# SEMI-QUANTITATIVE ASSESSMENT OF MYOCARDIAL PERFUSION ABNORMALITY ON DIFFERENT RECONSTRUCTED SPECT POLAR MAPS.

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BY

NUR SYAZANA BINTI MOHD ZAHIR

Dissertation submitted in partial fulfilment of the requirements for the degree of Bachelor of Health Science (Honours) (Medical Radiation)

JULY 2020

# CERTIFICATE

This is to certify that the dissertation entitled

**"Semi-Quantitative Assessment of Myocardial Perfusion Abnormality on Different Reconstructed SPECT Polar Maps."**

are the bona fide records of research work done by;

**Ms NUR SYAZANA BINTI MOHD ZAHIR**

During the period from September 2019 to June 2020 under my supervision. I have read this dissertation and that in my opinion it conforms to acceptable standards of scholarly and is fully adequate, in scope and quality, as a dissertation to be submitted in partial fulfilment for the degree of Bachelor of Health Science (Honours) (Medical Radiation)

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# DECLARATION

I hereby declare that this dissertation is the result of my own investigations except where otherwise stated and duly acknowledged. I also declare that it has not been previously or currently submitted as a whole for any other degrees at Universiti Sains Malaysia or other institutions. I grant Universiti Sains Malaysia the right to use the dissertation for teaching research and promotional purposes.

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Date: _______________

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# LIST OF ABBREVATION AND ACRONYMS

| | | |
|---|---|---|
| CAD | : | Coronary artery disease |
| SSS | : | Summed Stress Score |
| SRS | : | Summed Rest Score |
| SDS | : | Summed Different Score |
| FBP | : | Filtered back projection |
| CT | : | Computed Tomography |
| AC | : | Attenuation correction |
| $^{99m}$Tc-MIBI | : | Methoxy-isobutyl-isonitrile(MIBI) labelled with Technetium-99m |
| SPECT | : | Single-photon emission computed tomography (SPECT) |
| MPI | : | Myocardial perfusion imaging |
| AHA | : | American Heart Association |
| SNR | : | Signal to noise ratio |
| GTN | : | Glyceryl Trinitrate |
| 2D | : | Two Dimensional |
| 3D | : | Three Dimensional |
| RCA | : | Right Coronary Artery |
| LAD | : | Left Anterior Descending Artery |
| ECG | : | Electrocardiogram |
| IQR | : | Interquartile range |

ABSTRACT

**Aim:** The aim of this study is to assess the validation of summed segmental scores in detection accuracy CAD from different reconstructed polar maps.

**Method:** The summed scores (SSS, SRS and SDS) were obtained from standard filtered backprojection reconstruction (FBP) and iterative reconstruction with CT-AC that being performed on the raw emission data of 30 patients (15 male and 15 females) with known or suspected coronary artery disease who had undergone two-day stress-rest or rest-stress $^{99m}$Tc-MIBI myocardial perfusion SPECT. The reconstruction algorithms and the resulting projected polar maps were used to estimate the radioactivity distribution within the left ventricular myocardium of the heart.

**Result:** Mean ± SD for all summed scores is higher in FBP than CT-AC with SSS in FBP 32.60 ± 5.360, SRS FBP 31.60 ± 5.069 and SDS FBP 3.87 ± 3.159. Meanwhile for SSS in CT-AC is 28.27 ± 5.245, SRS CT-AC 27.20 ± 4.397 and SDS CT-AC 3.27 ± 2.449. There is statistically significant difference of SSS and SRS between FBP and CT-AC tested using Mann-Whitney test (p value = 0.002 for SSS and p-value = 0.001 for SRS). However, there is no statistically significant difference of SDS between FBP and CT-AC tested using Mann-Whitney test (p value = 0.633).

**Conclusion:** Summed scores studies reconstructed with FBP are statistically not significantly different from AC. However, compensation for attenuation artifact is much better with iterative reconstruction CT-AC that FBP as CT-AC for SPECT MPI allows improved specificity of RCA territory compared with FBP reconstruction SPECT MPI.

**Keywords:** Myocardial perfusion SPECT; Coronary artery disease; Semi-quantification; Scoring system; Filtered backprojection; CT-attenuation correction

# ABSTRAK

**Tujuan:** Kajian ini asasnya bertujuan untuk menilai kebolehan penjumlahan segmen skor dalam mengesan penyakit koronari arteri yang dibina daripada beberapa jenis kaedah peta kutub.

**Kaedah:** Penjumlahan skor (SSS, SRS dan SDS) diperoleh daripada kaedah algoritma persaringan semula (FBP) dan pembinaan berulang dengan CT-AC dengan menggunakan data mentah daripada 30 orang pesakit (15 lelaki dan 15 perempuan) yang disyaki atau diketahui mempunyai penyakit koronari arteri. Mereka telah menduduki protokol tekanan-rehat atau rehat-tekanan $^{99m}$Tc-MIBI miokardial perfusi SPECT selama 2 hari. Penggunaan algoritma dan penghasilan peta kutub adalah untuk menganggar penyebaran radioaktiviti oleh miokardium ventrikel kiri jantung.

**Keputusan:** Min ± Sisihan piawai untuk kesemua penjumlahan skor lebih tinggi dengan menggunakan kaedah pembinaan FBP berbanding CT-AC dengan jumlah SSS FBP 32.60 ± 5.360, SRS FBP 31.60 ± 5.069 dan SDS FBP 3.87 ± 3.159. Manakala SSS dengan menggunakan kaedah pembinaan CT-AC adalah 28.27 ± 5.245, SRS CT-AC 27.20 ± 4.397 dan SDS CT-AC 3.27 ± 2.449. Terdapat signifikan statistik yang berbeza SSS dan SRS antara FBP dan CT-AC diuji dengan ujian Mann-Whitney (nilai p = 0.002 bagi SSS and nilai p = 0.001 bagi SRS). Namun begitu, tiada signifikan statistik yang berbeza SDS antara FBP dan CT-AC diuji dengan ujian Mann-Whitney (nilai p = 0.633).

