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REVIEW

Comparing Novel Positron Emission Tomography Myocardial Perfusion Imaging with Conventional Single-Photon Emission Computed Tomography

Evangelia Vlontzou, MD

Department of Nuclear Medicine, Evagelismos Hospital, Athens, Greece

KEY WORDS: *single-photon emission computed tomography; positron emission tomography; myocardial perfusion imaging; coronary artery disease; myocardial ischemia; myocardial viability*

ABBREVIATIONS
ACC = American College of Cardiology
ASNC = American Society of Nuclear Cardiology
CAD = coronary artery disease
CFR = coronary flow reserve
FDG = fluorodeoxyglucose
LVEF = left ventricular ejection fraction
MBF = myocardial blood flow
PET = positron emission tomography
SPECT = single-photon emission computed tomography
Tl = thallium

Correspondence to:
Evangelia Vlontzou, MD,
Department of Nuclear Medicine,
Evagelismos Hospital,
Athens, Greece;
Tel: +30-213-2041437;
E-mail: lilia_vlontzou@yahoo.gr

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ABSTRACT

For myocardial perfusion imaging, single-photon emission computed tomography (SPECT) technology is widely accepted by the cardiological community. It is supported by rich literature and has acceptable diagnostic accuracy. However, it does have limitations with false positive studies especially in women and obese patients and underestimates multivessel coronary artery disease. Positron emission tomography (PET) technology appears to be able to improve the diagnostic accuracy in detecting coronary artery disease. It offers qualitatively better images with shorter acquisition times and lower radiation burden on patients and personnel. It has the advantage of absolute quantification of myocardial blood flow for multivessel coronary disease diagnosis and is superior in the assessment of myocardial viability. In absolute terms it is an expensive method but avoiding the cost of additional diagnostic tests in equivocal studies makes it cost effective. Its availability is improving and it is expected to help in advancing nuclear cardiology.

INTRODUCTION

Radioisotope imaging of myocardial perfusion started in 1970 and peaked in the 1990's with advanced single-photon emission computed tomography (SPECT) systems and new radiopharmaceuticals. Almost in parallel, positron emission tomography (PET) technology became possible but only recently won support and is recognized for use in the imaging of myocardial perfusion.[1-3] The main limitations delaying its timely use were the high cost of PET cameras hampering its availability, the cost and availability of radiopharmaceuticals for PET and the limited scientific literature.[4,5] The increasing use of PET in clinical oncology over the last decade led to a reassessment of PET technology in clinical cardiology. The position of SPECT imaging of myocardial perfusion is widely accepted, evidenced by a wealth of literature, familiar to physicians, with clear guidelines for managing patients. Despite that, it has disadvantages that lead to inconclusive results and necessitate further patient examinations. The insufficiency of attenuation correction and tracer activity in the liver and intestine with technetium-based radiopharmaceuticals, despite the experience of physicians, use of gated SPECT

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and image acquisition in prone position, SPECT still leads to non-diagnostic tests particularly in obese patients and women. The inability to absolutely quantify myocardial blood flow (MBF) with SPECT underestimates the degree of ischemia and presence of multivessel coronary artery disease (CAD).[6,7]

PET AND RADIOPHARMACEUTICALS

A growing literature shows that PET can be an alternative solution to SPECT limitations. The radiopharmaceuticals and their characteristics[8] for the two technologies are shown in Table 1. The radiopharmaceuticals for PET have better extraction fraction than SPECT tracers and more linear uptake at higher flow rates. The short half time of PET radiopharmaceuticals results in short-time protocols. The rest/stress study with ^{82}Rb can be completed in 20-30 minutes while the corresponding SPECT process requires more time from the patient as well as a busy laboratory,[9,10] since it takes 3-5 hours. The available improvements in SPECT hardware and software offer faster acquisition with lower dosimetry and qualitatively better imaging but they increase cost and are being introduced at a time of declining reimbursement and utilization.[10] A limitation resulting from the short half-life of PET radiopharmaceuticals is the inability to perform regular stress test with only alternative the pharmaceutical stress.

