Examining R Peak Changes in Ischemic Condition using Random Forest Classifier under Stress Test ECG

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***Abstract*— The most common clinical criteria for electrocardiographic diagnosis of myocardial ischemia include ST segment changes but not the QRS morphology. This study aimed to interpret the variations in the amplitude of the R wave that might be helpful in better diagnosis of ischemia during stress testing along with ST-segment changes. Exercise Stress Test (EST) electrocardiograms (ECGs) were reviewed in 152 subjects (89 ischemic and 63 non-ischemic) including 51 females and 101 males of mean age (56 ± 4.24 years). R wave amplitude was measured in the supine and immediate post-exercise period. ST segment variations were also measured during load and recovery stages at J+ 80ms. An index known as ΔRST was formed from the summation of variations in the amplitude of the R wave and average ST segment changes. At a cutoff point of -1.5 mm ΔRST index provided a sensitivity of 71.99% and a specificity of 63.63% in contrast to the ST segment criteria that showed 55.9 % sensitivity and 54.54% specificity due to a large number of false positive and negative responses. The Random Forest (RF) model showed the best performance for classifying ischemic and non-ischemic conditions using ΔRST criteria for both lead II and lead V5. The accuracy, precision, and F1 score of the model for lead II were 0.96, 0.94, and 0.97 respectively. The performance matrices for lead V5 are 0.96, 0.98, and 0.94 respectively.**

Keywords*— *exercise electrocardiogram, ischemic heart disease, random forest model, R wave amplitude, ST-segment

I. INTRODUCTION

Electrocardiogram (ECG) is a simple diagnostic test widely used to detect conduction disturbances, arrhythmias, myocardial ischemia, and changes in the myocardium. The ST segment correlates with the plateau phase of the cardiac action potential and it generally lies at the same level as the T-P segment [1]. Displacement in the ST segment is measured in terms of the height difference between the J-point and the PR segment. Generally, ST segment changes are measured at 60 to 80 ms from the J point [2]. The exercise stress test is a relatively safe and non-invasive method for detecting cardiac anomalies [3]. Significant information regarding exercise capacity, blood pressure response, development of arrhythmias, or symptoms of angina (chest pain) are derived during exercise which permits the detection of ischemia. The stress test is generally terminated when a subject has achieved their target heart rate. The failure to achieve 85% of the age-predicted heart rate is defined as chronotropic incompetence [4]. This maximum heart rate is calculated by subtracting the patient's age from 220 [5]. Besides ST segment changes other factors can also influence the elucidation of the cardiac stress test.

Bonoris et al. [6] reported an increment in the amplitude of R wave post-exercise in patients with ventricular dysfunction and narrowing of the multivessel coronary artery. An increase in R wave amplitude ⩾ 2mm at peak exercise [7] is a cardinal marker of ischemia. Another study [8] postulated that the QRS complex is influenced by the intracavitary blood mass. During strenuous exercise, the ischemic ventricle fails to reduce its volume which leads to the absence of the usual decrease in amplitude of the R wave. This is because during myocardial ischemia the left ventricle stops contracting as a result of which the blood pools inside the left ventricular chamber thereby increasing the QRS complex voltage. Consequently, an increase in R wave amplitude correlated with severe disease and segmental abnormalities in the left ventriculogram [9]. It has also been reported that the size of the left ventricular cavity determines the height of R wave amplitude in normal resting subjects [10]. Consequently, in a study by Cipriani et al. [11], acute myocardial ischemia caused a simultaneous increment in the amplitude of R wave and duration of QRS complex combined with elevation in the ST segment observed in leads facing the ischemic area. We have used Random Forest (RF) classifier in our study to compare ST segment changes with ΔRST which might be helpful in the accurate diagnosis of ischemic heart disease.

II. METHODOLOGY

A. Study Population

Treadmill stress test ECG dataset from 89 ischemic with an average age of 50.67 ± 10.95 years and 63 non-ischemic patients with an average age of 51.81 ± 12.37 years including 51 females and 101 males according to the standard Bruce protocol was used in the study. Age, weight, sex, heart rate, systolic and diastolic blood pressure, maximum metabolic equivalents (METs), rate pressure product, and end-of-test criteria were also examined.

B. Data Acquisition and Statistical Analysis

Dataset ECGs were recorded at a usual paper speed of 25 mm/s and 10 mm/mV using the standard 12-lead system. Bipolar limb lead II and precordial lead V5 were constantly recorded. The ECGs were recorded in supine, standing, pre-load, load 1, load 2, load 3, load 4, recovery 1, recovery 2, recovery 3, and end of test for each subject at an interval of 3 minutes. According to the Bruce protocol, the speed and the incline of the treadmill are increased at a duration of 3 minutes. All the patients reached different levels of load according to their capability. ST segment variations were measured at 80ms after the J point. For normality analysis, the Kolmogorov-Smirnov test was performed. 2 tailed Student's T-test was used to calculate the statistical significance. $P<0.05$ was regarded as the criteria of statistical significance.

