SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Modification of SMWT for remote heart's functional capacity determination from oxygen consumption rate

Siti Norhayati Md Yassin[1], Mohd Afzan Othman[1,*], Nurul Ashikin Abdul Kadir[1], Mohd Azhar Abdul Razak[1], Umar Alhassan Haruna[2]

[1] Department of Computer and Electronic Engineering (ECED), Faculty of Electrical Engineering, Universiti Teknologi Malaysia, Skudai 81310, Johor, Malaysia
[2] Department of Computer Science, Jigawa State Polytechnic Dutse Nigeria

ABSTRACT

Cardiovascular disease (CVD) is series of diseases affects blood circulation and heart which are fatal to human being. CVD patients recorded that every each of them must have at least one among the following behavioural risks: smoking, diabetes, obesity, hypertension, high cholesterol, and sedentary lifestyle. The diagnosis for CVD is commonly through cardiac stress test. It is a test where electrocardiogram will be used to monitor heart activity under induced stress such as walking on treadmill. However, the facilities for the cardiac stress test are very limited and increasing number of patients with potential CVD caused a long queue for an appointment. This situation makes it hard for healthy people living with behavioral risk wanting for their heart to be checked. Therefore, in this paper, we proposed to determine heart functional capacity which can be done anywhere and sufficient to access heart condition. For this proposal, despite using treadmill-test, Six-Minutes Walking Test (SMWT) is utilized. SMWT induces stress while the heart's endurance parameters such as heart rate is extracted. This study developed an integrated sensor device which comprises of a sensor to detect step count calculate distance, and a pulse sensor that detect heart rate. Then, oxygen consumption rate during the SMWT, is computed. Metabolic equivalent of task (MET) is equal to the oxygen consumption rate during activity over resting oxygen consumption rate. Heart functional capacity classification is about exercise intensity and the MET of SMWT can be compared to the classification which allows this paper to determine heart functional capacity remotely using SMWT. Based on the results, the heart's functional capacity classification after performing SMWT using sensor device is Class 1, the same when using manual calculation for distance and heart rate. The device sensor somehow produce error at 20.63% when calculating oxygen uptake. Nevertheless, this paper is identified that the SMWT is able to classify the heart's functional capacity.

Keywords:

Cardiovascular diseases; behavioural risk factor; stride counter; NYHA functional classification; submaximal exercise.

* *Corresponding author.*
E-mail address: afzan@fke.utm.my

https://doi.org/10.37934/araset.54.2.181190

1. Introduction

Recently, the World Heart Federation (WHF) has released a World Heart Report 2023: Confronting the World's Number One Killer [1]. In the report, the federation presented their findings based on 2021 health data and has classify cardiovascular disease (CVD) as the leading cause of death worldwide. The report also cited another research. The research, which is the Global Burden of Cardiovascular Diseases and Risks Collaboration, 1990-2021 research by Lindstrom *et al.,* [2] in 2022, reported that in the same year, 20.5 million people died because of various cardiovascular conditions. It was also reported that the figure accounted for around one-third of all global deaths. Therefore, the WHF has conducted a comparison and presented that there was a significant increase from the 12.1 million CVD deaths recorded in 1990.

Subsequently, CVD is a major health concern globally and researchers have conducted different studies on CVD since long time ago. Based on etymology, according to a book by Lopez *et al.* in 2022, cardiovascular is a combination from Greek word "kardio" and Latin word "vascula" which means heart and vessels respectively. Therefore, CVD or heart diseases mean diseases or disorders arise from the cardiovascular system including heart and blood vessels. In the same book, the CVD is mainly classified as coronary artery disease (CAD) which is also referred to as coronary heart disease (CHD), cerebrovascular disease, peripheral artery disease (PAD), and aortic atherosclerosis. CAD results from decreased myocardial perfusion that causes angina due to ischemia and can result in myocardial infarction (MI), and/or heart failure [3]. According to the World Heart Report 2023, ischemia or ischemic heart disease is currently the leading cause of premature death in 146 countries for men and 98 countries for women. Meanwhile, the World Health Organization (WHO) in an online factsheet article published in 2021, they reported that from estimated number of 17.9 million CVD death in 2019, 85% of the deaths were due to heart attack and stroke [4]. WHO also reported that more than three quarters of the recorded CVD deaths in 2019 occurred in low- and middle-income countries (LMICs). Clearly, with these sets of statistical data, the number of deaths is related to the equipment, knowledge and technology in which, the increasing number of patients with potential CVD will cause a long queue for an appointment for a cardiac stress test. In LMICs, the facilities are limited. On top of that, problem piling for low- and mid-income patients as they might spend more on traveling and accommodation expenses, since most of them could only afford to be treated at government hospitals. However, only certain government hospitals provide the facilities, but they are located at urban area and far from rural areas where the low– and mid-income patients usually reside.

