Brownian movement analyzed from psychophysiological measures associated with ischemic heart disease and Alzheimer’s disease

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Abstract. There are several coronary diseases that human beings can suffer from, which in themselves generate health deterioration and can lead to the development of other diseases that diminish the quality of life. Ischemic diseases are unique in that they are evidenced by blockages generated by the accumulation of fat that impedes circulation, triggering heart and brain-related problems. By means of fractional Brownian motion in relation to Hurst's parameter, an analysis of a data of 137 patients aged between 30 and 71 years, who present some type of ischemic disease such as mixed, restricted, effort angina and angina pectoris, is performed. The data used was European, which is found in the PhysioNet open-access medical research data repository, managed by the Massachusetts Institute of Technology Computational Physiology Laboratory. This data shows the Hurst coefficient calculations associated with each type of ischemic heart disease.

1. Introduction
Alzheimer’s disease is a chronic degenerative disease that affects the brain progressively causing neuroanatomical changes [1] and is one of the most prevalent dementias in older adults, and is characterized as the loss of cognitive functions and memory, which causes difficulties in the development of daily life [2]. Additionally, it is estimated that by 2030 a total of 82 million people will be diagnosed with dementia and by 2050 an estimated 152 million will be reported, of which Alzheimer’s disease has a prevalence between 50% and 60% of cases of dementia [3].

The risk factors associated with Alzheimer's disease and its high prevalence are found in clinical, family, and external aspects, which have shown an incidence in people with a diagnosis of Alzheimer’s disease [4], as well as those based on the genetic load of each person that may be active and cause the presence of Alzheimer’s disease [5]. Thus, these factors are under scientific study in order to understand Alzheimer’s disease; however, the factor related to cardiovascular diseases is an aspect of study, since these diseases prevent the circulation from flowing properly and in some cases prevent blood supply to the brain, however, these diseases could be associated with external factors such as smoking or clinical factors such as diabetes, blood or circulation diseases, which cause damage to other organs of the body [6].

Therefore, Pérez and Soto define cardiovascular diseases as a group of disorders caused in the heart and blood vessels, which, in recent times, have become a public health problem due to their high prevalence, thus, being one of the main causes of death around the world [7]. The World Health Organization (WHO) classifies these diseases into a group of 8 types, which are: arterial hypertension,
coronary heart disease, cerebrovascular disease, peripheral vascular disease, heart failure, rheumatic heart disease, congenital heart disease and cardiomyopathies [8].

Likewise, researchers Sánchez, et al., mention that heart attacks are derived from acute phenomena that originate through obstructions that impede blood flow to the heart or brain, the most frequent cause being the formation of fatty deposits on the walls of blood vessels [9]. Similarly, the WHO mentions that these diseases usually have their origin in the combination of a group of risk factors, such as diabetes, obesity, smoking, physical inactivity, harmful alcohol consumption, arterial hypertension, and hyperlipidemia [10].

One of the most recent investigations, conducted by Mejía, Cediel and García, shows that one of the most effective instruments for physiological recording is the PowerLab PL 3508 - 8/35 (ADInstruments®), which provides records of cardiac activity and electrical conductance of the skin, with disposable surface electrodes, thus obtaining indicators of heart rate variability. Likewise, for skin electrical conductance, this instrument requires two electrodes placed on the middle phalanges of the index and middle fingers of the non-dominant hand. Additionally, a mark button is used, which is manipulated by one of the evaluators in charge of the process, to generate precise marks in the physiological recordings associated with the presentation of visual stimuli; it should be noted that the sampling frequency for the recording of all signals corresponds to 400 Hz [11].

In addition to the aforementioned, research that has focused on the approach to heart rate, together with fractal geometry, affirms that the fractal dimension is a method that is capable of taking into account the complexity of the measurements taken by the electrocardiogram, identifying the exact location of the arrhythmias, taking into account that the performance of this method is measured by sensitivity and specificity indexes, thus achieving an accuracy of 98.83% in its analysis procedure [12-15].

It is of great importance to address dementias as a public health priority, since with the passage of time its prevalence is increasing becoming one of the most common and silent diseases of the XXI century, since it causes social and public health problems, due to the few protocols that are established [16]. Similarly, the WHO states that dementia is a public health problem that should be addressed as a priority worldwide since each year about 10 million new cases are being registered [3]. Because of this, it is essential to advance in research aspects focused on an adequate diagnosis that provides an appropriate approach [17].