C. Characterization of R Wave Amplitude

R wave amplitude was measured in the supine and instantaneous recovery period of the stress test. An increment in the R wave or no change in amplitude in the post-exercise stage was considered as an ischemic response whereas a decrease in amplitude was treated as a normal response [6]. This change in amplitude was expressed as ΔR. An index ΔRST was formed by the summation of the difference in the amplitude of the R wave: ΔR and average ST segment variations [6]. Fig. 1 depicts a typical stress test ECG waveform at load 2 stage recorded at a paper speed of 10mm/mv and 25mm/s.

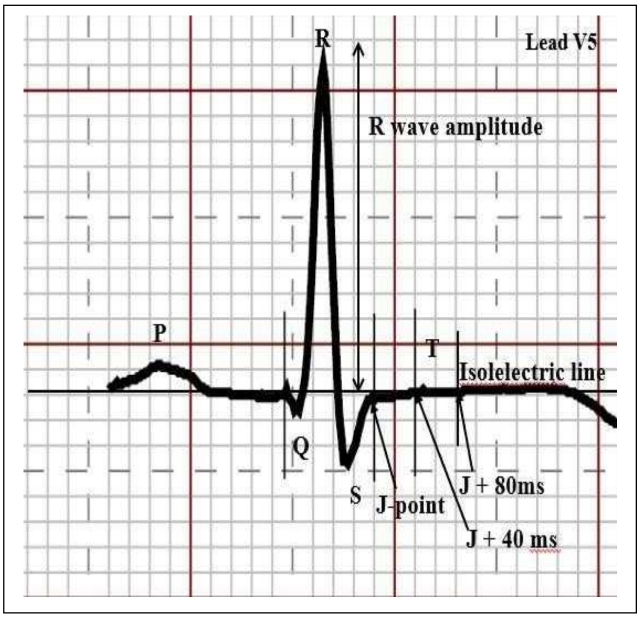

Fig. 1. Stress test electrocardiogram waveform at load 2 stage.

D. Feature Set

The feature set used for classifying comprises the average ST segment deviations at J+80ms, ΔR, ΔRST, heart rate, systolic blood pressure, metabolic equivalents, and rate pressure product. All these features were measured and analyzed for both leads II and V5. The missing values in the feature set such as ST segment displacement in load 3 were replaced by the mean values. 80% of the dataset was used as the training data whereas 20% of the data was utilized as the test data. Outlier values were removed to minimize error.

E. Random Forest Classifier

Random forest algorithm which comprises multiple decision trees uses the ensemble learning method [12]. It produces the final output by predicting the mean of the outcomes from several trees for determining the final class of the test object. It increases precision by reducing the overfitting of the dataset.

F. Performance Analysis

The RF model was analyzed based on the parameters such as accuracy, precision, recall, F1 score, and area under the curve. All these parameters were obtained from the following confusion matrix.

$$\text{Confusion matrix} = \begin{bmatrix} TP & FP \\ FN & TN \end{bmatrix}$$

PPV = (100*TP) / (TP+FP)

NPV = (100*TN / (TN+FN)

Sensitivity = TP / (TP+FN)

Specificity = TN / TN+FP

Accuracy = (TP+TN) / (TP+FP+TN+FN)

Precision = TP / (TP+FP)

Recall = TP / (TP+FN)

F1 score = 2*(Precision * Recall / Precision + Recall)

III. RESULTS

Table 1 depicts the mean ± SD values and the P value of the various clinical features such as age, peak systolic pressure, METs, heart rate, ST segment deviation, ΔR amplitude, and ΔRST between the two studied groups which was calculated using 2 tailed Student's t-test. ΔRST feature for both lead II and lead V5 showed significant changes in both ischemic and non-ischemic groups ($P<0.05$).

Table II shows the various diagnostic indices used for evaluating changes in ST segment at 80ms, ΔR, and ΔRST for leads II and V5. For lead II the sensitivity, specificity, PPV, and NPV for ST segment is 66.66%, 51.6%, 65.74%, and 54.23% respectively. On the other hand, in lead V5 the sensitivity, specificity, PPV, and NPV for ST segment respectively are 55.9%,54.54%, 67.53%, and 42.25%.

