Heart Rate Variability Analysis in Time and Frequency Domains

Undergraduate Project

An Undergraduate Project Submitted in Partial Fulfillment of the Requirements for the Degree of Bachelor in Medicine at University of Diyala/College of Medicine

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2022-2023

ABSTRACT OF PROJECT

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Indicators of the ability of the cardiovascular system's autonomic regulation, such as heart rate variability HRV, are crucial for assessing the cardiovascular system's functional status as well as various physiological and clinical conditions. There are many different ways to analyze HRV, including time- and frequency-domain analyses, non-linear analyses, and the analysis of RR intervals from the beats produced by the sinoatrial node. A variety of cardiovascular diseases, including arrhythmia, can be assessed using HRV. In this study, data from 13 participants was gathered and assembled in an exclusive cardiology clinic in the Iraqi province of Diyala. A Holter monitor had to be worn by each participant for the whole 24-hour recording period. After 24 hours of recording, the Holter was removed from the individual, and the data was later retrieved and archived for examination. Three groups of data were created from the data: controls, atrial flutter (AF), and ventricular ectopic (Vent. Ectopic). Wilcoxon signed-rank test was used to compare the HRV among the three groups.

According to our results, there are differences in the number of beats in the control, atrial flutter, and ventricular ectopic groups. In comparison to controls and patients with ventricular ectopic patients, the number of abnormal beats was substantially higher in AF patients. Comparing the ventricular ectopic group to the controls, the number was lower. When compared to the control and ventricular ectopic groups, AF patients had a considerably larger number of abnormal permillages. The time domain parameters of HRV: SDNN, SDANN, rMSSD, PNN50, and CV were significantly higher in patients with AF than in controls and ventricular ectopic patients. Similarly, the frequency domain parameters: power, LF, ULF, VLF, and HF were significantly higher in AF group.

According to our findings, HRV factors may make it possible to utilize the HRV index as a predictor of some heart illnesses. The results don't match what we found in the literature, which may be due to the HRV analysis's study population and various ECG recording timings. In order to validate our findings based on additional data analysis in both the temporal and frequency domains, we intend to gather more data and include some other factors such as age and gender.

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Introduction

The almost undetectable nature of data collection makes non-invasive techniques the preferred mode of inquiry for analyzing the functional activity of the human cardiovascular system nowadays. Today, it is more important than ever to apply analytical techniques, technological tools, and diagnostic techniques that can extract the most data possible about a person's health while having the least negative effects on that person's physical structure [1]. The greatest techniques for capturing the electrical activity of the heart and providing information to measure the intervals between heartbeats are electrocardiography (ECG) and Holter monitoring. The accuracy of determining cardiac parameters is significantly influenced by the data recording system's sample rate. Electrocardiographic data can be employed in systems for analysis, diagnosis, therapy, and recognition because they are highly particular to each individual [1]–[3].The number of beats per minute is referred to as heart rate. Heart rate variability (HRV) is a variation in the space between subsequent heartbeats. Heart-brain connections, dynamic non-linear autonomic nervous system (ANS), and ANS activities all contribute to the generation of HRV, which measures neurocardiac function. In order to assist us in adjusting to environmental and psychological difficulties, HRV is an emergent trait of interdependent regulatory systems that function on various time scales. The regulation of autonomic balance, blood pressure (BP), gas exchange, gut, heart, and vascular tone—the size of the blood vessels that control BP—are all reflected in HR. Heart rate variability (HRV) is regarded as a physiological phenomenon through which the time between two succeeding heartbeats can spontaneously fluctuate even in resting circumstances[4], [5] [6]. When studying disorders with pathology in the cardiovascular, nervous, endocrine, and other systems, heart rate variability is a very effective and crucial tool. This approach is used to describe the autonomic dysfunctions of patients, keep track of the autonomic function of the nervous system's normal oscillations, evaluate the effects of various therapies on the human body, and predict the progression of a disease. For conditions including hypertension, thyroid pathology, neurological problems, brain tumors, multiple sclerosis, and many other diseases, heart rate variability characteristics are crucial for diagnosis [1]. Reduced HRV has been linked to a worsening prognosis in the context of heart failure as well as an increased risk of dysrhythmias and sudden cardiac death in the recent post-heart attack period. Heart rhythm irregularities can be caused by underlying coronary artery disease, reentry phenomena (misdirected electrical flow), cardiotoxin exposure, ectopic foci (regions of the heart that send out improper electrical signals), drug side effects, and other factors. In addition to diminished HRV, factors that may encourage cardiac arrhythmias

