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Improving The Diagnostic Accuracy of Exercise Stress Testing in Detecting Coronary Heart Disease using St/Hr Hysteresis

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Abstract
Exercise electrocardiography (ECG) stress testing is a widely used non-invasive examination due to its low cost and ease of implementation; however, the standard ST-segment depression parameter has limited diagnostic accuracy. ST/HR hysteresis, which considers ST-segment changes relative to heart rate during exercise and recovery phases, offers greater diagnostic capacity than conventional parameters. This diagnostic study, conducted at Sanglah Hospital, Denpasar, from December 2018 to April 2019, assessed improvements in exercise stress testing for detecting CHD using ST/HR hysteresis. ST/HR hysteresis values were analyzed from secondary data of 134 patients, with 59 (44%) confirmed to have significant CHD via coronary angiography. ROC analysis identified an optimal cut-off of ≥0.026 mV (AUC 84.8%, sensitivity 79.7%, specificity 85.3%)—superior to conventional ST-segment depression (sensitivity 64.4%, specificity 49.3%). NRI analysis showed a 0.28 improvement when adding ST/HR hysteresis to standard parameters. Thus, ST/HR hysteresis enhances diagnostic accuracy and serves as an effective additional parameter for CHD detection.
Keywords: Coronary Heart Disease, Exercise Stress Testing, ST/HR Hysteresis, Electrocardiography, Diagnostic Accuracy

INTRODUCTION

One of the developments in the world of health is the epidemiological transition of diseases and the increase in life expectancy compared to previous decades. The cause of death that was initially dominated by infectious diseases and malnutrition about two centuries ago has shifted to cancer and cardiovascular disease (Zipes et al., 2018). Cardiovascular disease that is still the leading cause of death in the world is coronary heart disease (CHD) (Shi et al., 2016).

The prevalence of coronary heart disease in various countries is still high, for example in the United Kingdom it is estimated at 3%, while in Wales, Scotland and Northern Ireland it is 4%. (Bhatnagar et al., 2016). In America, 1 in 3 deaths is caused by cardiovascular disease. As many as 43.8% of the cardiovascular diseases that cause death are CHD. In 2015, it was estimated that heart disease was the cause of death of 17.9 million people worldwide, and it is expected to increase to 23.6 million by 2030 (Association, 2018).

Meanwhile, in Indonesia, the prevalence of heart disease in 2018 based on basic health research data (RISKESDAS) is 1.5%, where the province of Bali has a prevalence that is close to the national figure (RI, 2018). At the Sanglah Central General Hospital Denpasar itself, there were 10,974 patients with CHD who were controlled in integrated cardiac services in 2016 (around 60.3%).

Invasive coronary angiography is still the gold standard test for diagnosing CHD, although it has the drawback of being able to evaluate only the lumen of the coronary artery, not the existing plaque. Another examination that is often used is the cardiac training test with electrocardiography (ECG) which has the advantage of being able to evaluate the relationship between ischemia and complaints from sufferers (ESC et al., 2013).

In addition to the effect on mortality, cardiovascular disease is also directly or indirectly an economic burden, with an estimated cost of around 329.7 billion US dollars (around 4,624 trillion rupiah, with an exchange rate of 1 US dollar = 14,025 rupiah) (Association, 2018). Meanwhile, in Indonesia, based on the financial statements of the social security administration agency (BPJS) in 2016, for chronic outpatient patients around 4.2 trillion rupiah, which includes cardiovascular diseases (Health, 2016).

Various ways are done to overcome the problems caused by cardiovascular diseases above. One of the studies conducted by Kahn et al. that evaluated 11 types of recommendations for cardiovascular disease found that the application of aggressive prevention with early detection can reduce the burden of cardiovascular disease (Kahn et al., 2008).

In this era of high health costs with an increase in the prevalence of cardiovascular diseases, a better allocation of available resources is needed. The cardiac training test is a solution to the problem because it uses minimal cost, without radiation, is reliable and vital in the interpretation of the disease. Even in initial conditions with normal electrocardiography, the cardio test is reliable and relatively easy to perform with results comparable to Technitium–99 m sestamibi perfusion imaging (Vaidya, 2017).

