PVC Arrhythmia Decreases the Scaling Exponent: DFA As a Beneficial Biomedical Tool for Presymtomatic Diagnosis

Toru Yazawa and Tomoo Katsuyama

Abstract—**We made our own DFA (detrended fluctuation analysis) program. We applied it for checking characteristics for the heartbeat of various individuals. Healthy subjects showed a normal scaling exponent, which is near 1.0 (ranging 0.9 to 1.19 in our own temporary guideline). This is in agreement with the original report by Peng et al. published in 1990s. In the present study, we investigated the person who has an extra-systole heartbeat, which is so called as PVCs (premature ventricular contractions), and revealed that their arrhythmic heartbeat exhibited a low scaling exponent (around 0.7). Alternans, which is the heart beating in period-2 rhythms, exhibited a much low scaling exponent (around 0.6). We may conclude that if it would be possible to make a device that equips a DFA program, it might be useful to check the heart condition, and contribute not only in statistical physics but also in biomedical fields; especially as a device for health check, which is applicable for people who are spending an ordinary life, before they get seriously heart sick.**

Index Terms—**DFA, Heartbeat, PVC, Scaling Exponent, Time Series Analysis.**

I. Introduction

DFA (detrended fluctuation analysis) has been proposed as a method that is potentially useful to diagnose a heart condition by Peng et al. [1] in 1990s. However, it has not been appeared as a practical tool for the use in a bio-medical field. We have made our own DFA program (program made by Mr. K. Tanaka) [2]. We here demonstrate that our program can be useful to calculate the scaling exponent for persons, who have an extra-systolic heartbeat, for persons who have Alternans-heartbeats, and for other types of heartbeats, including normal, healthy hearts.

II. Method

A. Finger blood-pressure pulse

Heartbeats were recorded by a conventional electrophysiological method, either electrically (EKG) or mechanically in our series of studies. From human subjects we mostly used the finger pulse recording with a Piezo-crystal mechano-electric sensor, connected to a Power Lab System. (AD Instruments, Australia). All data were recorded at 1 KHz in rate of sampling.

B. DFA methods

We made our own programs for measuring beat-to-beat intervals (by Tanaka) and for calculating the approximate scaling exponent which is the DFA program (by Tanaka).

After recording EKG or finger pressure pulses, we first made the beat-to-beat interval time series. Then, we calculated the approximate scaling exponent from the time series data. For preparing figures in this report, we presented (1) heartbeat-data by plotting heart rates against time, which is the original data used for the DFA, (2) the approximate scaling exponents, which is the result of DFA, and (3) a graph. From the graph, one can read approximate a slope to which the exponent corresponds directly. As shown in the figures, beating hearts show a fluctuating pattern of intervals. One can recognize that we can hardly predict the scaling exponent by eye-observation of such time series data. Only a DFA program can do that. The scaling exponent reflects hidden information carried by quantitative measures in a dynamically changing interval of heartbeat and velocity of blood flow under the functional control of the autonomic nervous system. An EKG-chart data cannot tell us what the scaling exponent is. (Note: We are able to sense the value of an exponent with our eyes from an instant recording if we have hundreds of experiences to watch both, real fluctuation data and the DFA results.) The DFA methods have been documented [1], [3].

III. Results

A. Extra-systole

The subject, whose heart had an arrhythmia due to the ventricular extra-systole, exhibited an abnormal record such as shown in Fig. 1. This is so called as PVCs (premature ventricular contractions). We here show only one example, female age 58. We have more than 20 subjects who exhibit the ventricular extra-systole. All of them showed the same results; a lower exponent.

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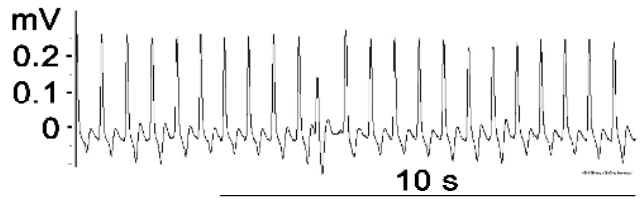

Fig. 1. Typical extra-systole pulse recorded from a finger by a piezo-crystal pulse-recording device (ADInstrument, Australira). Female 58. We consider a small beat is one heartbeat.