^{13}N-NH3 offers high quality images and the capability of absolute quantitative assessment of MBF. However, it suffers from an availability standpoint. Its production requires on-site cyclotron which increases the cost.[5,11] **^{15}O-H_2O** has the ability to diffuse freely across capillary and cell membranes and this makes the tracer almost ideal for quantitative assessment of myocardial blood flow. But the images are non-satisfactory and its use is restricted to sites with a cyclotron.[8,10] **^{82}Rb** can be produced from a ^{82}Sr/^{82}Rb generator and has better availability compared to the previous radiopharmaceuticals since the existence of the generator with proper patient handling makes it cost effective. ^{82}Rb is analogous to potassium and the 78 seconds of its half-life (t1/2) reduce the time between examinations and allow their repetition after 15 min if technical problems arise. However, the relative rather than the absolute myocardial flow is estimated and for this reason it does not solve the SPECT problem of low sensitivity in patients with diffuse microvascular or balanced disease.[12] Programs for absolute blood flow measurements with ^{82}Rb exist but this is not in wide use.

New radiopharmaceuticals like fluridipaz-F18 based on ^{18}F labeling are being developed and evaluated in order to overcome the existing limitations. These do not require on-site cyclotron, are produced with the technology and availability of radiopharmaceuticals for oncologic patients, have longer half life and allow stress tests and possibly have lower cost since they allow single patient doses.[13,14] In general, the PET radiopharmaceuticals have higher cost and limited availability with ^{82}Rb being the most commonly used. Because of the short half life, higher doses can be administered resulting in shorter duration studies.

RADIATION

It has been estimated that in the US population, 20% of the yearly collective radiation dose received is from radioisotope studies of myocardial perfusion and in a recent publication it was estimated that 7400 more cancers may occur based on myocardial perfusion testing frequencies in the US in 2008.[15] However, the relationship between this level of radiation exposure and cancer risk is disputed and physicians should follow the relevant recommendations in order to achieve the desired result with minimum risk.

The radiation burden for patients is lower with PET radiopharmaceuticals compared to SPECT because of the short half life despite the larger administered doses (Table 2).[16] For the laboratory personnel, despite PET radiopharmaceuticals

TABLE 1. Radiopharmaceuticals and Their Characteristics for the Two Technologies of PET and SPECT

Agent	Half-life	Production	Extraction	Myocardial Uptake-Mechanism
PET				
^{82}Rb	78 sec	Generator	50-60%	Na/K-ATPase (perfusion)
^{13}N-NH3	10min	Cyclotron	80%	Diffusion/metabolic trapping (perfusion)
^{15}O- H2O	2min	Cyclotron	Diffusible	Free diffusion
^{18}F-FDG	110min	Cyclotron	1-3%	Glucose transport/hexokinase (viability)
SPECT				
^{201}Tl	73h	Cyclotron	73%	Potassium analog
^{99m}Tc-Sestamibi/Tetrafosmin	6h Generator	50-60%	Mitochondrial uptake	

FDG = fluorodeoxyglucose; PET = positron emission tomography; SPECT = single photon emission computed tomography.

TABLE 2. Patient Radiation Exposure by the Most Frequent Diagnostic Nuclear Imaging Procedures[16]

Study	Total Body Effective Dose (mSv)
^{201}Tl stress and re-injection (110+37 MBq)	25.1
^{99m}Tc-sestamibi 1 day (370+1,100 MBq)	10.7
^{99m}Tc-sestamibi 2 days (1100+1,100 MBq)	16.0
^{201}Tl/	
^{99m}TcDual isotope (110+1,100 MBq)	27.3
^{82}Rb stress-rest PET (1100+1,100 MBq)	7.5
^{13}NH3 stress-rest PET (500+500 MBq)	2.0
$H_2{}^{15}O$ stress-rest PET (900+900 MBq)	1.7
^{18}F-FDG PET viability (259 MBq)	4.9

having high energy photons that could theoretically represent greater radiation burden, this is not confirmed because of differences in radiotracer administration, in various acquisition and stress-testing tasks.[17]

