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Survey on Early Detection of Coronary Heart Disease in Hypertensive Patients

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Abstract: When looking at the death rate due to cardiac disorders, the major part of the death is caused due to coronary heart disease (CHD). Most of the hypertensive cases if untreated lead to CHD. Since, the non-invasive tests are many a times not adequate to identify the arrival of the CHD, further analysis of the electrocardiogram (ECG) signals are necessary. Therefore, over here continuous wavelet transform (CWT) is used to map the changes observed in the ECG of normal sinus rhythm and hypertensive cases. The feature extracted can determine whether the hypertension (HT) is proceeding to the development of CHD or not. The CWT gives the frequency distribution on different segments of ECG which gives the power spectral density. Early detection of CHD can help to provide the early treatment to these patients and thereby reducing risks to their life. Difference in power spectral density helps us to identify the beginning of CHD in HT patients.
Keywords- Coronary heart disease, continuous wavelet transform, electrocardiogram, sinus rhythm, hypertension, feature extraction.

I. INTRODUCTION

Hypertension is a chronic condition when the blood-pressure in the vessels increases abnormally and remains raised during most part of the day risking the cardiac health of an individual. It is often called as a silent killer because it comes without any symptoms. Consistent high blood pressure majorly affects several body organs such as brain, heart and kidneys and also is a major cause of premature deaths, leading to 9.4 million deaths globally in 2013[2]. Talking about India, nearly three in ten Indians are having hypertension and is responsible for 17.5% of all deaths according to the data released in the article of India Spend, 2017[2].

Hypertension is a major risk factor for coronary heart disease. It leads to the development of myocardial ischemia. As the reduction in the lumen of the coronary arteries reduces the myocardium blood flow. Generally, in such cases if the ECG is taken then left ventricular hypertrophy (LVH) is diagnosed and henceforth which results into development of further ventricular arrhythmias[4]. Also, the endothelium gets affected and is altered in HT[4]. The deviation in the endothelial function increases the risk of CHD in HT as it favors vasoconstriction and thrombogenesis. Roughly around 30% of hypertensive cases have shown silent episodes of, myocardial ischemia due to reduced coronary flow reserve, to endothelial dysfunction and deviation in autonomic nervous system[4]. Hence, early detection of hypertension and its control can reduce the deaths due to CHD and Ischemia.

The ECG is the best way to analyze the heart's electrical activity. Already several systems have been proposed for real time disease detection using ECG [13], [14], [16]. By studying the anomaly of the ECG, we can understand the diversity of the cardiac abnormality. The natural pacemaker of the heart generates the electrical impulse which is propagated throughout the heart. The wave depolarization and repolarization produces a flow of electric current and it can be detected by placing the surface electrodes on the body. Hence, the generated waveform can be studied and analyzed to identify the abnormality. The ECG provides two kinds of information: (i) whether the electrical wave is normal or slow or irregular, and (ii) the amount of electrical activity passing through the heart muscle to analyze the part of heart overworked or abnormal[6].

The frequency of ECG signal ranges from 0.05 Hz to 100 Hz and its amplitude ranges from 1-10 mV. The ECG signals has 5 main components which are P, Q, R, S, and T waves. The ECG analysis basically depends on accurate detection of P wave, QRS complex and T-wave. The P wave depicts the excitation of upper chamber or atrium of the heart, while the QRS complex and the T-wave depicts the excitation of the lower chamber or the ventricles of the heart[7].

According to the medical investigation done (by European society of hypertension and European society of cardiology) early changes in the ECG can be observed in hypertensive cases which may be lead to CHD. Initial changes in the ECG includes [1][4]:

- ST changes (ST elevation or depression);
- changes in T segment (T-inversion or higher amplitude of T wave);
- changes in QRS complex (Low amplitude of QRS max)

Non-invasive diagnostic tests for CDH are mostly inadequate in Hypertension cases [4]. However, early detection of CHD in hypertensive cases can reduce the risk of deaths among the population.