In the same factsheet article, WHO also presented the way to prevent CVD which is by addressing the behavioural risk factors such as tobacco use, unhealthy diet and obesity, physical inactivity and harmful use of alcohol. Even though the behavioural risk factors have been identified, it is important to have the heart monitored as some studies have found out that as some CVD patients showed several symptoms, and many CVD patients did not show any symptoms [5, 6]. The best monitoring to diagnose CVD is through stress test. Stress test is a monitoring of heart rhythm, blood pressure and breathing while doing physical activities [7, 8]. Normally, stress test uses treadmill where patients need to walk or run at certain level depending on their ability and their body attached to electrocardiography (ECG) device [7]. ECG device is a medical instrument used to measure and record the electrical activity of the heart to assess its rhythm and diagnose cardiac conditions [9, 10].

In this study, the proposed self-stress test is a Six-Minute Walk Test (SMWT). SMWT is an exercise that asks people to walk for six-minute at their normal pace. In addition, the SMWT was equipped with automated distance calculator built using a tiny-sized IMU sensor as the distance travelled is related with the heart endurance. Meanwhile, the monitoring device would be a sensor which can detect pulse which later can convert the pulse into heart rate. Without the specialist to lead the test, this study purpose that the endurance of the heart to be presented as the heart's functional capacity classification.

One of the features of CVD is exercise intolerance which accompanied with symptoms of fatigue and shortness of breath [5, 11, 12]. Those symptoms gradually reduce their physical activity and then, worsening the exercise intolerance. This is heart's functional disability [13]. However, heart's functional capacity classification to address the behavioral risk of CVD has not been elucidated through sensor and technology. In this study, the heart's functional capacity is estimated by applying sensor technology to obtain related parameters and by using certified classification of heart's functional capacity to map the MET value. The significance of this study is that this study able to highlight the importance of early detection of CVD. This study could also promote a healthy lifestyle, rather than live a sedentary lifestyle. Accordingly, the objectives of this study are: 1) to apply the oxygen consumption equation to find metabolic equation of task for SMWT; 2) to perform validation test on the sensor devices for capturing data for the oxygen consumption equation parameter; 3) to determine heart's functional capacity classification upon SMWT by comparing the metabolic equivalent of task value for SMWT to New York Heart Association (NYHA) heart's functional capacity classification. The next subsection explains the subject and the SMWT experiment while the results of the heart's functional capacity procedures are presented in the next section.

2. Methodology

2.1 MET Values Measurement for SMWT

In this study, it is necessary to conduct the SMWT and collect data that pose as variables for oxygen consumption or VO_2max equation. SMWT is a test which able to assess the submaximal level of heart's functional capacity of an individual while walking on a flat, hard surface in a period of six minutes. The test requires weight, gender, and age of the subject along with the heart rate and the distance to be able to calculate the oxygen consumption, VO_2max which later can assess the submaximal level of heart's functional capacity.