IMAGE RESOLUTION

Imaging with PET provides higher spatial and temporal resolution compared to SPECT, and robust and common use of attenuation correction.[18] The higher temporal resolution permits dynamic imaging and the higher spatial resolution and the attenuation correction offers better sensitivity and specificity for CAD detection than SPECT. The correction of attenuation with PET is more accurate than in SPECT because of the uniform attenuation of high energy photons (511 vs 140 KeV for ^{99m}Tc). As a result of attenuation correction we have better image quality, especially in sub-populations like women where breast attenuation is frequent and in obese patients and the direct result compared to SPECT is an increase in specificity and normalcy rate leading to fewer inconclusive studies.[14] Yoshinaga et al[19] showed that in patients with equivocal SPECT, the quality of scans was rated as good in only 20% of SPECT vs 90% of PET. Bateman et al reached similar conclusions in matched patients.[20] The attenuation artifacts of PET are a lot fewer because of the higher imaging activity of the radiopharmaceutical tracer and the attenuation correction. The artifacts because of liver and intestine activity are more in SPECT studies than PET (41% vs 5%) and consequently the reader certainty was greater with PET than SPECT (96% vs 82%) independent of gender or body mass index, with 4% equivocal studies with PET and 18% with SPECT. Examples of PET myocardial perfusion images are displayed in Fig. 1-3.

DIAGNOSTIC CAPABILITY

The diagnostic accuracy of PET for CAD diagnosis has been verified in many studies. In Di Carli's meta-analysis,[21] 90% sensitivity and 89% specificity is reported from 9 studies, most with use of ^{82}Rb-PET. In direct comparison with ^{201}Tl-SPECT and ^{82}Rb or ^{13}N-NH3-PET in three studies, sensitivity was 91% for PET and 81% for SPECT, while specificity was 93% vs 85% in CAD diagnosis.[8] Even with technetium-based radiopharmaceuticals and gated acquisition, specificity was 93% for PET vs 73% for SPECT in Bateman's study and especially in the female population 86% vs 64%.[20] Using as a threshold luminal stenosis of 70%, the overall diagnostic accuracy for PET was 89% vs 79% for SPECT and this was due to the improved specificity of PET, while sensitivity was marginally greater at 87% vs 82%.

In the same study, recognized as the most notable, it was shown that PET was better than SPECT (71% vs 48%) in the diagnosis of multivessel CAD, probably related to differences in tracer kinetics between ^{82}Rb and ^{99m}Tc-sestamibi. The extraction fraction of radiopharmaceuticals for SPECT is limited to higher flow rates resulting in limited usefulness in patients with incipient coronary artery disease.[6,7]

^{82}Rb has relative higher extraction of the ^{99m}Tc-sestamibi at high flow rates and this could explain in part the improved ability of PET to recognize better multivessel CAD.[3] However, PET, at a 30% rate, misclassifies patients with multivessel disease as having one vessel disease or even misses some patients with balanced ischemia.[3]

One additional PET advantage is the capability of assessment of left ventricular ejection fraction (LVEF) at the peak of pharmaceutical stress and of course the change from rest, offering prognostic information which is additive to that determined by the extent and severity of perfusion abnormality alone.[22] Peak -stress myocardial function cannot be assessed with typical SPECT protocols. In Dorbala's study,[23] it is stated that by assessing the LVEF change, the diagnostic sensitivity for multivessel disease increases from 50% to 79%.

In general, PET appears more important because the number of false positive studies is reduced and offers high specificity compared to SPECT. The higher sensitivity of PET can be explained by the better spatial resolution and the better tracer extraction. Regarding the prognostic value for SPECT, there are a lot of data, while for PET only a few studies exist,[24-26] therefore the prognostic value of PET is not as well documented as SPECT.

MYOCARDIAL BLOOD FLOW

The capability of absolute quantification of myocardial blood flow (MBF) at rest and during stress and coronary flow