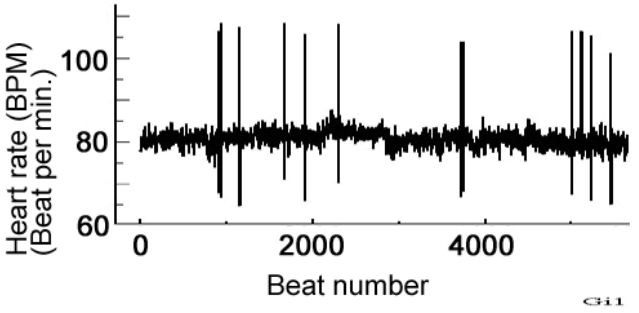

Fig. 2. Time series data of a long term recording. Twelve PVCs (premature ventricular contractions) are recorded. Female 58.

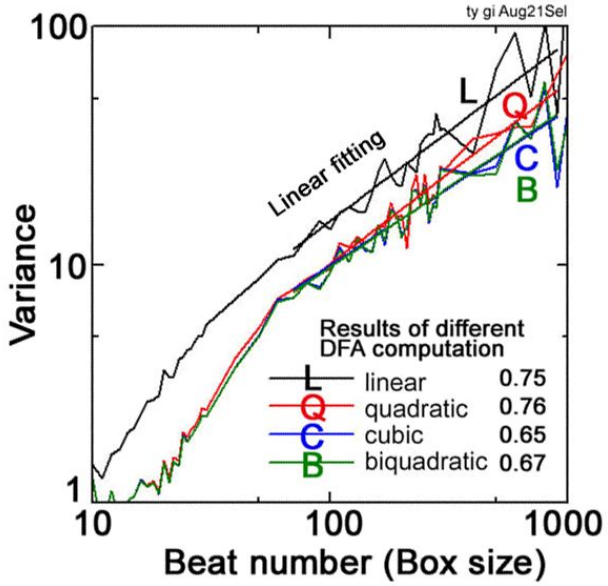

Fig. 3. An example DFA computation. The DFA at a final step needs to calculate the slope in the graph of Box-size vs. Variance. But in the mid-way of the DFA, the least-mean square methods were involved, with linear-, quadratic-, cubic-, and bi-quadratic-fitting methods (details are not shown here). This graph is the final step. This was made after a measurement of such a least-mean square fitting function under a various Box size. Those measurements were done from the interval time series data, which was converted from the original EKG data. When linear-, quadratic-, cubic-, and bi-quadratic fitting were performed, finally we obtain a steady result of DFA calculation (for example, there is no big difference between C and B in the figure) the result of B was determined as the scaling exponent. This means, an approximate scaling exponent was determined, and is way down below from the normal value (i.e., 1.0) in this figure. The scaling exponent for this heart was about 0.7. Female 58.

The ventricle extra-systole is: The ventricle muscle tried to generate its own rhythm before normal rhythmic discharges arrived to the ventricle. Therefore a lower/smaller pulse, comparing to a normal pulse, was generated (see a lower pulse in the figure). But this is considered by physicians as a not so serious problem of the heart, if this happens less frequently. Thus, it is considered as "benign" arrhythmia, though we cannot agree with the idea, because of DFA as shown below. If it may happen a lot, like more than 10 times per one minute, physicians may take great care of it finally.

As shown in Fig. 2, this person's extra-systole appeared less frequently; 13 times during the record, about 6,000 heartbeats, which is a recording period about for 1.5 hour. So, this person's heart is normal in terms of a physician's guideline.