include the use of stimulants or alcohol, smoking, the sympathetic nervous system being overworked as a result of psychological stress, and the use of specific drugs.

In this project, we are going to explain the history of HRV, its analysis and measurements in both time and frequency domains. Then, we will discuss the results we have got from our analysis of the data that we have collected and analyzed, and finish up the project with the main conclusions and possible future directions of the project.

The History of Heart Rate Variability

In 1965, Hon and Lee discovered that changes in the fetal heart's beat-to-beat variability were associated with fetal distress. This discovery led to the development of heart rate variability (HRV). Ewing et al. employed short-term HRV measurements as a sign of diabetic autonomic neuropathy in the 1970s. Wolf et al. demonstrated in 1977 that individuals with decreased HRV after a myocardial infarction had an increased mortality rate, and investigations have since proved that HRV is an accurate predictor of mortality after myocardial infarction (MI). HRV decreases 2 to 3 days after a MI, starts to recover after a few weeks, and reaches its peak but is not entirely recovered after 6 to 12 months. People with a persistently low HRV have a nearly three-fold higher mortality rate than those with a normal HRV[7], [8]. In the past ten years, people with a variety of cardiovascular diseases have been reported to have changes in HRV. Congestive heart failure is related with decreased vagal but retained sympathetic activity, increased LFP (one of HRV measures) and reduced circadian rhythms are seen in individuals with hypertension, and patients with denervated transplanted hearts have 90% lower heart rate variability (HRV). Reduced HF and LF (HRV measures) power each function as independent predictors of later sudden death after surviving cardiac arrest. At risk-stratifying patients, HF power reduction seems to be the better option [7][9].

Measurement of Heart Rate Variability

Time domain indices, geometric techniques, and components of the frequency domain are the common metrics used in the investigation of HRV. HRV measurements are typically made using 24-hour Holter recordings (long-term recordings) or shorter periods of time (0.5–5 minutes, or short-term recordings). Whether long or short-term recordings are used depends on the kind of investigation that needs to be conducted[10]. In this project, we focus on time and frequency domain analyses. Thus; only these two methods will be explained in details here.

Time Domain Analysis: Time domain analysis calculates the intervals between successive normal cardiac cycles or the variations in heart rate across time. The normal RR intervals (NN intervals), caused by sinus depolarization, or the instantaneous heart rate are then measured using a continuous ECG recording (Holter), often of 24 hours. The calculated time domain variables can be straightforward, like the mean heart rate, the mean RR interval, the difference between the longest and shortest RR interval, and the difference between the heart rate at night and during the day, or they can be more complex based on statistical measurements. These statistical time domain indices fall into two categories: instantaneous HR and intervals obtained from the differences between neighboring NN intervals, or beat-to-beat intervals or variables directly derived from the intervals themselves, such as the instantaneous HR. The most popular parameters in the time domain are listed in Table 1. SDNN, SDANN, and SD are the parameters in the first category, whereas RMSSD and pNN50 are the parameters in the second group [1], [4], [10]–[12]

The SDNN is a comprehensive measure of HRV that takes into account all the long-term factors including circadian rhythms that affect the variability during the recording period. An indicator of variability for the average of 5-minute intervals during a 24-hour period is SDANN. As a result, it offers long-term information. It is a sensitive indicator of low frequencies, such as circadian rhythm, positional changes, and physical activity. In general, SD is thought to represent how HRV varies throughout the day and night. Based on interval differences, RMSSD and pNN50 are the most often used parameters. These measurements are independent of day/night variations and correspond to short-term HRV alterations. These represent changes in autonomic tone, which are mostly vagally mediated. For clinical application, RMSSD ought to be chosen over pNN50 since it appears to be more stable (Sztajzel, 2004; Shaffer and Ginsberg, 2017; Georgieva-Tsaneva, 2019; Li, Rüdiger and Ziemssen, 2019).