However, in other studies, it is known that standard parameters using ST segment depression during cardiac training tests have limited diagnostic capacity. The use of ST/HR hysteresis measures continuous changes of the ST segment that also considers heart rate (*heart rate*/ HR) during cardiac training tests in some studies showed higher diagnostic ability. In addition to being better than the use of standard parameters of cardiac training tests, ST/HR hysteresis is also better than the parameters of *cardiopulmonary exercise test* (CPET) (Zimarino et al., 2013).

Knowing the weakness of the standard parameters used during the cardiac training test in detecting the presence of coronary heart disease, research will be conducted on the diagnostic accuracy of ST/HR hysteresis in the heart training test for the detection of significant coronary heart disease. This study was carried out because of a heart training test with Minimal cost, no radiation, reliable, and easy to do still has great potential to develop. By using ST/HR hysteresis it is hoped that it will increase the diagnostic capacity of the cardiac training test.

Based on the background presented, this research seeks to determine whether the use of ST/HR hysteresis can improve the diagnostic accuracy of cardiac stress tests in detecting coronary heart disease. Therefore, the primary objective of this study is to specifically assess the enhancement in diagnostic accuracy that ST/HR hysteresis provides for these tests.

Should the findings confirm that ST/HR hysteresis improves diagnostic accuracy, this research will offer significant benefits. Academically, it will contribute valuable data and guidelines for applying this method, while also enriching scientific evidence regarding its role as a non-invasive tool. Practically, it aims to provide a more effective and efficient examination technique, thereby supporting the use of ST/HR hysteresis to optimize the diagnostic process for coronary heart disease.

RESEARCH METHOD

This study is a diagnostic study to determine the diagnostic capacity of ST/HR hysteresis in the detection of CHD. Patients suspected of CHD who underwent a standard cardiac training test examination and also underwent an invasive angiography examination were then analyzed for ST/HR hysteresis values from the stored data. The ST/HR hysteresis value obtained was then carried out a diagnostic test and looked for a cut-off based on the *receiver operating characteristic* (ROC) curve.

The research was conducted in the non-invasive supportive examination room and cardiac catheterization room, Sanglah Denpasar Hospital. The research was carried out from December 2018 – April 2019. The population was all patients with suspected CHD who underwent cardiac training test examination and coronary angiography. The affordable population was all patients with suspected CHD who have undergone cardiac training tests and coronary angiography examinations at Sanglah Hospital.

Samples selected from affordable populations, after meeting inclusion and exclusion criteria. *Actual study subjects* are samples that have complete data to be included in the research. Samples are taken from secondary data and determined consecutively , namely sampling by assigning subjects who meet the criteria as research samples until the required number of samples is reached.

The research included all patients with suspected CHD who have undergone cardiac training test examination and coronary angiography at Sanglah Hospital, with ST/HR hysteresis data available. Meanwhile, it excluded patients with post-stent placement patients without symptoms, after coronary bypass surgery, and with incomplete cardiac training test data, ST/HR hysteresis or angiography.

In this study, the significance level of $p < 0.05$ was used, type I error was 5%, and the one-way hypothesis. Type II error of 10%. The estimated sample count is calculated based on the following formula (Sophia, 2009):

$$n = \left[\frac{Z\alpha \sqrt{2V_1} + Z\beta \sqrt{V_1 + V_2}}{(\theta_1 - \theta_2)^2} \right]^2$$

Zα with a α meaning of 0.05 (95% CI) : 1,64, with Zβ : 1,28. The AUC value of the previous known parameter, i.e. the AUC of the change in the ST segment = 0.66 (Fearon et al., 2000), θ1 – θ2 : differences The minimum AUC value that is considered meaningful is set at 0.15, so that i1 = 0.81. So,

Zα = 1.64;	Q11 = 0.81 : (2 - 0.81) = 0.68
Zβ = 1.28;	Q21 = 2 x 0.812 : (1 + 0.81) = 0.725
I1 – I2 = 0.1	Q12 = 0.66 : (2 - 0.66) = 0.492
θ2 = 0.66	Q22 = 2 x 0.662 : (1 + 0.66) = 0.525
θ1 = 0.81	

V1 = 0.68 + 0.725 – 2 x 0.812 = 0.0928

V2 = 0.492 + 0.525 – 2 x 0.662 = 0.1458

$n = (8.87)^2 = 78.677 \sim 79$

Number of samples (n) = 79

The variables are determined according to the planned research design. The variables are as follows:

1. The independent variable is ST/HR hysteresis
2. The dependent variable is coronary heart disease
3. The Control Variables were changes in ST segments and coronary angiography.