Many methods have been used for the analysis of ECG. Fourier transform is a powerful tool for data analysis, but it does not represent efficiently the abrupt changes in the signal. The main reason behind this is that the Fourier transform represents data as a sum of sine waves which are not localized in time or space. Then Short-time Fourier transform (STFT) was developed and introduced which is in time-frequency domain. STFT is achieved by slicing the signal using the window function and then moving along the frequency axis where we do Fourier analysis. However over here, once we decide the window length then the same length remains for the complete analysis of the signal unless we use a different window length[5].

Therefore, there is a need to use new class of functions which is wavelets as they are well localized in time and frequency. The wavelet transforms basically works in time scale plane unlike STFT. However, we have connection between the scale and the frequency. Over here out of different functions one atom is chosen say reference frequency which generates a mother wavelet. Then this reference frequency is accordingly scaled to represent other function in a signal.

Assume, that F2 is greater than F1. Now we can rewrite F2 in two ways:

Case(1): F1/s or (Multiplicative relation)

Case(2): F1+dF(Additive relation)

If multiplicative relation is chosen between F1 and F2 then case (1) is true. Hence we write F2 as F1/s. So that if s<1, then F2 is greater than F1. Like this we can build connection between the scale and the frequency. At last, mother wavelet is used to analyze the signal in Continuous Wavelet Transforms[5].

II. MATERIALS AND METHODOLOGY

Hypertension is one of the major risk factors which if undetected or untreated will results into severe cardiac disorder. It was responsible for 53.8% of all deaths due to heart disease, 55.7% of deaths due to stoke and 54.3 % deaths due to kidney disease in India in 2016 as per data [2]. Following section consists of proposed method where real patient ECG data is taken as input, pre-processed, feature extracted and analyzed using continuous wavelet transform.

To achieve the study, the inclusion criteria included the subjects who were reported to OPD of North Eastern Indira Gandhi Regional Institute of Health and Medical Sciences (NEIGRIMS). Initially, their physical examination (like measurement of height, weight, blood pressure) was conducted and later their 12-lead resting ECG was recorded in the ECG room. The recorded ECG was later evaluated by the cardiologist.

A. Block diagram

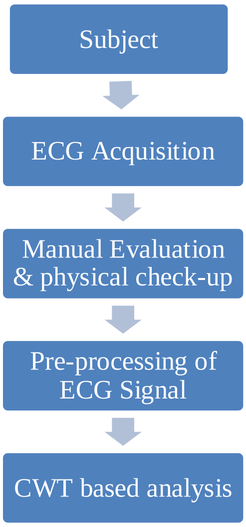
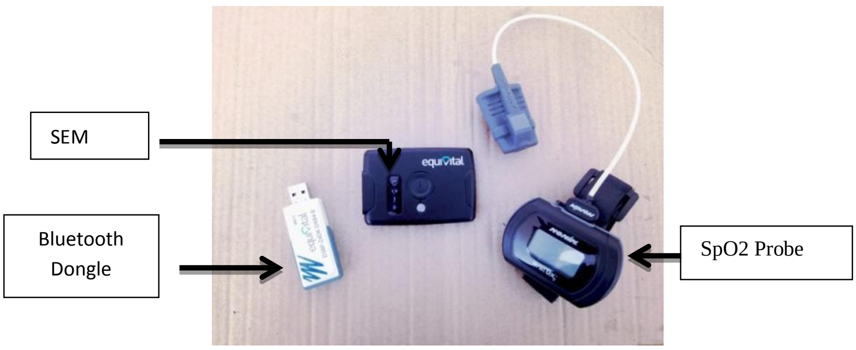