The aim of the present work is to analyze the electrocardiographic psychophysiological signals in patients with cardiac diseases, particularly those related to ischemic heart disease, taken from the European database in the PhysioNet open-access medical research data repository, managed by the Laboratory for Computational Physiology (LCP), Massachusetts Institute of Technology (MIT). To analyze the data of the electrocardiograms, the rescaled range method will be used in this work, with which it is possible to calculate the Hurst coefficient directly related to the fractional Brownian motion (FBM) and thus, be able to observe the persistence of the data, analyzed as a signal.

Heart diseases also known as ischemic diseases are conditions that cause damage to the heart or blood vessels by blockages or narrowing caused by accumulation of fat that hardens and prevents proper blood supply to organs and tissues [18] Now well within the most common heart disease is angina pectoris, which corresponds to a pain or pressure located in the central chest area, caused by lack of blood in the heart muscle, however the pain can move to areas of the arms, neck, face, back or shoulders [19].

Similarly, within the classification of angina there is mixed angina that presents episodes caused by increased demand for oxygen supply, where it is caused by excessive demand on the myocardium, causing a secondary angina [20]. However, there are other types of anginas that can appear at rest or with exertion, as is the case of rest angina, which tends to appear with minimal exertion before an activity or at rest, causing chest pain, spasms in the vessels [21]. But there is also exertional angina in which the body reacts to the excessive demand of activity as in the case of physical exercise that generates a lack of oxygen to the myocardium and therefore anginal pain [22].

The purpose of this research is to know how the Brownian movement and the Hurst coefficient can contribute to the characterization of cardiovascular diseases in order to generate early diagnoses that allow the prevention of other associated diseases.
2. Methodology
The present study presents a quantitative approach with a non-experimental cross-sectional design and descriptive scope. The records of 137 patients who underwent ambulatory electrocardiogram recordings with 48 of 90 complete recordings were taken from the European database in the PhysioNet repository. Two signals were taken, each sampled at 250 samples per minute with 12-bit resolution over a nominal input range of 20 millivolts. According to PhysioNet, the sample values were rescaled after digitization with reference to the calibration signals in the original analog recordings in order to obtain a uniform scale of 200 units per millivolt for all signals [23]. The type of ischemic heart disease analyzed were resting angina, effort angina, mixed angina, and angina pectoris. Angina is a type of chest pain caused by reduced blood flow to the heart.

The PhysioNet data series can be analyzed using FBM, because it is a physical method used by R Brown in 1821 in the study of the fertilization process of flowers, in which he observed the irregular oscillatory motion suspended in a fluid of pollen particles. According to Einstein, Brownian motion is described by the probability \( p(r, t) \) of finding a particle at position \( r \) at time \( t \), which satisfies the macroscopic diffusion equation [24].

Nowadays, beyond the study of the dynamics of a particle in a fluid, Brownian motion has a very wide range of different applications in areas such as hydrodynamics, polymer dynamics, seismology for vibration analysis, generation of pseudorandom sequences, among others [24]. The FBM is characterized through a parameter known as the Hurst coefficient (H). A FBM with Hurst parameter \( H > 1/2 \) is called a persistent process, i.e., increments of this process are positively correlated. In contrast, the increments of a FBM with \( H < 1/2 \) constitute what is called an antipersistent process, the increments being negatively correlated. For \( H = 1/2 \), an FBM corresponds to a Brownian motion that has independent increments [25].

To determine the value of H specifically, a partition of the time series is performed in subgroups, with each of these subgroups the standard deviation and the rescaled range is calculated, which is the result of the difference between the maximum value and the minimum value of cumulative deviations. Next, a linear regression is performed between the values of the natural logarithm (\( \ln(S_i) \)) of the rescaled range \( R_i \) and the standard deviation \( S_i \) of the data, with \( i \in \{1,2,3, ..., k \} \) and \( k \) is the number of partitions performed, and the natural logarithm of the quotient between the recessed range \( R_i \) and the standard deviation \( S_i \) of the data

\[
\ln(R_i/S_i), \text{ with } i \in \{1,2,3, ..., k \}.
\]

The following is the method known as the rescaled range, symbolized by the expression \((R/S)_M\), of the time series described in [26] under consideration \( X: \{x_i\} \) is composed by N values. The \((R/S)_M\) statistics follow the power law described in Equation (1), in which R corresponds to the rescaled range, S is the standard deviation of the data, M is the corresponding partition size, a is a constant and H is the Hurst coefficient.

\[
(R/S)_M = aM^H. \tag{1}
\]

Herein, a is a constant and H is the Hurst exponent which represents a fractal measure of long-range correlations in the analyzed released.