Basically, there are correlations between distance walked in the SMWT and the VO_2max. The distance is directly proportional to the VO_2max. One of the studies is conducted by Burr *et al.* in 2011 at which, the oxygen peak is used to predict aerobic fitness among healthy working adults aged 20- to 60-year-old [14]. In the study, the researchers found out that SMWT may be useful in the classification of aerobic fitness, which is associated with health outcomes. The equation for VO_2max is as in Eq. (1).

$$VO2max\ (ml/kg/min) = 70.161 + (0.023 \times distance) - (0.276\ \times weight) - (6.79 \times sex) - (0.193 \times resting\ HR) - (0.191 \times age) \tag{1}$$

In conclusion, it is important to consider individual characteristics, such as age, sex, and BMI, when using these equations to ensure accurate estimates of VO_2max and subsequently, MET values [15].

As the first step in determining the heart's functional capacity upon the SMWT, the MET value is measured to reflect the energy consumed during the SMWT which is directly proportional to heart's functional capacity [16-18]. The metabolic equivalent quantifies the intensity of physical activity which means for healthy person, certain physical activity produces a standard range of MET values. MET values of 1.0-1.5 is called sedentary, less than 3.0 MET is for light intensity physical activity, 3.0-6.0 MET is for moderate intensity physical activity and more than 6.0 MET representing vigorous intensity physical activity [19-21]. The equation to find the MET value is as in Eq. (2).

$$MET = (VO_2 \max of\ task\ (ml/kg/min)\ /\ VO2max\ of\ resting\ (3.5\ ml/kg/min)) \quad (2)$$

Then, the MET value obtained was mapped to the symptoms as per New York Heart Association (NYHA) heart's functional capacity classification. The NYHA heart's functional capacity suggested limitation to perform physical activity in each of the classes corresponding to usual symptoms which are fatigue, palpitation and dyspnea, when doing ordinary activity. Class I suggesting no limitation on physical activity as ordinary physical activity does not cause the usual symptoms; Class II has slight limitation of physical activity and ordinary physical activity results in the usual symptoms; Class III marked limitation of physical activity when less than ordinary activity causes usual symptoms; lastly, Class IV unable to carry on any physical activity without discomfort [22]. Thus, the table consisting of the MET value in comparison to NYHA functional classification is tabulated and is shown in Table 1.

Table 1
Table of MET values corresponding to the NYHA functional classification

CLASSIFICATION	SYMPTOMS	MET VALUE
Class I	No limitation on physical activity. The subject does not experience fatigue, dyspnoea or palpitation after performing physical activity.	>7
Class II	Slight limitation conducting physical activity. Ordinary activity caused fatigue, palpitation, dyspnoea or angina pectoris.	5
Class III	Obvious limitation to perform physical activity. Symptoms appear if attempt to do ordinary activity.	2-3
Class IV	Inability to perform any physical activity comfortably.	1.6

Table 1 is the standard in determining heart's functional capacity in this study. The MET value of SMWT obtained in the experiment conducted in this study will be interpreted using this table. The hypothesis is the least MET value of SMWT means least intense SMWT. If it is the case, based on Table 1, the least intense SMWT shows that the subject has inability to perform any physical activity comfortably.

2.2 Subject Background and Experiments Procedure

The subject background for the experiment were healthy and did not have health issues. According to the objectives of the study, there were three types of experiments conducted for this study. There were two experiment which each of the experiment is intended to validate the distance sensor and heart rate sensor respectively. While the third experiment is to observe the SMWT as a self-stress test to determine heart's functional capacity from oxygen consumption (VO_2max) equation.

For validation test, the device reliability was tested and was understand prior to the SMWT data collection by conducting simple tests. The test for distance sensor was a comparison test to actual distances. The device was brought to a walk at four different lengths, 10m, 40m, 100m, and 400m. The device was hold during the walks. A liquid crystal display (LCD) was connected to the device and the computed distance was displayed on the screen. The final distance is when the walking reaches the end of the length. The procedure was the same for all lengths.

Meanwhile, the test for the heart rate sensor is an elevated heart rate test. In this test, the heart rate of the subject was purposely elevated by asking them to perform heart stressing exercise depending on their fitness. The standard for the task is to be safe but able to increase the heart rate. The subject has to stop the exercise when they feel their heart beats faster and starting to gasping for air after exertion. The reliability of the heart rate sensor is test by comparing the heart rate reading before and after the exercise captured by the sensor with the ones obtained by taking radial pulse on the subjects' wrist and with the heart rate reading on a fingertip pulse oximeter.