Table III depicts the classification report of the RF model. Class 0 denotes ischemic and class 1 denotes non-ischemic condition. According to the classification report, the recall, precision, and F1 score for class 0 are 1.00, 0.9, and 0.95 respectively. On the contrary, the recall, precision, and F1 score for class 1 are 0.89, 1.00, and 0.94 respectively.

Fig.2 and Fig.3 depict the confusion matrix for the test set for both lead II and lead V5 respectively. It illustrates the count of true and false outcomes of the individuals belonging to the ischemic and non-ischemic groups. Less number of false classifications indicate that the predicted class correlates well with the actual class.

TABLE I. SIGNIFICANCE OF CLINICAL FEATURES IN STRESS TEST ELECTROCARDIOGRAMS

Measurements	Ischemic		Non-ischemic		P value
	Mean	***SD***	***Mean***	***SD***	
Age (years)	50.67	10.95	51.81	12.37	>0.05
Peak systolic pressure (mm Hg)	177.8	21.26	176.2	19.4	>0.05
METs	7.73	2.7	9.16	2.8	>0.05
Heart rate (bpm)	78.2	15.4	80.7	15.6	>0.05
ST segment (mm)	20.1	0.83	17.2	0.86	>0.05
ΔR amplitude (mm)	13.6	2.63	-5.9	2.78	<0.05
ΔRST (mm) lead II	4.2	3.46	-8.21	3.08	<0.05
ΔRST (mm) lead V5	2.9	3.2	-24.4	3.66	<0.05

TABLE II. DIAGNOSTIC INDICES OF STRESS TEST ELECTROCARDIOGRAM IN LEAD II AND LEAD V5

Leads	Features	Sensitivity	Specificity	PPV (%)	NPV (%)
II	ST	66.66	51.6	65.74	54.23
	ΔR	69.66	45.9	65.26	50.91
	ΔRST	70.78	43.42	61.94	48.42
V5	ST	55.9	54.54	67.53	42.25
	ΔR	61.11	58.62	69.62	49.27
	ΔRST	71.99	63.63	71.08	64.61

TABLE III. CLASSIFICATION RESULT OF RANDOM FOREST MODEL

Class	Precision	Recall	F1 score
Class 0	1.00	0.90	0.95
Class 1	0.89	1.00	0.94

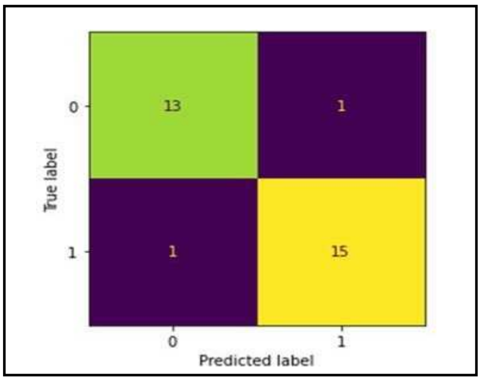

Fig. 2. Confusion matrix of random forest model for lead II

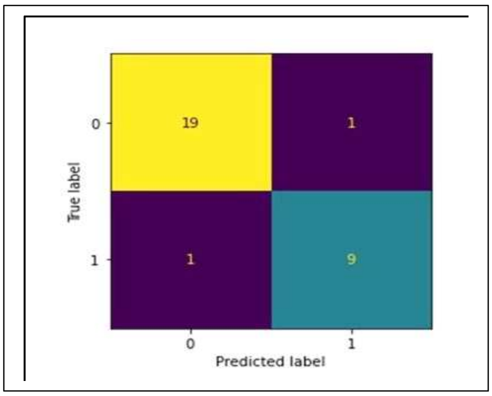

Fig. 3. Confusion matrix of random forest model for lead V5

Fig. 4 depicts the receiver operator characteristic curve (ROC) which is used to represent the area under the curve (AUC). It portrays the diagnostic value of a test between clinical sensitivity and specificity for every cut-off for classifying subjects as positive and negative. The AUC value for the ROC curve of the RF model lead II is 0.97.

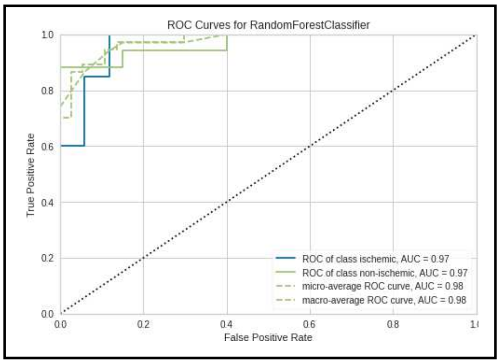

Fig. 4. ROC curve of random forest model for lead II

Fig. 5 similarly depicts the receiver operator characteristic curve (ROC) for the RF model in lead V5. The AUC in the ROC curve for classes 0 (ischemia) and class 1 (non-ischemic) is 0.99.

