99.9
2	M.D.+	66.2	98.9	99.5	99.2	99.4	99
3	AO.I.+	77.3	75.5	57.3	54.3	74.2	85.3
4	AO.S.+	55.1	28.1	27.4	29.1	20.1	**0.11**
5	AO.D.+	53.7	77.4	88.5	78.9	68.3	88.1
6	M.I.+	99.7	88.9	98.5	97.4	100	99.9
7	M.S.+	2.11	1.2	1.3	5.2	4.9	5.8
8	I.A.C+	88.1	97.2	57.9	7.3	8.3	9.9
9	M.AO.D+	88.9	78.5	67.4	87.2	88.3	85.4
10	T.I.&M.D+	8.23	9.5	10.3	5.99	4.9	4.1
11	P.S.+	88.9	89.9	98.4	8.54	10.3	11.5
12	I.D.+	99.5	93.4	92.4	10.7	11.7	12.5
13	I.V.C+.	96.6	91.3	97.2	55.2	65.4	74.3
14	C.M.+	15.8	24.1	38.5	11.1	15.4	11.4
15	M.D.++	97.3	98.3	92.9	99.3	88.1	89.5
16	AO.I.++	87.2	88.3	85.4	11.5	21.4	13.8
17	AO.S.++	55.99	74.9	84.1	89.3	88.4	87.5
18	AO.D.++	8.54	10.3	11.5	81.3	91.4	93.8
19	M.I.++	90.7	71.7	62.5	87.7	85.7	85.1

20	**M.S.++**	**0.19**	**0.11**	**0.18**	1.1	1.2	0.9
21	**I.A.C++**	89.3	87.4	88.5	85.4	82.9	90.4
22	**M.AO.D++**	90.5	81.4	72.8	80.8	70.8	80.1
23	**T.I.&M.D++**	88.3	87.5	86.5	89.3	91.3	90.9
24	**P.S.++**	91.3	90.4	92.5	89.4	92.8	95.3
25	**I.D.++**	88.7	84.7	85.1	88.7	90.2	91.2
26	**I.V.C.++**	95.6	94.5	93.7	98.1	92.5	96.7
27	**C.M.++**	96.1	94.5	96.8	99.1	94.2	93.6
28	**M.D.+++**	88.22	88.5	87.4	88.9	84.9	87.6
29	**AO.I.+++**	85.99	76.8	88.4	76.5	98.8	79.4
30	**AO.S.+++**	53..66	83..8	94..6	92.99	93.1	83..7
31	**AO.D.+++**	45.9	88.5	76.4	87.4	85.4	85.9
32	**M.I.+++**	45.66	45.0	47.7	4/.5	48.8	49.1
33	**M.S.+++**	1.11	2.12	1.4	**0.10**	**0.15**	**0.2**
34	**I.A.C+++**	88.6	87.4	88.9	84.9	87.6	88.9
35	**M.AO.D+++**	55.6	70.4	88.5	78.8	99.4	86.99
36	**T.I.&M.D+++**	55.7	4..6	2.99	3.1	3..7	10..7
37	**P.S.+++**	28.9	86.4	77.4	75.4	85.9	95.9
38	**I.D.+++**	82.99	74.7	94.5	74.8	84.1	74.6
39	**I.V.C.+++**	96.8	54.3	59.4	57.1	58.4	75.1
40	**C.M.+++**	17.4	6.0	18.5	8.4	7.9	8.2
41	**M.D.++++**	10.4	18.5	18.4	19.4	20.6	14.6
42	**AO.I.++++**	4..6	87.4	81.7	90.2	89.2	87.3
43	**AO.S.++++**	6.4	92.4	89.4	90.9	92.2	91.2
44	**AO.D.++++**	47.7	96.4	90.2	96.2	97.4	95.2
45	**M.I.++++**	54.3	91.3	87.3	85.5	89.4	89.8
46	**M.S.++++**	4.9	8.4	7.6	2.5	2	1.4
47	**I.A.C++++**	88.9	78.5	67.4	88.5	98.5	68.3
48	**M.AO.D++++**	78.23	89.5	90.3	91.8	88.6	11.9
49	**T.I.&M.D++++**	18.9	19.9	8.4	18.6	15.2	198.1
50	**P.S.++++**	99.5	93.4	92.4	96.7	93.1	84.2
51	**I.D.++++**	96.6	91.3	97.2	88.6	91.0	98.2
52	**I.V.C.++++**	95.8	94.1	98.5	87.1	88.4	98.8
53	**C.M.++++**	97.3	98.3	92.9	99.4	98.5	91.5