Lastly, to perform SMWT experiment, the experiment took place at Stadium Azman Hashim, Universiti Teknologi Malaysia (UTM). The standard procedure for SMWT is to first take heart rate reading and start walk on a flat non-impedance walkway and normally a straight track with 20 to 30 m length, in back-and-forth order. Then, after six minutes has surpassed, the travelled distance was calculated manually using measuring tools.

2.3 Design and Development of the Device

In this sub-section, the design and the algorithm of the sensor device development is discussed. Basically, the device is for remote heart's functional capacity determination system which comprises of development of the distance sensor and heart-rate sensor system embedded into a microcontroller. In this study, the whole system is tested to serve its function as distance calculator and heart rate detector. Using the data captured by the sensor, the oxygen consumption rate was calculated before leading this study to the final study which is to determine heart's functional capacity. The diagram of the whole system was shown in Figure 1.

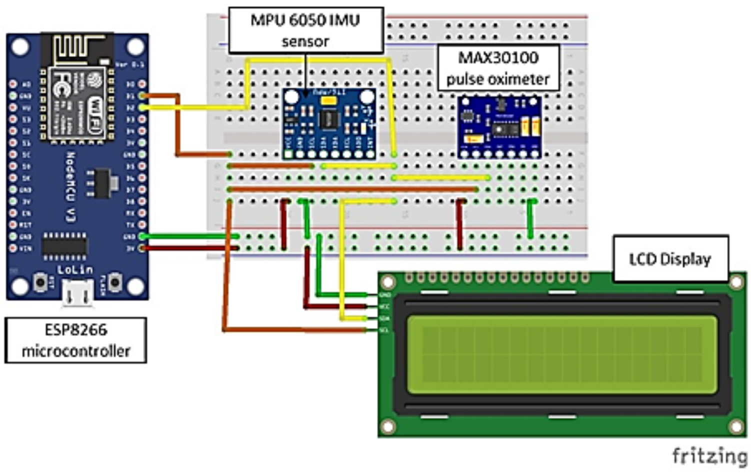

Fig. 1. Sketch of the circuit connection for the heart's functional capacity determination embedded system

Firstly, the components in the device were introduced and the functionality of the components was discussed. The microcontroller for this study is ESP8266. The microcontroller receives and send data to the distance sensor and heart rate sensor via its General-Purpose Input Output (GPIO) pin designated for Inter-Integrated Circuit (I^2C) bus. The microcontroller is powered by 10000 mA/hr at 2.1 A. The distance sensor used is an Inertial Measurement Unit (IMU) sensor, Adafruit MPU6050 which consisted of tri-axial accelerometer and tri-axial gyroscope. The heart rate sensor and pulse oximetry sensor used is Maxim Integrated MAX30100. The sensor can measure heart rate and SpO_2 levels in a range of 30 to 200 bpm and 0% to 100%, respectively.

Next, the algorithm applied onto the device are explained. The distance is computed by using mathematical expression which a multiplication of number of strides taken during walking with the distance between strides from the same walking. Stride which is a swing of one leg to advance forward from back of the other leg to the front, is calculated per swing. While step is the length between two different legs during walking when both legs touch the ground. The stride count is illustrated in Figure 2.

