

# Fractal Pattern of Heart Rate Variability Revealing Unknown Very Low Frequency Properties

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## Abstract

*The subject of our research was an analysis of heart rate variability based on non-linear method Multiscale Multifractal Analysis (MMA).*

*The analysis of HRV night-time recordings involved 5 groups of patients (285 subjects): 38 healthy patients, 103 with aortic valve stenosis, 36 with hypertrophic cardiomyopathy, 32 with atrial fibrillation, 59 coronary disease and 17 with congestive heart failure.*

*The end result of MMA is the Hurst surface  $h(q,s)$  measuring a persistence. This is the 3D plot of the local Hurst exponent  $h$  describing the scaling of the variance of the signal as a function of  $q$ , which is a magnitude of the fluctuations and the parameter  $s$  - a measure of the time scale (convertible to frequency).*

*In our research, we assessed the shape and form of the Hurst surface and based on the differences of these features we constructed 6 criteria. These criteria intended as a diagnostic tool for screening examination, allow to classify patients as healthy when all the criteria were fulfilled or ill when at least one criterion was negative.*

*We also prepared an additional criterion, distinguishing group of patients with atrial fibrillation and detecting heart rate variability pattern for this group.*

*In general for all of groups (285 patients), we obtained 76% of correct results (i.e. the accuracy). The percent of correct results for coronary disease: 70%, for hypertrophic cardiomyopathy: 61% patients, for atrial fibrillation: 86%, for aortic valve stenosis: 79% and 80% - for congestive heart failure patients.*

*These results allow us to draw a conclusion that Multiscale Multifractal Analysis can be used as an effective screening examination method (general 6 criteria) as well as there are clear heart rate variability multifractal pattern, which we can detect using our criteria.*

*This multifractal pattern can reflect a variety of physio-pathological processes, which at this stage of our research is not able to specify, so need further research.*

## 1. Introduction

We assess heart rate variability analyzing time intervals between consecutive R peaks in the ECG signal based on different groups of method.

There are time-domain, frequency-domain and non-linear analysis of heart rate variability, which are specified in official Guidelines to HRV analysis [1]. In the Guidelines we can mention a serious unsolved problem - 95% of the total HRV power lays in the very-low and ultra-low frequency bands (VLF and ULF). These ranges are hard to analyze and interpret, so its physiological background is still uncertain. That's why, we can see that it is important to find new methods and ways, which could allow to analyze these frequency ranges.

The solution of this problem could be analysis of HRV basing on Multiscale Multifractal Analysis (MMA), which is just a method suited specifically for VLF and ULF HRV bands.

## 2. Methods

Multiscale Multifractal Analysis lets us to analyze complexity of human heart rate and find characteristic scaling of fluctuations in signal. This method derives from the DFA [2] and MF-DFA [3] methods, but additional includes a dependence on time scale [4]. The end result of MMA analyzing wide range of time scale and allowing to describe multifractal features of heart rate, is the Hurst surface. This is the plot of the local Hurst exponent  $h$  depending the parameter  $q$  (magnitude of the fluctuations) and on the parameter  $s$  (a measure of the time scale).

The exponent  $h$  equal to 0.5 represents white noise,  $h > 0.5$  is a measure of long-range correlation of the signal, but for  $0 < h < 0.5$  we analyze anti-persistence (long-range anticorrelation, i.e. high frequencies prevail) of the signal [5].

The parameter  $q$  as an indicator of magnitude of fluctuation analyzes large fluctuations in the signal (for  $q > 0$ ) and small fluctuations for  $q < 0$ .

MMA [6] assess long – range correlation based on properties of the scaling of fluctuations.

Because of the fact that the main result of MMA-the Hurst surface is difficult to interpret directly in terms of physiology, in this research we analyze the shape and form of this surface  $h(q,s)$  and compare the values of local Hurst exponent in different areas in 3D plot.

### 3. Data

We analyzed night-time recordings for 38 heart rate variability of healthy subjects and 247 recordings of patients in four groups: coronary disease, hypertrophic cardiomyopathy, aortic valve stenosis and patients with atrial fibrillation, which are databases of the Cardinal Stefan Wyszyński Institute of Cardiology (Warsaw, Poland).

Table 1. Table shows the number and age of patients in the analyzed groups.