**Kesimpulan:** Penjumlahan skor menggunakan kaedah pembinaan FBP tiada signifikan statistik yang berbeza berbanding CT-AC. Namun begitu, kesan artifak pelemahan adalah lebih baik dengan menggunakan kaedah pembinaan berulang dengan CT-AC berbanding FBP kerana CT-AC untuk SPECT miokardial perfusi pengimejan membolehkan penambahbaikan spesifikasi bagi arteri koronari kanan berbanding kaedah pembinaan FBP.

**Kata kunci**: Miokardial perfusi SPECT; Penyakit koronari artery; Separa kuantitifikasi; Penjumlahan sistem; Persaringan semula; Pembetulan pelemahan.

# CHAPTER 1: INTRODUCTION

## 1.1 BACKGROUND OF THE STUDY

SPECT MPI is a well-established method for evaluation of known or suspected CAD (Slomka, Miller et al. 2019). It also provides information regarding distribution of blood flow to heart muscle and the function the heart. Imaging of cardiac perfusion involves use the radiopharmaceuticals which are taken up by muscle cells of the heart and is directly proportional to the coronary blood flow. The most frequently used radiopharmaceutical is $^{99m}$Tc-MIBI. Myocardial perfusion assessment can be performed by qualitative evaluation and semi-quantitative segmental scoring system. This semi-quantitative segmental scoring system can be used to detect CAD. (Czaja Monika et al. 2017).

In Hospital Universiti Sains Malaysia, interpretation of SPECT myocardial perfusion is done visually based on reconstructed three orthogonal slice images the heart **(Figure 1.a)**. Therefore, this work is intended to determine the accuracy of new method of evaluation using semi-quantitative polar map in interpreting SPECT myocardial perfusion images **(Figure 1.b).**

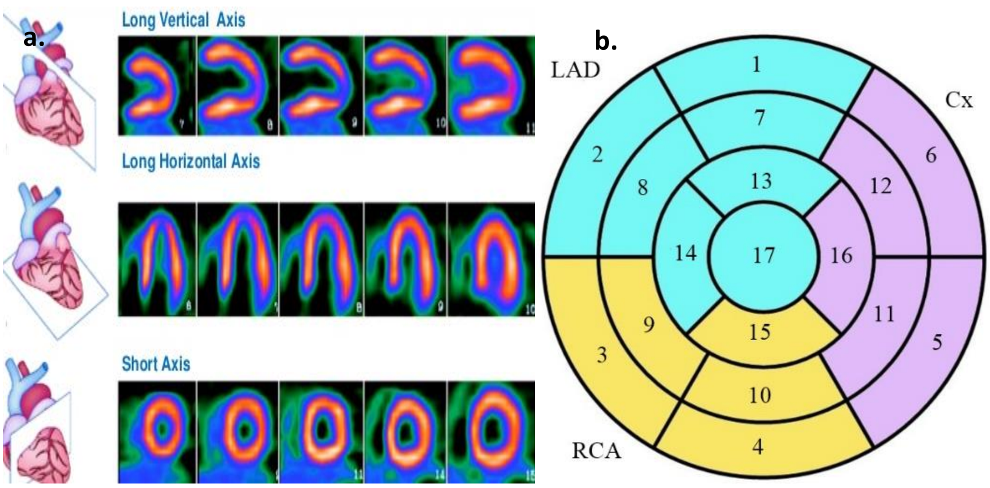

**Figure 1.** Assessment of SPECT MPI by: **a**. Reconstructed orthogonal slice images of heart and **b.** 17 segments division polar map established by American Heart Association (AHA, 2002).

## 1.2 AIM AND OBJECTIVES

### 1.2.1 MAIN OBJECTIVE

To evaluate semi-quantitative analysis using 17-segments polar map from myocardial SPECT images in the evaluation of myocardial perfusion abnormality using the FBP and CT-AC reconstruction methods.

### 1.2.2 SPECIFIC OBJECTIVES

1. To determine Sum Stress Score (SSS), Sum Rest Score (SRS) and Sum Difference Score (SDS) for filtered back projection (FBP) polar map.

2. To determine Sum Stress Score (SSS), Sum Rest Score (SRS) and Sum Difference Score (SDS) for iterative reconstruction with (CT-AC) polar map.

3. To compare mean value of Sum Stress Score (SSS), Sum Rest Score (SRS) and Sum Difference Score (SDS) between filtered backprojection (FBP) polar map and iterative reconstruction with (CT-AC) polar map.

## 1.3 PROBLEM STATEMENT

During interpreting images of heart using visual qualitative method, some defects were missed or misinterpreted. So, this work is intended to determine detection accuracy of coronary artery disease using semi-quantitative segmental scoring system. Furthermore, there may be slight variation in results of the sum scores between the polar maps generated by FBP and CT-AC. Hence this work is intended to assess the utilization of semi-quantitative analysis in detecting CAD as well as to assess the difference between summed scores obtain from FBP and CT-AC.

## 1.4 JUSTIFICATION OF STUDY

The significant of study is to acquire fundamental data in term of SSS, SRS and SDS on different reconstructed SPECT images to determine the myocardial perfusion abnormality. The data collected from this study may assist clinician in image interpretation and improved interpretation quality.

# CHAPTER 2: LITERATURE REVIEW

## 2.1 QUALITATIVE ASSESSMENT OF PERFUSION DEFECTS BY NUCLEAR MEDICINE PHYSICIAN.

Visual qualitative method in interpretation of myocardial perfusion defects were done using reconstructed 3 orthogonal slices or short axis, vertical axis and horizontal long axis of heart images. Interpretation of myocardial perfusion SPECT using conventional visual qualitative assessment of perfusion defects is usually subjective and prone to observer variability. The visual approach is based on observer dependent. It is very important for the physician to be familiar with normal regional variation and attenuation artifacts. (Hsu, Chen et al. 2008).