Table 1: Time Domain Parameters

Variable	Units	Description
SDNN	ms	Standard deviation of all NN intervals
SDANN	ms	Standard deviation of the averages of NN intervals in all 5-minute segments of the entire recording
SD (or SDSD)	ms	Standard deviation of differences between adjacent NN intervals
RMSSD	ms	Square root of the mean of the sum of the squares of differences between adjacent NN interval
pnn50	%	Percent of difference between adjacent NN intervals that are greater than 50 ms

Frequency Domain Analysis: The periodic oscillations of the heart rate signal that are broken down into different frequencies and amplitudes are described by frequency domain (power spectral density) analysis, which also provides information on how much of their relative intensity (also known as variance or power) is present in the heart's sinus rhythm. Similar to the electroencephalogram, we can divide HRV into its component ULF, VLF, LF, and HF rhythms that function within various frequency ranges using Fast Fourier Transformation (FFT) or autoregressive (AR) modeling. This is comparable to the way a prism refracts light into its individual wavelengths [1], [4], [6], [10]–[12]. Table (2) shows the details of frequency domain parameters.

Table 2: Frequency Domain Parameters

Variable	Units	Description	Frequency range
Total power	ms^2	variance of all NN intervals	<0.4 Hz
ULF	ms^2	ultra low frequency	<0.003 Hz
VLF	ms^2	very low frequency	<0.003–0.04 Hz
LF	ms^2	low frequency power	0.04–0.15 Hz
HF	ms^2	high frequency power	0.15–0.4 Hz
LF/HF ratio		ratio of low-high frequency power	

Methods

Subjects and Data Collection

The purpose of this study was to investigate the heart rate variability in time and frequency domains in patients with atrial flutter and ventricular ectopic. Data from 13 subjects was collected and compiled in a private medical cardiac facility in Diyala province in Iraq from July 2022 to December 2022. Each patient underwent a clinical evaluation that included taking their medical history, having a physical exam, checking their blood pressure, their height, weight, and any medication history. The investigation adhered to the ethical standards defined by the scientific committee of the institute of medicine faculty/ university of Diyala/Iraq.

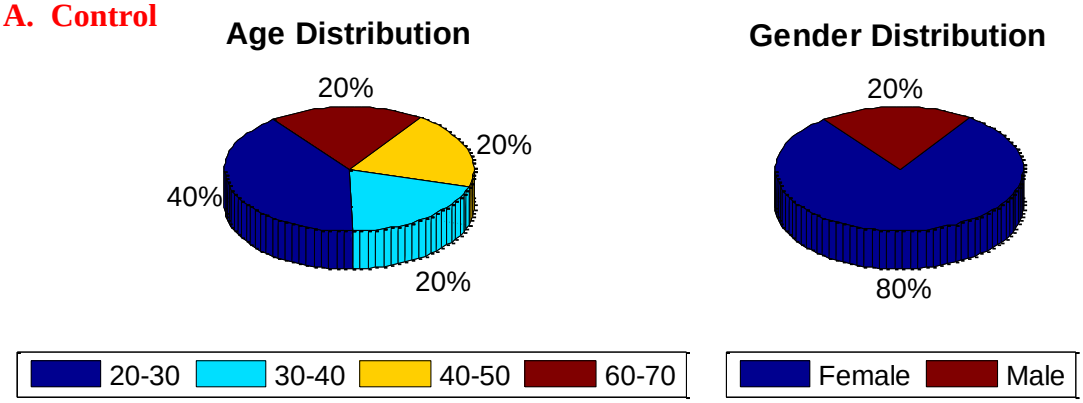
Each participant was required to wear a Holter monitor during the whole 24-hour recording period. A Contec TLC6000 Holter monitoring device, which was implanted under the participant's chest for 24 hours in accordance with the instructions in the user handbook provided by the manufacturer, was used to record and gather the data. The participants were instructed to carry on with their regular routines while also engaging in some workouts catered to their level of competence. The Holter was withdrawn from the subject after 24 hours of recording, and the data was then retrieved and archived for analysis.