Figure 1: Flow-chart

B. Data Acquisition

ECG data was collected from the real patients along with their analysis from NEIGRIMS.Out of the diagnosed subjects 30 patients of age group 39 to 84 years of each Normal sinus rhythm, Hypertensive case and CHD were selected and their ECG's were recorded by our ECG device EQ02 Life Monitor for 2 minutes each[8]. The device records two-channels of ECG which are Lead-I and Lead-II. Various age group of patients were selected as shown in Table 1. As per medical data, anomalies in the repolarization are generally observed in hypertensive patients in particular to the QRS complex and ST-T segment in lateral leads [4]. Hence, lead-I is chosen for the analysis. ECG device used to collect the data is EQ02 Life Monitor of Equivital brand. The EQ02 senses, records and intelligently processes data measured from the person and is able to transmit this over a wireless or wired interface. It is a two channel device. It has two components: (i) The sensor Electronics Module (SEM) and (ii) sensor belt. The sensor belt positions the SEM on the left side of the chest [3]. The value obtained is stored in .adicht format by the PC application "LabChart software" used for the configuration of SEM's and the Equivital data management. LabChart is incorporated software which records and analyzes the ECG data detected by the EQ02 device. It extracts the ECG features such as Heart Rate (HR), PR interval, QRS interval, QT and QT_c interval, T peak etc. Later the data was stored in the excel sheet such that it can be imported into the MATLAB R2017a. The collected data is preprocessed further by using MATLAB operators.



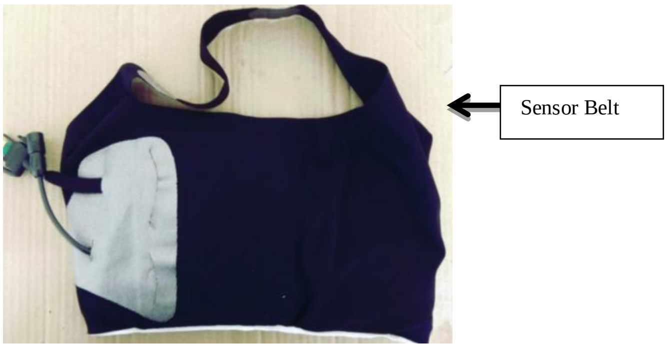


Figure 2: Equivital^{TM} LifeMonitor device

Table 1: Subjects included in study

Heart Conditions	No. of Patients	Age (Years)	Gender (F/M)	Heart Rate (bpm)
Normal Sinus Rhythm	30	40-60	8/22	70-85
Hypertension	30	35-72	9/21	70-110
Coronary Heart Disease	30	38-75	4/26	60-100

C. Preprocessing

Filter

Moving average filter is used for smoothing the noisy data. It slides a window of length *WindowSize* along the vector of data, computing the average in each window. Given a series and a fixed subset size, the first element of the moving average is obtained by taking the average of initial fixed subset of the number series. Then the subset is modified by "shifting forward", that is excluding the first number of the series and including the next value in the subset. The following equation defines a moving average filter of input vector [15]:

$$y(n) = \frac{1}{WindowSize}(x(n) + x(n-1) + \cdots + x(n-(WindowSize-1))) \quad (1)$$

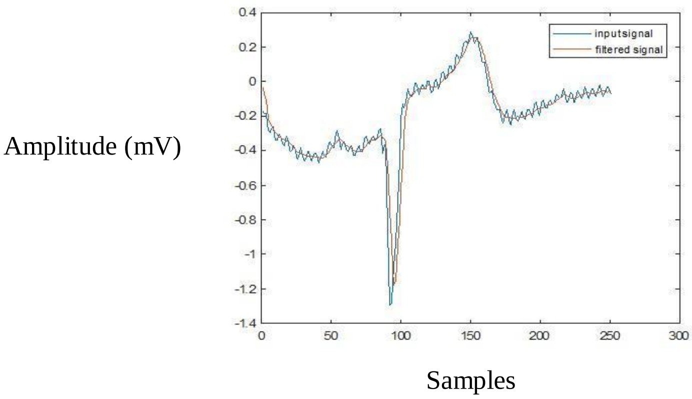


Figure 3: Applying moving average filter on signal

Amplitude Scaling:

We multiply the amplitude of a signal by a real number (β). As the ECG signal has very low amplitude, hence for further processing amplification of the signal is required so as to get better output. Consider a signal x(t) which is multiplied by a constant ' β ' and this can be indicated by :