However, our DFA revealed that the subject's heart shown in Figs. 1 and 2 exhibited low exponents, about 0.7 (Figs. 3 and 4). This (0.7) is not normal. The 'skipping heartbeat' makes the subject feel very uncomfortable. So the person is not feeling very well, even though the physician says it is okay. It might be not very good psychologically. Needless to say, ventricular tachycardia is a serious cause for a life threatening cardiac dysfunction. Importantly, this tachycardia is derived from repetitive, very fast beatings, in other words, a series of extra-systoles. Although the causes of the extra-systole have not been fully understood by now, we confirmed by DFA, that at least one reason of this person's extra-systole is due to the autonomic nervous system dysfunction. Because, this person's extra-systole totally disappeared after two years. When the person explained, that her (female 58) environments had improved, in other words, the psychological stress of life had been decreased during the year, the person's scaling exponent was pushed up as close as to 0.9 (data not shown).

B. Alternans with low exponent

We have examined DFA of an Alternans person (Fig. 5). The Alternans was documented in 1872 by Traube. However, the Alternans did not get particular attention from doctors until recently, indeed before Alternans was noticed as harbinger of death.

C. Extraordinary high exponent

We have met a person who had a high scaling exponent, which was 1.5. But the time series look like as being normal (see Figs. 6 and 9B). This man was tall but not fat, apparently healthy. However, his heart rate at rest was relatively high (70) comparing to that of normal man (60) (see Fig. 9A). We wondered why. We asked him and finally found out that he has two more brothers, who both had already died because of detail-unknown heart problem. This high exponent might be some sign for a certain heart or heart-control system problem, although we have no idea for the reason. We consider that cardiac physicians may identify the reason, why the family has a potential risk, if they study his family.

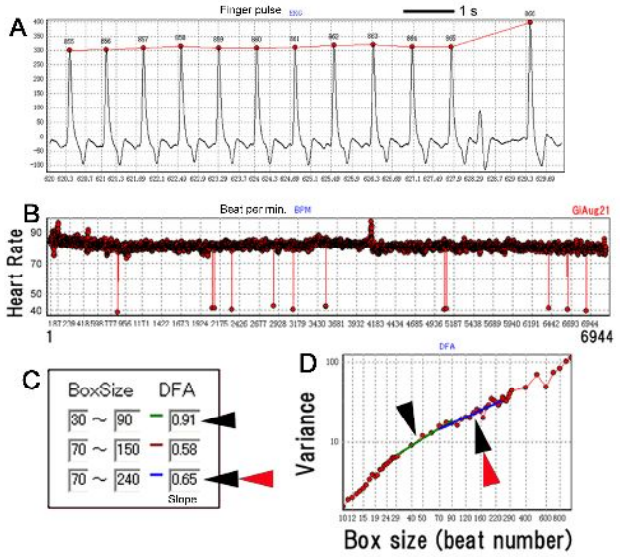

Fig. 4. Automatic computation of the DFA. The same subject shown in Figs. 1, 2 and 3. (A), partial recording of a finger-pulse test, which shows an extra-systole. (B), Time series for about 7000 heartbeats. Sporadically appearing extra-systoles can be seen by downward swings. (C), DFA results at various box size. (D), Slope shows the scaling exponents as indicated in C. Female 58.

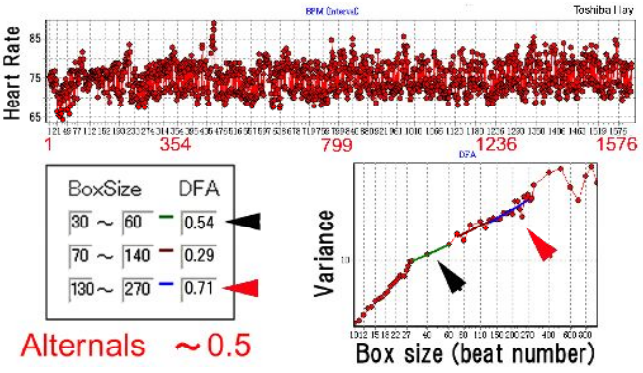

Fig. 5. Alternans shows very low scaling exponents. Heart rate trace clearly shows an abnormality of its rhythm. The scaling exponents were 0.5 to 0.7 at different Box size. Male 55. We have 4 human Alternans subjects and many model animals too. All of them exhibited a low scaling exponent like this example.