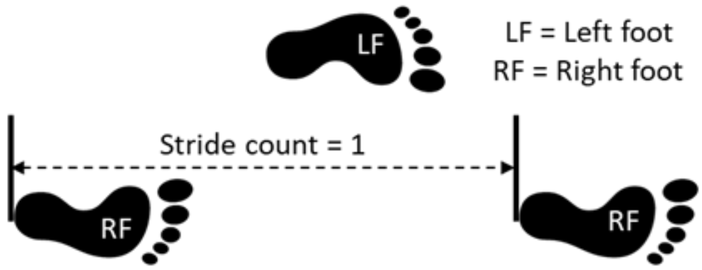

Fig. 2. Illustration of the walking stride

Generally, the IMU sensor is applied to detect the leg swing by one leg which by using Arduino IDE, a program is created to count the swing in order to count the number of strides. The algorithm to count the stride was applying acceleration detected by the accelerator of the IMU sensor and formulated the acceleration values using total displacement vector as in Eq. (3).

$$Total\ displacement\ vector\ = \sqrt{((a_x \cdot a_x) + (a_y \cdot a_y) + (a_z \cdot a_z))} \quad (3)$$

Total displacement vector basically collects acceleration, a at x- (a_x), y- (a_y), and z-axis (a_z). Accelerometer referenced to gravitational force which is 1g downward. Meanwhile, the effects of gravitational magnitude results in the vector of the gravity itself. Basically, this function calculating 3D vector of gravity using acceleration. Besides that, walking such in SMWT is a type of uniform acceleration vector which an equal amount of velocity increases in equal intervals of time.

The strides are counted when the differences between total displacement vector calculated at 380 ms now is more than 0.9 of the total displacement then. At every 380 ms, the total displacement vector is calculated. Finally, the walking distance, D (m) is computed using the number of strides and the mean distance between the strides, D_s (cm) which obtained in a pre-experiment by measuring the length of the strides manually. The formulae to calculate the distance is as in Eq. 4.

$$Distance, D\ (m) = (number\ of\ strides\ \times Ds(cm)) \times 100 \quad (4)$$

Whereas the heart rate detection works by calc The MAX30100 sensor works based on the principles of photoplethysmography (PPG), a non-invasive optical technique used to detect changes in blood volume. The sensor uses two LEDs (one red and one infrared) which these lights were projected across the finger from one side. On the other side of the finger, there is a photodiode to measure the amount of light absorbed or reflected by the blood vessels in the tissue being monitored. When the blood vessels expand and contract with each heartbeat, the amount of light absorbed or reflected changes, allowing the sensor to measure the heart rate and oxygen saturation. In other words, the changes in blood volume with each heartbeat cause a characteristic pattern in the PPG signal that can be processed to extract the heart rate.

3. Results and Discussion

3.1 Heart's Functional Capacity Parameter Validation Test – Distance

The sensor has been validated that it able to detect the stride when subject was walking. The walking distance was a product of mean distance between strides by the subject and the mean distance between the strides is 106 cm. The final reading was in metre (m) where 1 m equals to 100 cm. In this section, the results shown should express the reliability of the algorithm and the whole distance estimation system. The distances measured using the system compared to the actual length of the walking track are shown in Table 2.

Table 2
Distance computed by developed algorithm programmed for IMU sensor compared to actual distance

Actual distance (m)	Computed distance (m)	Percentage of error (%)
10	9.54	4.7
40	44.52	10.7
100	104.94	4.8
400	351.92	12.8

Based on the tabulated results in Table 2, it can be said that there is slight difference between the computed distance and the actual distance for the walking track with shorter track up to 100 metre. However, there are two times the computed distance exceeds the actual distance. The reason is because steps taken during walking are random and the final step could be few centimetres less or more than the finish line. On the other hand, the test performed on walking track with longer length could not get accuracy less than 10%. Usually, the SMWT is conducted on 10 to 30 m pathway. However, doing it on longer track is possible, just that the consistency of the stride lengths is reduced. Consequently, the computed distance which depends on the same stride length from the beginning to the end is lesser than the actual distance.

In conclusion, the part of the system developed to get the distance parameter for the VO_2max is reliable to measure the distance with satisfying performance and can be proceed with the SMWT experiment.

3.2 Heart's Functional Capacity Parameter Validation Test – Heart Rate

In this experiment, a simple task was assigned to test the algorithm design for the heart rate detection system. All subjects accomplished the task which their heart rate get elevated for the pulse oximeter embedded system able to take resting and elevated heart rate. The heart rate read by the pulse oximeter system, radial pulse, and fingertip pulse oximeter are tabulated in Table 3. The validation of the data is done by comparing the data recorded by the sensor device with the data counted manually. Additionally, the sensor data were also compared to data recorded by fingertip oximeter. The results from the comparison which in a form of percentage of errors are presented in Table 4.