## 2.2 SEMI-QUANTITATIVE ASSESSMENT OF PERFUSION DEFECTS BY VISUAL SCORING SYSTEM.

Semi-quantitative visual scoring system using a left ventricular-segmented polar maps (17 or 20 segments) and scored with a five-point scale was developed and is widely used to standardize myocardial perfusion SPECT interpretation and aid in diagnoses of CAD (Holly, Abbott et al. 2010). The polar map is a 2D display of 3D distribution of radiopharmaceutical activity of the left ventricle. The left ventricular myocardial wall in tomogram perfusion images are divided into several segments, most commonly used is the 17 segments (**Figure 1.b**). The polar maps represent radionuclide counts within the left ventricle wall and is represented as rings for polar locations around the heart starting with the base as the outer-most ring and progresses towards the apex at the center. The counts in the polar map are normalized as percentage of overall maximum wall count. Each segment is scored separately using a 5-point scoring system (**Table 1**) ranging from 0 (normal uptake) to 4 (no uptake). This semi-quantitative scoring system provides a standard and reproducible assessment of perfusion defect severity by means perfusion deficit on polar map.

SSS, SRS and SDS can provide valuable diagnostic and prognostic parameters (Dabbagh Kakhki *et al.*, 2014). The proper interpretation of cardiac perfusion imaging using the semi-quantitative method not only enables the diagnosis of significant stress ischemia, but also provides valuable prognostic information hence influencing the choice of treatment to be provided to the patients; either optimal pharmacological therapy or invasive treatment (Czaja Monika et al. 2017).

## 2.3 EVALUATION OF SPECT MYOCARDIAL PERFUSION ABNORMALITY WITH FBP DATA CORRECTION.

FBP is a reconstruction algorithm that is still the most widely used in clinical SPECT image reconstruction due to its simplicity, speed and computational efficiency. Two major steps are undertaken in FBP which are filtering the data followed by back projection of the filtered data. The measured attenuation of all projections is simply summed or averaged evenly and contributes to intensity values for each pixel. This process is repeated for all pixels and all angles. The limited resulting projection sets will cause star artefact leading to blurring of the image. To overcome this blurred image, the projections are filtered using Butterworth filter before being back projected onto the images (Lyra and Ploussi, 2011). A study by Salihin and Zakaria showed that Butterworth filter is the most appropriate filter for myocardial SPECT whereby it has the best compromise between SNR and image detail.

FBP requires pre-defined gender specification. This is important due to the anatomical difference between male and female. The presence of diaphragmatic attenuation in males and breast attenuation in females may result in lower accuracy in detection of CAD if the uncorrected slices are used and reconstructed with FBP. True defect from disease and attenuation due to diaphragm is hard to be distinguish from each other on the polar map of images reconstructed with FBP (Pretorius *et al.*, 2003).

## 2.4 EVALUATION OF SPECT MYOCARDIAL PERFUSION ABNORMALITY WITH ITERATIVE RECONSTRUCTION CT-AC DATA CORRECTION.

Iterative reconstruction starts with an initial estimated image from a uniform activity distribution. Then, a set of projection data is estimated from the initial estimate image using a mathematical process which is called forward projection. The resulting projection data are then compared with recorded projections data and the different between those two projections data are used to update the earlier estimated image. This process will be repeated until the calculated and measured data are smaller or equal to the specified preselected value (Lyra and Ploussi, 2011).

Nowadays, even with progressive medical technology, soft tissue attenuation is still a hindrance in the path of the diagnostic accuracy of myocardial perfusion imaging. Soft tissue photon attenuation produces inhomogeneous defects which decreases the particularity of the SPECT MPI test, thereby making it difficult to distinguish between coronary artery disease and the attenuation artifacts. This may lead to predominant increase in false positive studies (Raza *et al.,* 2016). Some of the common attenuation artefacts found are diaphragmatic and breast attenuation. In addition, an obese patient may show lateral wall artefact. These artefacts sufficiently can affect the study quality and accuracy. Therefore, to overcome and better discriminate perfusion defects from artefacts in MPI studies such as soft-tissue attenuation and prominent subdiaphragmatic gastrointestinal activity, AC by CT has widely been used. The attenuation effect problem has recently been addressed with the advancement of technology and development of newer processing software. Evaluation of SPECT myocardial perfusion using iterative-CT(AC) reconstruction method is able to eliminate false perfusion deficits from attenuation of emission by extra-cardiac tissues (Pazhenkottil, A.P et al. 2011).

AC is very important in SPECT-MPI as heart itself is an organ located posterior to the sternum, superior to the diaphragm and in between the lungs hence is exposed to possible source of attenuation. Therefore, we need eliminate these surrounding tissues with the use of AC. Massood et al. first proved that clinical based CT-AC of MPI indeed improve diagnostic accuracy of MPI SPECT. With the used of AC, separation of normal and abnormal polar map regions can be seen clearly, and this is achieved by overcoming the attenuation and subsequently reducing the artifacts.  This is the reasons why The American Society of Nuclear Cardiology (ASNC) and the Society of Nuclear Medicine and Molecular Imaging (SNMM) have jointly recommend the use of AC in every SPECT MPI studies to eventually improve the image and remove the attenuation artifacts (Heller, Links et al. 2004).

# CHAPTER 3: MATERIALS AND METHODS

## 3.1 RESEARCH DESIGN

This study was a retrospective study utilizing information that has been collected and kept in a database as patient record. The aim of this study is to determine the value of semi-quantitative method of myocardial perfusion SPECT with 17-segments polar map and assess the difference the SSS, SRS and SDS between FBP polar map and iterative reconstruction with (CT-AC) polar map in the assessment of coronary artery disease

## 3.2 SCOPE OF STUDY.

This study involved data from 30 patients who underwent SPECT MPI in Hospital Universiti Sains Malaysia (Hospital USM) from October 2018 to October 2019.

## 3.3 STUDY LOCATION

The data was collected from computer database of Nuclear Medicine Unit at Nuclear Medicine, Radiotherapy and Oncology Department, Hospital USM.

## 3.4 RECRUITMENT

30 patients randomly selected based on the predefined inclusion and exclusion criteria. The number of patients recruited was based on the number of available patients in the database of Nuclear Medicine Unit at Hospital USM within the stipulated time period.

## 3.5 INCLUSION CRITERIA

1. Patient with known or suspected Coronary Artery Disease (CAD), who had underwent two-days stress-rest $^{99m}$Tc-MIBI SPECT myocardial perfusion imaging procedure from October 2018 to October 2019.