$x(t) \quad \beta\, x(t) \qquad (2)$

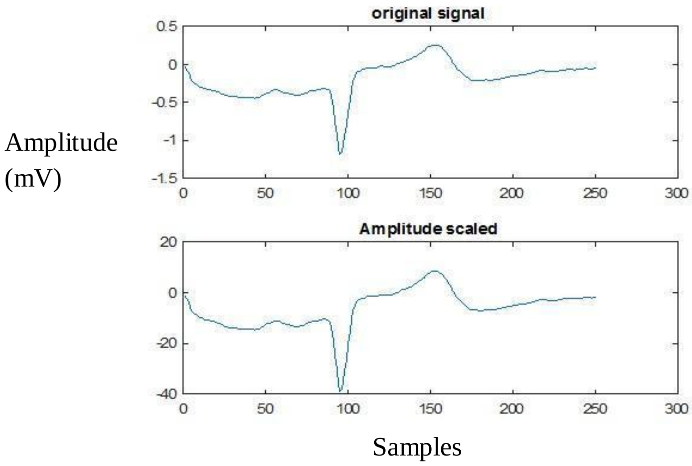


Figure 4: Amplitude scaling (β =200)

D. Continuous wavelet transform (CWT) based Analysis

The CWT breaks down the signal into wavelets. Wavelets are nothing but the small oscillations which are localized in time. Unlike Fourier transform, in CWT the time-localization information is not lost. The CWT is used to map the changing properties of non-stationary signals like ECG. In CWT, we use time scale plane instead of time-frequency plane, but we have connection between the scale and frequency. Hence, we are able to switch back and forth between both the domains. The CWT is the convolution function with scaled and shifted version of mother wavelet, ψ function. The continuous wavelet transform of a function x(t) at a scale (a>0) $a \in R^+$ and translational value $b \in R$ is expressed as:

$$X_w(a,b) = \frac{1}{|a|^{1/2}} \int_{-\infty}^{\infty} x(t)\bar{\psi}\frac{(t-b)}{a}\,dt \quad (3)$$

Where ψ(t) is mother wavelet and overline represents complex conjugate function.

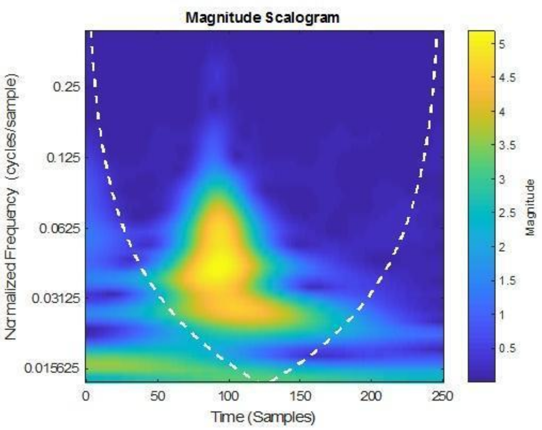


Figure 5: Energy distribution of a signal using CWT

In this paper, we have used the Continuous wavelet transform to find the systolic dysfunction of the heart. By using CWT one can analyze the difference in energy level at different segments of the ECG. This would help us to inspect the functioning of the heart's chambers and arteries by comparing the energy ranges in the ECG signal.

III. RESULTS

In normal case, it is observed that QRS systolic function is having the frequency between 30-50 Hz and the energy does not scatter and remains confined to QRS regionas shown in figure 6(b) indicating that the ventricles perform normally. The difference observed in energy dispersion is 100 – 120 ms.