Groups of patients	Age*	Number
Healthy	36±12	38
Coronary disease	46±16	59
Hypertrophic cardiomyopathy	30±8	36
Aortic valve stenosis	65±5	103
Atrial fibrillation	68±9	32
Congestive heart failure	55±11	17

\* average age ± standard deviation

### 4. Results

#### 4.1. The Hurst surface for healthy patients

The Hurst surface – the final results of MMA is a plot of the local Hurst exponent  $h$  as a function of the parameter  $q$  and  $s$ .

At the beginning of our analysis, we plotted the mean Hurst surface for healthy patients (based on calculated mean values of local Hurst exponent  $h$  for all healthy patients), which is shown in Fig. 1. Based on the shape of this mean surface and differences between surfaces for every healthy and ill patient and mean surface, we prepared 6 general criteria classifying patients as healthy (all the criteria are fulfilled) or ill (at least one criterion is unfulfilled).

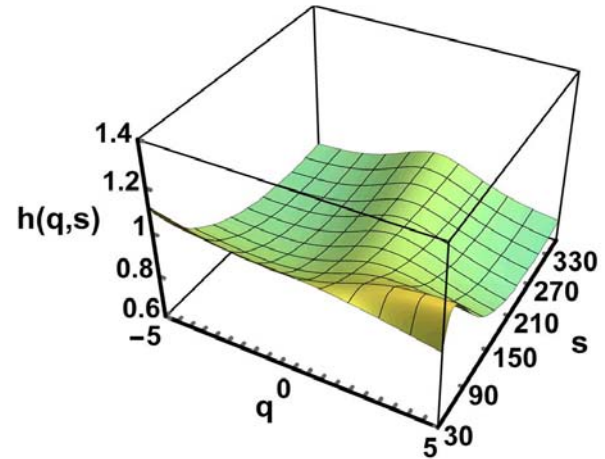


Fig. 1. Figure shows the mean Hurst surface for healthy patients.

#### 4.2. MMA as a screening examination method – 6 general criteria

Firstly, preparing criteria, we divided Hurst surfaces to 10 areas, what is shown in Tab.2.

Tab. 2. Table shows areas, on the Hurst surfaces and range of variables  $q$  and  $s$  for these areas.

Area	Range of $q$	Range of $s$
1a	$q \in [-3, -1]$	$s \in [270, 330]$
1b	$q \in [-1, 1]$	$s \in [270, 360]$
2a	$q \in [-1, 0]$	$s = 300$
2b	$q \in [0, 0.5]$	$s = 300$
3	$q \in [2, 5]$	$s \in [270, 330]$
4	$q \in [4, 5]$	$s \in [30, 60]$
5a	$q \in [-2, 1]$	$s \in [150, 210]$
5b	$q \in [-1, 1]$	$s = 360$
6a	$q \in [4, 5]$	$s \in [6, 60]$
6b	$q \in [4, 5]$	$s = 30$

After that, we prepared 6 general criteria analyzing shape of these areas and maximum and minimum values of local Hurst exponent on these divided areas.

#### The 6 general criteria:

##### The 1<sup>st</sup> criterion

The criterion 1 is fulfilled when:

- $\max[h_{1a}(q,s)] < \max[h_{1b}(q,s)] + 0.04$
- $\max[h_{1a}(q,s)] < 1$
- $\max[h_{1b}(q,s)] < 1.1$

### The 2<sup>nd</sup> criterion

This criterion has two possibilities of fulfillment:

- 1) 1<sup>st</sup> possibility to fulfill the criterion :
  - areas 2a and 2b could be fitted to parabola opens downward (it means that these areas have raised surface)
- 2) 2<sup>nd</sup> possibility to fulfill the criterion:
  - area 2a could not be fitted to parabola, but area 2b has raised surface
  - $\max[h_{1b}(q,s)] < 0.94$

### The 3<sup>rd</sup> criterion

The criterion 1 is fulfilled when:

- $\max[h_3(q,s)] < \max[h_{1a}(q,s)]$
- $\max[h_{1a}(q,s)] < 1.1$
- $\max[h_3(q,s)] < 1.23$

### The 4<sup>th</sup> criterion

The criterion includes information about the lowest value of  $h(q,s)$  in the whole Hurst surface and is fulfilled in situation when:

- $\min[h(q,s)] \in [0.4, 0.82]$
- $\min[h(q,s)] + 0.01 < \min[h_4(q,s)]$
- $\min[h_4(q,s)] > 0.5$

### The 5<sup>th</sup> criterion

The criterion correlates the highest values for two areas 5a and 5b and this criterion is fulfilled when:

- $\max[h_{5a}(q,s)] < \max[h_{5b}(q,s)]$
- $\max[h_{5b}(q,s)] - \max[h_{5a}(q,s)] < 0.5$

### The 6<sup>th</sup> criterion

The criterion includes 3 sub-criteria, which should be fulfilled:

- $\max[h_{6a}(q,s)] + 0.03 > \max[h_{6b}(q,s)]$
- $\max[h_{6a}(q,s)] > 0.8$
- $\max[h_{6b}(q,s)] > 0.5$

## 4.3. Additional criterion

We prepared also additional condition, which is the one of combination of general criteria, lets us to diagnose patients with atrial fibrillation. This combination includes 6 condition:  $\{1, 0, 0, 0, 1, 0\}$ , where “0” means that this criterion was unfulfilled, but “1” means that this criterion was positive. This means that only 1<sup>st</sup> and 5<sup>th</sup> criteria should be fulfilled.

This additional criteria leads to characteristic and highly repetitive multifractal pattern of heart rate variability for atrial fibrillation.

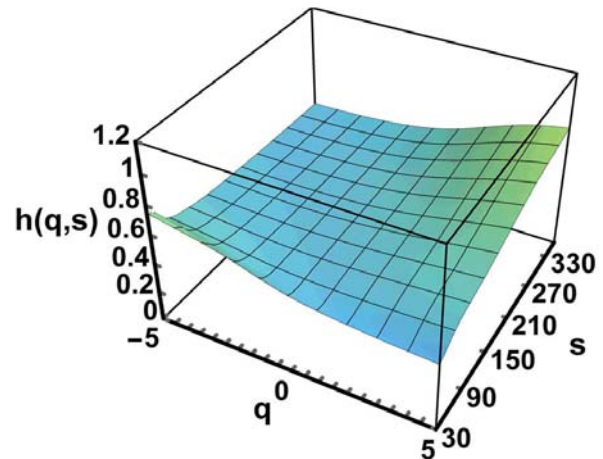


Fig. 2. Figure shows the mean Hurst surface for patients with atrial fibrillation.

The Fig. 2. shows that surface for atrial fibrillation, has raised area for high values of  $s$ , so for very low frequencies. Generally, the surface for AF is described as a ‘white noise’, so we guess that is very interesting result and addition the other standard methods are not able to describe these frequencies ranges. In future this result can allow us to interpret the multifractal physiological processes, which are not able to specify for standard methods of analysis.

## 4.4. Diagnostic test

We calculated also measures of diagnostic test in order to check reliability of applied method and diagnostic criteria - both general 6 criteria and additional criterion. We based on measures like: sensitivity (1), specificity (2), positive predictive value (PPV) (3), negative predictive value (NPV)(4) and accuracy (5) for every group, which is shown in tab. 3.

Tab. 3. Table shows the results of test according to criteria based on shape of the Hurst surface with measure of sensitivity (1), specificity (2), PPV (3), NPV (4) and accuracy (5).

Groups of patients	(1)	(2)	(3)	(4)	(5)
Coronary disease	0,68	0,74	0,80	0,60	0,70
Hypertrophic cardiomyopathy	0,47	0,74	0,63	0,60	0,61
Aortic valve stenosis	0,81	0,74	0,89	0,58	0,86
Atrial fibrillation	1,00	0,74	0,76	1,00	0,76
Congestive heart failure	0,94	0,74	0,62	0,97	0,80

We also calculated measures of diagnostic test for additional criterion detecting Multifractal pattern and distinguish patients with atrial fibrillation, what shows tab.4.

Tab. 4. Table shows the calculated measures of diagnostic test for patients with atrial fibrillation.

Groups of patients	(1)	(2)	(3)	(4)	(5)
Atrial fibrillation	0,84	0,99	0,96	0,98	0,98

## 5. Conclusion

These results shows that Multiscale Multifractal Analysis can be used as an effective screening examination method based on 6 general criteria. Additionally, another, additional condition allow also to classify subjects with atrial fibrillation. Very effectiveness of presented criterion is an evidence for existence of clear and highly repetitive HRV multifractal pattern for AF. This pattern shows also that atrial fibrillation is not a 'white noise' and has raised surface for very low frequencies. Because of this interesting feature can reflect a variety of important physiological processes. Unfortunately, at this stage of our research we are not able to specify them and this topic needs further study.

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