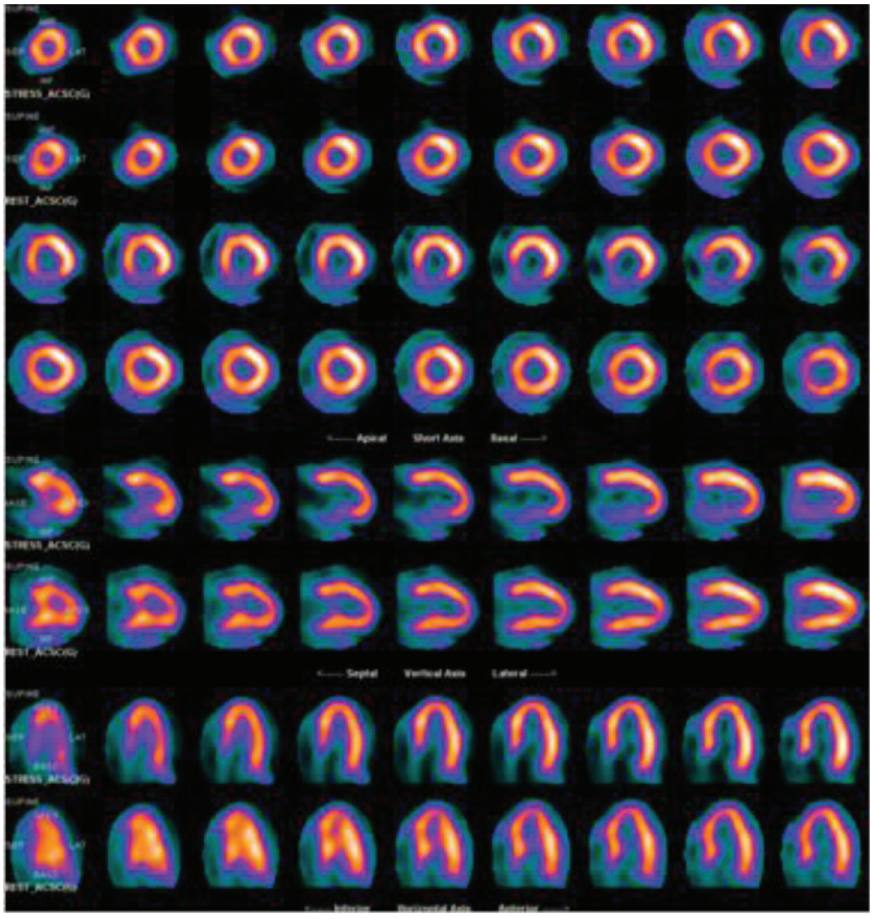

FIGURE 1. Myocardial perfusion PET images using ^{82}Rb in a patient with severe angina. PET shows reversibility in the inferior wall region.