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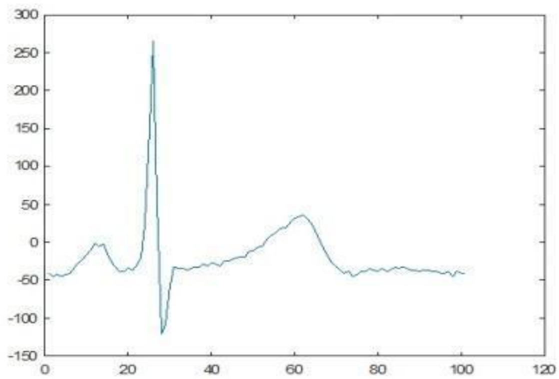
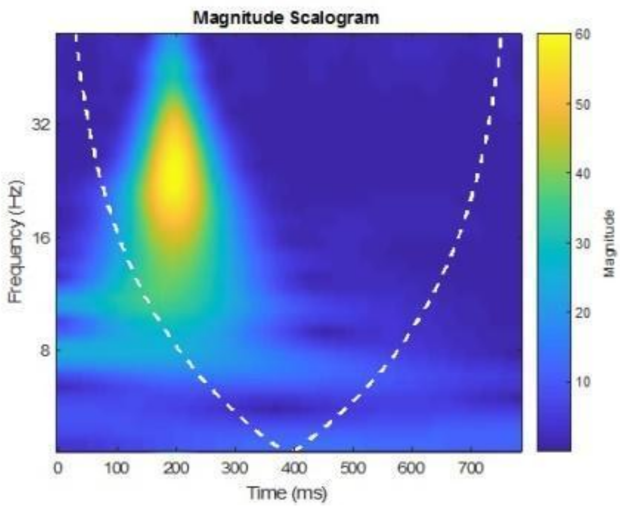


(a)



(b)
Figure 6: (a) Normal ECG (b) Normal CWT

The Table 2 shown below contains the value of power observed in QRS region and scattering of energy observed in the QRS region for normal subjects.

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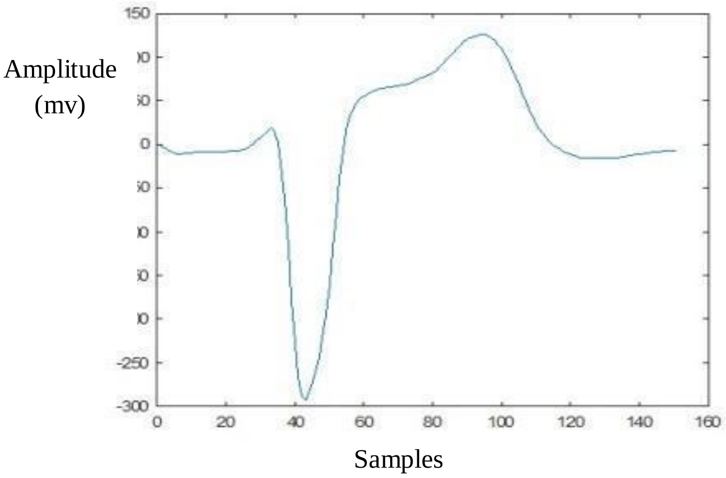
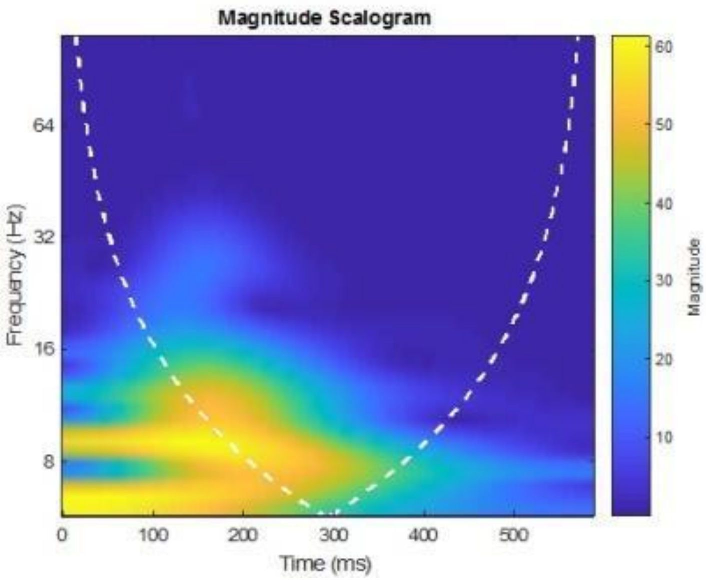
Table 2: Power and scattered energy in QRS region observed in the case of Normal subjects in lead 1