The data was classified into three groups: controls, atrial flutter (AF), and ventricular ectopic (Vent. Ectopic). The first category (control) had data from normal subjects, the second category (AF) had 5 patients and Vent. Ectopic group had data from three subjects only. The distribution of data (age and gender) in each group is depicted in Figures 1 (A, B, and C).

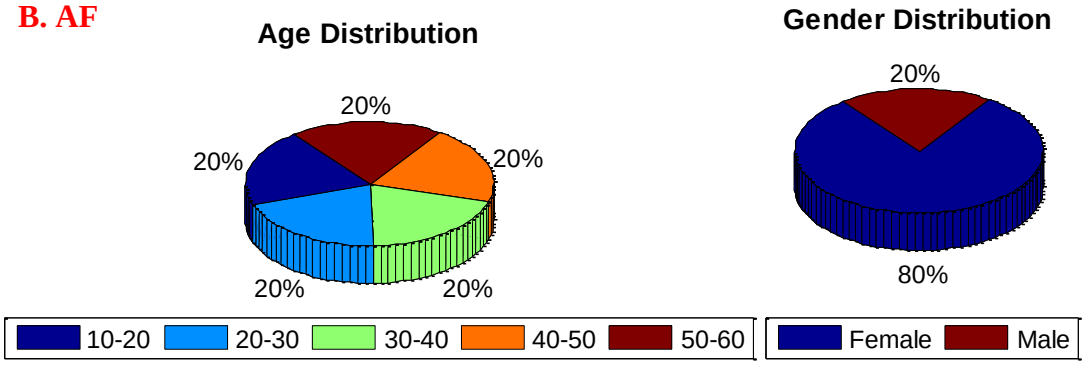
Statistical Analysis

Different parameters of heart rate variability in time domain (SDNN, SDANN, PP50, rMSSD, and CV) and frequency domain (Power, ULF, VLF, LF, and HF) were compared among the three groups using Wilcoxon signed-rank test. Statistical significance was defined as a *p*-value of less than 0.05. All data analysis was done using MATLAB package (2015a).

A. Control



B. AF



C. Vent. Ectopic

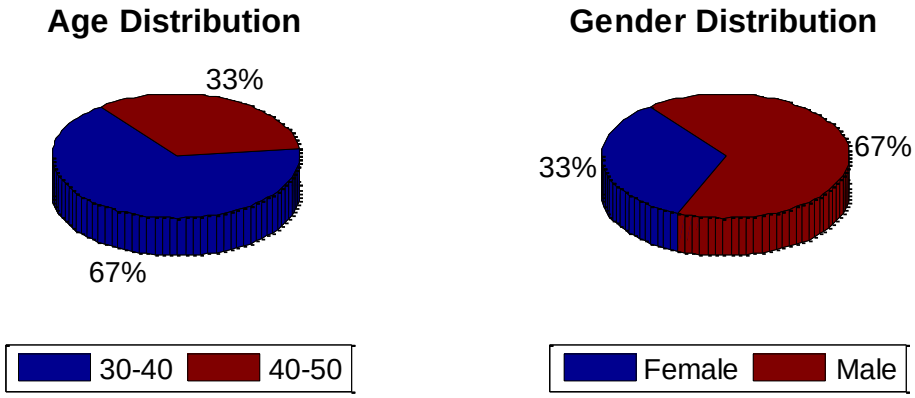


Figure 1: Age and gender distribution of the control, Atrial flutter (AF), and ventricular ectopic (Vent. Ectopic) groups. Each group did not have a decent mix of ages which made it difficult in determining the age and gender impact on heart rate variability.