2. Irrespective of gender and age.

### 3.6 EXCLUSION CRITERIA

1. Incomplete Stress-rest $^{99m}$Tc-MIBI SPECT myocardial perfusion imaging procedure (eg: stress only or rest only studies).

2. $^{99m}$ Tc- MIBI SPECT myocardial viability study.

### 3.7 PROTOCOL OF MYOCARDIAL PERFUSION SPECT

All patients had undergone two-days stress-rest or rest-stress protocols. Approximately 20 mCi of $^{99m}$Tc-MIBI was injected intravenously for each study.

For the rest procedure, GTN was given sublingually followed by intravenous administration of $^{99m}$Tc-MIBI 15 minutes later. SPECT acquisition was performed 30-45 minutes after injection of radiopharmaceutical.

For the stress study, patient was required to nil-by-mouth at least 4 hours prior to undergoing stress procedure. Patient would then undergo either an exercise stress test using a treadmill or a pharmacological stress test using dipyridamole, adenosine or dobutamine. Pharmacological stress test was preferred for patients who are unable to adequately exercise. The stress test was conducted as per department protocol (**Figure 9**). Upon completion of stress test, patient was allowed to eat, and Myocardial Perfusion SPECT was performed approximately 45 minutes after the stress test.

Both stress and rest imaging procedures were done in conjunction with ECG monitoring to evaluate heart movement, overall heart function and to keep tract of the patient's heartbeat. Patient with myocardial ischemia will result in a serious abnormal heart rhythm.

## 3.8 ETHICAL APPROVAL

Human Research Ethics Committee of USM (JEPeM) has reviewed the research proposal for ethical consideration and has given the consent to conduct this study. This study was assigned under study protocol code USM/JEPeM/19120863 with ethical clearance validation from 3rd March 2020 until 2nd March 2021 (**Appendix C**).

## 3.9 ASSESSMENT OF MYOCARDIAL PERFUSION ABNORMALITY USING SEMI-QUANTITATIVE SEGMENTAL SCORING SYSTEM

### 3.9.1 DATA ACQUISITION AND RECONSTRUCTION.

SPECT acquisition performed with a Dual-head SPECT / CT (GE Discovery* NM/CT 670 Pro) which is combination of a gamma camera and computed-tomography (CT). SPECT system were equipped with a low-energy-high resolution collimator. A 20% window centring at 140 keV energy peaks was used. A total of 60 projections (10 seconds per projection) over 180 ° arc (step-and-shot mode) were acquired. Zoom factor of 1.45 was used.

All images were stored in a 64×64 matrix. Reconstruction of tomographic images were done by two methods which were FBP and iterative reconstruction-(CT-AC). Both reconstruction methods were available in SPECT processing software developed by GE Healthcare. Scatter correction and Butterworth filter with cutoff frequency 0.52, order 5 used during FBP reconstruction to improve the clinical images by reducing noise and preserving the image resolution. Every time AC was used for iterative reconstruction, the alignment of emission and transmission slices were visually checked and corrected, if necessary (**Figure 10**). The goal of image co-registration was to precisely superimpose, in all three dimensions, cardiac radiotracer activity data from the SPECT scan and the cardiac attenuation data from the CT scan. The reconstructed data was then transferred to the Xeleris work station and the reconstructed 3D-tomographic image of left ventricular wall perfusion was then transformed into a polar map.

### 3.9.2 DATA ANALYSIS

#### 3.9.2.1 17 SEGMENTS POLAR MAP.

A 2D polar map was generated from the reconstructed 3D tomographic images using GE Myovation Evolution software developed by GE Healthcare. Two polar maps for each patient which had been reconstructed with FBP and CT-AC were developed. The Left ventricular myocardial walls in tomogram perfusion images were divided into 17 segments. The analysis was done by calculating average values (expressed as a percentage of the maximum) in 17 different regions of the left ventricular wall. When a perfusion defect (lower radiotracer activity) was found, its location was determined in relation to the segments affected by ischemia.

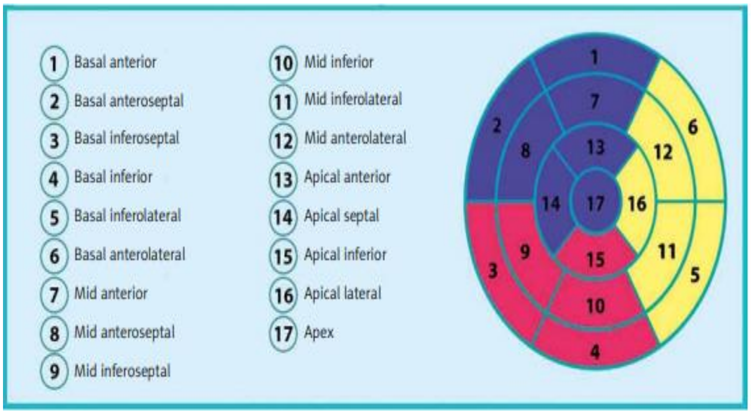


**Figure 2**. 17 segments division polar map established by American Heart Association (AHA, 2002).

The segments are numbered in counter clockwise order. Based on the 17-segments polar map (**Figure 2**), basal segments are numbered 1–6, middle segments as 7–12, and 13-16 indicates para-apical segments. This figure also assigns the segments to particular coronary artery groups. The area assigned to the left anterior descending artery and its branches is marked with blue, the group of segments assigned to the circumflex artery and its branches is marked with yellow, and the right coronary artery group is marked with red. The setting of polar map segments to its specific coronary arteries is approximate and schematic and it may vary depending to the type of left ventricular vascularization.