Subjects	Y-axis (frequency in Hz) indicates Power at QRS	X-axis (time in msec) indicates scattering of Energy	Condition
Subject 1	34 Hz	115 ms	Normal
Subject 2	30 Hz	120 ms	Normal
Subject 3	30 Hz	100 ms	Normal
Subject 4	32 Hz	107 ms	Normal
Subject 5	28 Hz	120 ms	Normal
Subject 6	34 Hz	101 ms	Normal
Subject 7	32 Hz	105 ms	Normal
Subject 8	36 Hz	100 ms	Normal
Subject 9	34 Hz	118 ms	Normal
Subject 10	32 Hz	98 ms	Normal
Subject 11	28 Hz	100 ms	Normal
Subject 12	32 Hz	105 ms	Normal
Subject 13	34 Hz	110 ms	Normal
Subject 14	32 Hz	110 ms	Normal
Subject 15	34 Hz	120 ms	Normal
Subject 16	34 Hz	118 ms	Normal
Subject 17	36 Hz	101 ms	Normal
Subject 18	40 Hz	105 ms	Normal
Subject 19	34 Hz	98 ms	Normal
Subject 20	36 Hz	105 ms	Normal
Subject 21	32 Hz	106 ms	Normal
Subject 22	34 Hz	100 ms	Normal
Subject 23	32 Hz	125 ms	Normal
Subject 24	30 Hz	130 ms	Normal
Subject 25	32 Hz	120 ms	Normal
Subject 26	32 Hz	90 ms	Normal
Subject 27	30 Hz	125 ms	Normal
Subject 28	36 Hz	115 ms	Normal
Subject 29	34 Hz	112 ms	Normal
Subject 30	30 Hz	105 ms	Normal

In coronary heart disease case, the frequency of QRS complex has further reduced to 10-16 Hz and also the energy over QRS complex looks scattered indicating that the ventricles contract with very low energy. Apart from that elevation is observed in ST segment as it has got raised from the baseline as shown in figure 7(a-b).



(a)



(b)

Figure 7: (a) CHD (b) CHD CWT

The Table 3 shown below contains the value of power observed in QRS region and scattering of energy observed in the QRS region for CHD subjects.

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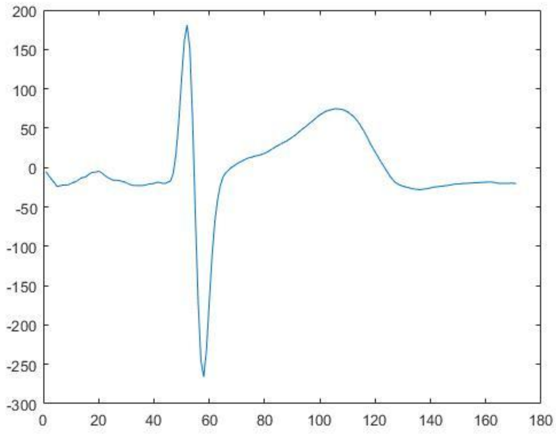
Volume 10 • Issue 2 pp. 358-371 June 2018-Dec 2018 www.csjournals.com

Table 3: Power and scattered energy in QRS region observed in the case of CHD subjects in lead 1