The relationship of the research variables can be illustrated in the following diagram:

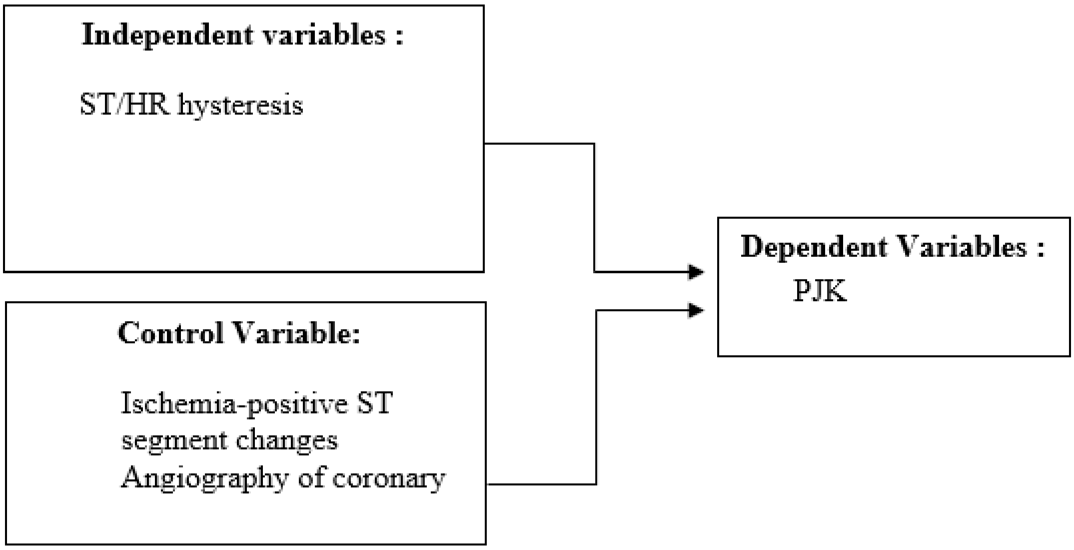

Figure 1. Relationships Between Variables

Operational definition of research variables
Coronary Heart Disease: narrowing of the coronary vessels of the heart ≥50% in the main coronary artery or ≥ 70% in one/several major branches known through coronary angiography examination, where the condition causes chest complaints (generally chest pain or tightness) during activity or stress.
Changes in the ST segment are positive for ischemia, changes in the ST segment that are positive indicate the presence of ischemia when performing a heart training test which is divided into 2 criteria:
Diagnostic criteria for myocardial ischemia (positive response)
The depression of the ST segment > 1 mm below the isoelectric line at 60 milliseconds after the J point (when the ST segment is horizontal depression or downsloping).
The depression of the ST segment > 1.5 mm below the isoelectric line at 80 milliseconds after the J point (when the depression of the ST segment is upsloping).
The elevation of the ST segment (and the elevation of the J point) > 1 mm at 80 milliseconds after the J point.
Elevation of the ST segment in aVR. This condition is considered to be like a horizontal ST segment depression
Suggestive criteria of myocardial ischemia
Segment depression between 0.5 – 1 mm below the isoelectric line at 60 milliseconds after the J point (when the ST segment depression is horizontal or downsloping).
The depression of the ST segment was > 0.7 mm and < 1.5 mm below the isoelectric line at 80 milliseconds after the J point (when the depression of the ST segment was upsloping).
The elevation of the ST segment (with J point elevation) is between 0.5 mm and 1 mm

