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The Role of Radionuclides and Physical Parameters in SPECT and PET Cardiac Imaging

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Abstract:
This research aimed to *Demonstrate if myocardial perfusion by positron emission tomography (PET) study provides an accurate means for diagnosing coronary artery disease (CAD) the ability to record changes in left ventricular function from rest to peak stress and to quantify myocardial perfusion comparing to single photon emission tomography (SPECT),*
Methodology: *20 studies of PET and SPECT cardiac cases divide as: Group 1: 10 studies of SPECT cardiac cases divided into 5perfusions (3 ischemia, 2infraction) and 5 viability. Group 2: 10 studies of PET cardiac cases divided into 5 perfusions (3 ischemia, 2 infraction) and 5 viability. In this retrospective Study data was collected from both SPECT and PET unit from the patient's files which include the calculation of all the physical parameters "EF, EDV, ESV" which shows the perfusion of the heart. Descriptive statistics are done by using Descriptive statistics calculation in SPSS program.*
Result: *Regards to our results, there is significant difference in quantitative physical parameters which are Ejection Fraction, End Diastolic volume and End systolic of the heart for both STRESS and REST studies in SPECT and PET, by calculating the Std. deviation we found that the Std. deviation of STRESS study in PET is much smaller than it is value in SPECT that means the accuracy of PET is much higher than SPECT*
Conclusion: *In conclusion, we find that PET is highly accurate method for assessing myocardial perfusion and metabolism in evaluation of coronary heart diseases, and allow more accurate detection of ischemic and infarcted myocardium than SPECT. PET has less radiation burden to patients than SPECT because of short lived radionuclides used. In addition, PET has higher spatial resolution than SPECT. But nowadays they use SPECT more than PET because PET is more expensive, require cyclotron and unavailable in all hospitals.*

1. Introduction

Nuclear medicine considered as a branch of medical imaging that uses small amounts of radioactive material to diagnose and determine the variety of diseases, which include two applications SPECT and PET. [1]

SPECT, Single Photon Emission Computed Tomography scan uses a radioactive material to create 3-D pictures by gamma camera. [2]

PET, positron emission tomography scans that produce 3-dimentional image of functional process of the body, which is useful in assessment of physiological abnormality. [3]

For cardiac scan, there are some parameters that used to evaluate different types of heart disease such as Coronary Artery Disease, Silent Ischemia, and Angina which are: ejection fraction (EF) 50-70%, end systolic volume (ESV) 50-100ml, end diastolic volume (EDV) 100-160ml, stroke volume (SV) 60-100ml/beat in normal persons. [4]

1.1. Anatomy and Physiology of the Heart

The heart is a muscular pumps organ about the size of your fist and its primary function is to pump oxygenated blood to the rest of the body. It is made-up of four chambers, the right and left atria on the top, and the right and left ventricles on the bottom. The septum is a thin muscular wall that separates the right and left sides of the heart. Each contraction of the heart occurs in response to a carcontrical impulse that starts in the upper portion of the heart. Blood is move in a closed circuit through the body by the pumping of the heart. The heart contracts and pumps blood out to the body (systole) and relaxes to fill with more blood (diastole). [5]

The heart muscle itself is like all other organs in the body and requires oxygen to function. The oxygen-rich blood is circulated to the heart muscle through the coronary arteries. There are two main arteries: the right coronary artery and the left main coronary artery, both starting at the aorta (the main blood vessel of the body). These vessels then branch off into smaller and smaller vessels along the surface of the heart. [6]

1.2. Types of Heart Disease

There are many different types of heart disease. Some are congenital (humans who are born with heart problems), and the others develop over time and affect people later in life. There are some of the most common heart diseases such as coronary artery diseases, silent Ischemia and Angina. [7] Coronary Arteries disease is Blockage in the coronary arteries, a condition in which the heart muscles do not get enough blood and oxygen. The most effect of coronary artery disease is sudden death without warning. This usually happens in individuals who have had heart attacks or other heart damage. [8] Silent Ischemia is form of coronary artery disease in which the blood flow to the heart muscle is reduced but with very little pain or symptoms. When discomfort is experienced, it is usually during physical exertion. It is appearing as Hypo perfusion (cold defect) on stress perfusion scan. [9]

