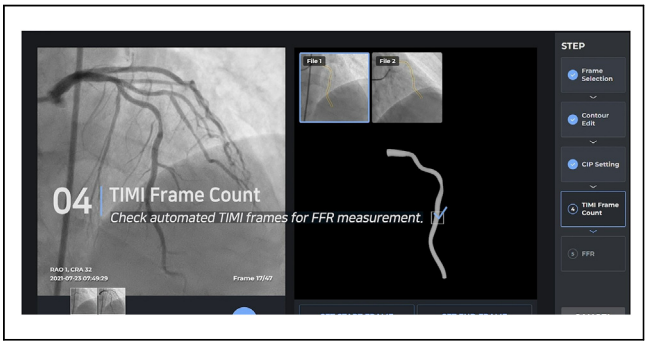

RESULTS Unlike most other companies making manual measurements, two of the four main processes have been automated, and the other two processes, CIP and TIMI Frame selection, are also automated through clinical trials. Currently, 10 centers in Korea are undergoing clinical trials for KFDA licenses, and data verified by Pilot will also be released in January, so it will be available during the conference.

CONCLUSION FFRxa, which measures FFR based on two Angiograms, the most important diagnostic method, proves to be the fastest and most accurate than any products currently available. Looking at the changes in FFR's new paradigm, we believe that it will be of great support to all medical staffs to perform the PCI procedure more conveniently.

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A Comprehensive Analysis on Severity of Stenosis Detection in Coronary Arteries Using Synchronized Electrocardiogram and Photoplethysmogram

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BACKGROUND Ischemic heart disease (IHD) is the main leading cause of death globally, which is responsible for 8.9 million deaths, around 16% of the world's total death in 2019. The same scenario happened in Malaysia, where the Department of Statistics Malaysia recorded 17% mortality caused by IHD in 2020. Coronary artery disease (CAD) is the most common form of IHD. It affects the coronary arteries of the heart and if not timely treated, it can lead to adverse effects such as heart attack or sudden cardiac death. CAD detection among IHD patients is complex and relies on a combined assessment of traditional cardiovascular risk factors, clinical symptoms, blood tests, and non-invasive tests such as electrocardiography (ECG) and exercise stress tests. The 12-lead ECG analysis can often reveal the evidence of a previous heart attack or one that is in progress. However, sole ECG analysis has low specificity and sensitivity, whereas ECG might be normal in patients at rest during angina. Non-invasive screening of CAD is normally done through an exercise stress test which is often inconclusive, and its sensitivity varies from about 14% to 88% for the detection of CAD. Invasive coronary angiography (ICA) is the gold standard method to diagnose CAD while coronary computed tomography angiography (CTA) is becoming more efficient as a non-invasive tool for a larger group of patients. Due to the complexity of both imaging tools, researchers have focused on the non-invasive method of electrocardiography (ECG) and photoplethysmography (PPG) for early IHD diagnosis. For CAD detection, heart rate variability (HRV), T-wave inversion, and ST-T abnormalities are among the observed parameters from ECG and PPG. Analysis of ECG and PPG are currently able to differentiate healthy from CAD subjects, but not on the severity level of the stenosis. Moreover, ECG and PPG waveforms are often analyzed separately whereas their synchronization could produce a few important parameters such as pulse arrival time (PAT) and pulse wave velocity, which are highly correlated with arterial stiffness in assessing CAD.

METHODS The objective of this study is to thoroughly analyze ECG, PPG, or their synchronized features that can differentiate the severity of stenosis in the coronary artery. This study includes 91 newly diagnosed IHD subjects (age: 54.22 ± 9.7 years) from Hospital Canselor Tuanku Muhriz (HCTM), Cheras, Malaysia. The subject's demographic data, vital signs parameters, and blood test results are collected with the patient's consent. Simultaneous recordings of single-lead ECG (lead II) and left index finger PPG are made for 10-minutes using a MAX86150EVS module (by Maxim Integrated) in the supine position, at rest. The percentage of coronary stenosis from ICA and CTA, as well as 12-lead ECG output, are collected as the benchmark in categorizing patients into their respective groups of case (stenosis≥70%) and control (stenosis<70%). Recorded waveforms are processed with signal filtering, quality indexing, and fiducial point detection. This signal processing is done automatically and successfully detected 11 fiducial points of ECG, 4 fiducial points of PPG and 5 fiducial points of second derivative PPG. A total of 155 time and frequency domain features are analyzed, concerning peak intervals, amplitudes, slope, and area by manipulating the previously detected fiducial points. This includes the measurement of pulse arrival time (PAT), the ratio of PAT between different PPG peaks, and the ratio of PAT over one complete pulse for the synchronized waveform. Statistical analysis of independent sample t-test and correlation matrix are employed to see the relation between features and target groups. Statistically significant features ($p<0.05$) are identified and used as inputs for machine learning (ML) algorithms to classify the subjects into severe and non-severe stenosis groups. Five ML algorithms investigated in this study are artificial neural network (ANN), discriminant analysis, decision tree, k-nearest neighbors, and support vector machine. Each ML model is trained with accumulative input features and validated with a 5-fold cross-validation method using 70% training data. The remaining 30% of the data are used to evaluate the detection performance.

RESULTS The initial study on 91 subjects showed that there is no correlation between demographic data (age, body-mass index, gender), blood sugar, lipid profile, and vital signs data of systolic blood pressure, heart rate, and HRV to the severity of stenosis in the coronary arteries. Nevertheless, 10 out of the 155 features extracted are found statistically significant in differentiating case from the control groups. Six significant from ECG are the rise time of R-peak ($p=0.022$), the rise time of P-peak ($p=0.049$), ST-T segment ($p=0.036$), QT interval ($p=0.028$), duration of R-peak to T-offset ($p=0.027$), and duration of T wave ($p=0.049$). For PPG and its second derivative waveform, only one feature is found statistically significant, which is the area ratio between the systolic and diastolic phases ($p=0.042$), both area are separated at the dicrotic notch location. The area is significant as changes in the systolic phase in the PPG is corresponds to the ST segment, which is when the ventricles are contracted. Meanwhile, synchronized ECG-PPG features highlighted three significant features of the PAT ratio between onset and notch ($p=0.031$), PAT ratio between systolic and diastolic ($p=0.044$), and the time ratio of PAT-onset to the current and preceding R-peak ($p=0.044$). These embodied ratio features of PAT are more significant than the original feature of PAT, although previous studies have shown them to be efficient in differentiating healthy subjects and CAD subjects. These 10 features are used as important predictors for the ML algorithms. After classification, it is found that the ANN model has successfully classified severe and non-severe stenosis of the coronary arteries with the highest accuracy, sensitivity, and specificity of 92.59%, 100%, and 81.82%, respectively. Slightly low specificity is attained because the total number of subjects in the control group is lower than the case group. The ML model has been properly trained as the value of area under the receiver operator characteristics curve is high (AUC_ROC=0.9261).

CONCLUSION To summarize, this study reveals the features from the STT segment in ECG, changes of in the systolic phase in PPG, as well as PAT from synchronized ECG-PPG are important predictors for severity of stenosis detection in the coronary arteries. This study has shown that non-invasive analysis of ECG features in combination to the analysis of PPG features is a potential tool or a promising method that can be adopted as an alternative technique to pre-diagnose CAD. Nevertheless, the specificity of the proposed technique may be improved with a greater number of control subjects.