3. Results
The Hurts coefficient was found for each of the electrocardiographic series of the 137 patients; of these 137 patients, 131 (95.62%) were men and 6 (4.37%) were women. The maximum age of the men was 73 and the minimum 30 years, while in women the maximum age was 71 and the minimum 70 years. Table 1 shows the average Hurst coefficient of the records collected in PhysioNet for four types of ischemic heart disease present in the European data; due to the few data found for the female gender, the Hurst averages are highly subject to the particularities of the three patients analyzed in Resting angina and Angina pectoris disease.

Regarding the male gender, there are 48 patients with presence of Mixed angina, with an average age of 49.37±8.71 years and an average of 0.952±0.461 in their H coefficient with respect to the
electrocardiographic records, which indicates a high dispersion and volatility of the data and therefore difficult characterization of the disease in relation to the H coefficient. For Resting angina disease, the 53 patients were analyzed with an average age of 52.11±7.39 years and an average of 1.032±0.522 in their H coefficient with respect to the records obtained. Regarding Angina pectoris, 6 patients were analyzed with mean age of 64±9.85 years and an average of 1.423±0.365 in the records in relation to the H coefficient, and finally for Effort angina 24 patients were analyzed with mean age of 57±7.76 years and an average H coefficient of 0.671±0.62 in the records.

Table 2 shows the relationship between age and average Hurst coefficient associated with the records of patients with the presence of mixed angina, resting angina and effort angina in age intervals by decades. Zero was recorded in certain age intervals because there were no patients with these ages. Angina pectoris disease has not been included because there are few data and per interval the average would be conditioned to the value of only two or three patients.

**Table 1.** Coefficient H results for four types of ischemic heart disease, total patients, and ages.

| Gender | Type of heart disease | Total patient | Maximum age | Minimum age | H average |
|--------|-----------------------|---------------|-------------|-------------|-----------|
| Female | Mixed angina          | 0             | 0           | 0           | 0.000     |
|        | Resting angina        | 3             | 70          | 70          | 0.011     |
|        | Angina pectoris       | 3             | 71          | 71          | 1.050     |
|        | Effort angina         | 0             | 0           | 0           | 0.000     |
| Male   | Mixed angina          | 48            | 62          | 30          | 0.952     |
|        | Resting angina        | 53            | 71          | 40          | 1.032     |
|        | Angina pectoris       | 6             | 73          | 55          | 1.424     |
|        | Effort angina         | 24            | 66          | 46          | 0.672     |

**Table 2.** Mean H for mixed, resting and effort angina in age classification of patients in intervals.

| Ages by decades | Mixed angina | Resting angina | Effort angina |
|-----------------|--------------|----------------|---------------|
| 30-39           | 1.099        | 0.000          | 0.000         |
| 40-49           | 0.848        | 1.049          | 0.769         |
| 50-59           | 1.070        | 1.239          | 0.268         |
| 60-69           | 1.026        | 0.575          | 0.958         |
| 69-71           | 0.000        | 1.582          | 0.000         |

4. Conclusions

In the search for a relationship between the Hurst coefficient and some coronary diseases, it has become evident, after analysis of the database provided by PhysioNet, that there is great volatility and dispersion in the patient records, which requires the researchers to analyze the data in relation to the time and conditions of the registry. Due to the desire to find a relationship between the Hurst coefficient and the electrocardiographic measurements, it is necessary to structure a protocol that guarantees the homogeneity of the registry, as well as linking a more equitable number of people by gender and age.

From the study carried out by Brown on the analysis of the irregular oscillatory movement and the contribution of Einstein on the condition of probability described in the Brownian movement, the contribution of physics in the various fields is evident, in particular for this work in physics medical. By means of the MBF and the H parameter it is possible to observe persistence in any series of data, then the relationship of this coefficient should be aligned to the patient's own characteristics according to their electrocardiographic measurements, since, under generally daily conditions in them, it is possible to establish future behaviors in relation to the evolution of the disease they suffer.