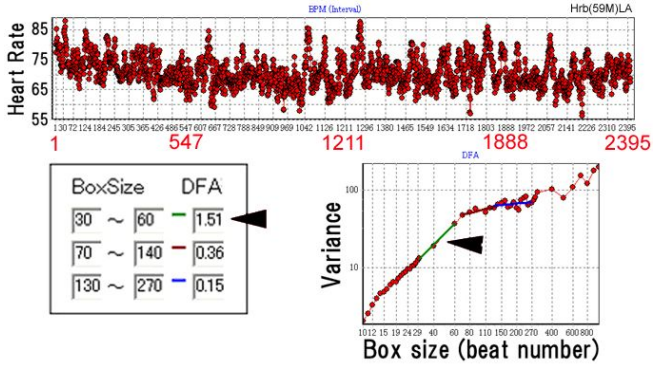

Fig. 6. A DFA example for a person who has a high scaling exponent. Male 59.

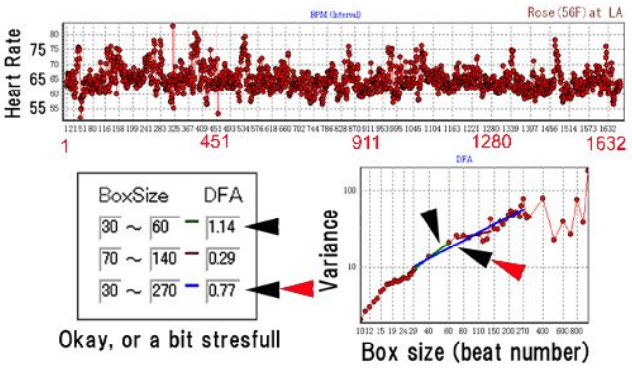

Fig. 7. A typical normal DFA for a middle aged subject. Female 56.

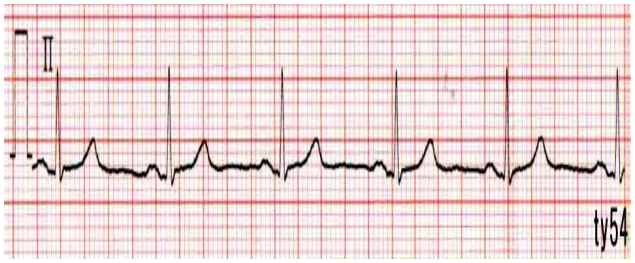

Fig. 8. EKG obtained at hospital health check. Male 54.

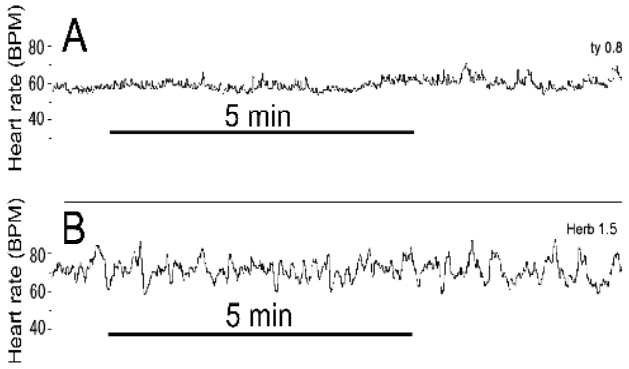

Fig. 9. Time series data of two persons. (A), Normal size healthy mail, age 55. We cannot find any abnormality from the heartbeat recording itself. This heartbeat looks normal, compared to the other person in Fig. 5, who has Alternans. This person's EKG during this health check (Fig. 8) showed no problem with his heart, but the DFA pointed out, that his scaling exponent was 0.8, slightly below than normal (1.0). The detailed examination of his pulse record finally revealed that he had abnormal heartbeats. (B), A tall, close to 2 m high, healthy mail, age 59. This time the series again looked kind of normal. But this person had a scaling exponent of 1.5, which is shown in Fig. 6. We find out that the person's family seems to have cardiac problems. Both A and B were recorded simultaneously at rest. Note that heart rate of B is greater than that of A in average, though B's body size is greater than A's (Generally, we notice, big body mass lowers heart rate).