1. **Coronary angiography**: an invasive examination that is performed to evaluate the lumen of coronary blood vessels so that it can be determined whether there is a narrowing and its degree. Evaluation was carried out on the right coronary artery, left main coronary artery, left anterior descending artery (Left Anterior Descending Artery), and circumflex coronary artery (Left Circumflex Coronary Artery).
2. **ST/HR hysteresis:** ST/HR hysteresis is the ratio of the area formed from the depression values of the ST segment during recovery and during exercise with the changes in HR that occur. The calculation was carried out by integrating the difference in the curve of the ST change value during training with the recovery time to the minimum HR value to the maximum HR in 3 minutes of recovery. The value obtained is divided by the difference in

HR during the period for normalization of ST/HR hysteresis considering the decremental factor of HR during recovery, then the final result is expressed in mV units. The calculation can be done manually assisted by software on the computer or automatically by a treadmill.

Research Materials

Secondary data containing data on patients undergoing cardiac training tests and coronary angiography, accompanied by ST/HR hysteresis data stored on the cardiac training test examination (GE Case Stress Test System, GE T2100 Treadmill).

Research Instruments

Medical records.

Research Procedure

Research Procedures

Subjects who underwent cardiac training test examinations at Sanglah Hospital were recorded with complete data including changes in ST and ST/HR hysteresis segments. Then an examination was carried out on the coronary angiography data in the cardiac catheterization room to find the availability of subject data. All research samples have been managed according to standard procedures

Research Flow

Subjects who underwent cardiac screening and coronary angiography based on appropriate clinical manifestations at Sanglah Hospital were an affordable population of this study. From this population, subjects who met the inclusion criteria and did not meet the exclusion criteria were taken as samples consecutively until they met the required number of samples. Based on the secondary data from the subject, the data collection sheet was filled. The results of the examination carried out have been verified by a specialist in heart and vascular diseases of the prevention & rehabilitation division and the invasive division. The data is then collected by the researcher and then analyzed.

Data Analysis

Data analysis is carried out in several stages, namely:

1. Receiver Operating Characteristic (ROC) curve analysis. This analysis aims to obtain the best cut-off point of ST/HR hysteresis for CHD detection. In this analysis, ST/HR hysteresis will be a categorical variable, and CHD is determined through coronary angiography as the refference variable. Then an ROC curve will be formed consisting of the X and Y axes. The X axis is 1-specificity, and the Y axis is the sensitivity. The best cut point is a specific ST/HR hysteresis that produces the highest accuracy value in detecting CHD based on coronary angiography.
2. Univariate analysis aims to describe the characteristics of the research subject in the form of a table, and will divide the research subjects into two groups based on the category of ST/HR hysteresis whose cut-off point has been predetermined, namely the group with ≥ cut-off value and the group with < cut-off value. Numerical data with normal distribution will be presented in the form of mean ± standard deviation. Numerical data with abnormal distributions will be presented in a median form. Data that is categorical will be presented in the form of frequency distribution.
3. Diagnostic analysis, in the form of sensitivity and specificity values. The independent variable in this study was ST/HR hysteresis. The dependent variable is CHD. In this analysis, positive prediction values (NPV), negative prediction values (NPN), positive probability ratios (RKP), negative probability ratios (RKN), accuracy, and net reclassification improvement (NRI) will also be obtained.

Data analysis was carried out using the IBM Statistical Package for the Social Science (SPSS) Statistic 25 program.

RESEARCH RESULTS

During the period from December 2018 to April 2019, an observational study was conducted with a diagnostic test design, which took place at Sanglah Hospital, Denpasar. This research was conducted in the non-invasive supporting examination room and cardiac catheterization room of Sanglah Hospital Denpasar.