Table 4: Difference average test (MS++)

	d1I	d2-I	d3-I	Average	σ	ε_a
MS+	2.11	1.2	1.3	1.537	0.499	4.76
MS++	**0.19**	**0.11**	**0.18**	**0.160**	**0.04**	
MS+++	1.11	2.12	1.4	1.543	0.510	4.68

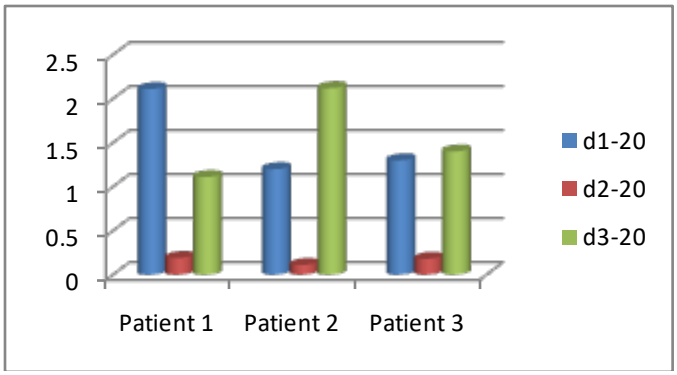

Figure 7 Difference average test histogram (MS++)

The number of patient is n<30, then we have to use Student table which gives:

N = 3, the DOF (degree of freedom) = 2 , α =0.05 =5%

And Zα = 4.303.

For (MS+, MS++), εa= 4.76>Zα =4.303, the difference is then significant.

For (MS++, MS+++), εa= 4.68>Zα =4.303, the difference is then significant.

The difference average tests concerning the minimal fisher distance relative to (MS+ , MS++) and (MS++ , MS+++) are then significant with the risk of 5 %.We can verify that the anonymous patients MS++ are well classed.

B: MS++ ; MS+++ ; MS++++ (Table 5 and Fig. 8).

Table 5: Difference average test (MS+++)

	d1J	d2-J	d3-J	Average	σ	ε_a
MS++	1.1	1.2	0.9	1.067	0.153	7.68
MS+++	0.10	0.15	0.2	**0.15**	**0.05**	
MS++++	2.5	2.0	1.4	1.967	0.551	5.693

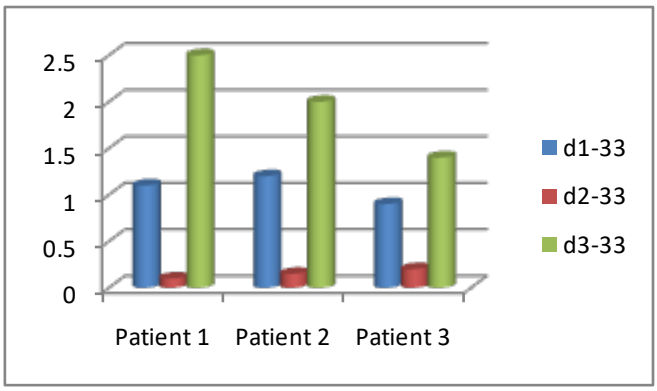

Figure 8 Difference average test histogram (MS+++)

For (MS++, MS+++), εa= 7.68>Zα =4.303, the difference is then significant.

For (MS+++, MS++++), εa= 5.693>Zα =4.303, the difference is then significant.

The difference between the Fisher distances relative to (MS++ , MS+++) and (MS+++ , MS++++) are then significant with the risk of 5 %. We can verify that the anonymous patients MS+++ are well classed.

C. ***Clinical confirmation***

Here is the result concerning the diagnosis of the first disease (MS++):

- It is amoderately mitral stenosis (MS ++) characterized by Vmax = 1.4 m/s, pressure gradient, $\Delta Pmax = 8\ mmHg$, $T_{1/2}$ = 160 ms and surface S = 1.4cm^2.

The results concerning the diagnosis of the second disease (MS+++) are:

- It is a severe mitral stenosis (MS+++) characterized by : Vmax = 2 m/s, pressure gradient $\Delta Pmax = 16\ mmHg$, $T_{1/2}$ = 210 ms and surface S = 1 cm^2.

CONCLUSION

In this paper we have performed an automatic quantification of cardiac diseases 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 53 classes (1normal and 52 cases of diseases). Our method, performed in this study, permits to confirm the classification of 2 kinds of diseases: MS+++ and MS+++. Quantification results obtained by the bioimpedance signals analysis is confirmed by those obtained with Echo-Doppler method and cardiac catheterization. Researchers are actually orientated for the investigation of other kinds of cardiac diseases and anomalies of the peripheral cardiovascular system with the use of hemodynamic bioimpedance parameters like arterial compliance and flowing hemodynamic resistance.

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