Article published online: 2022-03-24

Original Article

The effect of body mass index on high versus low administered activity protocol myocardial perfusion imaging scan time and effective dose using a cadmium zinc telluride camera in clinical practice

ABSTRACT

Cadmium Zinc Telluride (CZT) crystal-based myocardial perfusion imaging (MPI) cameras have increased count sensitivity compared to Anger cameras and can be used to lower either the injected activity or the image acquisition time. Institutions adopting CZT cameras need to decide whether to lower the injected activity or imaging time or attempt to lower both with a compromise. The aim of our study was to compare the scan time required to obtain similar count images using high activity protocol (HAP) versus low activity protocol (LAP) stratified by body mass index (BMI) and assess the impact on effective dose and our clinic workflow. Using a CZT camera, a cohort of 100 consecutive clinical patients imaged with LAP rest-stress MPI with approximately 185 MBq and 555 MBq activity was retrospectively compared to a similar cohort of 100 consecutive clinical patients imaged with HAP rest-stress MPI using approximately 370 MBq and 1110 MBq. Administered activity and BMI both had a statistically significant effect on scan time and radiation effective dose. LAP scans took an average of 9 min longer than HAP scans overall, $P < 0.0001$ and larger BMIs took longer than smaller BMIs, $P < 0.0001$. In addition, scan times were longer in men than women, $P = 0.007$. Effective dose was inversely proportional to BMI with an overall decrease of approximately 50% comparing LAP to HAP. For the same CZT camera, the LAP increased scan time while lowering the radiation effective dose when compared to HAP. The increase in scan time increased proportionally to BMI. The effective dose was inversely proportional to BMI. This increase in time did not have a significant impact on our local workflow, but its implications should be considered in the setting of LAP implementation, especially in obese or high patient volume practices.

Keywords: Body mass index, cadmium zinc telluride camera, low dose, myocardial perfusion imaging, radiation exposure, scan time

INTRODUCTION

Myocardial perfusion imaging (MPI) is a crucial modality for the evaluation of cardiac disease. Its important role in diagnosing myocardial perfusion abnormalities led to an increase in popularity with a major contribution to noninvasive cardiac imaging growth from 1999 to 2008.[1] This in turn contributed toward increasing medical radiation exposure. With increasing emphasis on decreasing radiation dose, it is imperative to explore new methods of imaging using lower radioactivity while maintaining reasonable scan time, image counts, and clinic workflow.

Access this article online	
Website: www.wjnm.org	**Quick Response Code**
DOI: 10.4103/wjnm.WJNM_123_20	

Kalpna Prasad, Chad C. Adams, Eiping Quang, Justin Taylor, Derek J. Stocker

Department of Radiology, Walter Reed National Military Medical Center, Bethesda, Maryland, USA

Address for correspondence: Dr. Kalpna Prasad, Department of Radiology, Walter Reed National Military Medical Center, 8901 Wisconsin Avenue, Bethesda, Maryland 20889, USA. E-mail: kalpna.prasad.civ@mail.mil

Submitted: 26-Aug-2020, **Revised:** 01-Jan-2021, **Accepted:** 04-Apr-2021, **Published:** 07-Aug-2021

How to cite this article: Prasad K, Adams CC, Quang E, Taylor J, Stocker DJ. The effect of body mass index on high versus low administered activity protocol myocardial perfusion imaging scan time and effective dose using a cadmium zinc telluride camera in clinical practice. World J Nucl Med 2021;20:247-52.