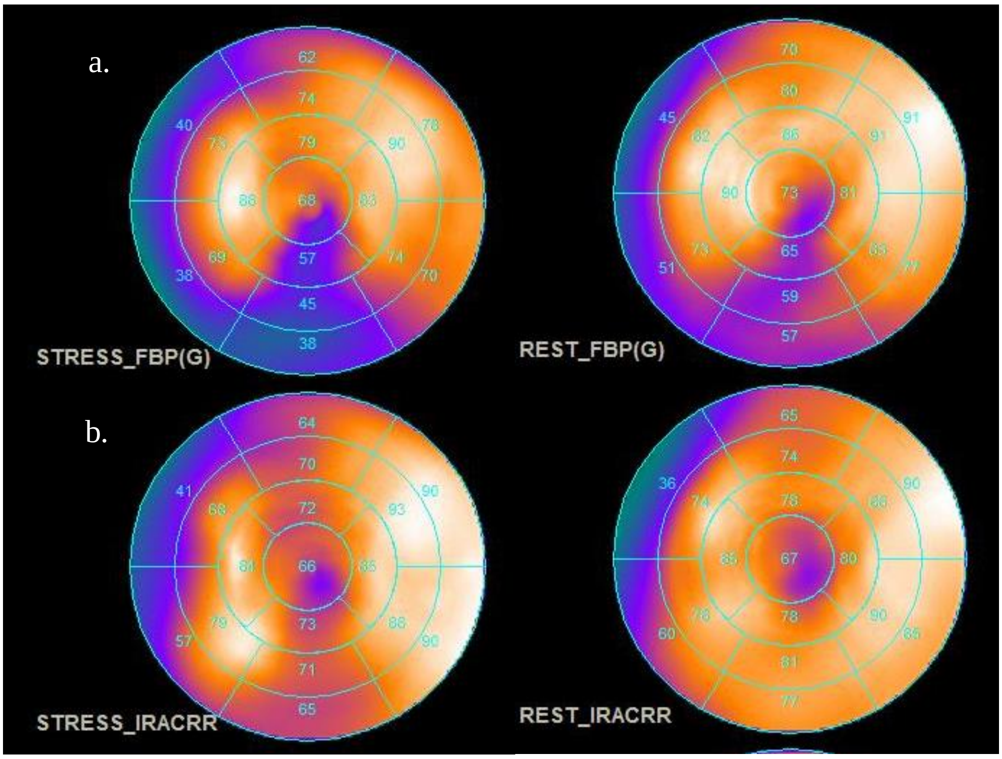


**Figure 3.** 17 segments of polar map show **a.** Stress and rest perfusion (%) with FBP and **b.** Stress and rest perfusion (%) with iterative reconstruction-(CT-AC). The values inside the segments indicate as percentage radiotracer accumulated. This myocardial perfusion results are achieved in Nuclear Medicine and Radiotherapy department Hospital USM (GE Myovation evaluation software).

### 3.9.2.2 Five-point scale

The left ventricular perfusion deficit is represented by a score of 0-4 with normal perfusion with 100% radiotracer accumulation has a score of 0 where else total impairment with 40% or less radiotracer accumulation has a score of 4. **Table 1** summarizes the breakdown of score, percentage radiotracer accumulation and description of perfusion.

| **Perfusion** | **Percentage radiotracer accumulated** | **Score** |
|---|---|---|
| Normal perfusion | 100 % | 0 |
| Mild impairment of perfusion | >80% | 1 |
| Moderate impairment of perfusion | 60% to 80% | 2 |
| Significant impairment of perfusion | 40% to 59% | 3 |
| Total impairment | <40% | 4 |

**Table 1.** A five-point scale for scoring myocardial perfusion

#### 3.9.2.3 SSS, SRS and SDS

Based on 17-segment 5-scale scoring system, SSS, SRS and SDS are calculated. SSS is sum of individual scores derived from 17 segments polar map during a stress study while SRS is the sum of individual scores derived from 17 segments polar map during a rest study. When SSS amounts to less than 4, the perfusion is considered normal or minimally abnormal (no significant perfusion disturbances), a result of 4–8 scores indicates mildly abnormal perfusion, 9–13 scores indicates moderately abnormal perfusion and 13 or more scores represent there is presence of significant extensive ischemia (**Table 2**). SDS can be calculate by subtracting SRS from SSS. SDS used to describe the degree to which the deficit or ischemia is reversible.

| SSS | SDS | Result |
|---|---|---|
| <4 | <2 | Normal or minimally abnormal result |
| 4-8 | 2-4 | Mildly abnormal result |
| 9-13 | 5-6 | Moderately abnormal result |
| >13 | >6 | Significantly abnormal result |

**Table 2**. Interpreting left ventricular perfusion scores. SSS- summed stress score and SDS-summed difference score (SDS).

## 3.10 STATISTICAL ANALYSIS.

Categorical variables such as gender were expressed as percentage. The mean ± standard deviation values of SSS, SRS and SDS for filtered back projection (FBP) polar map and iterative reconstruction with (CT-AC) polar map were acquired using descriptive analysis. Normality test were done to determine type of analysis to be done to compare either mean or median between two reconstructed method. Mean or median of SSS, SRS and SDS were then compared between FBP and CT-AC reconstruction methods of using Mann-Whitney test. P values less than 0.05 ($p < 0.05$) indicated significant difference. All data analyses were computed using SPSS 24.0 IBM.

# CHAPTER 4: RESULTS

The characteristic (gender) of the study population (n=30) were presented in **Table 3**.

| | | Frequency | Percent | Cumulative Percent |
|---|---|---|---|---|
| Gender | Male | 15 | 50.0 | 50.0 |
| | Female | 15 | 50.0 | 100.0 |
| | Total | 30 | 100.0 | |

**Table 3**: Gender Analysis

**Interpreting left ventricular perfusion scores.**

Example 1:

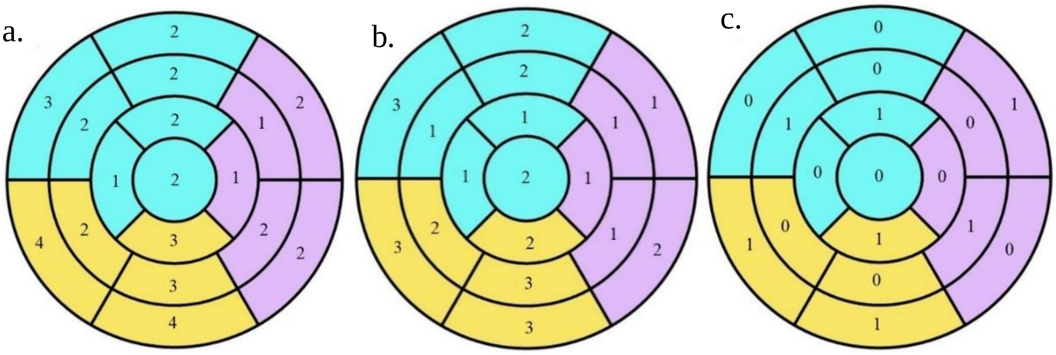


**Figure 4.** The above figure represents myocardial perfusion scoring during a. stress b. rest and c. different scores of stress and rest study using FBP reconstruction method. In this case (patient number 20), the summed score of perfusion deficits amounted to 38 during stress and 31 during rest. This result in SDS amounted to score of 7. The most severe perfusion deficit is located within antero-inferior wall according to AHA segmented scores. The artery responsible for the ischemia are LAD and RCA group. Due to the number of segments affected by stress perfusion deficits (more than one) and the SDS score of 7, the examination result is significantly positive.

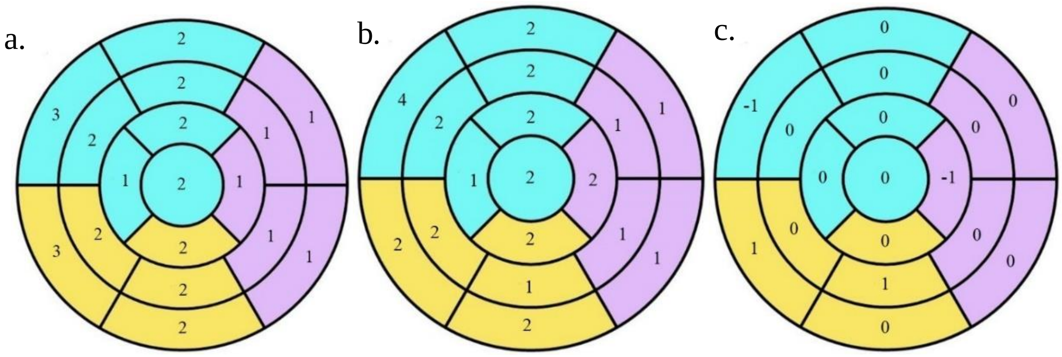


**Figure 5.** The figure presents myocardial perfusion scoring during a. stress b. rest and c. different scores of stress and rest study with used of iterative reconstruction with CT-AC method. In this case (same patient as in **Figure 4**), the summed score of perfusion deficits amounted to 30 during stress and rest. This result in SDS amounted to score of 0, that indicate examination result is significantly negative.

Example 2:

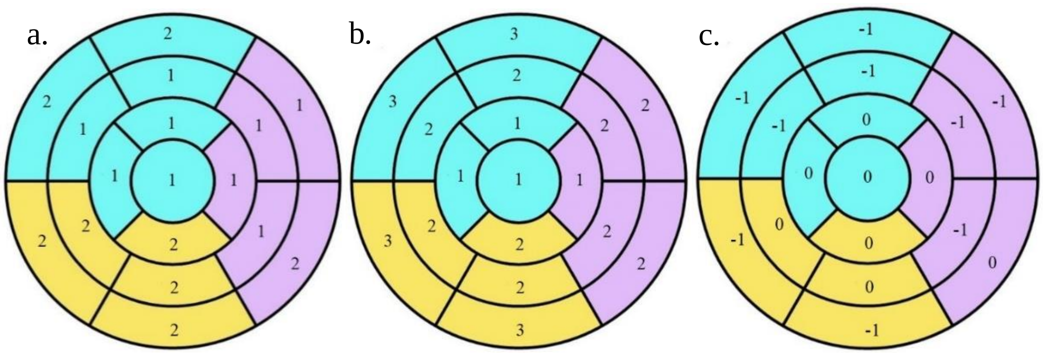


**Figure 6.** The above figure represents myocardial perfusion scoring during a. stress b. rest and c. different scores of stress and rest study using FBP reconstruction method. In this case (patient number 1), the summed score of perfusion deficits amounted to 25 during stress and 34 during rest . This result in SDS amounted to score of -9. According to the data from this patient, rest scores was worse than the stress scores which were 34 vs 25 hence it indicates a paradoxical change.

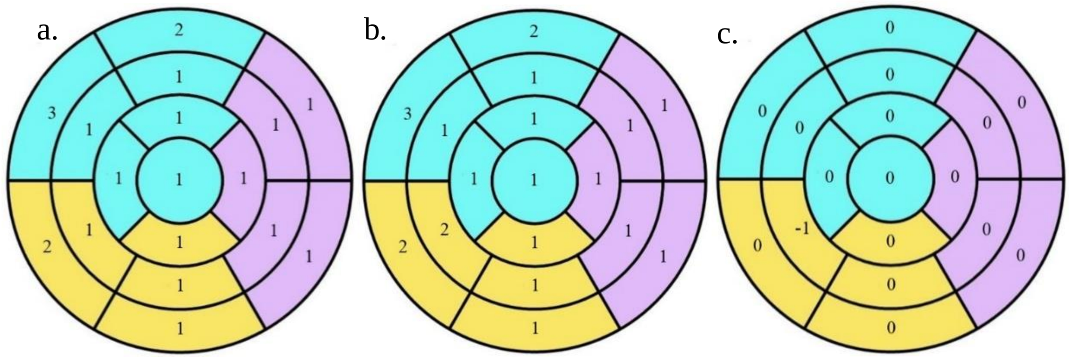


**Figure 7.** The above figure represents myocardial perfusion scoring during a. stress b. rest and c. different scores of stress and rest study using iterative reconstruction with CT-AC method. In this case (same patient as in **Figure 6**), the summed score of perfusion deficits amounted to 21 during stress and 22 during rest. This result in SDS amounted to score of -1. According to the data from this patient, rest scores was one digit more than the stress scores which were 22 vs 21 hence it indicates a paradoxical change.