Results

Heart Rate and Beats Number Changes among Control, Atrial Flutter, and Ventricular Ectopic Groups

Statistical analysis was conducted using the signed rank Wilcoxon test to compare the average heart rates of the three groups. Our findings indicated that the heart rates of the three groups did not differ significantly, while the atrial flutter patients' heart rates were lower than those of the ventricular ectopic beats group and the controls. The overall number of beats reduces as we move from the control group to the AF and Ventricular ectopic groups. In ventricular ectopic patients as compared to those with AF and normal, the decline was significant (p-value 0.05). Regarding the number of abnormal beats, it was significantly higher in AF patients than controls and ventricular ectopic patients. The number was less in ventricular ectopic group comparing to the controls. The number of abnormal permillage was significantly higher in AF patients compared to the control and ventricular ectopic groups. No difference has been observed in the number of abnormal permillage between the control and ventricular ectopic groups. Figure 2 illustrates how the three groups differed in terms of heart rate, total number of beats, abnormal beats, and abnormal permillage.

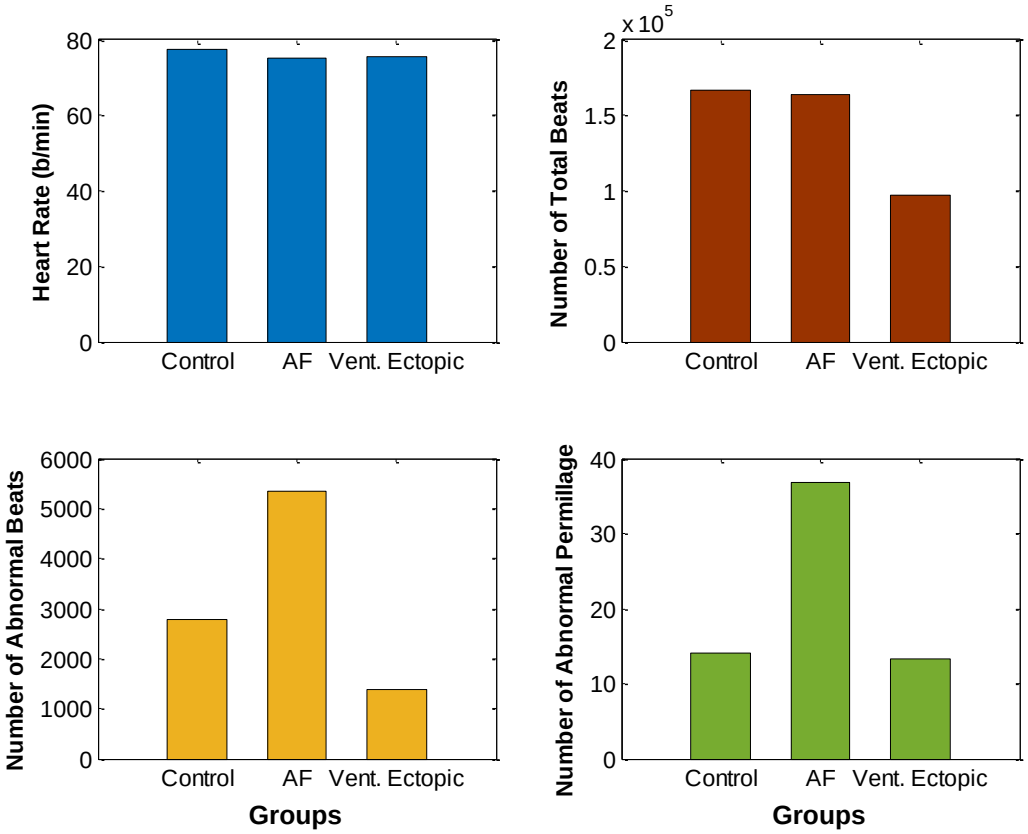


Figure 2: Changes in the heart rate, total number of beats, abnormal beats, and abnormal permillage among control, atrial flutter, and ventricular ectopic groups.