Background

Medical radiation exposure from MPI comes from the required use of radiotracers and in 2009, Fazel *et al*. reported radiotracer doses associated with MPIs to be a leading contributor among various medical imaging modalities to overall medical radiation exposure.[2] Single isotope, technetium-99 m (^{99m}Tc) rest-stress MPI is now the most commonly utilized protocol with injected activity of approximately 10 millicuries (mCi) or 370 megabecquerel (MBq) at rest, and 30 mCi or 1110 MBq at stress, which contribute to this radiation exposure.[3] Medical radiation has been theorized to increase cancer risk, although the risks remain unknown and likely very low at doses under 50 mSv.[4-7] Berrington de Gonzalez *et al*. reported an estimated lifetime risk of 10 cancers per 10,000 MPI for both men and women based on high activity ^{99m}TcMPI obtained at 50 years age.[4] While this only represents a theoretical risk of a 0.001% increase in likelihood of radiation-related cancer, increasing societal perception, and concern over medical radiation exposure and their potential for increasing cancer risk has resulted in significant efforts directed toward lowering medical radiation exposure. Methods include the incorporation of appropriate use criteria for imaging,[8] the application of the recommendations identified in the "Image Wisely" campaigns,[9] and the use of novel image reconstruction software with new cardiac-specific single photon emission computed tomography (SPECT) cameras utilizing software and hardware advancements for dose reduction.[10] Cardiac-specific cadmium zinc telluride (CZT) solid-state technology cameras introduced in the United States in 2007 offer faster image acquisition times as well as improved spatial resolution and image quality as compared to conventional Anger SPECT cameras, and as such, are gaining increased popularity.[11] These CZT cameras offer flexibility in protocol selection with regard to radiopharmaceutical activity and scan times.[12] Imaging protocols that use predetermined threshold counts for image acquisition have an inverse relationship between administered radiopharmaceutical activity and scan time, therefore, all else unchanged, low activity protocols (LAP) have longer scan time compared to high activity protocols (HAP) on the same camera. Reducing the injected activity by 50% should theoretically increase the scan time by 100% to maintain the exact number of counts. However, this acquisition time may be impacted in clinical practice by the patient population, based on the patient body habitus, overlapping bowel activity or attenuation, or patient motion, and by technologist imaging parameters such as camera positioning or timing of acquiring images post injection. High volume nuclear medicine practices with predominantly obese patient population may be reluctant to adopt the LAPs *in lieu* of faster scan times and patient throughput, and may prefer to continue using HAPs on newer CZT cameras. Nuclear medicine practices considering LAPs in pursuit of radiation exposure reduction using CZT cameras need to balance injected activity reduction with a clinically acceptable relative increase in scan time based on workflow and patient convenience.

Many studies have demonstrated decreased radiotracer activity and scan time using CZT cameras, especially in comparison to Anger SPECT cameras.[13-17] Published data are lacking in that these data are not stratified by body mass index (BMI) for LAP and HAP exams using the same CZT camera. Having undergone a performance improvement (PI) project trial of both HAP followed by LAP on the same CZT camera in similar patient cohorts, we present confirmatory findings of the effect of BMI on scan time and radiation effective dose for HAP and LAP as well as the impact on clinical workflow in our patient population. These findings helped in successful implementation of HAP and LAP as routine clinical practice in our institution.

MATERIALS AND METHODS

Initially, a cohort of 100 consecutive patients referred for MPI to our academic nuclear medicine clinic were imaged using ^{99m}Tc sestamibi HAP of 10 mCi (370 MBq) at rest and 30 mCi (1110 MBq) at stress as a 1 day rest–stress protocol on the new CZT camera. Subsequently, a cohort of 100 consecutive clinical patients were imaged with the same 1 day rest-stress protocol using the LAP of 5 mCi (185 MBq) at rest and 15 mCi (555 MBq) at stress while continuing to obtain standard acquisition threshold of 1 million counts for the left ventricle.[17] No patients were excluded from analysis. The low activity selection was based on the presumption of lowering the radiation effective dose to the patients by approximately half and bring it in the range of 6 millisieverts (mSv) from the 12 mSv range as calculated using online RADAR medical procedure radiation dose calculator.[18] The LAP patient cohort was retrospectively compared to the HAP cohort. Imaging was performed approximately 1 h after intravenous injection of the rest and stress ^{99m}Tcsestamibi injection, using either exercise or pharmacological stress modality as determined clinically by a cardiologist. Injected radiotracer activity was consistent despite age, sex, body habitus, and BMI. All imaging was performed using a cardiac-specific CZT camera (D-SPECT, Spectrum Dynamics, Caesarea, Israel) in upright position as recommended by manufacturer for rest and stress. This was followed by an additional stress image obtained in supine position as part of our routine clinical protocol to assess attenuation artifacts.[19] Standard software (QPS and QGS, Cedars-Sinai Medical Center, Los Angeles, California, USA) was used to reformat acquired images into axial, vertical and horizontal long axis projections. The images were transferred to a HERMES viewing station (Hermes Medical Solutions, Sweden) for clinical interpretation. Only upright rest and upright stress imaging data was used for scan time comparison between LAP and HAP cohorts, as this is routine protocol in most clinical practices. Additional supine stress images obtained at our clinic were not used in scan time assessment for either cohort. A consistent preset of 1 million counts for the left ventricle was implemented for image acquisition and applied for both protocols. Radiation effective dose between the two cohorts was predicted based on the mean radiopharmaceutical activity received by patients. Comparison between the two groups was made using the mean values of administered activity, radiation effective dose, and the scan time for rest, stress, and total MPI acquisitions. The institutional review board approved this retrospective evaluation of clinical imaging with exemption under the auspices of a PI project, and the requirement to obtain informed consent was waived.