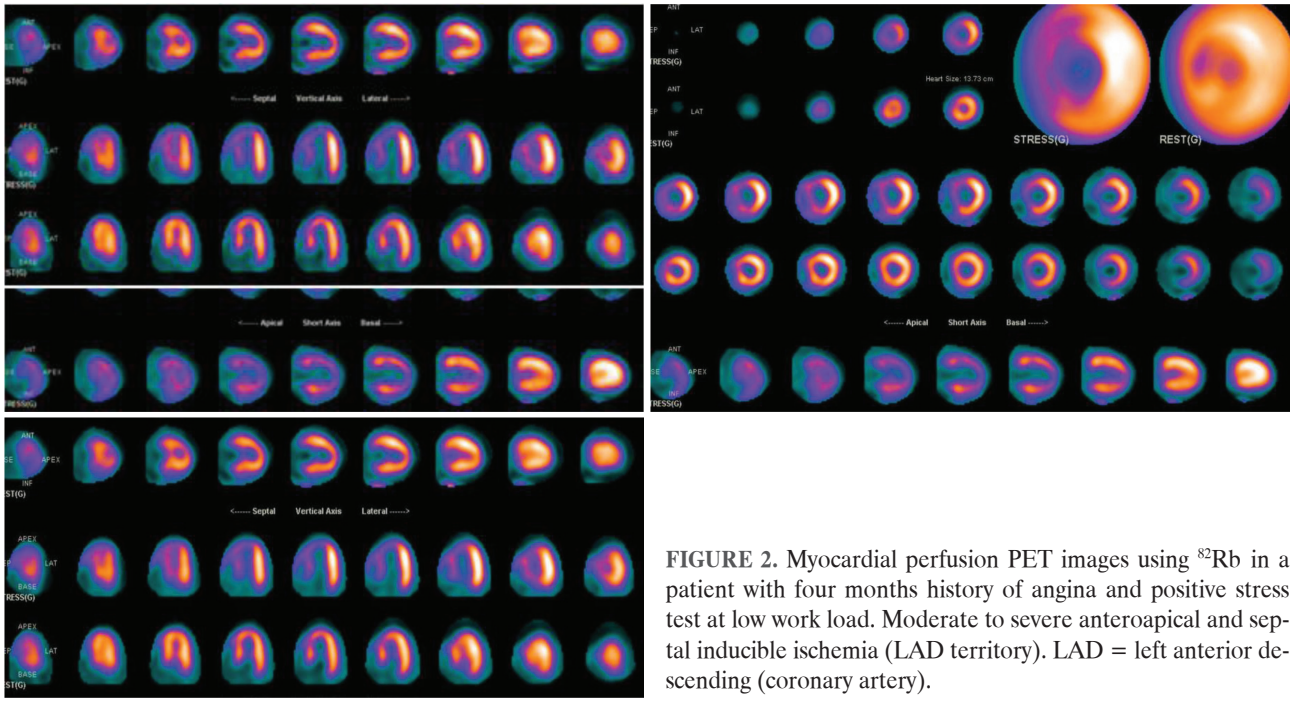

FIGURE 2. Myocardial perfusion PET images using ^{82}Rb in a patient with four months history of angina and positive stress test at low work load. Moderate to severe anteroapical and septal inducible ischemia (LAD territory). LAD = left anterior descending (coronary artery).

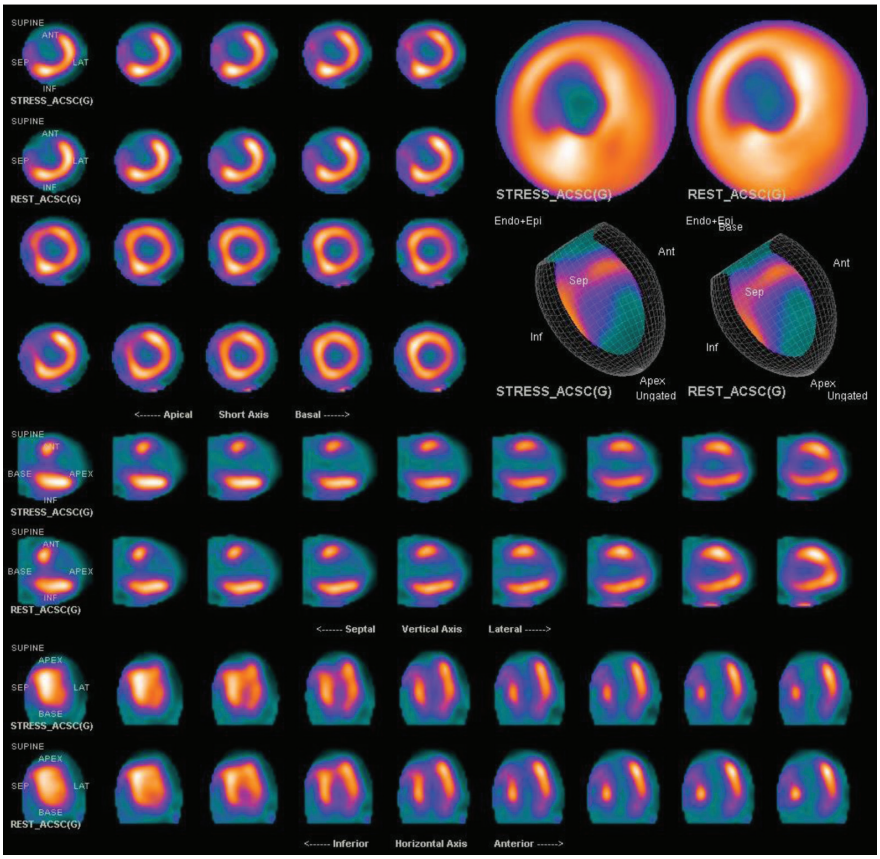

FIGURE 3. Myocardial perfusion PET images using ^{82}Rb in a patient with previous myocardial infarction shows stable defect in anteroseptal and apical region.

reserve (CFR) by dynamic PET is an important PET advantage. The high temporal resolution of PET enables dynamic imaging providing robust and reproducible time activity data needed to quantify regional and global MBF in milliliters per minute per gram of tissue, thus PET is able to quantify absolute MBF and coronary flow reserve.[27] ^{13}N-NH3 and ^{15}O-H_2O have been used for these measurements and constitute a non invasive gold standard for the assessment of MBF and CFR.[28,29] ^{82}Rb has also been used but with limitations because it requires a correction for its lower extraction fraction.[6] Several methods have been used with ^{82}Rb to achieve sufficient accuracy for the evaluation of CFR and in quantification of MBF and it is expected that they will help in implementing flow quantification into clinical PET practice because ^{82}Rb is the most frequently used radiopharmaceutical. However, it is accepted that the involvement of microcirculation plays a critical role in pathogenesis of many cardiac disorders and the quantitative flow measurement is useful in cases like widespread CAD with balanced ischemia, evaluation of collateral flow and identification of endothelial dysfunction in preclinical disease. Also CFR measurements with PET can provide prognostic information. Patients with normal perfusion but pathological CFR <2 were independently associated with higher annual event rate (1.4% vs 6.3%) and cardiac death rate (0.5% vs 3.1%) in the study of Herzog et al.[30] The clinical value of flow quantification with PET is a promising method for patient risk stratification and an object of many studies because there is no credible technique in SPECT.