The samples in this study are all patients with suspected CHD who have undergone cardiac training tests and coronary angiography at Sanglah Hospital. The patients involved in this study amounted to 134 people consisting of 106 males (79.1%) and 28 females (20.9%), with a mean age of 55.4 ± to 8.8 years (the youngest age was 33 years, and the oldest was 74 years). There were 59 CHD patients with significant lesions (44%), with details of 18 patients (13.4%) 1-vessel disease, 19 patients (14.2%) 2-vessel disease, 22 patients with 3-vessel disease, and 10 patients (7.5%) with left-main lesions. Normal/insignificant angiography results were obtained in 75 patients (56%). For the 134 patients, the value of ST/HR hysteresis stored in the cardiac training test device was recorded. The study population was grouped into 2 groups based on the value of ST/HR hysteresis to the cut-off according to the results of the ROC curve analysis.

ROC Curve Analysis

The value limit to determine the cut-off value of ST/HR hysteresis uses data collected from this study by creating an ROC curve. The ROC curve expressing the value of ST/HR hysteresis as a diagnostic tool is shown in Figure 2. Based on the ROC curve analysis, the best cut off point value in using the ST/HR hysteresis value to detect CHD was ≥ 0.026 mV with an area under curve/AUC value of 84.8% (IK 95% 77.7%-91.2%, p<0.001), sensitivity 79.7% and specificity 85.3%. The sensitivity and specificity values of ST segment changes in this study were 64.4% and 49.3%, respectively.

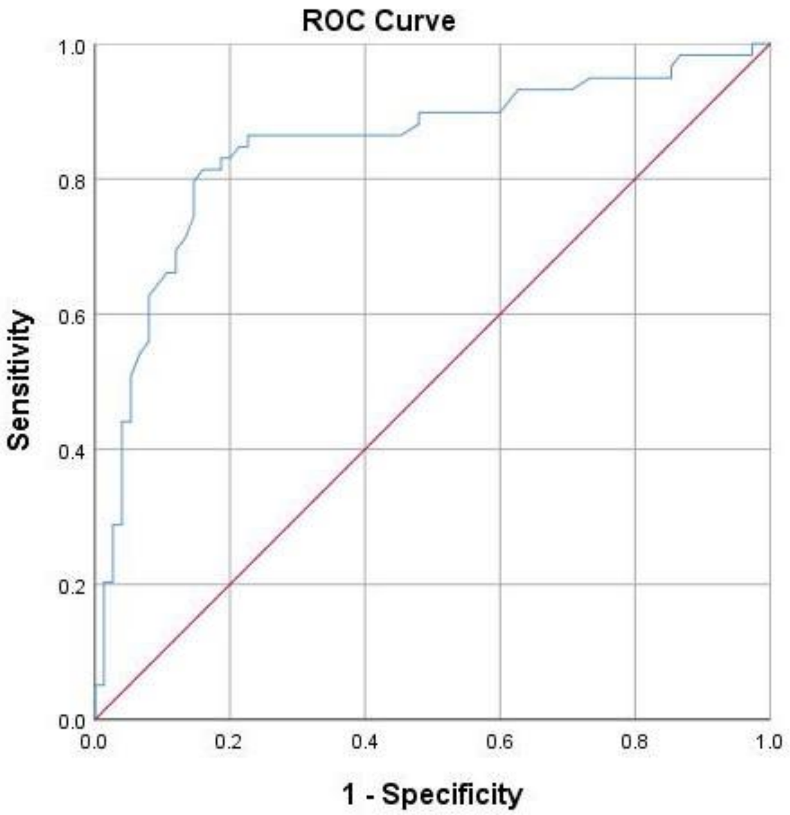

Figure 2. ROC curve in determining the cut off point of the ST/HR hysteresis value for CHD detection

Characteristics of Research Subjects

The results of the descriptive analysis of the study population are shown in table 5.1, grouped into two groups based on the ST/HR hysteresis value based on the *cut off point* of the ROC curve analysis. There were 59 CHD patients with significant lesions (44%), with details of 18 patients (13.4%) 1-vessel disease, 19 patients (14.2%) 2-vessel *disease*, 22 patients with 3-vessel *disease*, and 10 patients (7.5%) with *left-main lesions*. A total of 58 patients had a ≥ ST/HR hysteresis value of 0.026 mv, while 76 patients had an ST/HR value of < 0.026 mV.