The H coefficient is not a value that characterizes the diseases, but it can be linked as a parameter that can contribute to decision-making on the treatment of diseases, previously based on properly applied protocols.
Acknowledgments
The authors of this work thank the Laboratory for Computational Physiology, Massachusetts Institute of Technology, United States of Americas, for generating databases with electrocardiographic records of some coronary diseases, which allow us to conduct research with the objective of contributing from mathematics and physics in health areas. We also thank the Universidad Pontificia Bolivariana, Bucaramanga, Colombia, and the members of the project Creation and implementation of a multicomponent diagnostic evaluation protocol in patients with major neurocognitive disorder (TNC) Alzheimer’s type: a multidisciplinary study through the use of fractal geometry in brain images.

References
[1] Bohórquez A 2019 Guía Alzheimer 2019, Comunicación y Conducta, Consejos para Familiares (Madrid: EULEN Servicios Sociosanitarios)
[2] World Health Organization (WHO) 2013 Demencia: una Prioridad de Salud Pública (Washington: World Health Organization)
[3] Alzheimer’s Disease International 2018 Informe Mundial Sobre el Alzheimer 2018 La Investigación de Vanguardia Sobre la Demencia: Nuevas Fronteras (Londres: Alzheimer’s Disease International)
[4] Armenteros F 2017 Revista Cubana de Enfermería 33(2) 159
[5] Campdelacreu J 2014 Neurologia 29(9) 541
[6] National Institute of Health (NIH) 2019 Las Demencias Esperanza en la Investigación (México: National Institute of Health)
[7] Pérez Y, Soto A 2017 Factores de Riesgo de las Enfermedades Cardiovasculares (Madrid: Universidad Complutense de Madrid)
[8] Baumgartner H, et al. 2021 Revista Española de Cardiología 74(5) 436:e1
[9] Sánchez A, et al. 2016 Revista Mexicana de Cardiología 27(3) 98
[10] Organización Panamericana de la Salud 2010 Prevención de las Enfermedades Cardiovasculares. Directrices para la Evaluación y el Manejo del Riesgo Cardiovascular (Washington: Organización Panamericana de la Salud)
[11] Mejía M, et al. 2019 Respuestas Psicofisiológicas 57 100
[12] Gallegos G, Huamani P 2019 Advances in Science, Technology and Engineering Systems Journal 4(5) 143
[13] Kiani K, Maghsoudi F 2019 Journal of Bioinformatics and Systems Biology 2(3) 53
[14] Rodríguez I, Jattin J, Bautista J 2019 Medicina Interna de México 35(4) 492
[15] Rodríguez I, et al. 2021 Medicina Interna de México 37(4) 475
[16] Ministerio de Sanidad, Consumo y Bienestar Social 2019 Plan Integral de Alzheimer y Otras Demencias (2019-2023) (España: Ministerio de Sanidad, Consumo y Bienestar Social)
[17] Ministerio de Salud Gobierno de Chile 2017 Plan Nacional de Demencia 2017 (Chile: Ministerio de Salud)
[18] Pérez C 2020 Proyecto de Intervención Educativa: Autocuidado en Pacientes con Enfermedades Cardiovasculares (Santa Cruz de Tenerife: Universidad de La Laguna)
[19] Bonet R, Garrote A 2008 OffArm: Farmacia y Sociedad 27(11) 52
[20] Maseri A, et al. 1985 The American Journal of Cardiology 56(9) E30
[21] Sellén J, et al. 2010 Revista Cubana de Investigaciones Biomédicas 29(2) 274
[22] Blasco A, et al. 2003 Información Terapéutica del Sistema Nacional de Salud 27(2) 33
[23] Goldberger A, et al. 2000 Circulation 101(23) e215
[24] Giraldi H, Campos E 2015 Boletín de la Sociedad Mexicana de Física 29(2) 103
[25] Yerlikaya F, et al. 2014 Journal of Computational and Applied Mathematics 259 843
[26] Rodríguez E 2012 Cuadernos Latinoamericanos de Administración 8(14) 41