Angina is discomfort or pain that occurs when your heart is not getting enough oxygen and nutrients. A narrowing of the arteries or muscle spasms in the coronary arteries may cause angina. It is important to note that angina is not a heart attack and does not usually cause permanent heart damage, even though it causes pain. [10]

Myocardial infarction Necrosis of myocardial tissue, because of coronary occlusion. It is appearing as Hypo perfusion on rest–stress perfusion and decreased uptake with metabolic imaging. [11]

1.3. Basic SPECT Physics and Instrumentation

A single-photon emission computerized tomography (SPECT) scan to assess the function of internal body's organs. A SPECT scan is a type of nuclear imaging test that use gamma emitters radionuclides detected by gamma camera to create 3-D image. [12]

SPECT has been applied to the heart for myocardial perfusion imaging. It is an effective non-invasive diagnostic technology when assigns patients for clinically significant coronary artery disease (CAD) in the following state of diagnosing CAD in patients with an abnormal resting electrocardiogram (ECG) and restricted exercise tolerance; or determine myocardial viability before Send patient for myocardial revascularization has a far greater sensitivity for detecting silent ischemia than stress ECG. Collect the data of exercise SPECT studies in over 1,000 patients revealed a 90 % overall sensitivity for detecting CAD. In myocardial viability, studies indicate that, even in patients with severe irreversible thallium defects on standard exercise-redistribution imaging, thallium reinjection generate information regarding myocardial viability that is similar to that provided by positron emission tomography (PET). [13]

1.4. Physical parameter that effect quality of SPECT image:

There are different physical factors that affect the quality of SPECT images like number of frames per projection, number of projections per scan and time per projection in gated myocardial SPECT scan.[14]The aim of the present work was to evaluate physical acquisition parameters affecting the cardiac imaging to improvement the patient's examination time and image quality that obtained with the gamma camera and workers radiation protection (through decreasing time of radiation exposure) in cardiac SPECT facility.

Cardiac functional parameters such us ejection fraction (EF), end diastole volume (EDV), end systole volume (ESV) were evaluated. [15] The decreasing of scan time to half or the number of projections per scan to half or increasing the number of frames per scan from 8 to 16 at the same duration has insignificant effect in the cardiac functional parameters used with gated SPECT scan. [16]

1.5. SPECT radiopharmaceuticals for cardiac studies

Radiopharmaceuticals for SPECT cardiac imaging, thallium-201 and two technetium-99m labelled radiopharmaceuticals (Sestamibi and Tetrofosmin) are available commercially. [17]

Radionuclide	**Principal mode of decay**	**Physical half-life**	**Principal photon energy in Kev (abundance) (%)**	**Production method**
Tc-99m	Isomeric transition	6 hr.	140 (89)	Generator (Mo-99)
Tl-201	Electron capture	73.1 hr.	69-83 (Hg x-rays), 135 (2.5), 167 (10)	Cyclotron

Table 1: Physical Characteristics of Single-Photon Radionuclides Used in Clinical Nuclear Medicine

1.6. Basic PET Physics and Instrumentation

Positron emission tomography (PET), it is a nuclear medicine imaging technique that produce 3D image of functional process of the body. It is more useful in identifying the physiological abnormalities compared to other modalities. The principle of PET based on measure the two annihilation photons emitted from a radionuclide with 511Kev energy for each, the emission occurred in back to back pattern 180 from each other by coincidence to detect any functional abnormalities within human bodies. This allows more accurate information from PET/CT compare to PET or CT alone. In addition, because of the high sensitivity and short-lived radionuclide PET is useful for all patients with different procedure. [18]

This event is obtained and identified along their lines of response (LORs) that determine the exact time and location where the annihilation occurred between the detectors that lead to formation of sinogram that can used for data corrections. Because PET scanners consist of multi rings detector it may or may not contain septa of photon-absorptive material, which can provide collimation that acquired in 2D slice in detectors with septa and, 3D slice in detector without septa obtained without collimation, allows all coincidence photon from all axial angle in FOV to be accepted. [19]

1.7. PET Radionuclide for Cardiac Studies

Radionuclide	Physical half-life(min)	Positron energy(MeV)	Range in soft tissue(mm)	Production method
C-11	20	0.96	4.1	Cyclotron
N-13	10	1.19	5.4	Cyclotron
O-15	2	1.73	7.3	Cyclotron
F-18	110	0.63 5	2.4	Cyclotron
Rb-82	1.3	3.15	15.0	Generator (Sr-82)