COMPLEMENTARY INFORMATION

The recent wide use of PET/computed tomography (CT) imaging systems offers complementary morphological and functional information like calcium scoring, increasing the prognostic value of the method and the negative prognostic value, especially in patients with low CAD prevalence.[31] Recently, special pinhole collimators and arch arrangements of SPECT detectors have increased the SPECT count sensitivity but cost is also significantly increased and current availability is limited.[32] Despite that, the count sensitivity of PET remains greater and its high quality images lead to high interpretive certainty and greater diagnostic accuracy.

MYOCARDIAL VIABILITY

Positron emission tomography with ^{18}F-FDG is considered

by many the gold standard for the assessment of myocardial viability, based on the notion that the assessment of only the myocardial perfusion is not enough to predict function recovery after revascularization. ^{18}F-FDG is the best known radiopharmaceutical for oncology but also for the assessment of myocardial viability. ^{18}F-FDG uptake has been observed in areas of markedly reduced or absent radiopharmaceutical uptake in SPECT. Tillisch et al[33] compared the ^{18}F-FDG uptake in patients with advanced CAD and affected regional and global function before and after revascularization and showed that imaging of viable myocardium was superior with ^{18}F-FDG-PET compared to SPECT, in patients benefiting from revascularization. Approximately 30-50% of scarred tissue areas with ^{201}Tl showed FDG uptake and were characterized as viable. Later in 2007, Schinkel et al[34] in a comprehensive and systematic review, showed higher sensitivity of ^{18}F-FDG-PET (92%) compared to ^{201}Tl and technetium based radiopharmaceuticals, including magnetic resonance imaging and dobutamine echocardiography. The specificity was highest for dobutamine echocardiography and the highest negative prognostic value was with ^{18}F-FDG-PET. With ^{201}Tl reinjection the viability assessment was comparable to FDG but the weight of evidence favors the use of FDG.[35] Recent data from the Ottawa-Five substudy of PARR2[36] show that when ^{18}F-FDG-PET is available and is used by experienced personnel it has the advantage in assessing patients who will benefit from revascularization. ^{18}F-FDG-PET accurately predicts the improvement of global LVEF and of regional wall motion after revascularization, especially when blood flow is reduced by >50% and there is relatively high glucose uptake. Even in perfusion imaging with ^{82}Rb, ^{18}F-FDG-PET often shows additional viable tissue in patients with fixed ^{82}Rb perfusion defects or in patients with only partial stress-inducible reversibility.[8]

RECOMMENDATIONS

An advantage of SPECT over PET is that its wide use for many years has validated its prognostic and diagnostic value in many patient groups. The increasing use of PET leads to the need to select patients who will benefit from it. There are no guidelines as to which patients should be subjected to PET or SPECT, although the reasons for performing a PET study should follow previously published ACC/ASNC guidelines and appropriateness criteria for nuclear cardiac imaging. However, a recent ASNC statement recommended that PET be considered as the first line option for patients referred for myocardial perfusion test when a nuclear perfusion test is indicated.[37] Patients that would benefit from PET until now are those with equivocal SPECT, obese patients and women because of attenuation correction, patients that cannot undergo stress test and are subject to pharmaceutical stress because of higher diagnostic accuracy in PET and patients with highly suspected CAD and normal SPECT study, as well as patients with highly suspected multivessel CAD or diffuse microvascular disease because of the quantification of absolute myocardial flow. However, claustrophobic or excessively obese patients are not suitable for PET, especially in hybrid PET/CT systems. In patients who can exercise, the exercise stress test adds important information to that of the images in SPECT. Finally, PET imaging in patients with advanced ischemic heart disease and left ventricular dysfunction historically have been the driving force for viability assessment because of PET's accuracy in predicting the functional recuperation after revascularization.[1,2]

CONCLUSIONS

Positron emission tomography (PET) perfusion imaging offers better images with higher resolution and better attenuation correction than SPECT perfusion imaging. PET protocols are shorter and the patients are exposed to less radiation. All these lead to enhanced diagnostic certainty and accuracy and PET will enable nuclear cardiology to survive for years to come. However, at this time, SPECT myocardial perfusion imaging continues to be the main method, because this technique has been standardized for the protocols employed and has been tested in all patient populations.