Statistical methods

A fully interacted linear model was used to evaluate the contribution of BMI, sex, and administered activity to scan time under rest and stress conditions. Significance was assessed by performing a Type II ANOVA (R package car; Fox and Weisberg, 2019). Contrasts were performed using the emmeans package (Lenth, 2020). All analyses use an alpha of. 05. Radiation effective dose were estimated by a nuclear physicist based on the mean radioactive dose patients received.[18]

RESULTS

Two hundred patients were retrospectively evaluated for scan time, 100 undergoing HAP and 100 undergoing LAP. Demographic characteristics of patients in the 200 reviewed records are shown in Table 1. Patients tended to be older (68.3y ± 12.3) and moderately overweight (28.8 BMI ± 6.1), with slightly more males (55%) in the sample. In general, the 100 patients that underwent HAP and the 100 patients that underwent LAP had similar ages ($P = 0.06$), sex ($P = 0.39$), height ($P = 0.37$), weight ($P = 0.61$), and BMI ($P = 0.92$).

Observed scan times are depicted in Figure 1; both sets of data were analyzed with a linear model. For rest scans [Figure 1a], analysis confirmed a significant interaction between BMI and scan time ($P < 0.0001$). The model also identified significant main effects of sex (men took longer than women, $P = 0.007$). For Stress scans [Figure 1b], analysis again confirmed a significant interaction between BMI and scan time ($P < 0.0001$) but no effect of Sex ($P = 0.78$). On average, men had total (rest + stress) scan times of 20.57 (±5.49) minutes and 10.42 (±3.48) min for LAP and HAP respectively versus averages of 17.69 (±6.29) min and 9.93 (±3.09) min for woman. Figure 2 depicts average scan times for all patients for LAP and HAP, without BMI stratification. As compared to HAP, LAP demonstrated expected significant reduction in mean radiation effective dose of 49% in rest, 49% in stress, and 49% in total rest-stress MPI [Figure 3]. As expected, an increase in imaging time was noted in LAP [Figure 2]. Table 2 summarizes LAP and HAP scan times and radiation effective doses in the two cohorts without BMI stratification. Table 3 summarizes LAP and HAP scan times and effective doses with BMI stratification. Figure 3 depicts average effective doses of LAP and HAP exams without BMI stratification. Figure 4 depicts average effective doses of LAP and HAP examinations with BMI stratification.

The total increased scan time of 9 min did not significantly impact patient throughput in our low volume clinic and was preferred due to the almost 50% radiation dose reduction benefit obtained with the LAP as compared to the HAP. Our clinic continued to offer same number of appointment slots to patients and no staffing changes or overtime was required when using the LAP. All images were clinically interpreted by the same team of board certified nuclear medicine physicians and nuclear cardiologists, none of whom deemed any of the images to be nondiagnostic quality requiring repeat imaging

Table 1: Patient and protocol characteristics

Characteristics	Mean±SD	
	High activity MPI	Low activity MPI
Age (years)	69.8±10.9	66.6±13.4
Male:female	59:41	52:48
Weight (kg)	85.0±21.5	83.5±17.6
Height (cm)	172±11	170±11
BMI (kg/sqm)	28.8±6.9	28.7±5.1
Rest activity (mCi)	10.4±0.4	5.28±0.17
Stress activity (mCi)	31.1±1.3	16.0±0.5

SD: Standard deviation; MPI: Myocardial perfusion imaging; BMI: Body mass index

Table 2: Average scan time and radiation effective dose

	Mean±SD		Change with LAP (%)
	HAP, MPI	LAP, MPI	
Rest imaging time (min)	8.43±3.27	15.8±5.90	+7.37 (+87)
Stress imaging time (min)	1.77±0.63	3.40±1.23	+1.63 (+92)
Total imaging time (min)	10.2±3.40	19.2±6.00	+9.00 (+88)
Rest effective dose (mSv)*	3.46±0.13	1.76±0.06	−1.70 (−49)
Stress effective dose (mSv)*	9.09±0.38	4.68±0.13	−4.41 (−49)
Total effective dose (mSv)*	12.6±0.40	6.44±0.14	−6.16 (−49)