Subjects	Y-axis (frequency in Hz) indicates Power at QRS	X-axis (time in msec) indicates scattering of Energy	Condition
Subject 1	24 Hz	160 ms	CHD
Subject 2	24 Hz	160 ms	CHD
Subject 3	26 Hz	220 ms	CHD
Subject 4	16 Hz	205 ms	CHD
Subject 5	22 Hz	220 ms	CHD
Subject 6	18 Hz	190 ms	CHD
Subject 7	22 Hz	205 ms	CHD
Subject 8	20 Hz	200 ms	CHD
Subject 9	16 Hz	218 ms	CHD
Subject 10	15 Hz	198 ms	CHD
Subject 11	18 Hz	190 ms	CHD
Subject 12	16 Hz	155 ms	CHD
Subject 13	20 Hz	180 ms	CHD
Subject 14	16 Hz	185 ms	CHD
Subject 15	18 Hz	170 ms	CHD
Subject 16	22 Hz	210 ms	CHD
Subject 17	16 Hz	185 ms	CHD
Subject 18	16 Hz	240 ms	CHD
Subject 19	14 Hz	260 ms	CHD
Subject 20	16 Hz	200 ms	CHD
Subject 21	15 Hz	230 ms	CHD
Subject 22	16 Hz	190 ms	CHD
Subject 23	18 Hz	200 ms	CHD
Subject 24	20 Hz	180 ms	CHD
Subject 25	20 Hz	170 ms	CHD
Subject 26	16 Hz	220 ms	CHD
Subject 27	16 Hz	198 ms	CHD
Subject 28	15 Hz	200 ms	CHD
Subject 29	18 Hz	180 ms	CHD
Subject 30	22 Hz	156 ms	CHD

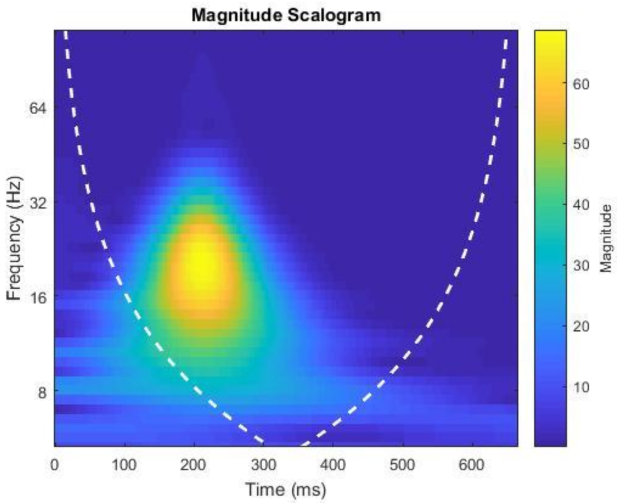
In hypertensive case, it is observed that the frequency has reduced than the normal case. Over here the frequency at QRS complex is between 16-32 Hz. As we can see in the figure 8(b) that the energy is confined and concentrated at QRS region and power with which the ventricles contract has decreased.

Amplitude (mv)



Samples

(a)

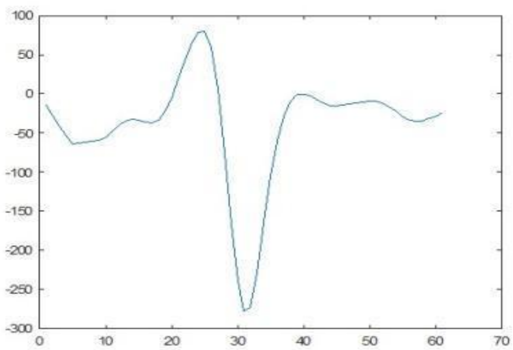


(b)

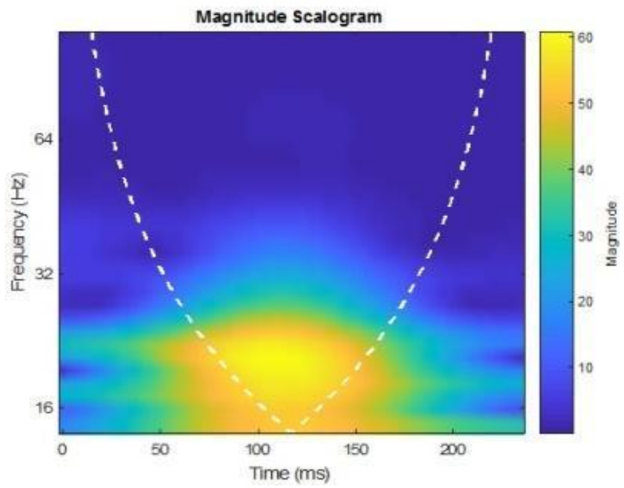
Figure 8: (a) Hypertension ECG (b)Hypertension CWT

Yet in few hypertensive cases it was observed, though the frequency found is between 16-32 Hz. However, as we can see in the figure 9(b) that the energy has got scattered as it scatters in CHD. Hence, the power with which the ventricles contract has been reduced.