REFERENCES

1. Beller G. Will cardiac positron emission tomography ultimately replace SPECT for myocardial perfusion imaging? *J Nucl Cardiol* 2009; 16:841-843.
2. Udelson J. Advances in myocardial perfusion imaging. *J Nucl Cardiol* 2012; 19:S1-2.
3. Di Carli M, Hachamovitch R. Should PET replace SPECT for evaluating CAD? The end of the beginning. *J Nucl Cardiol* 2006; 13:2-7.
4. Knuuti J. Should we use more PET-CT in clinical cardiology? *Eur J Nucl Med Mol Imaging* 2008; 35:887-888.
5. Cerquiera MD. Diagnosis and prognosis of coronary artery disease: PET is superior to SPECT: Con. *J Nucl Cardiol* 2010; 17:678-682.
6. Beanlands R, Youssef G. Diagnosis and prognosis of coronary artery disease: PET is superior to SPECT: Pro. *J Nucl Cardiol* 2010; 17:683-695.
7. Heller G. Practical issues regarding the incorporation of PET into a busy SPECT practice. *J Nucl Cardiol* 2012; 19:S12-18.
8. Machac J. Cardiac positron emission tomography imaging. *Semin Nucl Med* 2005; 35:17-36.
9. Heller GV, Calnon D, Dorbala S. Recent advances in cardiac PET and PET/CT myocardial perfusion imaging. *J Nucl Cardiol* 2009; 16:962-969.
10. Bateman T. Advantages and disadvantages of PET and SPECT in a busy clinical practice. *J Nucl Cardiol* 2012; 19:S3-11.