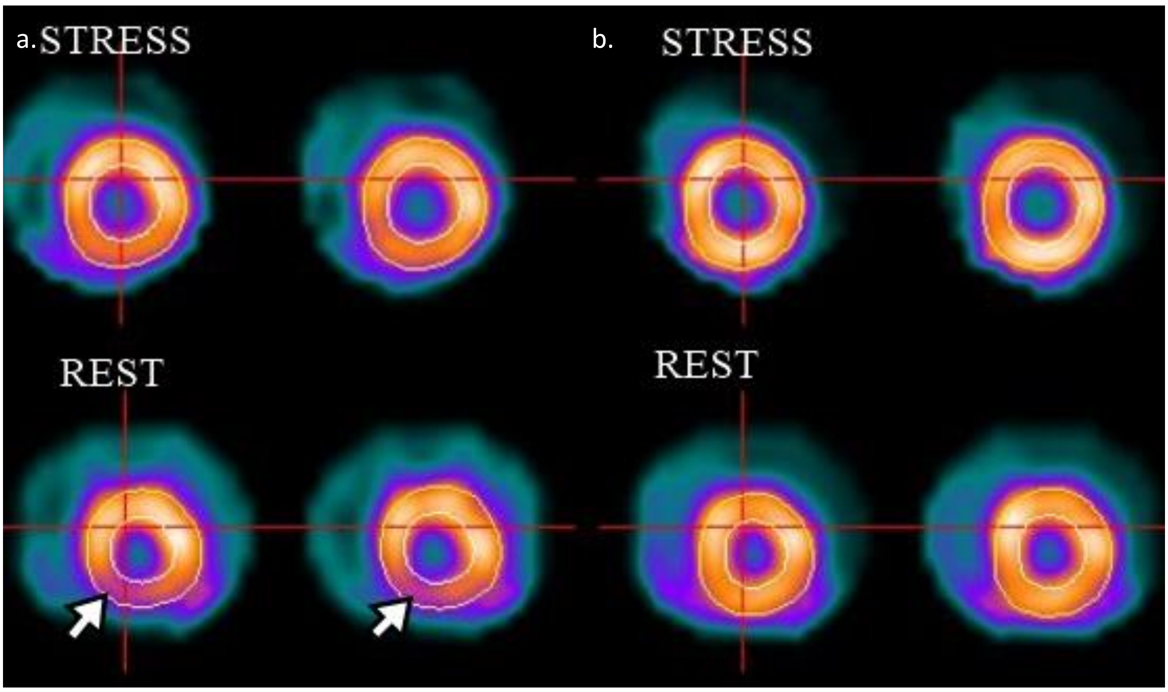


**Figure 8.** Short axes of heart image reconstructed with a. FBP (asses as significantly abnormal result, with perfusion defect in inferior wall-arrow) and b. Attenuation correction (assess as normal) of same patient as in **Figure 4.**

**Descriptive analysis**

The mean ± SD SSS is higher in FBP 32.60 ± 5.360 than CT-AC, 28.27 ± 5.245 with 95% CI of mean 30.60,34.60 and 26.31,30.23 respectively. The mean ± SD SRS is higher in FBP 31.60 ± 5.069 than CT-AC, 27.20 ± 4.397 with 95% CI of mean 29.71,33.49 and 25.56,28.84 respectively. The mean ± SD SDS is higher in FBP 3.87 ± 3.159 than CT-AC, 3.27 ± 2.449 with 95% CI of mean 2.69,5.05 and 2.35,4.18 respectively.

**Testing normality**

| | Mean | Median | Normality distributed | Test used |
|---|---|---|---|---|
| SSS FBP | 32.60 | 32.50 | Yes | Non-parametric Mann-Whitney |
| SSS CT-AC | 28.27 | 27.00 | No | |
| SRS FBP | 31.60 | 30.50 | No | Non-parametric Mann-Whitney |
| SRS CT-AC | 27.20 | 25.50 | No | |
| SDS FBP | 3.87 | 3.00 | No | Non-parametric Mann-Whitney |
| SDS CT-AC | 3.27 | 3.50 | No | |

**Table 4**: Normality test for SSS, SRS and SDS for FBP and CT-AC reconstruction methods.

**Statistical Analysis**

There was statistically significant difference of median between SSS FBP and CT-AC tested using based on the Mann-Whitney test (p value = 0.002). The median SSS of

FBP (32.50, IQR 9) was significantly higher compared to SSS of CT-AC (27.00, IQR 6). There was also statistically significant different of median SRS between FBP and CT-AC tested using Mann-Whitney test (p value = 0.001). The median SSS of FBP (30.50, IQR 5) was significantly higher compared to SSS of CT-AC (25.50, IQR 6). However, there was no statistically significant different of median SDS between FBP and CT-AC tested using Mann-Whitney test (p value = 0.633).

| Variable | Median (IQR) SSS | | Z statistic | P value[a] |
|---|---|---|---|---|
| | FBP | CT-AC | | |
| SSS | 32.50 (9) | 27.00 (6) | 3.148 | 0.002 |
| SRS | 30.50 (5) | 25.50 (6) | 3.421 | 0.001 |
| SDS | 3.00 (5) | 3.50 (4) | 0.477 | 0.633 |

[a] Mann-Whitney test

**Table 5**. Comparison of SSS, SRS and SDS between FBP and CT-AC (n=30).

# CHAPTER 5: DISCUSSION

In semi- quantitative analysis of myocardial perfusion using 17 segment polar maps, it is possible to determine perfusion scores by means of SSS, SRS and SDS (Czaja Monika et al. 2017). During stress test, blood flow through heart is maximized making any blockage of coronary arteries easier to detect. In addition, stress test will lead to increase in myocardial tissue demand leading to increase radiotracer localization within the myocardial tissues. However reduced blood flow due to blockage in coronary arteries would cause a reduction in radiotracer localization at the affected site in comparison to other sites thus making the deficit more apparent. Semi-quantitative measure such as SSS is used in quantifying the deficit during stress. During resting condition however, adequate blood flow to the healthy myocardial tissues is achieved and this is reflected by the homogenous radiotracer uptake throughout the myocardium. Rest study and the ensued SRS value is then compared with SSS value during stress study and the resulting SDS value is the measure of deficit.