Heart Rate Variability in Time Domain

After examining the variations in heart rate, we looked into the variations in the time domain parameters that might be seen across the three groups. The time-domain HRV (TDH) reflects autonomic homeostasis, which is crucial for assessing the mental and metabolic health of an individual. The standard deviation of the NN intervals (SDNN), also known as the standard deviation of normal-to-normal R-R intervals, is the parameter with the simplest calculation. As shown in figure 3, our research revealed that SDNN is highest in atrial flutter patients and lowest in the control group. The SDNN levels between the control and ventricular ectopic groups did not clearly differ. Our statistical analysis showed that there is a significant increase in SDNN in atrial flutter patient (P-value <0.05, signed- ranked test) comparing to the controls. SDANN, which reflects the standard deviation of the duration of average NN intervals every 5 minutes from the record, showed the same trend as SDNN. It significantly increased in AF patients with no clear difference between the control and ventricular ectopic groups, see figure 3. One more time the same trend has been shown in the values of: rMSDD (The root mean square of successive differences between normal heartbeats), PNN50 (The percentage of adjacent NN intervals that differ from each other by more than 50 ms), and CV (coefficient of variation). The three primary HRV measures, SDNN, RMSSD, and PNN50, reflect the parasympathetic compensation (ideal) in response to sympathetic stress at the desired level to preserve physiological equilibrium. As a result, these are also signs of good mental, metabolic, circadian, and intestinal health. rMSSD is strongly backed by research and is considered the most relevant and accurate measure of Autonomic Nervous System activity over the short term so it is highly used in predicting some related diseases. Heart rate variability is when there is a small change in the interval between your heartbeats. These slight changes only lengthen or shorten the time between beats by a fraction of a second. With the exception of sophisticated equipment, these changes cannot be detected. Heart rate variability may be present in healthy people, but it can also be a sign of other health difficulties, such as cardiac disorders and psychological problems like anxiety and depression as will explain in the discussion section.