SD: Standard deviation; HAP: High activity protocol; LAP: Low activity protocol; MPI: Myocardial perfusion imaging

Table 3: Average scan time and radiation effective dose stratified by body mass index

	Mean scan time (±SD)		Mean effective dose (±SD)	
	HAP	LAP	HAP	LAP
Normal and underweight (BMI <24.99)				
Rest	6.07 (±4.18)	11.19 (±4.79)	3.83 (±0.18)	1.91 (±0.07)
Stress	1.31 (±0.72)	2.52 (±1.21)	10.54 (±0.59)	5.22 (±0.35)
Total	7.38 (±4.24)	13.71 (±4.94)	14.37 (±0.63)	7.12 (±0.36)
Overweight (25< BMI <30)				
Rest	8.24 (±1.39)	14.96 (±4.05)	2.98 (±0.17)	1.46 (±0.06)
Stress	1.71 (±0.33)	3.18 (±0.78)	8.09 (±0.52)	3.99 (±0.24)
Total	9.95 (±1.43)	18.14 (±4.13)	11.07 (±0.56)	5.44 (±0.26)
Obese (BMI >30)				
Rest	10.31 (±2.73)	19.03 (±5.73)	2.25 (±0.11)	1.27 (±0.05)
Stress	2.17 (±0.57)	4.07 (±1.20)	6.20 (±0.31)	3.40 (±0.21)
Total	12.48 (±2.78)	23.10 (±5.86)	8.45 (±0.34)	4.67 (±0.22)

SD: Standard deviation; HAP: High activity protocol; LAP: Low activity protocol; BMI: Body mass index

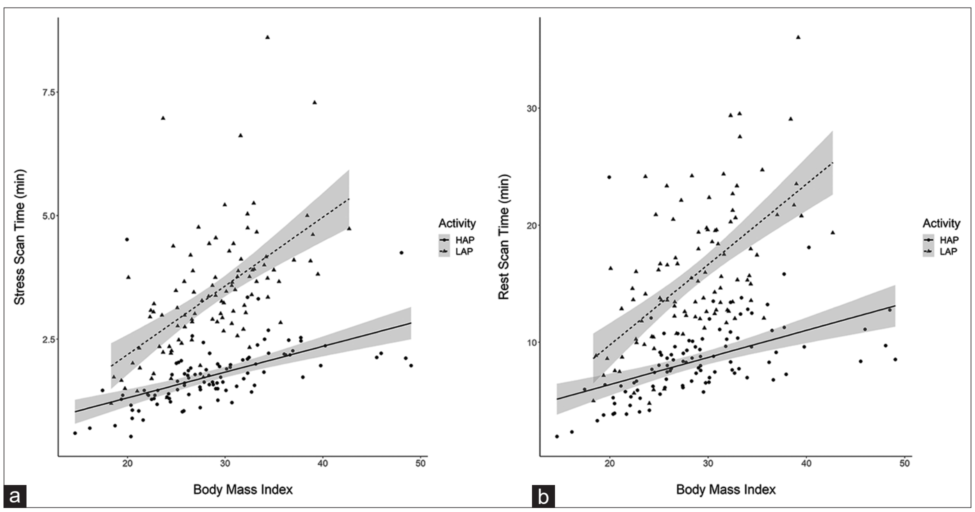

Figure 1: (a) Linear model of body mass index versus scan time in rest images (b) linear model of body mass index versus scan time in stress images

in either cohort. No patient complaints were encountered regarding scan time during acquisition, as noted by the performing technologists.

DISCUSSION

MPI is an essential noninvasive imaging test for myocardial perfusion evaluation. During the early part of the century, when MPI utilization was at its highest, the majority of imaging was performed using HAPs, which significantly contributed to medical radiation exposure. Growing societal awareness of medical radiation and its related risks combined with industrial appreciation of safe utilization of radiological procedures have resulted in widespread efforts, in recent years, to decrease radiation from medical imaging by developing newer technology, such as CZT cameras, that enable LAPs, such as those described herein regarding MPI. In addition, LAPs decrease medical radiation exposure not only to the patients but also to their close contacts and caregivers, medical staff,[20] and to the community. Lower radiotracer utilization also suggests a direct financial benefit with decreased cost associated with acquisition and preparation.