Table 3
Heart rate computed by developed algorithm programmed for oximeter sensor compared to radial pulse and fingertip oximeter device

Subject	Heart Rate Before (bpm)			Heart Rate After (bpm)		
	Fingertip*	Self-count*	Prototype*	Fingertip	Self-count	Prototype
A	88	85	86	115	117	119
B	67	72	68	103	130	94
C	81	77	69	106	120	97

**Fingertip = Fingertip pulse oximeter, Self-count = Radial pulse, Prototype = heart rate sensor system developed in this study.*

Table 4
The percentage of differences as the results of comparisons between fingertip pulse oximeter with radial pulse, and between the developed heart rate detection system and radial pulse

Percentage of differences with 'Self-count*'	Before		After	
	Fingertip* (%)	Prototype* (%)	Fingertip (%)	Prototype (%)
A	3.47	1.17	2	2
B	7.19	5.71	23	32
C	5.06	10.96	12	21

**Fingertip = Fingertip pulse oximeter, Self-count = Radial pulse, Prototype = heart rate sensor system developed in this study.*

The data from the pulse oximeter system developed from this study is the one in the column named 'Prototype'. As can be seen, the values are tabulated as the results and as the comparison to radial pulse. The radial pulse is a manual count by feeling the lymph node beats representing the heartbeat in one minute. In other words, this method required no device and thus, be a reference point for the two heart rate detection devices.

During the test, the sequence of taking the heart rate is radial pulse, fingertip pulse oximeter and heart rate sensor. In addition, the subjects were different in fitness level and thus, different in breathing recovery. Hence, resulting in greater differences for 'after' data for fingertip oximeter and the heart rate sensor. However, as the results are only based on one trial set. The error with the radial pulse could be reduce if the trial set is done more than once.

3.3 Determination of Heart's Functional Capacity

The SMWT was performed on a 400 m marathon track which the average time taken walking for 400 m is around six minutes. Therefore, this makes the measurement of the actual distance at the end of the SMWT easier. This is because, the actual distance is required in the validation process of the distance measured by the distance sensor. In addition, the VO_2max and the MET value calculated based on the distance obtained by the distance sensor was compared with the VO_2max and the MET value calculated based on the actual distance. Finally, the heart's functional capacity was classified for both MET values which is after mapping the MET values to the NYHA functional classification. The following Table 5 is the data for the SMWT parameters (distance and heart rate), VO_2max, MET value, and the functional classification depending on the type of distance measurement. The other parameter for VO_2max has remained constant for age, gender and weight (age = 32 years old, gender = 1; female, weight = 60kg).

Table 5
Table of VO2max, MET values, heart rate and heart's functional capacity class for distance measured manually on track and distance measured by distance sensor developed in this study

Distance (m)	Resting heart rate (bpm)	VO_2max (ml/kg/min)	MET value	Heart's functional capacity class
Distance measured by sensor = 377.36	Heart rate sensor = 96	31.21	8.92	Class I
Distance measured manually = 389.9	Radial pulse = 92	38.39	10.97	Class I

Based on Table 5, which after seeing the computed distance results in other experiments in Table 2, the distance sensor could not achieve better result of distance measurement if being tested on longer track (i.e. 400 m). Therefore, when walking for six minutes which is approximately walking for 400 m, the measured distance is lesser than the actual. Other than that, the table also shows the heart rate sensor measured by the sensor is four beats lesser than the radial pulse beat. On the other hand, Table 6 shows the error for each value in a comparison between data by the sensor and the manual measurements.