D. Normal exponent

The DFA revealed that a typical person who ages normally, often shows a normal exponent or a little bit lower exponent (Fig. 7). As shown in the figure, the scaling exponents were unstable at a different box size. We would say that this person's heart could be normal, but having a little bit of a stressful life, because the DFA showed roughly 0.77 when measuring the entire range of the box size (see Fig. 7). If a person is in perfect health, the person would have a perfect exponent of 1.0 at this entire range of the Box size, instead of having the scaling exponent of 0.77 as shown in Fig. 7.

E. DFA is beneficial

Typical EKG chart is shown in Fig. 8. There are no Q-T elongation and no S-T elevation and so on. It looks normal. However, the DFA revealed, that his heart exhibits a low scaling exponent, 0.8 (see Fig. 9A). So we performed a detailed examination of his pulse record for a period of 60 min. And finally we discovered that he had an abnormal heartbeat, such as an extra-systole and even tachycardia too (data not shown).

IV. Discussion

To perform DFA we normally need a pretty long term recording of heartbeats [1]. On the other hand, for an ordinal EKG done for a hospital health check, it would take a very short period of time. Indeed, a typical EKG needs only 6 beats or so, as shown in Fig. 8. Therefore, EKG recordings at medical health check unfortunately are useless for the DFA due to the short period length of recording.

Other important recording condition is the rate of digital sampling. Our DFA method needs the heartbeat recording at 1 KHz, i.e., 1000 dot per second. This notion was derived from our own previous research. According to our own cardio-vascular experiments on crabs and lobsters and much older great heritages of the crustacean heart research [4] [5] (see also ref [12]), we have had experienced that cardio-regulatory nerve impulses exhibits fluctuation of about 1 millisecond in time scale [6] [7]. Since the autonomic nerve activities directly affect the fluctuation of the rate of heartbeat [8], we must observe the fluctuation of the heartbeat in the time scale of 1 millisecond at a lowest limit. Therefore, we considered that the heartbeat fluctuation must be observed with a time scale in millisecond order, although the size of data increases dramatically comparing to the way of ordinal EKG recording. This notion which is derived from our crustacean studies must be applicable to the human heart too, because life on earth uses identical DNA-genetic control systems as the conventional way in the development of structure and function of the cardio-vascular system [9] [10] [11]. Unfortunately, the conventional Holter EKG recording system has not equipped 1 millisecond resolution in time scale (about 4 – 8 millisecond). So, we needed to record human heartbeat by our own machine. This is why we preferred our own system to collect data instead of using the existing data base. Thus, we are always performing recording at a rate of 1 millisecond (1 KHz sampling) for the rate of data sampling.

Using the DFA, and using the principles of 1/f scaling in the dynamics of the cardio-vascular system [13], we have demonstrated the scaling exponents reflect the balance of the control system, that is, the autonomic nervous system. In other words, the DFA can determine whether the entire body system is functioning in sick or in healthy by the scaling exponent. If we notice that the scaling exponents are lower, we must assume that the subjects are not normal and the subjects might be exhibiting Alternans, skipping-beats, or other abnormal heartbeats.

Empirical evidences illustrate the dynamics of adaptive heart movement behavior in a range of multi-elementally actions in the heart and nerve cells. Those are including molecules contributing for heart muscle contraction, molecules for regulating ionic flow of the myocardium, molecules for generating pace-making signals for contraction, molecules for neuro-muscular transmission, and so on. We expect that future research will identify parameters that determine the interaction between a heart task (e.g., occurring rhythmically inside the heart) and control processes (e.g., occurring rhythmically in the brain). Moreover, we must consider the interaction between the heart and external factors in the environment (e.g., circadian rhythms) and biological, behavioral and medical factors (e.g., stress, fighting, and disease). However, we must pay attention to the fact that all of such elements are nonlinearly connected. That means that the best way to identify parameters is the way of complex dynamics analysis together with traditional physiological methods. Therefore, collaborating together of biology and physics is the outstanding solution in the future study.

We might conclude that the DFA has benefits. As a tool for diagnosing the heart condition, DFA can find out something more than those tests, which were not be able to be checked out by a simple EKG.

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