Given the practicality of LAP provided by CZT cameras, a compromise needs to be made between lowering the radiopharmaceutical activity to obtain radiation reduction benefit and significantly increasing scan time. As demonstrated herein, the activity reduction in the LAP follows expected prediction of approximately 50% radiation reduction. The consequence of the decrease in dose is an increase in scan time. This increase in scan time was statistically significantly associated in our study with increases in BMI. Our linear model and effective dose table allows a clinic to predict the average scan time and effective dose for a patient for any BMI within the range of our data (BMI approximately 20–40). For example, using these models to generate predictions for rest imaging when using HAP yields an estimated scan time of 6.7 min (95% confidence interval [CI]: 5.6–7.8) for a normal BMI individual (BMI = 21.5) and 9.8 min (95%

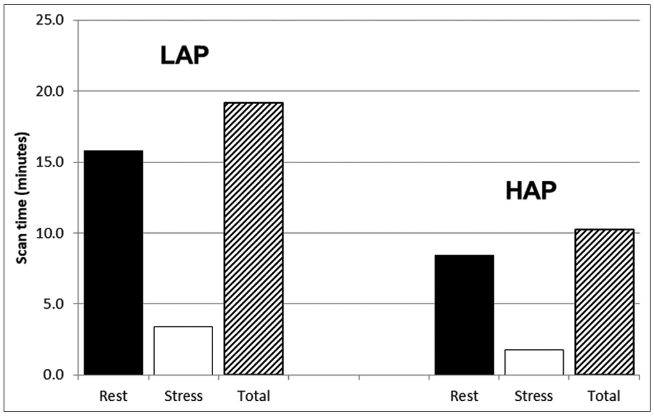

Figure 2: Average scan time for low activity protocol and high activity protocol examinations

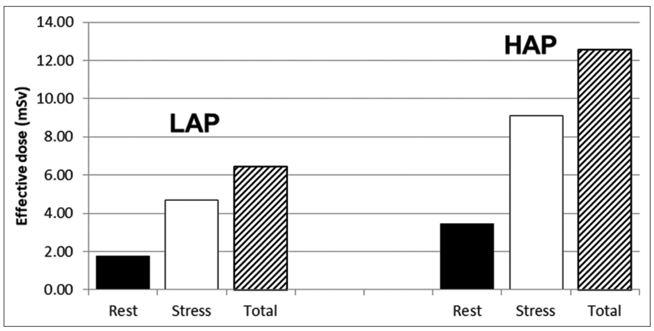

Figure 3: Average radiation effective dose for low activity protocol and high activity protocol examinations

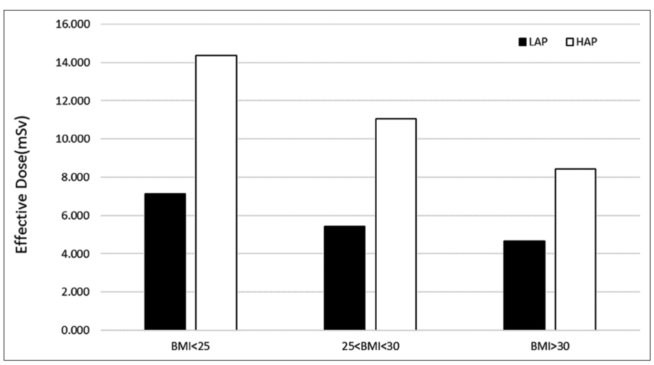

Figure 4: Average radiation effective dose for low activity protocol and high activity protocol exams stratified by body mass index

CI: 8.8–10.9) for an obese individual (BMI = 30.0) with effective doses of approximately 4 mSv and 2 mSv, respectively. Those same parameters using LAP result in an estimated scan time of 10.9 min (95% CI: 9.6–12.3) at normal BMI and 19.9 min (95% CI: 18.7–21.1) at obesity with effective doses of approximately 2 mSv and 1 mSv, respectively. At stress, HAP yields an estimated scan time of 1.4 min (95% CI: 1.2–1.6) at normal BMI and 6.7 min (95% CI: 5.6–7.8) at obesity with effective doses of approximately 10 mSv and 6 mSv respectively, whereas LAP results in an estimated scan time of 2.4 min (95% CI: 2.1–2.7) at normal BMI and 10.9 min (95% CI: 9.6–12.3) at obesity with effective doses of approximately 5 mSv and 3 mSv respectively. In addition to the BMI factor, the total scan time (rest + stress) for male patients was an average of 2.88 min longer for LAP and 0.49 min longer for HAP when compared to female patients, likely due to a larger thorax and thus greater attenuation. These numbers will further inform a clinic in the decision of which protocol to use for a given patient taking into account BMI and sex.