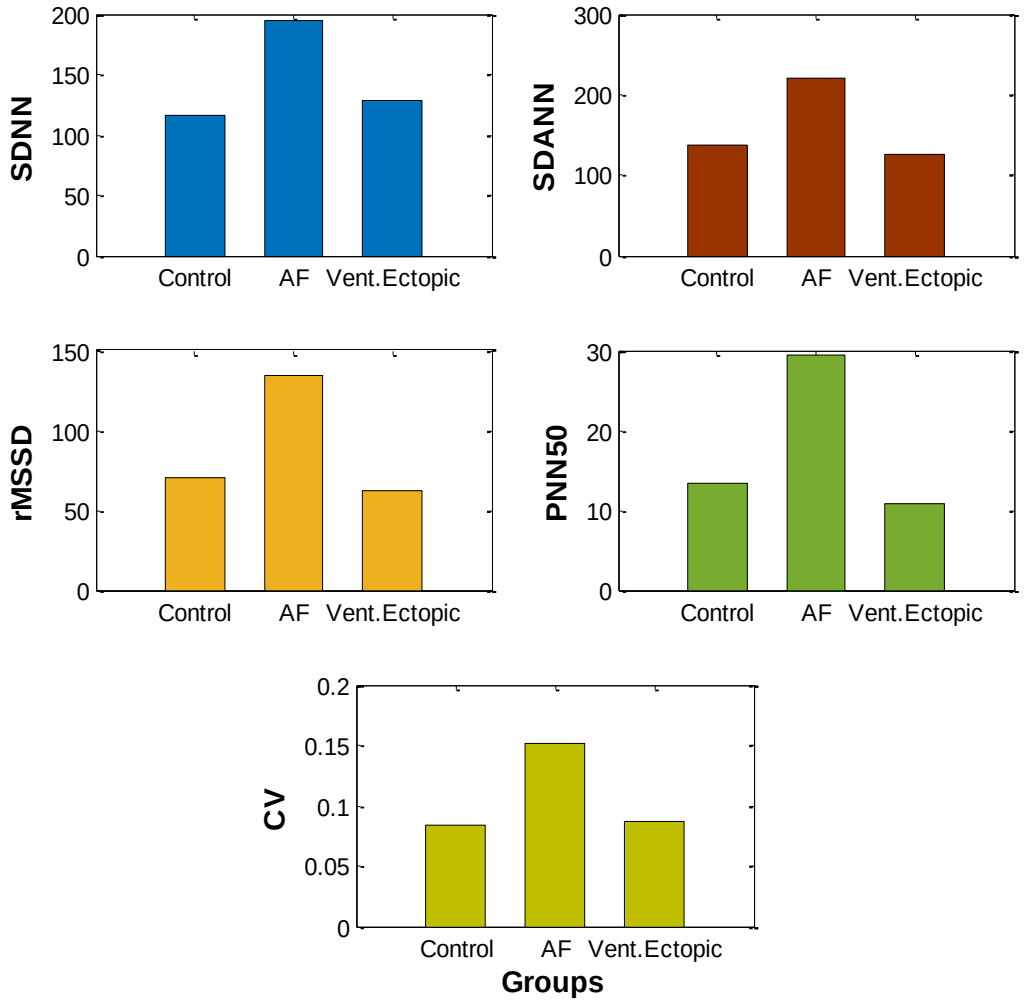


Figure 3: Changes in the parameters of heart rate variability in time domain. All five parameters (SDNN, SDANN, rMSSD, PNN50, and CV) have the highest value in patients with atrial flutter.

Heart Rate Variability in Time Domain

High frequency range (HF), low frequency (LF), very low frequency (VLF), and ultra-low frequency (ULF) bands are the four frequency ranges used for HRV study. The analysis is typically conducted on 5-minute intervals rather than the complete cardiac record. One of the suggestions that we have followed in this project is to perform frequency analysis in blocks of five minutes. The first parameter is the total power which is The total power of RR interval variability is the total variance and corresponds to the sum of the four spectral bands, LF, HF, ULF and VLF. The total power had the highest value in patients with AF (see figure 4), it was significantly higher than its value in control and ventricular ectopic groups. As expected the total power

in controls was significantly higher than in ventricular ectopic patients. We can see that the total power has the same trend as in SDNN and SDANN as they strongly correlated to the total power and ULF as we will see here in this section. The power in the ultra-low frequency range (ULF) was significantly higher in AF patients thatn in control and ventricular ectopic groups (*p-value* <0.05). Though controls showed a lower ULF than ventricular ectopic patients but it did not reach the level of significance (figure 4). Both VLF and LF were significantly higher in AF patients than the other two groups. No difference was observed between their values in controls and ventricular ectopic patients. Finally, we have HF parameter which was significantly higher in AF group than control and ventricular ectopic groups. Controls and ventricular ectopic patients did not show a significant difference in HF parameter as shown in figure (4).