Table 6
Percentage of error of the data obtained from sensor to the data obtained by manual calculation

Parameter	Percentage of error (%)
Distance	3.27
Heart rate	4.26
VO_2max	20.63
MET	20.61

Table 6 shown that the error percentage of MET values and VO_2max is greater and that was due to the greater error for the distance and the heart rate sensor. The error could be reduced with more sets of trials and subjects.

4. Conclusion

In conclusion, the SMWT modification for remote heart's functional capacity determination from oxygen consumption rate is possible but requires more sets of trials as improvement. The oxygen consumption equation was applied to determine the MET value for the Six-Minute Walk Test (SMWT). Meanwhile, the validation tests for the sensor devices used to collect data for the oxygen consumption equation parameters were successful, ensuring the accuracy and reliability of collected data. Finally, by comparing the SMWT-derived metabolic equivalent of task value to the NYHA heart's functional capacity classification, this study could effectively classify the functional capacity of individuals undergoing the SMWT. This practical application may enhance healthcare professionals' ability to assess and monitor patients with heart's functional capacity conditions. This study produced finding that can revolve around the importance of early detection of CVD so that management with counselling and medicines can begin. Consequently, the problem in high demand of stress test facilities can be tackled. Besides that, this study also provided healthy person with unhealthy lifestyle or with behavioural risks, an option to get their heart checked at early stages. Lastly, future research should build on these foundations to further explore the utility of metabolic equivalent of task and sensor technology in cardiovascular.

Acknowledgement
This work was supported/funded by the Ministry of Higher Education (MOHE) Malaysia under Fundamental Research Grantt Scheme (FRGS/1/2020/ICT05/UTM/02/1).

References
[1] Di Cesare, M., H. Bixby, T. Gaziano, L. Hadeed, C. Kabudula, D. Vaca McGhie, J. Mwangi, B. Pervan, P. Perel, and D. Piñeiro. "World Heart Report 2023: Confronting the World's Number One Killer." *World Heart Federation: Geneva, Switzerland* (2023).
[2] Lindstrom, Megan, Nicole DeCleene, Henry Dorsey, Valentin Fuster, Catherine O. Johnson, Kate E. LeGrand, George A. Mensah et al. "Global burden of cardiovascular diseases and risks collaboration, 1990-2021." *Journal of the American College of Cardiology* 80, no. 25 (2022): 2372-2425. https://doi.org/10.1016/j.jacc.2022.11.001
[3] Lopez, Edgardo Olvera. "Cardiovascular Disease." StatPearls. 2023.
[4] World Health Organization. *World Health Organization Fact Sheets: Cardiovascular diseases (CVDs).* 2021.
[5] Lu, Lei, Min Liu, RongRong Sun, Yi Zheng, and Peiying Zhang. "Myocardial infarction: symptoms and treatments." *Cell biochemistry and biophysics* 72 (2015): 865-867. https://doi.org/10.1007/s12013-015-0553-4