Table 2: Positron-Emitting Radionuclides: Physical Characteristics

2. Materials and Methods

20 cases of cardiac 10 PET and 10 SPECT was collected from: King Fahd Medical City (KFMC), King Saud medical city (KSMC), Princes sultan military medical city (PSMMC), Security forces hospital (SFH). SPECT cases divided into 5perfusion (3 ischemia, 2infraction) and 5 viability, PET cases divided into 5 perfusions (3 ischemia, 2 infraction) and 5 viability. All cases are varied between male and female with main history of chest pain and shortness of breath, to assist any abnormalities and changes in physical parameter due to different disease (ischemia and infraction). In this retrospective Study data was collected from both SPECT and PET unit from the patient's files which include the calculation of all the physical parameters "EF, EDV, ESV" which shows the perfusion of the heart. Descriptive statistics are done by using Descriptive statistics calculation in SPSS program. Generally, nuclear medicine Cardiac imaging has two modalities, which are PET and SPECT, and all have protocols of Rest and Stress. Stress performed by two methods: (i) Pharmacological agents (Dipyridamole, Adenosine, Dobutamine). (ii) Physical exercises (treadmill, bicycle) but it is especially for SPECT.

4. Results

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
SPECT_ST	6	6.00	76.00	51.5000	24.28786
PET_ST	6	33.00	65.00	49.3333	14.32015
SPECT_Rst	6	35.00	70.00	57.6667	12.72268
PET_Rst	6	39.00	76.00	53.6667	13.73560
Valid N (list wise)	6				

Table 3: shows the min., max, mean and Standard deviation values for Stress in both SPECT and PET and REST in both SPECT and PET

Paired Samples Test									
		Paired Differences					t	do	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	SPECT_ST - PET_ST	2.16667	20.65349	8.43175	-19.50784	23.84118	.257	5	.807
Pair 2	SPECT_Rst - PET_Rst	4.00000	10.82589	4.41965	-7.36108	15.36108	.905	5	.407

Table 4: shows significant difference in ejection fraction in STRESS and REST studies in both SPECT and PET

By Comparing the ejection fraction of STRESS study in both SPECT and PET, we observed that the Standard Deviation of PET = (14.32015) is less than that of SPECT = (24.28786) and there is significant difference between STRESS study in SPECT and PET = (0.807). This means that the STRESS PET study is more accurate. And, the Comparison of the ejection fraction of REST study in both

SPECT and PET, the Std. Deviation of SPECT = (12.72268) and PET = (13.73560) are almost equal. While there is significant difference between REST study in SPECT and PET (0.407) this means that the REST PET study is more accurate.

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
SPECT_EDV_ST	6	67.00	375.00	141.0000	116.77500
PET_EDV_ST	6	97.00	171.00	133.3333	26.12789
SPECT_EDV_Rst	6	65.00	135.00	101.5000	29.63613
PET_EDV_Rst	6	93.00	165.00	128.8333	30.66214
Valid N (list wise)	6				

Table 5: shows the min., max, mean and Standard deviation values for end diastolic volume in STRESS Study for both SPECT and PET and end systolic volume in REST study for both SPECT and PET

Paired Samples Test									
		Paired Differences					T	do	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	SPECT_EDV_ST - PET_EDV_ST	7.66667	119.97277	48.97868	-118.23704	133.57037	.157	5	.882
Pair 2	SPECT_EDV_Rst - PET_EDV_Rst	-27.33333	40.46562	16.52002	-69.79940	15.13273	-1.655	5	.159

Table 6: shows significant difference in end diastolic volume of STRESS and REST studies in both SPECT and PET

By Comparing the end diastolic volume of STRESS study in both SPECT and PET, we observed that the Standard Deviation of PET = (26.12789) is less than that of SPECT = (116.77500) and there is significant difference between STRESS study in SPECT and PET = (0.882). This means that the STRESS PET study is more accurate. And Comparison of the end diastolic volume of REST study for both SPECT and PET, the Std. Deviation of SPECT = (29.63613) and PET = (30.66214) are almost equal. While there is significant difference between REST study in SPECT and PET (0.159), this means that the rest PET study is more accurate.