Table 1. Description of the characteristics of the subjects and the study variables based on the value of ST/HR hysteresis (< 0.026 mv vs ≥ 0.026 mV)

Variable	**ST/HR hysteresis**	
	Value < 0.026 mV (n = 76)	**Value ≥ 0.026 mV (n = 58)**
Ages (averages ± SD)	54,14± 8,7	57,07±8,6
Gender, n(%)		
	59 (77,6%)	47 (81%)
Women	17 (22,4%)	11 (19%)
PJK, n(%)		
1 *Vessel Disease*	4 (5,3%)	14 (24,1%)
2 *Vessel Disease*	2 (2,6%)	17 (29,3%)
3 *Vessel Disease*	6 (7,9%)	16 (27,6%)
Lesi *left-main*	1 (1,3%)	9 (15,5%)
Angiography normal / lesi non-significan	64 (84,2%)	11 (19%)
Criteria for change in the ST,n(%) segment		
Positive	47 (61,8%)	54 (93,1%)
Negatives	29 (38,2%)	4 (6,9%)

ST/HR hysteresis in CHD detection

A total of 58 patients had an ST/HR hysteresis value of ≥ 0.026 mv, with 47 patients (81%) indeed with CHD. Meanwhile, of the 76 patients with an ST/HR value of < 0.026 mV, 64 patients (84.2%) were indeed with normal angiography results or non-significant lesions. The use of ≥ 0.026 mV ST/HR hysteresis value to detect CHD had an area under curve/AUC value of 84.8% (95% IK 77.7%-91.2%, p<0.001), sensitivity 79.7% and specificity 85.3%. The results of diagnostic analysis of ST/HR hysteresis compared to coronary angiography can be seen in table 2 below.

Table 2. Diagnostic capacity analysis of ST/HR hysteresis

		Coronary angiography (gold plating)	
		PJK (+)	PJK (-)
ST/HR hysteresis	PJK (+)	47	11
	PJK (-)	12	64
Sensitivity = 47 : 59 = 79.7%			
Specificity = 64 : 75 = 85.3%			
Positive conjecture = 47 : 58 = 81%			
Negative guess value = 64 : 76 = 84.2%			
Positive probability ratio = 0.797 : (1-0.853) = 5.42			
Negative probability ratio = (1-0.797) : 0.853 = 0.24			
Accuracy = 111 : 134 = 0.83			

Comparison of the use of ST/HR hysteresis with the use of ST segment change criteria in the detection of CHD

The results of the diagnostic analysis of ST/HR hysteresis were then compared with the analysis of the use of ST segment change criteria in the detection of CHD using net reclassification improvement (NRI) analysis to determine whether there was an increase in the accuracy of CHD diagnosis using ST/HR hysteresis compared to using ST segment changes. In the calculation, NRI was obtained as 0.28.

Table 3. Analysis of net reclassification improvement from the use of ST/HR hysteresis compared to standard criteria using ST segment changes in CHD detection

PJK (+) : red color		Standard criteria using ST segment changes			
PJK (-) : black color		Positive	Negatives	Total, split	Total
ST / HR hysteresis	Positive	**45** / **9**	**2** / **2**	**47** / **11**	58
	Negatives	**12** / **35**	**0** / **29**	**12** / **64**	76
	Total, split	**57** / **44**	**2** / **31**	**59** / **75**	
	Total	101	33		134
NRI = (2 – 12) : 59 + (35 – 2) : 75 = -0,1695 + 0,4459 = 0,2764 ~ **0,28**					

One of the developments in the world of health is the epidemiological transition of diseases and the increase in life expectancy compared to previous decades. The cause of death that was initially dominated by infectious diseases and malnutrition about two centuries ago has shifted to cancer and cardiovascular disease (Zipes et al., 2018). Based on estimated data *world health organization* (WHO) in 2015 around 20 million people suffered from cardiovascular disease. Cardiovascular disease that is still the leading cause of death in the world is coronary heart disease (CHD) (Shi et al., 2016).

The prevalence of coronary heart disease in the UK is estimated at 3%, while in Wales, Scotland and Northern Ireland it is 4%. The prevalence of the disease is accompanied by an increase in the number of drugs issued and actions taken as treatment in the last decade (Bhatnagar et al., 2016). Based on European statistical data in 2017, there were 11.3 million new cases of CHD and it was the cause of death of 3.9 million people or 45% of the total causes of death in Europe (Wilkins et al., 2017).