[6] Karjalainen, J. "A loud third heart sound and asymptomatic myocarditis during Mycoplasma pneumoniae infection." *European Heart Journal* 11, no. 10 (1990): 960-963. https://doi.org/10.1093/oxfordjournals.eurheartj.a059620
[7] Vilcant, Viliane, and Roman Zeltser. "Treadmill stress testing." In *StatPearls*. *StatPearls Publishing* (2022).
[8] Kharabsheh, Suleiman M., Abdulaziz Al-Sugair, Jehad Al-Buraiki, and Joman Farhan. "Overview of exercise stress testing." *Annals of Saudi medicine* 26, no. 1 (2006): 1-6. https://doi.org/10.5144/0256-4947.2006.1
[9] Mirvis, David M., and Ary L. Goldberger. "Electrocardiography." *Heart disease* 1 (2001): 82-128.
[10] Morris, Francis, William J. Brady, and A. John Camm, eds. *ABC of clinical electrocardiography*. John Wiley & Sons, 2009.
[11] Del Buono, Marco Giuseppe, Ross Arena, Barry A. Borlaug, Salvatore Carbone, Justin M. Canada, Danielle L. Kirkman, Ryan Garten et al. "Exercise intolerance in patients with heart failure: JACC state-of-the-art review." *Journal of the American College of Cardiology* 73, no. 17 (2019): 2209-2225. https://doi.org/10.1016/j.jacc.2019.01.072
[12] DeVon, Holli A. "Symptoms, sex differences, and special populations: Building the science of ischemic heart disease." (2020).
[13] Bohannon, Richard W., Deborah J. Bubela, Ying-Chih Wang, Susan S. Magasi, and Richard C. Gershon. "Six-minute walk test vs. three-minute step test for measuring functional endurance." *The Journal of Strength & Conditioning Research* 29, no. 11 (2015): 3240-3244. https://doi.org/10.1519/JSC.0000000000000253
[14] Burr, Jamie F., Shannon SD Bredin, Marc D. Faktor, and Darren ER Warburton. "The 6-minute walk test as a predictor of objectively measured aerobic fitness in healthy working-aged adults." *The Physician and sportsmedicine* 39, no. 2 (2011): 133-139. https://doi.org/10.3810/psm.2011.05.1904
[15] Jetté, Maurice, Ken Sidney, and G. Blümchen. "Metabolic equivalents (METS) in exercise testing, exercise prescription, and evaluation of functional capacity." *Clinical cardiology* 13, no. 8 (1990): 555-565. https://doi.org/10.1002/clc.4960130809
[16] Rostagno, Carlo, and Gian Franco Gensini. "Six minute walk test: a simple and useful test to evaluate functional capacity in patients with heart failure." *Internal and emergency medicine* 3, no. 3 (2008): 205-212. https://doi.org/10.1007/s11739-008-0130-6
[17] Ritti-Dias, Raphael Mendes, and Breno Quintella. "The six-minute step test as an alternative for functional capacity assessment in patients with cardiovascular diseases." *Arquivos Brasileiros de Cardiologia* 116 (2021): 896-897. https://doi.org/10.36660/abc.20210252
[18] Ritt, Luiz Eduardo Fonteles, Eduardo Sahade Darzé, Gustavo Freitas Feitosa, Jessica Santana Porto, Gabriela Bastos, Renata Braga Linhares de Albuquerque, Cristiane Miura Feitosa et al. "The Six-Minute Step Test as a Predictor of Functional Capacity according to Peak VO 2 in Cardiac Patients." *Arquivos Brasileiros de Cardiologia* 116 (2021): 889-895. https://doi.org/10.36660/abc.20190624
[19] Haskell, William L., I-Min Lee, Russell R. Pate, Kenneth E. Powell, Steven N. Blair, Barry A. Franklin, Caroline A. Macera, Gregory W. Heath, Paul D. Thompson, and Adrian Bauman. "Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association." *Circulation* 116, no. 9 (2007): 1081.
[20] Mendes, Márcio de Almeida, Inácio Da Silva, Virgilio Ramires, Felipe Reichert, Rafaela Martins, Rodrigo Ferreira, and Elaine Tomasi. "Metabolic equivalent of task (METs) thresholds as an indicator of physical activity intensity." *PloS one* 13, no. 7 (2018): e0200701. https://doi.org/10.1371/journal.pone.0200701
[21] Tashiro, Hiroki, and Koichiro Takahashi. "Clinical impacts of interventions for physical activity and sedentary behavior on patients with chronic obstructive pulmonary disease." *Journal of Clinical Medicine* 12, no. 4 (2023): 1631. https://doi.org/10.3390/jcm12041631
[22] Feinstein, Alvan R. "Diseases of the heart and blood vessels: nomenclature and criteria for diagnosis." *JAMA* 189, no. 11 (1964): 869-870. https://doi.org/10.1001/jama.1964.03070110071036

Name of Author	Email
Siti Norhayati Md Yassin	sitinorhayati@graduate.utm.my
Mohd Afzan Othman	afzan@utm.my
Nurul Ashikin Abdul Kadir	ashikin.kadir@utm.my
Mohd Azhar Abdul Razak	mohdazhar@utm.my
Umar Alhassan Haruna	ahumar@jigpoly.edu.ng