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
SPECT_ESV_ST	6	16.00	354.00	91.3333	129.62356
PET_ESV_ST	6	35.00	102.00	71.3333	30.20375
SPECT_ESV_Rst	6	20.00	88.00	44.1667	24.37553
PET_ESV_Rst	6	35.00	91.00	62.8333	24.38374
Valid N (list wise)	6				

Table 7: Shows the min., max, mean and Standard deviation values for end systolic volume STRESS study in both SPECT and PET and end systolic volume REST study in both SPECT and PET

Paired Samples Test									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	SPECT_ESV_ST - PET_ESV_ST	20.00000	121.77520	49.71452	-107.79524	147.79524	.402	5	.704
Pair 2	SPECT_ESV_Rst - PET_ESV_Rst	-18.66667	29.44600	12.02128	-49.56834	12.23501	-1.553	5	.181

Table 8: shows significant difference in end systolic volume of STRESS and REST studies in both SPECT and PET

By Comparing the end systolic volume of STRESS study in both SPECT and PET, we observed that the Standard Deviation of PET = (30.20375) is less than that of SPECT = (129.62356) and there is significant difference between STRESS study in SPECT and PET = (0.704). This means that the Stress PET study is more accurate. And, the Comparison of the end systolic volume of REST in both SPECT and PET, the Std. Deviation of SPECT = (24.37553) and PET = (24.38374) are almost equal. While there is significant difference between REST study in SPECT and PET = (0.181), this means that the rest PET study is more accurate.

5. Discussion

Regards to our results, there is significant difference in quantitative physical parameters which are Ejection Fraction, End Diastolic volume and End systolic volume which is most important quantitative parameters to evaluate blood flow and the function of the heart of both STRESS and REST studies in SPECT and PET, and by calculating the Std. Deviation it is found that the Std. Deviation of STRESS study in PET is much smaller than it is value in SPECT that means the accuracy of PET is much higher than that in SPECT but in case of rest study it is noticed that there is no great different in Std. Deviation because there is no overload in the heart. According to Ryo Nakazato, (2013). It is found that, when SPECT-MPI, PET-MPI compared, they have several distinct advantages, PET has improved image quality as compared with SPECT, due to the improved count statistics, robust attenuation and scatter correction, as well as better tracer characteristics. PET has demonstrated higher diagnostic accuracy for detection of CAD than SPECT. Also Dr. Faulhaber (2006), observed less artifacts with PET, higher spatial resolution and the capability to perform quantitative measurements at the peak of stress and speed, also less imaging time than SPECT. Alexánderson E (2006), concluded that the cardiac viability, (PET) using FDG is considered the gold standard, FDG PET study represents a better technique to detect myocardial viability, compared to thallium reinjection SPECT protocol. but other another prefers spect over pet. According to Dr. Jain, the main positives of SPECT are that it's much more available and widely used and much cheaper than PET. While PET is more expensive in terms of purchasing equipment, SPECT radio tracers also have half-lives of up to six hours, allowing a lot of imaging time, while PET tracers only have a half-life of about 75 seconds. SPECT radio tracers are also much cheaper and more abundant than PET tracers. Also Dr. Berman, observed, SPECT has issues, including long scan times and low-resolution images prone to artifacts and attenuation. Some artifacts can easily be misidentified as perfusion defects. SPECT also does not provide a quantifiable estimate of the blood flow, whereas PET does, but SPECT issues have been partially resolved by technological progress, cutting scan times with triple-headed cameras, improved cameras, computer-aided image enhancement and visual tracking systems to monitor and compensate for patient movement during long scans. Dr. Peter concluded that, PET is not rapidly replacing SPECT because it does have some drawbacks. "PET is better, but not so much better than SPECT, if a new technology is decidedly better it will replace the old technology quickly. Dr. Faulhaber agreed, saying PET is only "a little bit better" than SPECT imaging.

6. Limitations

We didn't work in PET viability cases for several reasons including: lack of cooperation of some hospitals with us to get some of studies. Limit number of PET device in our hospitals in Saudi Arabia because it is expensive and unavailable. We face many problems in acceptance to collect data.

7. Conclusion

In conclusion, we find that PET is highly accurate method for assessing myocardial perfusion and metabolism in evaluation of coronary heart diseases, and allow more accurate detection of ischemic and infarcted myocardium than SPECT. PET has less radiation burden to patients than SPECT because of short lived radionuclides used. In addition, PET has higher spatial resolution than SPECT. But nowadays they use SPECT more than PET because PET is more expensive, require cyclotron and unavailable in all hospitals.

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