Both set studies will look same in normal patient. In an ideal situation, the SSS would be higher than the SRS thus the resulting SDS is indicative of reversible perfusion defect or ischemia. However, in some instances, SRS value are higher than SSS value, resulting in a negative SDS value. This is due to existence of paradoxical situation in which significant increases in rest scores with an excellent exercise or pharmacological tolerance (Lafitte *et al.*, 2013). This case normally happened to patient with valvular heart disease such as aortic stenosis or mitral stenosis. A coronary stenosis detected when a myocardial segment takes up radiopharmaceutical at rest but not or less during cardiac stress study. This is called a reversible defect perfusion (Gibbons *et al.*, 2002). Defect in a region of both stress and rest images (fixed defect) could either attenuation artifact (normal study) or an area of myocardial infraction (abnormal study). ECG-gated stress image is very useful in differentiating between these two defects. An area of myocardial infarction will show abnormal wall motion and wall thickening while in attenuation artefact, wall motion and wall thickness will be seen as normal (Dvorak et al., 2011).

Image quality from the SPECT studies basically depend on several factors such as spatial resolution (detail or sharpness), contrast and statistical noise on the images. Therefore, to preserve the quality of the images, specialized reconstructed software such as image filtering is used. Image filtering (Butterworth filter) used in this FBP reconstruction technique not only maintain the resolution and overcome statistical noise but also preserves good quality of reconstructed images in spite of low counts in raw projection images that is very helpful in everyday practise of nuclear medicine departments. Based on the result, mean ± SD for all summed scores is higher with the FBP reconstructed method compared to CT-AC reconstructed method. This resulted in good detection of radiopharmaceutical distribution despite of low radioactive activity as well as low count in the raw projections. Maria Lyra and Agapi Ploussi are also in agreement that Butterwort filter is the appropriate filter for $^{99m}$Tc images to be used in clinical practise. Other 3D reconstruction methods including resolution recovery such as image filter and scatter correction help in preserving the quality of reconstructed images despite the reduction of counts in raw projections.

Masood et al. first approved the clinical worthiness of CT-attenuation correction of MPI and proved that it can improve the diagnostic accuracy of MPI SPECT. Sometimes, increased in number of myocardial segments perfusion defects may be due to the attenuation artifact. Besides gives fixed perfusion defects, that attenuation artifact may also produce reversible perfusion defects as well. Attenuation caused by body shift and relative anatomic positions during stress and rest imaging is common especially when rest and stress studies are done on different days. Utilization of CT for attenuation correction alleviates this problem as better anatomical correlation could be applied. Furthermore, despite not applying image filtering or scatter correction for iterative reconstruction, normalcy rate (normal myocardial perfusion studies) result of CT-AC method is much better than FBP. This is shown in this study as CT-AC reconstruction method increases the normalcy rate (normal myocardial perfusion studies) as compared to FBP method. This was achieved by reducing the number of studies with mildly abnormal result, likely attributed to attenuation artifacts.

As mention earlier, soft tissue attenuation and subdiaphragmatic gastrointestinal activity play a major role in SPECT MPI as they can affect diagnostic accuracy by decreasing specificity. Application of AC improved detection accuracy of perfusion defects in inferior wall which is supplied by RCA. This was proven by the significant result of normal study upon utilization of attenuation correction method (based on same patient in **Figure 5**). A previous study by Raza et al., also showed significantly higher values of normalcy rates in attenuation corrected images in all three coronary arterial territories, more marked in RCA region. This is likely due to the more homogenous count distribution in CT-AC reconstructed images. Moreover, iterative reconstruction with AC also normalized the perfusion defect likely caused by attenuation artifacts hence yielding normal study.

The disagreement between true and false perfusion defects has been a major challenge for nuclear physician. Our result shows that CT-AC successfully reduces the number of false-negative results. However, it is important to consider small defects more closely especially for SDS of group 2-4. This is because, small defects in FBP and CT-AC images may represent true defect and is associated with risk of ischemia thus should be considered in the patient management. Besides, with FBP reconstruction method, disease and attenuation caused by diaphragm are indistinguishable from each other in polar map. Furthermore, sub-diaphragmatic activity adjacent to the heart, mainly liver and bowel activity due to the hepatobiliary excretion of $^{99m}$Tc-MIBI may affect myocardial perfusion imaging. The scatter radiation from sub-diaphragmatic activity can lead to a false increase in inferior myocardial wall uptake that may mask a true perfusion defect in this region. Likewise, the scatter radiation may also lead to higher count in this region with other regions appearing to have relatively lower activity hence giving a false impression of perfusion defect elsewhere.

The current SPECT/CT systems involve SPECT image data and CT data obtained for attenuation correction sequentially. If any substantial amount of patient motion is detected during CT acquisition, the heart will be seen in different locations on the adjacent SPECT projection images. Although there is included software to align the SPECT and CT datasets, misregistration my occur if full care during image fusion (CT attenuation map coregistration with SPECT images) as it may lead to a new kind of artifact. An error of registration image of 7mm can lead to a substantial degradation in quality of attenuation corrected images (Dvorak *et al.*, 2011). Superimposed of cardiac radiotracer uptake with lung can produce artifacts simulating large and severe perfusion defects which mostly involve the lateral wall.

Other abnormalities need to be considered during the evaluation of perfusion result such as transient ischemic dilation of left heart ventricle. This phenomenon occurs when multi-vessel coronary artery disease with balanced and generalized subendocardial ischemia affecting all walls of the left ventricles. Its occurrence should be treated as positive result even in the absence of significant perfusion deficits. Next, it is important to consider the accumulation of radiotracer in the right ventricle (Czaja Monika et al. 2017). In most cases, the right ventricle is almost invisible in a scintigraphy image which make being negligible when used of diagnostic imaging techniques due to the complex geometrical shape of the right ventricle. Besides, perfusion imaging of right ventricle is difficult mainly because of thin wall which is almost not visualized with standard SPECT MPI. However, if there is increased in radiotracer uptakes of right ventricle it may indicate right ventricular hypertrophy. Right ventricular hypertrophy makes heart wall thickening and makes it possible to visualize through MPI (Sciagrà, 2019).