In America, 1 in 3 deaths is caused by cardiovascular disease. A total of 92.1 million people suffer from cardiovascular disease, of which around 2300 people die every day or an average of 1 death every 38 seconds, of which 43.8% of the cardiovascular diseases that cause death are CHD. More specifically, in the U.S. 1 in 7 deaths are caused by CHD, with an average of every 40 seconds a person has a heart attack. In 2015, it was estimated that heart disease was the cause of death of 17.9 million people worldwide, and it is expected to increase to 23.6 million by 2030 (Association, 2018).

Meanwhile, in Indonesia, the prevalence of heart disease in 2018 based on basic health research data (RISKESDAS) is 1.5%, where the province of Bali has a prevalence that is close to the national figure (RI, 2018). At the Sanglah Central General Hospital Denpasar itself, there were 10,974 patients with CHD who were controlled in integrated cardiac services in 2016 (around 60.3%).

The most frequent complaints that can be caused by CHD are chest pain with location, characteristics, duration and relationship with typical activities. Other complaints that may also be shortness of breath, palpitations or tiredness. The physical examination carried out includes examination for anemia, hypertension, heart valve disease, cardiomyopathy or arrhythmia.

Screening for other comorbidities such as diabetes, thyroid function and kidney disease is also recommended (ESC et al., 2013).

Invasive coronary angiography is still the gold standard test for diagnosing CHD, although it has the drawback of being able to evaluate only the lumen of the coronary artery, not the existing plaque. Another examination that is often used is the cardiac training test with electrocardiography (ECG) which has the advantage of being able to evaluate the relationship between ischemia and complaints from sufferers (ESC et al., 2013).

In addition to the effect on mortality, cardiovascular disease is also directly or indirectly an economic burden, with an estimated cost of around 329.7 billion US dollars (around 4,624 trillion rupiah, with an exchange rate of 1 US dollar = 14,025 rupiah) (Association, 2018). Meanwhile, in Indonesia, based on the financial statements of the social security administration agency (BPJS) in 2016, for chronic outpatient patients around 4.2 trillion rupiah, which includes cardiovascular diseases (Health, 2016). In BPJS's 2017 financial statements, the projected cost deficit for the following year is estimated at 13.48 trillion rupiah (Health, 2016). Another problem that exists is the imbalance of costs incurred by hospitals with the rates used by BPJS references (Indonesian Case Base Groups / ina-CBGs) which makes it difficult for hospitals to provide services to patients with heart disease according to standard guidelines because the claims obtained are lower than the costs incurred (Mardiah, 2018).

Various ways are done to overcome the problems caused by cardiovascular diseases above. One of the studies conducted by Kahn et al. that evaluated 11 types of recommendations for cardiovascular disease found that the application of aggressive prevention with early detection can reduce the burden of cardiovascular disease (Kahn et al., 2008).

In this era of high health costs with an increase in the prevalence of cardiovascular diseases, a better allocation of available resources is needed. The cardiac training test is a solution to the problem because it uses minimal cost, without radiation, is reliable and vital in the interpretation of the disease. Even in initial conditions with normal electrocardiography, the cardio test is reliable and relatively easy to perform with results comparable to Technitium–99 m sestamibi perfusion imaging (Vaidya, 2017).

However, in other studies, it is known that standard parameters using ST segment depression during cardiac training tests have limited diagnostic capacity. The use of ST/HR hysteresis measures continuous changes of the ST segment that also considers heart rate (heart rate/ HR) during cardiac training tests in some studies showed higher diagnostic ability. In addition to being better than the use of standard parameters of cardiac training tests, ST/HR hysteresis is also better than the parameters of cardiopulmonary exercise test (CPET) (Zimarino et al., 2013).