Amplitude (mv)



Samples (a)



(b)
Figure 9: (a) Hypertension ECG (b) Hypertension CWT

The Table 4 shown below contains the value of power observed in QRS region and scattering of energy observed in the QRS region for HT subjects.

Table 4: Power and scattered energy in QRS region observed in the case of HT subjects in lead 1

Subjects	**Y-axis (frequency in Hz) indicates Power at QRS**	**X-axis (time in msec) indicates scattering of Energy**	**Condition**
Subject 1	24 Hz	**200 ms**	HT
Subject 2	30 Hz	100 ms	HT
Subject 3	28 Hz	100 ms	HT
Subject 4	20 Hz	110 ms	HT
Subject 5	15 Hz	**250 ms**	HT
Subject 6	26 Hz	150 ms	HT
Subject 7	26 Hz	140 ms	HT
Subject 8	22 Hz	**190 ms**	HT
Subject 9	22 Hz	**160 ms**	HT
Subject 10	28 Hz	140 ms	HT
Subject 11	30 Hz	140 ms	HT
Subject 12	22 Hz	120 ms	HT
Subject 13	24 Hz	110 ms	HT
Subject 14	20 Hz	130 ms	HT
Subject 15	20 Hz	150 ms	HT

Subject 16	22 Hz	120 ms	HT
Subject 17	16 Hz	100 ms	HT
Subject 18	20 Hz	110 ms	HT
Subject 19	18 Hz	**190 ms**	HT
Subject 20	22 Hz	100 ms	HT
Subject 21	22 Hz	160 ms	HT
Subject 22	20 Hz	**190 ms**	HT
Subject 23	24 Hz	100 ms	HT
Subject 24	20 Hz	**160 ms**	HT
Subject 25	26 Hz	120 ms	HT
Subject 26	24 Hz	115 ms	HT
Subject 27	22 Hz	**200 ms**	HT
Subject 28	18 Hz	**180 ms**	HT
Subject 29	24 Hz	110 ms	HT
Subject 30	22 Hz	100 ms	HT

The Table 5 the difference of ranges of power and scattering of energy observed in the subjects of normal sinus rhythm, CHD and hypertensive cases.

Table 5: Consolidated result obtained after analyzing ECG using CWT

Heart Conditions	**Power at QRS complex**	**Morphology of Energy at QRS**	**Power at ST Segment**
Normal Sinus Rhythm	28 - 40 Hz	Confined: 100 ± 40	Not elevated
Hypertension	16-33 Hz	Confined : 120 ± 20 Scattered: 190 ± 20	Little elevated
CHD	8 -16 Hz	Scattered: 195 ± 40	Highly elevated

IV. CONCLUSION

In this paper, the ECG signals of normal sinus rhythm and CHD patients were taken and analyzed by using CWT.Later on, the ECG of hypertensive subjects were analyzed and compared with normal and CHD cases. The proposed method is simple mathematical based algorithm that offers the information regarding the hearts functionality. As we know that by employing CWT one can find out the power spectrum in the ECG signal. Over here, while analyzing the power spectrum in different hypertensive subjects it was observed most of the subjects were having low power (between 16 – 33 Hz) than normal case and no dispersion in energy. Whereas, in 9 out of 30 subjects more scattered energy (which is 195 ± 20) was observed (as in Table 4). Hence, we can conclude that those few cases of HT subjects can be the patients who may be heading towards the onset on CHD. As in CHD patients the energy will scatter and the power during ventricular systole will reduce to 8 – 16 Hz. Also ST segment will gets elevated showing the presence of power in that region. As HT being a major risk factor for CHD, by looking at reducing power and scattered energy level of QRS and ST segment we can conclude whether the HT case is proceeding to the development of CHD or not.

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