Other than throughput implications, increase in scan times may also result in patient discomfort, increased motion artifact, image quality degradation from attenuation, and increased patient wait times. Clinicians need to evaluate their goals with regard to radiation dose reduction, clinic throughput, and patient population demands in terms of total imaging time and staffing when considering an optimal LAP. Practices with limited camera time and/or high patient volume and/or a large percentage of high BMI patients may opt for HAP. Practices that perform a limited number MPIs daily and/or have copious camera time and/or a smaller percentage of high BMI patients may opt for LAP. At our institution, we have opted for a hybrid model. We utilize the LAP for patients with a BMI under 30 and HAP for patients with a BMI over 30. We feel this is the best compromise for our clinic's needs, balancing increased scan time with patient throughput.

Interestingly, although reducing the injected activity by 50% is theorized to increase the scan time by 100% to maintain the number of counts, our results demonstrated only 88% increased scan time, on average. It is possible that decreased activity caused decreased camera dead time and more counting efficiency. Another possibility is that because the LAP began after the HAP had been introduced and established on the new camera, the technologists became comfortable with the new CZT camera and became better at patient positioning by the time LAP was introduced. It is also possible that during the longer scan time for LAP, more activity from the GI tract added to acquired counts. Finally, some of the difference may be accounted for by differences in patient factors between the two groups; gender, age, body shape, etc.

While this project aimed to achieve clinically acceptable radiation dose reduction, it has several limitations. Separate cohorts were used for analysis, rather than performing LAP and HAP consecutively on the same patients. This was done because it was felt to be inappropriate to perform MPI studies using both LAP and HAP on the same patient, given the overall goal of radiation dose reduction. In addition, for the same BMI, upper body anterior thoracic fat can influence attenuation and scan time as opposed to lower body fat, which may influence scan time in the cardiac specific cameras. Although our project did not analyze the findings in relation to distribution of body fat, we were able to stratify our data using BMI, an admittedly imperfect tool. Partial IV infiltrations may also be a more significant problem using LAP due to the already low amount of radiotracer administered. Evaluation for possible infiltration was not performed in either cohort, as injection site is not included in imaging for myocardial perfusion. Finally, we did not assess syringe/tubing residual to determine the true administered activity which may contribute to significantly longer rest scan times if there was significant syringe residual activity.

A strength of our protocol was that all routine patients sequentially referred to our clinic were included in the analysis, minimizing selection bias. We used a single D-SPECT camera for imaging, which is not equipped with computed tomography (CT), thereby eliminating any additional radiation contribution from CT attenuation correction. Extrapolation of our findings to similar camera systems should be simple and practical for similar patient populations.

New knowledge gained

Scan time increases proportionally with BMI in both LAP and HAP MPI. The effective dose is inversely proportional to BMI. This article provides a linear model for estimating scan time based on BMI as well as average effective doses stratified by BMI which will assist a clinic's decision on using LAP versus HAP to achieve the optimal balance of radiation reduction and throughput.