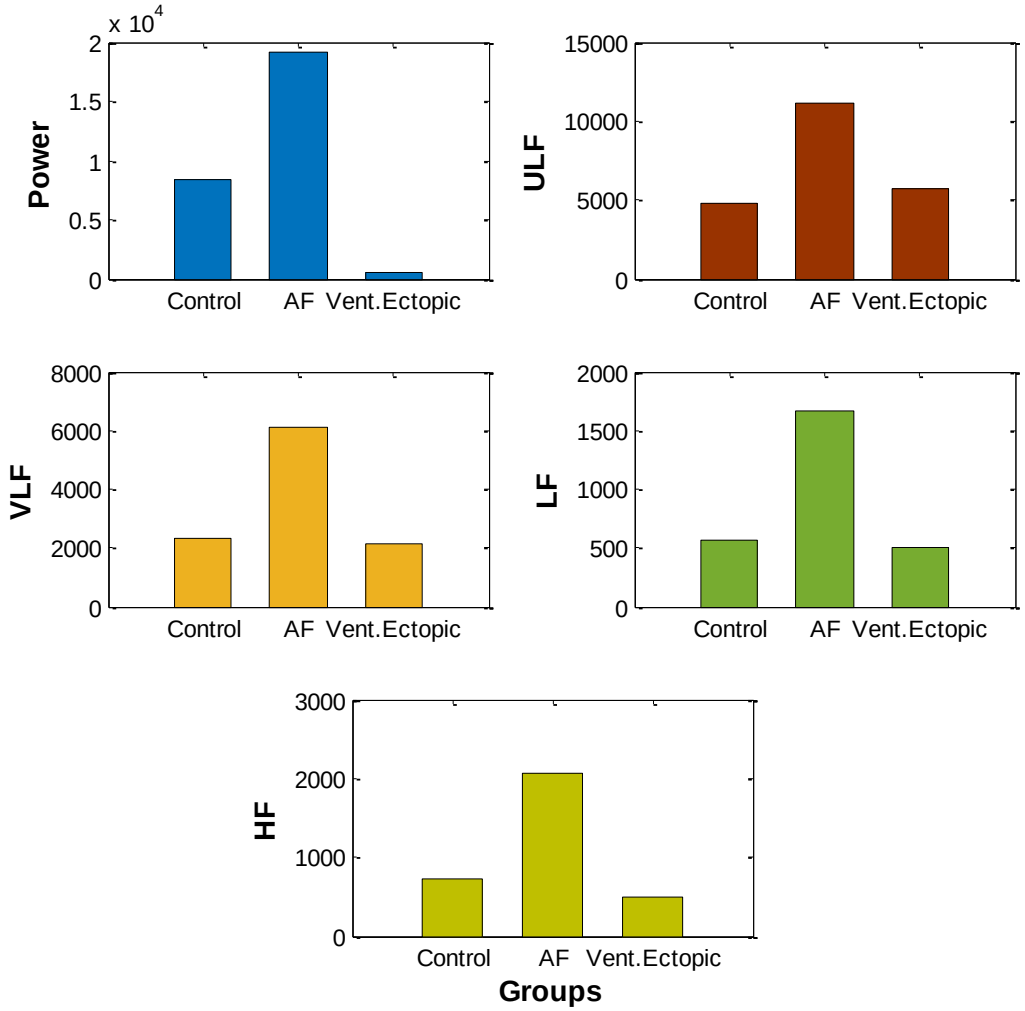


Figure 4: Changes in the parameters of heart rate variability in frequency domain. All five parameters (Power, ULF, VLF, LF, and HF) have the highest value in patients with atrial flutter (the same trend as in time domain).

Discussion

In order to effectively treat cardiac illnesses, it is crucial to distinguish between healthy and sick persons. A rise in population health and an improvement in healthcare quality would result from the employment of interdisciplinary techniques to deal with health issues. The examination of heart rate variability (HRV) can therefore be a useful tool for assessing cardiovascular functioning. For HRV analyses, there are often two categories of techniques: (1) time-domain analysis like SDNN, SDANN, rMSSD, PNN50, and CV; (2) frequency-domain analyses like LF, HF, ULF, and VLF.

Our results showed that the HRV parameter in time and frequency domains are at their highest level in patients with atrial flutter. This can be used in building an algorithm to classify the heart diseases, so HRV parameters provide the possibility to use the HRV index as a predictor of some heart diseases. In atrial flutter patients compared to controls, SDNN considerably increased. According to two previous long-term follow-up trials, which we reviewed in the literature, lower HRV was associated with a higher incidence of AF. After adjusting for the typical AF risk variables, a second study found no statistically significant connection between lower SDNN and incident AF. A recent study found that the development of AF was associated with both elevated rMSSD and decreased HRV. These inconsistent results may be related to different ECG recording times and the study population used for the HRV analysis. Despite the numerous published experimental and clinical investigations, measuring HRV is still an academic approach rather than a standard clinical tool. There are a number of factors that can explain this situation, including the fact that there is still disagreement over which HRV parameter is the most accurate for clinical use despite the relative evidence of the robust nature of parameters like SDNN and the HRV index. This is because the parameters vary depending on gender, age, drug interactions, and coexisting diseases.

Conclusions and Future Direction

Recent years have seen a rise in the use of heart rate variability as a method for examining the pathophysiology of arrhythmogenesis. Our findings indicated that HRV fluctuate and may be more sensitive in AF patients. We are gathering more information and broadening our study to incorporate age and gender parameters as a further step to confirm our findings.

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