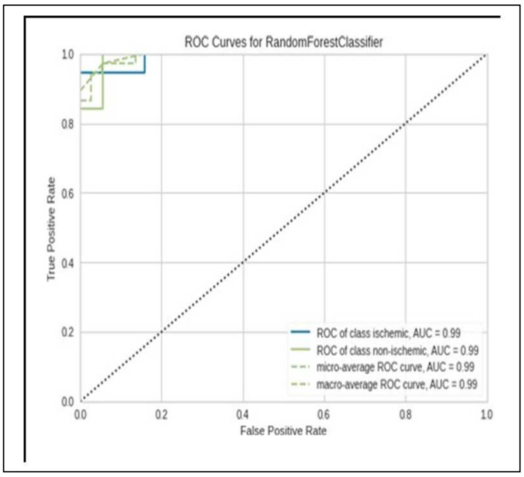

Fig. 5. ROC curve of random forest model for lead V5

IV. DISCUSSION

The most studied parameter of EST ECG is ST depression which has been found to correlate well with the presence of myocardial ischemia and coronary artery disease. Bayene et al. [13] correlated ST segment changes with ischemia exhibited by thallium-20 I imaging and concluded that standard criteria of ST do not correlate well with ischemia. Administration of digitalis, hypokalemia, hyperventilation, and defect in intraventricular conduction are prone to false. positive ST responses [14]. Intake of food may induce ST and T wave changes in normal ECG. Even exaggerated atrial repolarization waves may cause ST segment depression [15,16]. The sensitivity and the false negative responses due to depression of the ST segment depend on the severity of the disease. As potassium is known to be released from the ischemic cells it reduces the velocity of conduction due to a decrease in resting membrane potential. This leads to the formation of the giant R wave where the mean QRS axis will be directed towards the acute infarction zone [17].

We have demonstrated that a significant increment in R wave amplitude is observed besides ST segment deviations during ischemia. In our study, for standard bipolar lead II, we noted a sensitivity of 69.66% and specificity of 45.9% for the ΔR attribute. Compared to ST criteria though the sensitivity increased from 66.66% to 69.66%, the specificity reduced from 51.6% to 45.9%. Using the ΔRST index, at a cut-off of ≥-1.5mm the specificity was 70.78%, which is somewhat higher than ST and ΔR but a lower specificity of 43.42%. On the contrary, for precordial lead V5, we obtained better values compared to lead II. It was noted that for lead V5, sensitivity was found to be 61.11% and a specificity of 58.62% for ΔR attribute. Using the ΔRST index, at a cut-off of ≥-1.5mm the sensitivity was 71.99%, and a specificity of 63.63% which is somewhat higher than both ST and ΔR. Diagnostic accuracy is affected by the prevalence of a disease. The PPV value showed an increase from 67.53% to 71.08% for ΔRST in lead V5. PPV increases while NPV decreases with increase in the prevalence of a disease. Machine learning techniques have shown the ability to make accurate predictions in various domains including healthcare [18]. The dataset which was used to categorize ischemic and non-ischemic conditions through RF classifier was created using the clinical attributes of ECG such as heart rate, METs, peak systolic pressure, average ST-segment depression, depression at different stages of loads, ΔR and ΔRST index. The confusion matrix displays the actual and false results of classification. It is important to estimate the performance of the models with the help of validation methods as it will affect the prediction accuracy. The sensitivity and specificity of ST segment deviations were lower due to a large number of false positive and negative responses. The AUC for the model is 0.99 which shows that a higher AUC has a better ability to classify the ischemic and non-ischemic conditions. 10-fold cross-validation which has less variance compared to the hold out method was performed [19]. It showed a cross-validation score of 0.959.

In our study, it has been also noted that in the non-ischemic group, 21 men showed an increment in the R wave amplitude in the mean age group of 52 whereas only 7 women from the mean age group of 51.7 showed an increment in R wave. The mean increase in the amplitude of R wave for males was 248 μV and for females, it was 212 μV.

V. CONCLUSION

ΔRST index was thus more useful in detecting ischemia and coronary artery disease with higher sensitivity and specificity among the studied groups to reduce the false responses due to primary ST changes. There were variations concerning age, gender, and heart rate but they did not reach a statistical significance. The RF model for lead II is having accuracy and precision of 0.944 and 0.961. Similarly, for lead V5, the RF classifier showed the best results (AUC=0.99), with an accuracy of 0.963 and a precision of 0.981. Hence, lead V5 is the most suitable one to indicate ischemia. For future studies, further analysis of ΔRST index is necessary in a wider range of population.

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