ST/HR hysteresis is the ratio of the area formed from the depression values of the ST segment during recovery and during exercise with the changes in HR that occur. The area formed from these 2 consecutive linear functions (exercise and recovery) can be either a negative ("clockwise" recovery loop) or a positive ("counterclockwise" recovery loop). Negative values are generally found in normal people, while positive values indicate a myocardial ischemic condition. (Zimarino et al., 2013).

Characteristics of Research Subjects

The sample in this study amounted to 134 people consisting of 106 men (79.1%) and 28 women (20.9%), with an average age of 55.4 ± 8.8 years (youngest age 33 years, and oldest 74 years). The findings of this study are in accordance with most other study results, where the proportion of men suffering from CHD is higher than that of women (Maas and Appelman, 2010). Age at risk of CHD from studies that produced CHD prediction models (Bösner et al., 2010) namely ≥55 years, while in other studies it is said that the risk of suffering from CHD begins to increase after the age of 40 (Roeters van Lennep et al., 2002). The findings of the study are in accordance with the results of this study, where the average patient evaluated with suspicion of CHD was 55 years old.

There were 59 CHD patients with significant lesions (44%), with details of 18 patients (13.4%) 1-vessel disease, 19 patients (14.2%) 2-vessel disease, 22 patients with 3-vessel disease, and 10 patients (7.5%) with left-main lesions. Normal/insignificant angiography results were obtained in 75 patients (56%). The sensitivity and specificity values of ST segment changes in this study were 64.4% and 49.3%, respectively. This study is in line with the statement in the guidelines of cardiac training tests, where cardiac training tests have limitations in diagnostic accuracy, sensitivity and specificity vary with a sensitivity range of 68% and specificity of 77% (Perki, 2016).

ROC Curve Analysis

In this study, a cut off point of ST/HR hysteresis value for CHD detection was 0.026 mV which showed good accuracy with an area under curve/AUC value of 84.8% (IK 95% 77.7%-91.2%, p<0.001), sensitivity 79.7% and specificity 85.3%. These results are similar to the results of a study conducted by Barnabei et al. on 56 patients, with a cut-off of ST/HR hysteresis obtained also 0.026 mV, AUC 82% (95% IK 69.9-91.3, p=0.001). In this study, it was also found that the accuracy of the diagnosis of ST/HR hysteresis was better than CPET (Barnabei et al., 2011). In a study by Lehtinen et al. that evaluated the use of ST/HR hysteresis in CHD detection, an AUC value of 89% was obtained which was higher than the AUC value of the use of ST segment depression at peak which was only 76% (p<0.001) and ST segment depression during recovery with a value of 84% (p = 0.006) (Lehtinen, 1999). However, in another study by Stanciu et al. that compared the results of perfusion imaging with a test using dipyridamol, a different cut-off value was obtained which was 0.015 mV (Stanciu et al., 2011). These differences may result from differences in populations and research methods used.

Comparison of the use of ST/HR hysteresis with the use of ST segment change criteria in the detection of CHD

This study also evaluated the improvement of diagnostic accuracy of cardiac training tests if added ST/HR hysteresis parameters using analysis net reclassification improvement (NRI). NRI values are in the range of -2 to 2. In this study, an NRI result of 0.28 was obtained which indicates that there is an increase in the ability to detect CHD by cardiac training tests when the ST/HR hysteresis parameter is added (Leening et al., 2014).

Research Limitations

This study has several limitations, namely the selection of research subjects is carried out by consecutive sampling (non-probability sampling) and the research is carried out using secondary data. This study has also not thoroughly analyzed the relationship of risk factors to ST/HR hysteresis. It is also necessary to develop research with long-term follow-up to determine the prognosis value of ST/HR hysteresis.

CONCLUSION

This diagnostic study demonstrated that ST/HR hysteresis offers superior diagnostic accuracy compared to standard parameters in exercise stress testing for coronary heart disease (CHD). With an optimal cut-off of ≥0.026 mV, it effectively detects CHD presence and, when used as a complement to conventional cardiac exercise test parameters, significantly enhances overall diagnostic performance. For future research, prospective multicenter studies could validate these findings across diverse populations, incorporating advanced imaging correlations and long-term outcomes to refine cut-off values and assess clinical implementation feasibility.

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