11. Stabin MG. Radiopharmaceuticals for nuclear cardiology: Radiation dosimetry, uncertainties, and risk. *J Nucl Med* 2008; 49:1555-1563.
12. Bengel FM, Higuchi T, Javadi MS, Lautamδki R. Cardiac positron emission tomography. *J Am Coll Cardiol* 2009; 54:1-15.
13. Yalamanchili P, Wexler E, Hayes M, et al. Mechanism of uptake and retention of F-18 BMS-747158-02 in cardiomyocytes: A novel PET myocardial imaging agent. *J Nucl Cardiol* 2007; 14:782-788.
14. Le Guludec D, Lautamδki R, Knuuti J, Bax JJ, Bengel FM; European Council of Nuclear Cardiology. Present and future of clinical cardiovascular PET imaging in Europe – a position statement by the European Council of Nuclear Cardiology (ECNC). *Eur J Nucl Med Mol Imaging* 2008; 35:1709-1724.
15. Berrington de Gonzalez A, Kim KP, Smith-Bindman R, McAreavey D. Myocardial perfusion scans: Projected population cancer risks from current levels of use in the United States. *Circulation* 2010; 122:2403-2410.
16. Thompson RC, Cullom SJ. Issues regarding radiation dosage of cardiac nuclear and radiography procedures. *J Nucl Cardiol* 2006; 13:19-23.
17. Schleipman AR, Castronovo FP Jr, Di Carli MF, Dorbala S. Occupational radiation dose associated with Rb82 myocardial perfusion positron emission tomography imaging. *J Nucl Cardiol* 2006; 13:378-384.
18. Rahmin A, Zaidi H. PET versus SPECT: strengths, limitations and challenges. *Nucl Med Commun* 2008; 29:193-207.
19. Yoshinaga K, Chow BJW, Williams K, et al: What is the prognostic value of myocardial perfusion imaging using rubidium-82-positron emission tomography? *J Am Coll Cardiol* 2006; 48:1029-1039.
20. Bateman TM, Heller G, McGhie A, et al. Diagnostic accuracy of rest/stress ECG-gated Rb82 myocardial perfusion PET: comparison with ECG-gated T c-99m sestamibi SPECT. *J Nucl Cardiol* 2006; 13:24-33.
21. Di Carli M, Hachamovitch R. New technology for noninvasive evaluation of coronary artery disease. *Circulation* 2007; 115:1464-1480.
22. Lertsburapa K, Ahlberg AW, Bateman TM, et al. Independent and incremental prognostic value of left ventricular ejection fraction determined by stress gated rubidium 82 PET imaging in patients with known or suspected coronary artery disease. *J Nucl Cardiol* 2008; 15:745-753.
23. Dorbala S, Samson U, Limaye A, et al. Diagnostic value of changes in left ventricular ejection fraction during peak vasodilator stress gated cardiac PET-CT: correlation with the extent of angiographic coronary artery disease (abstract) *Circulation* 2005; 112:II-365.
24. Gibbons RJ, Chareonthaitawee P. Establishing the prognostic value of Rb82 PET myocardial perfusion imaging: A step in the right direction. *JACC Cardiovasc Imaging* 2009; 2:855-857.
25. Dorbala S, Hachamovitch R, Curillova Z, et al. Incremental prognostic value of gated Rb82 positron emission tomography myocardial perfusion imaging over clinical variables and rest LVEF. *JACC Cardiovasc Imaging* 2009; 2:846-854.
26. Schenker MP, Dorbala S, Hong EC, et al. Interrelation of coronary calcification myocardial ischemia, and outcomes in patients with intermediate likelihood of coronary artery disease: a compined positron emission tomography/ computed tomography study. *Circulation* 2008; 117:1693-1700.
27. Kaufmann PA, Camici PG. Myocardial blood flow measurement by PET: technical aspects and clinical applications. *J Nucl Med* 2005; 46:75-88.
28. Hunt SA, Abraham WT, Chin MH, et al. ACC/AHA 2005 Guideline Update for the Diagnosis and Management of Chronic Heart Failure in the Adult: a report of the ACC/AHA Task Force on Practice Guidelines (Writing Committee to Update the 2001 Guidelines for the Evaluation and Management of Heart Failure): developed in collaboration with the American College of Chest Physicians and the International Society for Heart and Lung Transplantation: endorsed by the Heart Rhythm Society. *Circulation* 2005; 112:e154-235.
29. Cury RC, Cattani CA, Gabure LA, et al. Diagnostic performance of stress perfusion and delayed-enhancement MR imaging in patients with coronary artery disease. *Radiology* 2006; 240:39-45.
30. Herzog BA, Husmann L, Valenta I, et al. Long term prognostic value of 13N-ammonia myocardial perfusion positron emission tomography: Added value of coronary flow reserve. *J Am Coll Cardiol* 2009; 54:150-156.
31. Sampson UK, Dorbala S, Limaye A, Kwong R, Di Carli MF. Diagnostic accuracy of rubidium-82 myocardial perfusion imaging with hybrid positron emission tomography/computer tomography in the detection of coronary artery disease. *J Am Coll Cardiol* 2007; 49:1052-1058.
32. Slomka PJ, Patton JA, Berman DB, Germano G. Advances in technical aspects of myocardial perfusion SPECT imaging. *J Nucl Cardiol* 2009; 16:255-276.
33. Tillisch J, Brunken R, Marshall R, et al. Reversibility of cardiac wall-motion abnormalities predicted by positron tomography. *N Engl J Med* 1986; 314:884-888.
34. Schinkel AF, Bax JJ, Poldermans D, Elhendly A, Ferrari R, Rahimtoola SH. Hibernating myocardium: diagnosis and patient outcomes. *Curr Probl Cardiol* 2007; 32:375-410.
35. Go RT, MacIntyre WJ, Saha GB, et al. Hibernating myocardium versus scar: severity of irreversible decreased myocardial perfusion in prediction of tissue viability. *Radiology* 1995; 194:151-155.
36. Abraham A, Nichol G, Williams KA, et al. 18F-FDG PET imaging of myocardial viability in an experienced center with access to 18F-FDG and integration with clinical management teams: the Ottawa-FIVE substudy of the PARR 2 trial. *J Nucl Med* 2010; 51:567-574.
37. Cerquiera MD, Allman KC, Ficaro EP, et al. Recommendations for reducing radiation exposure imaging. *J Nucl Cardiol* 2010; 17:709-718.