CONCLUSION

Using the data in this article, a clinic planning to utilize a CZT cardiac camera will be able to estimate an average scan time and effective dose for each patient based on their BMI. This will inform the decision on which patients are appropriate for LAP versus HAP. This decision will be impacted by many factors unique to each clinic such as camera availability and patient volume.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Andrus BW, Welch HG. Medicare services provided by cardiologists in the United States: 1999-2008. Circ Cardiovasc Qual Outcomes 2012;5:31-6.
2. Fazel R, Krumholz HM, Wang Y, Ross JS, Chen J, Ting HH, *et al.* Exposure to low-dose ionizing radiation from medical imaging procedures. N Engl J Med 2009;361:849-57.
3. Dorbala S, Di Carli MF, Delbeke D, Abbara S, DePuey EG, Dilsizian V, *et al.* SNMMI/ASNC/SCCT Guideline for cardiac SPECT/CT and PET/CT 1.0. J Nucl Med 2013;54:1485-507.
4. 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;122:2403-10.
5. Berrington de González A, Mahesh M, Kim KP, Bhargavan M, Lewis R, Mettler F, *et al.* Projected cancer risks from computed tomographic scans performed in the United States in 2007. Arch Intern Med 2009;169:2071-7.
6. Smith-Bindman R, Lipson J, Marcus R, Kim KP, Mahesh M, Gould R, *et al.* Radiation dose associated with common computed tomography examinations and the associated lifetime attributable risk of cancer. Arch Intern Med 2009;169:2078-86.
7. National Research Council. Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2. Washington, DC: The National Academies Press; 2006. p. 65-90.
8. Hendel RC, Berman DS, Di Carli MF, Heidenreich PA, Henkin RE, Pellikka PA, *et al.* ACCF/ASNC/ACR/AHA/ASE/SCCT/SCMR/SNM 2009 Appropriate Use Criteria for Cardiac Radionuclide Imaging: A Report of the American College of Cardiology Foundation Appropriate Use Criteria Task Force, the American Society of Nuclear Cardiology, the American College of Radiology, the American Heart Association, the American Society of Echocardiography, the Society of Cardiovascular Computed Tomography, the Society for Cardiovascular Magnetic Resonance, and the Society of Nuclear Medicine. J Am Coll Cardiol 2009;53:2201-29.
9. Garcia E. Dedicated Solid-State Cardiac Systems for Myocardial Perfusion Imaging Image Wisely. Available from: https://www.imagewisely.org/Imaging-Modalities/Nuclear-Medicine/Dedicated-Solid-State-Cardiac-Systems. [Last accessed on 2018 Jun 01, [Last accessed on 2020 Dec 30].
10. Cerqueira MD, Allman KC, Ficaro EP, Hansen CL, Nichols KJ, Thompson RC, *et al.* Recommendations for reducing radiation exposure in myocardial perfusion imaging. J Nucl Cardiol 2010;17:709-18.
11. Garcia EV, Faber TL, Esteves FP. Cardiac dedicated ultrafast SPECT cameras: New designs and clinical implications. J Nucl Med 2011;52:210-7.
12. Herzog BA, Buechel RR, Katz R, Brueckner M, Husmann L, Burger IA, *et al.* Nuclear myocardial perfusion imaging with a cadmium-zinc-telluride detector technique: Optimized protocol for scan time reduction. J Nucl Med 2010;51:46-51.
13. Oddstig J, Hedeer F, Jögi J, Carlsson M, Hindorf C, Engblom H. Reduced administered activity, reduced acquisition time, and preserved image quality for the new CZT camera. J Nucl Cardiol 2013;20:38-44.
14. van Dijk JD, Jager PL, Ottervanger JP, Slump CH, de Boer J, Oostdijk AH, *et al.* Minimizing patient-specific tracer dose in myocardial perfusion imaging using CZT SPECT. J Nucl Med Technol 2015;43:36-40.
15. Nkoulou R, Pazhenkottil AP, Kuest SM, Ghadri JR, Wolfrum M, Husmann L, *et al.* Semiconductor detectors allow low-dose-low-dose 1-day SPECT myocardial perfusion imaging. J Nucl Med 2011;52:1204-9.
16. Einstein AJ, Blankstein R, Andrews H, Fish M, Padgett R, Hayes SW, *et al.* Comparison of image quality, myocardial perfusion, and LV function between standard imaging and single-injection ultra-low-dose imaging using a high-efficiency SPECT camera: The MILLISIEVERT study. J Nucl Med 2014;55:1430.
17. Nakazato R, Berman DS, Hayes SW, Fish M, Padgett R, Xu Y, *et al.* Myocardial perfusion imaging with a solid-state camera: Simulation of a very low dose imaging protocol. J Nucl Med 2013;54:373-9.
18. RADAR Medical Procedure Radiation Dose Calculator and Consent Language Generator. Available from: https://www.doseinfo-radar.com/RADARDoseRiskCalc.html. [Last accessed on2018 Jun 01].
19. Ben-Haim S, Almukhailed O, Neill J, Slomka P, Allie R, Shiti D, *et al.* Clinical value of supine and upright myocardial perfusion imaging in obese patients using the D-SPECT camera. J Nucl Cardiol 2014;21:478-85.
20. Einstein AJ. Multiple opportunities to reduce radiation dose from myocardial perfusion imaging. Eur J Nucl Med Mol Imaging 2013;40:649-51.